BATTERY INTERNAL RESISTANCE MEASUREMENT - AC METHOD PHASE CALCULATION ALGORITHM

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Abstract:

The internal resistance characterizes the capability of a battery to handle certain load. It determines the battery's power output and a general requirement is that the internal resistance must be significantly lower than the resistance of the applied load [1]. Internal resistance of battery can actually reflect its own characteristics which include the battery state of health, state of charge, inconsistency and thermal runaway [2].

This paper proposes design of measurement device and implementation of numerical method for phase calculation, and impedance calculation from samples of AC test current that flows through the battery and AC voltage measured on the battery cell.

Keywords: *Battery Internal Resistance, Battery Model, AC Internal Battery Resistance, Phase Calculation Algorithm, Discrete Fourier Transform.*

1. Introduction

Internal resistance of a battery has to be considered with some caution, because it is not a simple ohmic resistance and depends on the way it is used for its determination, and also on the state of charge of the battery. With most battery systems the internal resistance increases when the end of discharge is approached, because of reduced conductivity of the formed compounds [1]. There are two methods for determining battery's internal resistance: *AC* and *DC* internal resistance measurement. Because of the complexity of the internal battery resistance, there are several different equivalent models for batteries. For the purposes of this paper the common Thevenin's Equivalent circuit of batteries [3] is used as shown in *Figure 1*.

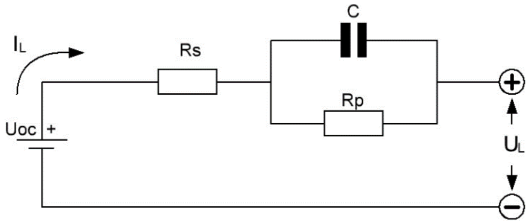

Figure 1. *Thevenin's Equivalent circuit of a battery*

The internal resistance of a battery consists of ***ohmic resistance Rs*** (also known as *electrolyte resistance*) and ***polarization resistance Rp*** (also known as *charge transfer resistance*). The ohmic resistance is composed of *electrode material resistance*, *electrolyte resistance*, *separator resistance*, and *contact resistance* of each part. Polarization resistance is the resistance caused by *polarization in electrochemical reaction*. Polarization includes the *electrochemical polarization* and *concentration polarization*.

In the DC method, the unloaded battery is rapidly loaded and the voltage drop is measured to determine the value of the resistance. *Figure 1* shows that the current flows through electrolyte resistance and charge transfer resistance since the capacitor does not allow the flow of DC current. Therefore, the resulting resistance value represents a combination of ohmic resistance and polarization resistance R_{DC} = Rs + Rp.

In the AC test method, the AC signal of the specified amplitude and frequency is applied to the battery. The amplitude is selected so that the battery remains in the linear mode. By changing the frequency, it is possible to determine the different types of battery resistance. Thus, one of the basic tests in the battery production process is measurement of internal resistance at a frequency of 1 kHz. In this case, capacitor C represents low AC resistance. Resistance obtained in this way corresponds to electrolyte resistance, i.e. $R_{AC-1kHz} = R_s$.

Charge transfer resistance can be calculated simply by subtracting electrolyte resistance measured at 1kHz frequency from resistance measured using DC method i.e. $R_p = R_{DC} - R_{AC-1kHz}$.

Previous statement can be mathematically confirmed as follows: We observe the battery in an AC circuit, as shown in *Figure 2*.

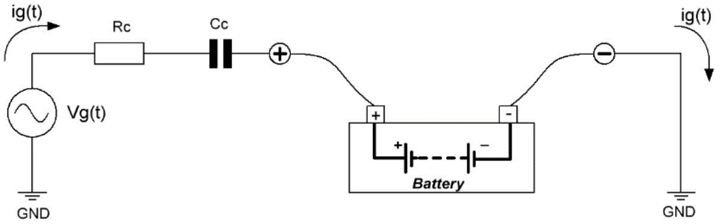

Figure 2. *Battery in AC circuit*

The source generates a voltage waveform described by the relation (1) and forces the current described by the relation (2).

$$v_g(t) = V_g * \sin(\omega t + \varphi_g) \tag{1}$$

$$i_g(t) = I_g * \sin(\omega t) \tag{2}$$

The AC voltage on the battery is given by the relation (3).

$$u(t) = U * \sin(\omega t + \varphi) \tag{3}$$

The AC voltage on the battery $u(t)$ and generator current $i_g(t)$ are precisely measured, and the phase angle of the current can be chosen as 0° (zero crossing detection must be accomplished in phase calculation algorithm) so the impedance of the battery can be calculated according to the relation (4).

$$Z = \frac{U}{I_g} e^{j\varphi} = |Z| e^{j\varphi} \tag{4}$$

Based on Thevenin's equivalent circuit of battery shown on *Figure 1* impedance Z can be expressed as follows:

$$Z = R_s + \frac{R_p}{1 + \omega^2 C^2 R_p^2} - j \frac{\omega C R_p^2}{1 + \omega^2 C^2 R_p^2} \tag{5}$$

Figure 3 shows the change of the first, second and third part of the impedance in dependence of the frequency. First part of impedance is electrolyte resistance Rs and it has constant value, independent of the frequency. The second and third parts are the functions of Rp and C and are dependent on the frequency.

