BATTERY CONDITION EVALUATION TECHNIQUE APPLIED TO A UPS BATTERY CHARGER SYSTEM

Telles B. Lazzarin; André L. Fuerback; Rodrigo da Silva; Ivo Barbi
Instituto de Eletrônica de Potência - INEP
CEP:88040-970 – Caixa Postal:5119 – Florianópolis – Santa Catarina
Fone:(47)91834032 – Fax (48)3234542 – e-mail: telles@inep.ufsc.br

***Abstract* – This paper aims to present a proposal of an UPS Lead–Acid battery charger, together with an on-line battery's useful life test system. The charger control structure is designed to perform a charging algorithm that ensures at the same time, the bulk charge into every battery in the pack and an output voltage correction due to environmental temperature offsets. The batteries useful live evaluation system, considered here, is based on battery impedance measurement, in a way that: increases on impedance value mean a reduction of its useful life. By monitoring the battery pack impedance the user is capable of improve the UPS system reliability.**

***Keywords* – Battery charger, current source, impedance measurement, lead–Acid battery.**

I. INTRODUCTION

Most part of today's UPS (*Uninterrupted Power Supply*) uses stationary lead-acid batteries that, under appropriate conditions of use, have a useful life around three to four years, according to manufacturers. But, there are two kinds of problems when dealing with these batteries: the first one comes from an insufficient recharge process, which eventually will lead to a capacity reduction of the battery pack; the second and more serious, it's related to several factors such as inappropriate voltage levels, temperature offsets, deep discharges and electrodes sulfating process, that either acting alone or together might cause reductions above 50% in batteries useful life.

Thus, for the last 15 years, research it's been developed in order to find ways to evaluate the battery's degradation level while they are connected to their respective charging system (Figure 1). That would bring the advantage of the on–line battery pack useful life evaluation, which reduces its aging and maintenance costs. One of the methodologies that is under study, and has shown good results, is based on battery's internal resistance evaluation. On previous studies [1] [2], some writers have shown that resistance deviations around 20% of its initial value are correlated to a charge capacity decrease down to 80%, at which this kind of battery is considered being in the end of its useful life [3]. Moreover, studies also show that the impedance module resembles the battery's internal resistance; therefore one can analyze only the module.

The battery's impedance measurement technique consists of injecting an alternated current into the accumulator to measure the alternating voltage drop component. With these measures the impedance module is calculated, in the injected current frequency bandwidth, and the results can be used to analyze its capacity [1] [2] [4] [5]. This technique is often used in packs where the batteries are connected in series so the injected current has a single branch to flow.

The results presented by Hawkins [1] show that the battery's impedance varies with its capacity, frequency, charge level and temperature. Therefore, becomes necessary to pick a frequency, or a band of frequencies, where its behavior was previously known in order to perform the impedance measurements right. It's also needed to monitor the batteries temperature and charge level to always perform the evaluations under the same charge conditions, best around 100% charge level.

Due to some questionings on the conclusions gotten with the impedance measurement results, this work considers to integrate the measurer to the battery charger (Figure 1). The main goal is to get a periodic battery analyzer, that holds these periodic measures and the own battery values, allowing to judge its useful life through their comparisons and analysis.

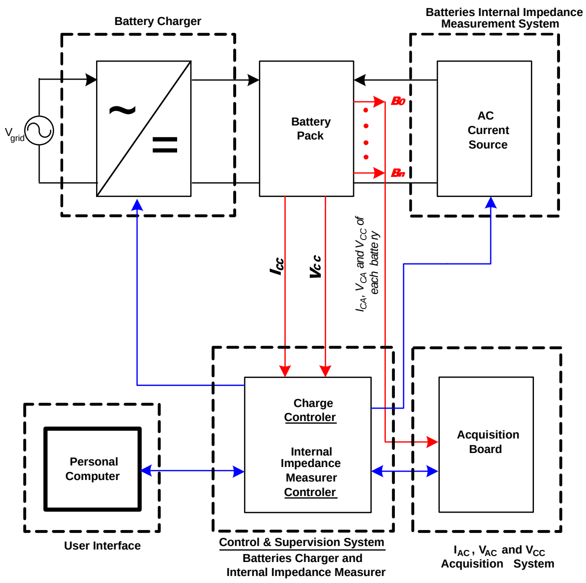

Figure 1 –Block diagram of the considered system.

