A FAST METHOD OF IDENTIFYING RECHARGEABLE BATTERIES CONDITION AND DEFECTS

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Abstract: The paper presents fast method of identifying industrial and general use rechargeable batteries condition and defects exemplary lithium-ion cells. The proposed method is based on measuring a internal battery electrical impedance for selected frequency points and the next the results are compare with reference characteristics. Diagnostic process is performed for a few minutes when the battery is charging or discharging. So far used, the most popular methods require controlled charging and discharging cells to determine approximately of their capacity and need a long time of the diagnostic process (about few hours to over a dozen hours). The new method allows the dramatically reduction of measurement time and in effect reduces financial work costs of service. The paper shows a various setup systems with commonly use RLC impedance bridges were used in the research. The analysis of measurements allowed to determine the specific spectral function, which indicates rechargeable battery condition. Moreover, it is also possible to apply the obtain method to another electrochemical cell type.

Keywords: Lithium-ion batteries, Electrochemical impedance spectroscopy

1. INTRODUCTION

The correctness work of automation and electronics systems in many industrial applications depend on the reliability of the battery power supply. Often defects or internal damage in the batteries can't be unseen at first glance (Mohanty et al., 2016). In the effect it unexpected after some time disrupts system's work and produces financial losses. The commonly used diagnostic methods are impractical because they require long hours controlled charging and discharging cells process.

The present method based on an impedance spectroscopy of the internal battery impedance for selected frequency points. The cell internal impedance spectroscopy is currently used worldwide in many science centers as a research technique for electrochemical cells (Frank et al., 2015; Depernet et al., 2012; Huang et al., 2015; Yokoshima et al., 2015; Ferg et al., 2013; Kindermann et al., 2015) and fuel cells (Lepage et al., 2012). However, this method is so far extremely rarely used for electrochemical battery in industrial applications. This is due to technical difficulties in measuring small impedance values and with a DC bias (electromotive force of a cell). Impedance spectroscopy is well known in field of electrochemistry and physics. AC (alternating current) investigation, especially those implemented over a wide frequency range can provide knowledge of materials structure and properties. The impedance spectra and the phase shift angle (current versus voltage) are used to determine the electric substitute diagram of investigated object.

Moreover, the impedance spectra and its phase shift angle are used to obtain the Nyquist curve in the complex plane. The each Nyquist curve point (P_{Nyq}) has coordinates given by equation 1.

$$P_{Nyq} = (Re\{Z\}, Im\{Z\}) \tag{1}$$

$$Re\{Z\} = |Z| \cdot cos\,\varphi \tag{2}$$

$$Im\{Z\} = |Z| \cdot sin\,\varphi \tag{3}$$

where:
Z – the impedance of investigated object,
φ – phase shift angle,
Re{Z} – real impedance part,
Im{Z} – imaginary impedance part.

The impedance is a complex number and it consists of real part (eq. 2) - mainly related to resistive effects and imaginary part (eq. 3) - mainly related to capacitive or inductive effects.

The application of impedance spectroscopy follows that the large variety of battery cells, all of they have several common elements – among others all batteries have porous electrodes, separator, energy-storing material and conductive additive. Instead of focusing on particular chemical compositions and structure, a general approach to battery kinetics can be based on analyzing the impedance spectra of the above common components (Barsoukov and Macdonald, 2005).

2. METHODOLOGY OF RESEARCH

Impedance measurement can be performed in an exemplary ways: using RLC bridge with high capacity capacitors (10 mF and 3.3 mF) for DC bias separation and resistors connected to controlled high performance stabilized power supply unit – fig. 1. The stabilizer consists two-step stabilization system with integrated circuits LM7824 and LM317 as the end voltage source. This solution provides the very large value of ripple rejection coefficient. The According to the superposition theorem in electrical circuits, the battery current is a sum of AC signal generated by RLC bridge and the DC signal from stabilized power supply unit. The RLC bridge HIOKI 3522 and Hameg 8118 were used. The resistor R_p is used to control charging or discharging current. If the switch is preset in position "1" on figure 1 then the battery is charging, and if it is preset "2" then the battery is discharging through resistor R_d.

Another measurement way uses the current source – Fig. 2. The physical implementation of the current source based on also two integrated circuits LM7824 and LM317, which the second one is configured as the proper DC end current source. Theoretically the current source is an open circuit for the AC signal from RLC bridge and the DC signal is blocked in capacitors (similar to the previous diagram). The value of current in the current source is controlled in range of -1.5 A to 1.5 A.