For frequencies less than 10 Hz the second part gives an approximate value of $R_p\,(\omega \to 0)$. The third part is imaginary and has measurable amounts in the range of 10Hz to 1kHz. If the impedance is presented in a complex plane (Nyquist diagram) then a semicircle is obtained (the imaginary axis is with a minus sign) as shown in *Figure 5*. The crossing points of Nyquist curve with the real axis give the values R_s and R_s+R_p. The R_s is obtained when the frequency is very high (AC method), and R_s+R_p when the frequency is very low (the DC method).

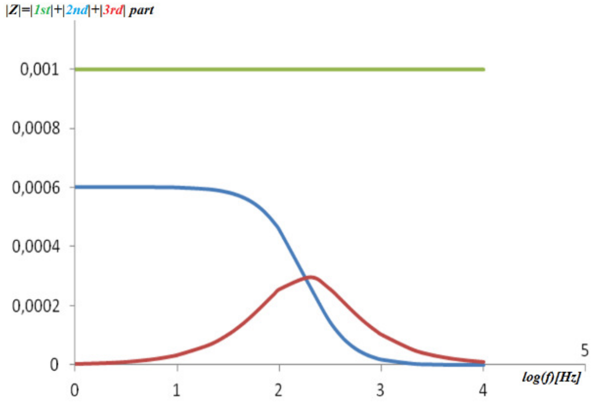

Figure 3. *Change of the first, second and third part of the impedance in dependence of the frequency (100Ah battery)*

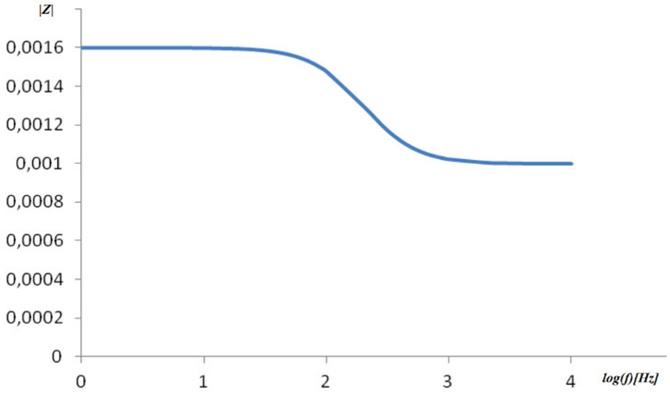

Figure 4. *Diagram of impedance as a function of frequency*

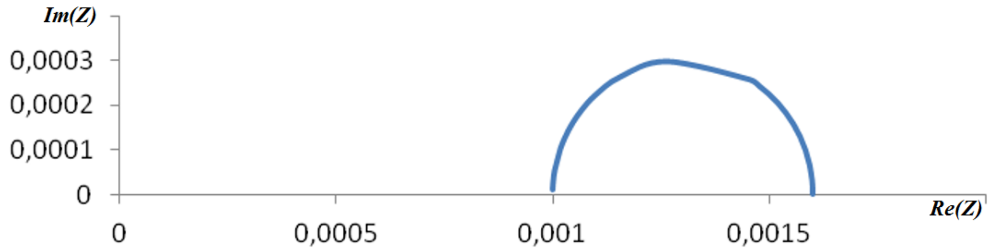

Figure 5. *Diagram of impedance in complex plane*

2. Block structure of a battery internal resistance measurement device

Figure 6 shows the block structure of an internal battery resistance measurement device. Device generates sine wave voltage signal with amplitude from 0-12V and frequency of 1kHz. Sine wave voltage is generated with programmable waveform generator IC, controlled by microprocessor and amplified with audio amplifier capable of sourcing up to 250mA current. Current from the generator flows through *coupling impedance* (resistor R_C and capacitor C_C in series), *fuse* (Cartridge fuse), *probes* (Kelvin probes), *test object* (battery) and *internal shunt resistor* (for current measurement).

Considering that the device measures resistance of up to 5Ω, the coupling impedance is selected so that, at a frequency of 1kHz, it has a dominant value (about 10 times of a test object resistance). That way the source can be considered as a constant current source although strictly speaking it is not.
In this case, it is important that the current remains within the limits determined by the gain of the amplifier in the contour of the internal shunt resistor, i.e. that the amplifiers remain in the linear mode. This condition is fulfilled with an adequate selection of gain and coupling impedance, knowing that the load has a resistance less than 5Ω, as previously stated.