II. SYSTEM DESCRIPTION

The considered system consists of a battery charger with the following characteristics: a charging algorithm that reaches the bulk voltage, guaranteeing that the batteries are 100% recharged; floating voltage reference compensation due temperature offsets, preventing insufficient recharge, irreversible sulfating and premature corrosion of the positive grating; sulfating protection, applying every 6 months a recharge process in the pack, even when fully charged, using bulk voltage to promote the electrolyte mixture. This problem might occur when the batteries are held long periods under the same charge state.

Each one of these characteristics aims to optimize the batteries useful life. It's also considered, the addition to the charger, a circuit to evaluate the batteries useful life through the measurement of its impedance, continuous voltage and the temperature. These measures will be made periodically and kept in the microcontroller until the user connects itself with the system, through a PC (Personal Computer), and download the data for further analysis.

When placing together the impedance measurer and the battery charger, one can make periodic checkups, getting the pack status to detect possible imperfections and/or the batteries useful life end. With the data base created throughout the use of the equipment it is possible to analyze the variation of the impedance and not only its magnitude. The charger power circuit design methodology (transformer, rectifier and Buck converter) follows the traditional methodologies and is presented in [6]. In this work it will be given special attention to the batteries evaluation system.

III. BATTERIES EVALUATION SYSTEM

The batteries evaluation system proposal consists of a circuit with impedance, continuous voltage and temperature measurers. The impedance circuit measurer injects and measures an alternating current (I_{CA}) in the batteries pack, measures the alternating voltage drop caused on each battery (V_{CAn}) and, with voltage and current values, calculates the battery impedance module (Z_n) in the frequency of the injected current, as illustrated in Figure 2.

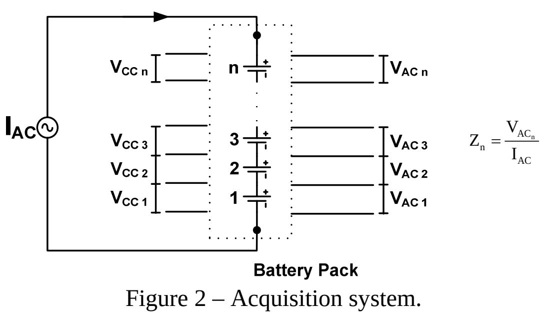

Figure 2 – Acquisition system.

To verify the batteries bulk voltage and possible problems such as short circuit in its cells, the measurement of the continuous voltage (V_{CC}) in each battery is made, as also illustrated in Figure 2.

A. AC Current Source Design

Due to AC current source circuits found in literature and the desired features, the circuit presented in [4] is considered as basis, of course with some modifications. The suggested circuit applies the AC current (60 Hz) into the battery pack, that might come from the electric grid, does the electric isolation and voltage levels matching through a transformer (T_1) and uses a series capacitor (C_1), on the secondary winding, to block any continuous current components and to limit the AC current that has been injected into the battery pack. It's also considered to place a high value electrical resistance (R_1) in series with the capacitor, through S_1 relay, so C_1 can be pre-charged and will always be charged with V_{bat} as long as S_1 remains on the position "2". To inject the AC current in the batteries, the secondary winding is connected in series when placing S_1 on the position "1", as illustrated in Figure 3.

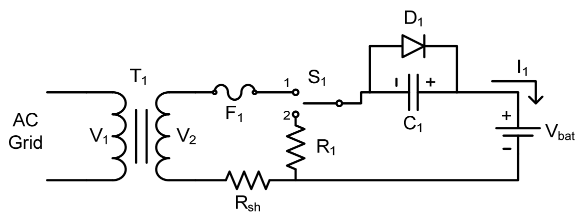

Figure 3 – AC current source electric circuit.

The analytical study of the circuit presented in Figure 3 shows that the current source behavior can be described by means of equation (1), which it's also used to find the peak value of the AC current injected in the battery pack.

$$I_1 = C_1 \cdot \sum_{n=1}^{k} \frac{V_{2n} \cdot n \cdot \omega}{\left(1 - (n \cdot \omega)^2 \cdot L_{T1} \cdot C_1\right)} \cdot \cos(n \cdot \omega \cdot t) \cdot \quad (1)$$

L_{T1}→ Transformer leakage.

B. Acquisition Board Design

The batteries internal impedance measurement technique rests on an adequate circuit to measure the AC current and voltage components on each battery. Besides these two measures, it has also been considered to measure the continuous voltage, aiming to monitor the individual voltages of each battery of the pack. The difficulties found in these acquisitions are the low AC voltage levels to be measured, due to batteries low internal resistance and the high voltage offset, due to batteries series connection. Moreover, the AC voltage is overlapped to the DC voltage of each battery.