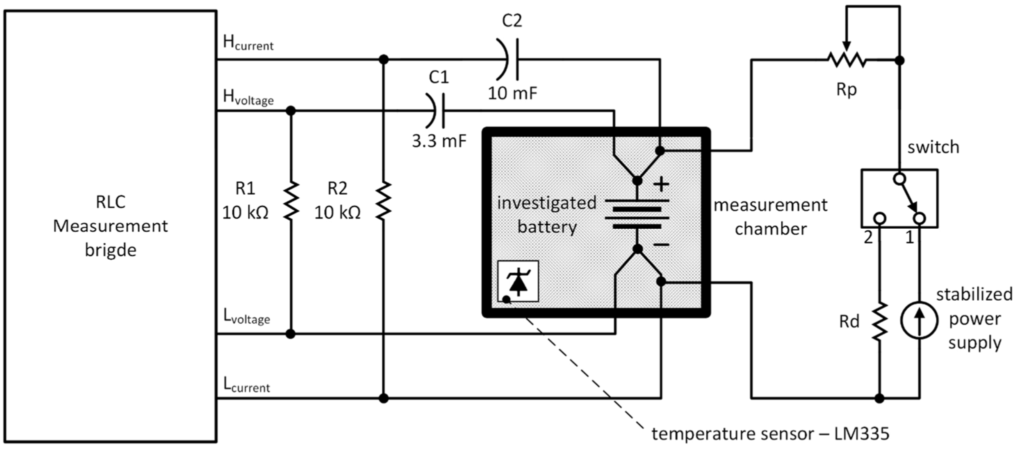

Fig. 1. Simplest schematic of measurement circuit with voltage DC source

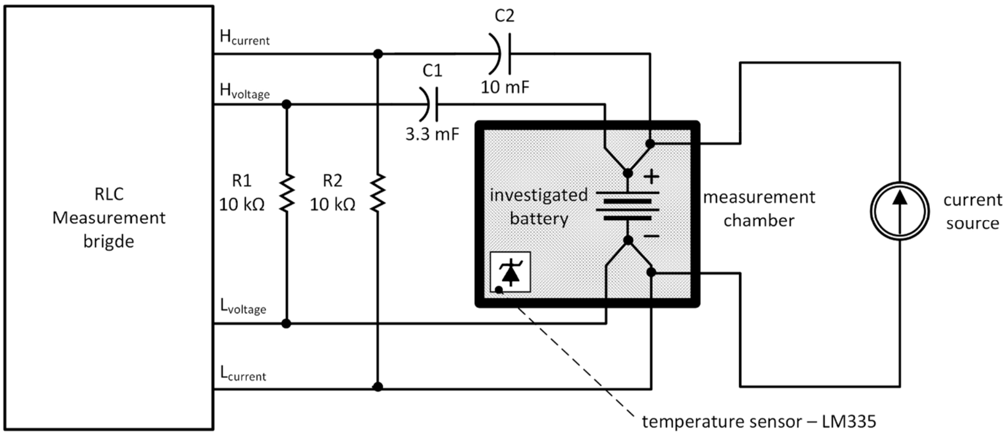

Fig. 2. Simplest schematic of measurement circuit with current DC source

As a result of the analysis of many experiments, the electrical properties of circuit on Fig. 1. are better in compare to properties on Fig. 2. It is related to the lack of impedance stability of current source on Fig. 2. at the medium and high frequency as a result of action of the external AC signal (from RLC bridge). Therefore, the circuit on Fig. 1 was qualified to mainly measurements.

3. RESULTS

The experiments were performed using three rechargeable batteries each the Li-Ion ICR18650-22FU Samsung (nominal voltage of 3.7 V). The first one is a new unused battery, the second one is after 200 cycles and the third is worn out (after more than 2000 cycles). A capacity of the new battery is 2.2 Ah. The impedance measurements (using RLC bridge – Fig. 1) were made simultaneously charging or discharging process. Before beginning an every experiment, the measurement setup was calibrated (in full frequency spectra) for short circuit and open circuit (in the place of battery). In this way, the influence of resistance of current wires and capacitive reactance of capacitors were eliminated. The figure 3 presents the exemplary Nyquist characteristic during the battery discharging.