The device records the AC voltage directly from the test object and AC current from the internal shunt resistor. Coupling capacitors at the measurement channels separates AC voltage and DC voltage from battery. Thus, the device collects only the samples of a useful AC signal and blocks the DC signal. An additional measuring channel is used to record the DC voltage of the battery. Based on the recorded voltage and current waveforms, the microprocessor in the device performs the Discrete Fourier Transformation. Based on the results for the first harmonic it is possible to determine the effective values of the voltage and current, the phase shift between them and at the end the impedance of the test object.

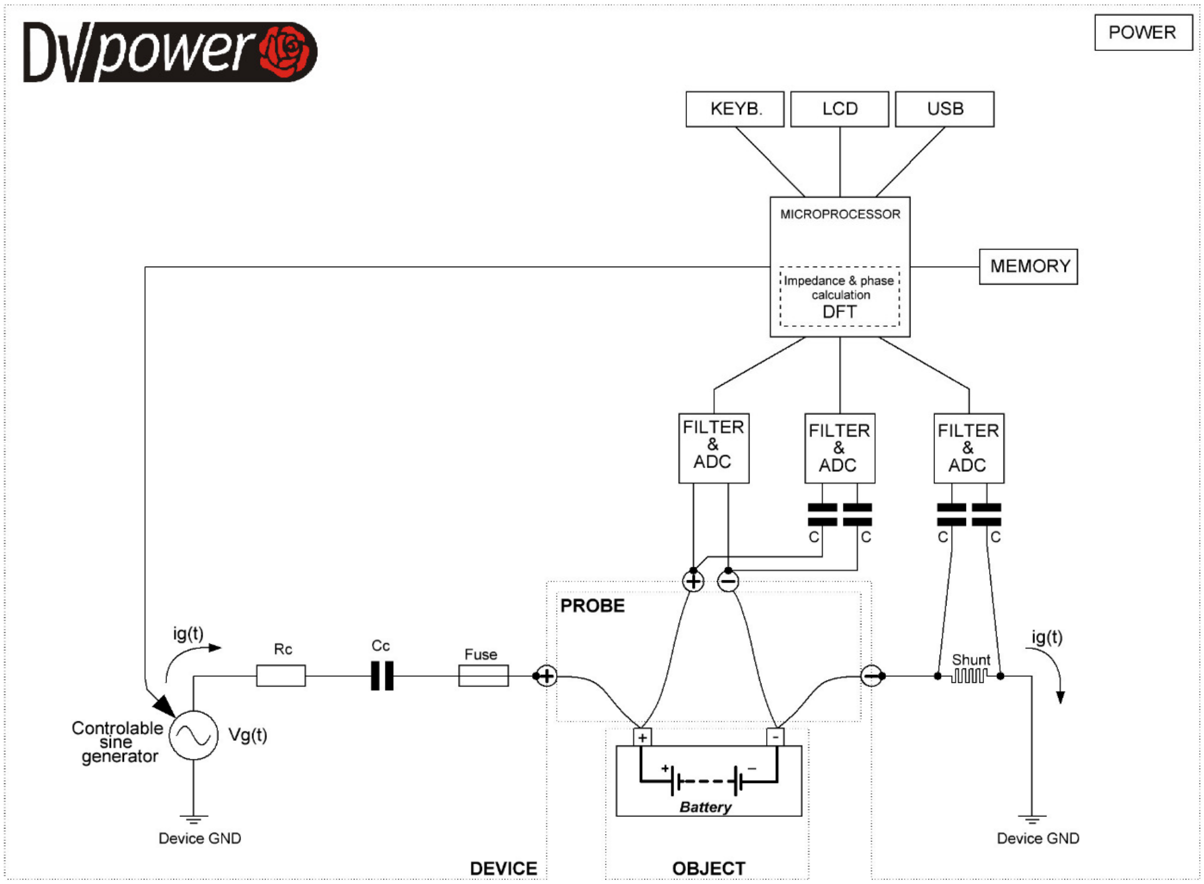

Figure 6. *Block structure of DV Power Battery Resistance Tester (BRT)*

This is the basic difference of the *DV power* concept to determine the internal resistance of a battery relative to the concepts of competing devices that use dedicated hardware modules for phase measurement. This paper describes the algorithm for phase shift calculation between the voltage and the current based on collected signal samples.

Since the system generates only a sinusoidal signal of one constant frequency, it is sufficient to calculate the Fourier coefficients for the basic harmonic only. For this reason, it is crucial that the signal generator within the device generates a signal of a precisely determined and strictly fixed frequency. Noise in the generator contour must be filtered as much as possible. Any deviation in the frequency of the generated signal and presence of higher harmonics significantly reduces the accuracy and repeatability of measurements. Also, the sampling frequency is accurately determined, and the samples are uniformly distributed over the entire interval of interest.

From voltage and current amplitude values, module of impedance can be calculated, and with phase shift it is possible to split real and imaginary part of the impedance. In this case, the real part of impedance is of interest, because it represents AC internal resistance of battery.

Once the result is generated, it is displayed on the LCD screen and the device enters the *hold mode*, where it waits for a new current detection. Results can be saved so that they can later be compared and used to assess the condition of the battery.

Reference:

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