The acquisition board, considered in this work, can be split in to four parts: the first one, shown in Figure 4, is composed of a set of resistive dividers (gain), one multiplexer and two voltage followers (used as buffers). The other three parts are used to acquire all the other necessary signals. That is, the batteries DC and AC voltage portions, and the current injected in the bank. Figure 5 shows the block diagram of the batteries DC voltage measurer stage, the structure used to measure the AC voltage is described through block diagram in Figure 6 and finally, the structure to measure the AC current injected in the battery pack is shown in Figure 7.

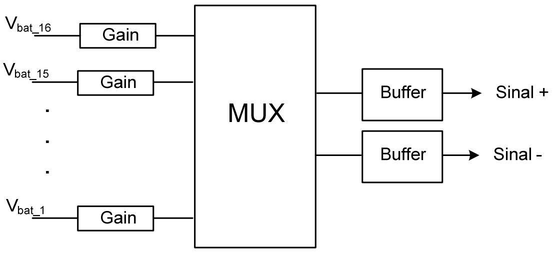

Figure 4 – Battery selection circuit.

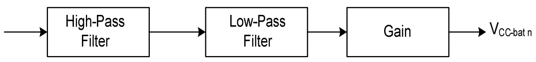

Figure 5 – DC voltage acquisition diagram.

Figure 6 – AC voltage acquisition diagram.

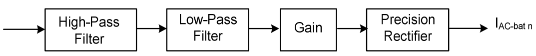

Figure 7 – AC current acquisition diagram.

C. Monitoring System

The battery charger monitoring is done through the Microchip® microcontroller PIC®18F4331. The block diagram presented in Figure 8 gives us an overview of the monitoring system created with the PIC to control the batteries charging algorithm, impedance evaluation system, serial communication with PC and user interface.

The microcontroller main function is to control the system when performing a battery evaluation routine. This can happen in two ways: one through an internal clock implemented through a PIC timer, which informs to the system to make the measurements; and the other one by means of a button in which the user, when desired, can request the batteries analysis. The measurements will only be made if the batteries are fully charged, this means that the charger must be in the maintenance voltage stage, holding the voltage V_{bat} on fluctuation level and maintenance current on the batteries. It is considered that these measurements are automatically made on a weekly basis. This period choice considers the batteries useful life on average, around 3 to 4 years, and that its capacity does not change significantly in one week.

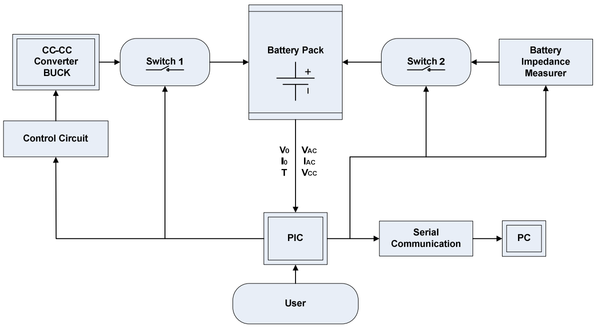

Figure 8 – Monitoring system block diagram.

While the impedance measurements have been done on the batteries the system disables the charger power stage, switching off S_1, detaching the charger from the batteries. After this, it closes S_2 to inject the AC current in the battery pack. Later, the PIC determines which battery must be evaluated, makes the measures of DC voltage (V_{CC}), AC voltage (V_{AC}), AC current (I_{AC}), temperature and stores these values on its EEPROM (Electrically Erasable Programmable Read Only Memory).

Because this memory is non-volatile, it can retain the data avoiding information losses during an unexpected system disconnection. When finishing the measurements, the PIC then releases the batteries charger again. With the stored AC/DC voltages and AC current measurements, the microcontroller can estimate the impedance of each battery and perform a quick test.

At the implemented system the stored measurements of voltage and current are sent to a computer, where a dedicated program calculates the impedance. This strategy improves the impedance value accuracy's, but it possess disadvantages such as the need for more room on EEPROM, to store the data, and removes from PIC the possibility to analyze the values of the measurements.