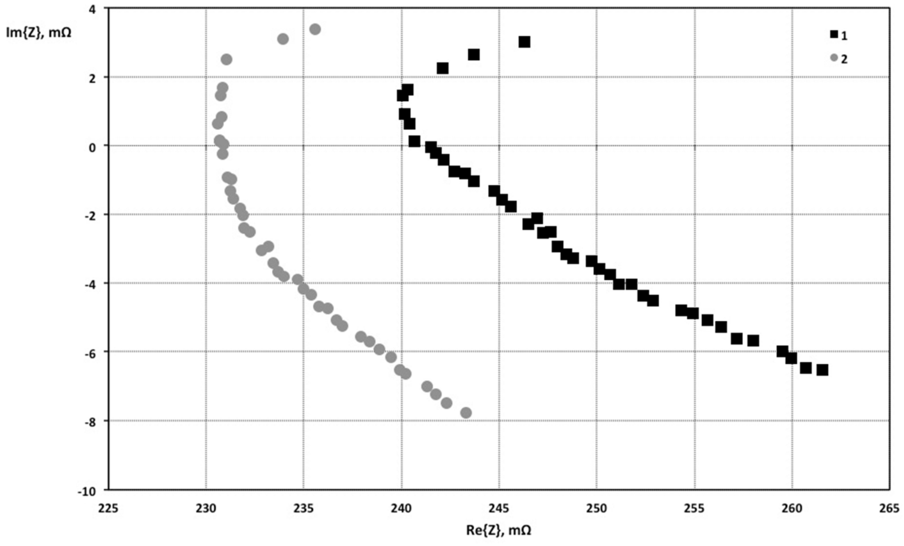

Fig. 3. Nyquist characteristic of internal impedance of investigated battery during the discharging process: 1 – the beginning of discharging, 2 – after 90 minutes of discharging. Experiment conditions: discharging current 1 A (0.455 Capacity), temperature 23°C

The most important characteristics are given by (eq. 4) presents the frequency spectra of impedance module to impedance module at 10 kHz ratio (individual for each battery).

$$r(f) = \frac{|Z(f)|}{|Z_{10kHz}|} \tag{4}$$

where:
f – frequency,
Z(f) – internal impedance of battery,
Z_{10kHz} – internal impedance of battery at 10 kHz.

The characteristics of Fig. 4 show nine points only for each battery. It enough to quick rating of the condition of the battery. All curves touch at only one point – at frequency of 10 kHz. Moreover, the wide temperature range (22℃ to 60℃) measurements have proved the very low and negligible influence of temperature changes for points position of Fig. 4. It is a consequence that, the above characteristics include relative values. An exact explanation of this effect in the field of electrochemistry is the subject of our further research.

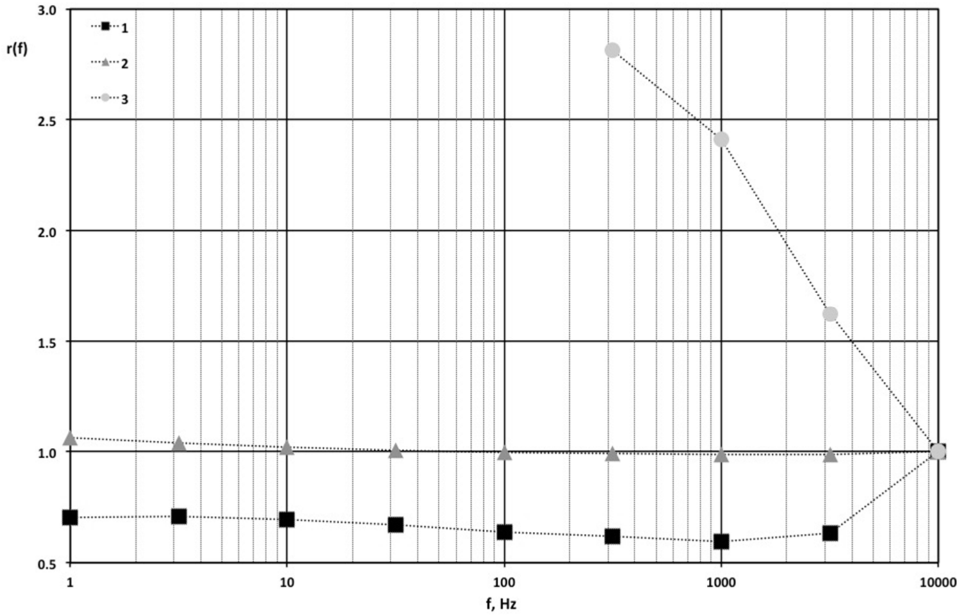

Fig. 4. The frequency spectra of *Z(f)/Z₁₀ₖHz* ratio for three batteries while beginning discharge process: 1 – new, unused battery, 2 – after 300 cycles battery, 3 – worn-out battery. Experiment conditions: discharging current 1 A (0.455 Capacity), temperature 24℃

4. CONCLUSION

The research results indicate a relationship between Li-Ion battery defects or their degree of deterioration and the frequency characteristics of battery internal impedance obtain by impedance spectroscopy method. The measurement procedure takes about 4 minutes of time only. This is an incomparably better result than so far used methods that require many hours diagnostics process. The new-presented method will be useful during service works in an industrial facility and it dramatically reduces financial costs. Results of our research (eq. 4) shows that the *r(f)* ratio is a very apt coefficient to indicate Li-Ion battery condition. Although the coefficient has the form of a specific spectral function, diagnostic process requires only few measurement frequency points (exemplary nine points on Fig. 4). A satisfactory effect can be obtained for three measurement points: 10 Hz, 1 kHz, 10 kHz, however, the more number of points ensures greater accuracy. Searching for new methods to quick exam rechargeable batteries condition is well known technical problem in many science centers (Huber et al., 2016; Huber et al., 2017; Zhao et al., 2017).

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