The impedance reference value of each battery of the bank, used in the calculation of the normalized impedance and in the evaluation of its useful life, must be gotten from the data measured. It has been suggested that when the battery is new, or right after the first charge cycle, that it should've be submitted to at least twenty impedance measurements, sequentially and under the same charge conditions. Then the average of these impedance measurements becomes their reference values. This is necessary because there are significant differences between the individual batteries impedances. This is easily achieved in this system due to the fact that the evaluation circuit was integrated on the battery charger, so these measurements can be done when installing the battery pack.

IV. EXPERIMENTAL RESULTS

This research was initiated performing an experiment to verify the methodology of the impedance test and the impedance frequency response of lead-acid batteries. The tests consisted of injecting an alternating current of 5A, from 10 Hz to 1000 Hz, in three batteries, each one under a different remaining useful life.

Figure 9, presents the impedance modules of these three previously mentioned batteries, where battery C, that it's totally damaged, have a very higher impedance value when compared to the others. Among the two remaining batteries A and B, one new and the other damaged, battery B possess an impedance around 50% to 80% greater than battery A (depending on the frequency). This behavior proves that the capacity's reduction of the battery (or the end of its useful life) causes an increase in the batteries impedance. These test results strengthen the impedance technique, being visible that the batteries internal impedance varies with the reduction of its capacity, and that this phenomenon can be monitored through the impedance's module. Finally, the batteries phases, presented in Figure 10, do not change with the end of its useful life. These conclusions demonstrate that this technique can be implemented to assist in the monitoring of the batteries useful life in UPS systems.

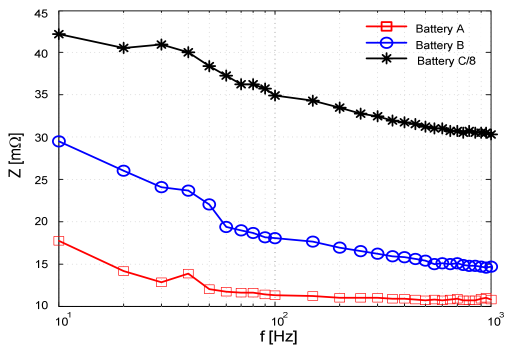

Figure 9 – Batteries impedance module.

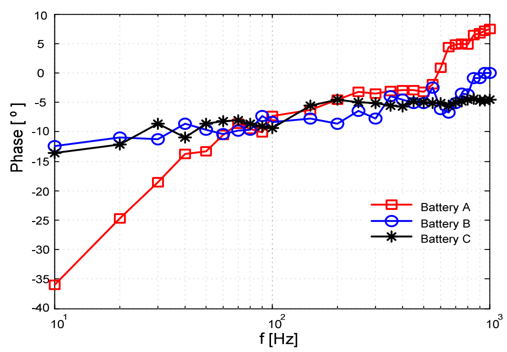

Figure 10 – Batteries impedance phase.

It was built then a battery charger prototype of the considered system, with charge current up to 8A that was next connected to a sixteen 12V@36Ah battery pack, associated in series, resulting in 192V DC link.

The recharge current was set to 4,6A due to capacity of the batteries. When initiating the test, the battery pack presented a voltage of 180 V. The voltage and the load current behaviors during the recharge process are shown in Figure 11 and Figure 12, respectively.

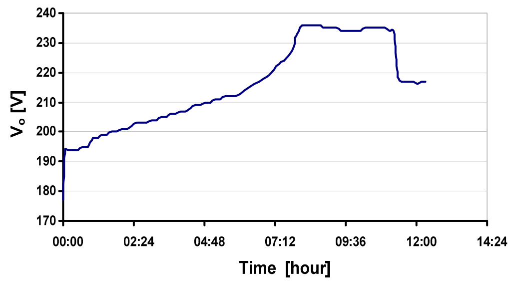

Figure 11 – Battery pack voltage.

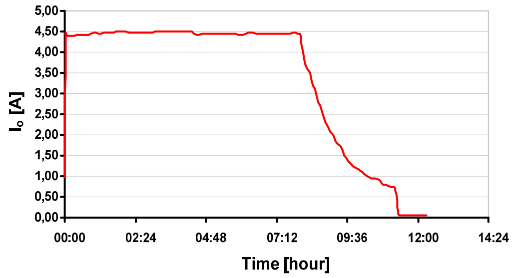

Figure 12 – Battery pack charge current.

After that, during the month of Jan/06, fifty measurements in the bank of batteries have been made to evaluate the considered system. The results of the 1, 2, 3, 4 and 16 batteries impedance behavior of the bank are presented in Figure 13 (magnitude) and in Figure 14 (normalized value).

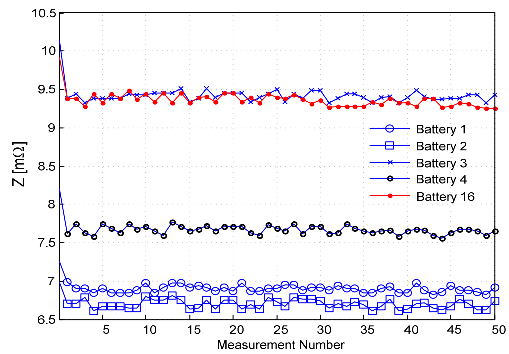

Figure 13 – Impedance measurements.

Notice that even using batteries of same brand/model, the impedance values vary from 6,5mΩ to 9,5mΩ, which means, next to 31%. It strengthens the proposal to analyze only the normalized value. Another excellent factor is the impedance magnitude order that is in the band of some "mΩ" that restricts the maximum error of the impedance measuring system around ±2%, due to the used circuits.

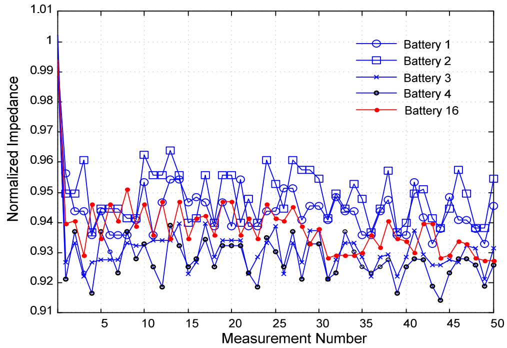

Figure 14 – Normalized impedance.

The measurements results of the some batteries continuous voltage are shown at Figure 15. It can be seen a variation around 60 mili-Volts, which shows that the batteries were evaluated under the same charge state [1] [2].

The temperature measurements during the tests are presented in Figure 16. It can be seen a variation around 1°C, which also shows that the batteries were evaluated around the same biasing point as needed.

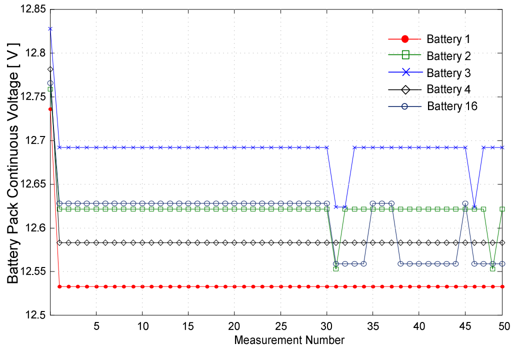

Figure 15 – Continuous voltage.

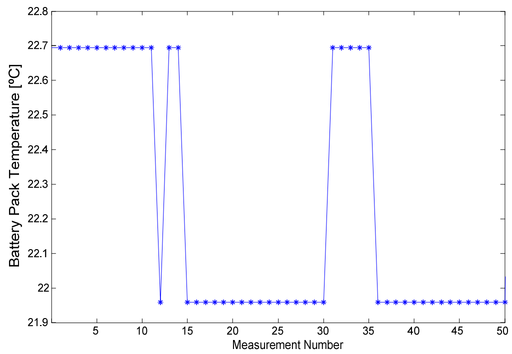

Figure 16 – Ambient temperature.

V. CONCLUSION

The considered battery charger control system has been capable of recharge the batteries applying the adequate charging algorithm performing the reference compensation due to temperature offsets. Moreover, the system prevents problems such as sulfating of the batteries, applying a recharge in the battery pack each 6 months.

The embedded battery charger evaluation system allows us to get a description of the measures of continuous voltage, impedance, normalized impedance and temperature, of all the evaluations executed in the battery pack. These data are displayed in graphs for the user, who can evaluate the batteries while the system is on-line. The module's graph of the normalized impedance directly shows the state of the battery useful life. When its value is above of 120% of the battery reference value, it can be considered inadequate for the use [1] [2] [4] and [5]. But it is interesting to observe the temperature in the bank during the measures and the continuous voltage, which can bring information of short circuits on its cells, short circuit in wires of the measuring system, discharged battery and other problems. It is considered to use a reference value of the impedance for each battery, calculated through measured values while it stills new. This because the impedance varies with model, capacity, method of construction and even inside of the same set of batteries.

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