On-line Battery Impedance Measurement Using Oscillation Excitation

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Abstract—**This paper introduces a method of monitoring the internal impedance in a power system. An online measurement technique is presented to determine the internal impedance of the battery. At any given time, uses an excitation current generated by the oscillator circuit and the voltage response is measured. A proper structure of an electrical circuit which could completely simulate the performance of a battery in dynamic load conditions is announced.**

Keywords- Battery; online; Impedance measurement;

I. INTRODUCTION

DC power is required for types of telecommunication equipment and control equipment used at electric utility. A DC power source for these applications is a battery charger [1].

A bank of standby batteries is utilized as a backup DC power source when the AC power supply goes off line, as during a power failure at the electric utility.

Battery systems include of individual cells. A single electrochemical cell comprised of a positive plate, a negative plate, and an electrolyte. Each storage battery with multiple cells being connected in series to form a battery bank having a higher voltage[2].

Each cell has different characteristics, such as energy storage capacity and discharge rates [3]. A low-capacity cell will discharge more rapidly than the other cells. If a cell is over-discharge, then its recharging characteristics are weakened and lead to permanent damage. The damaged battery will have less capacity and will be discharged faster than a healthy battery. A damaged cell affects the operating characteristics of the entire battery. The failure of a cell can cause destruction of the battery system and accompanying equipment. Therefore, there is a need for a system to monitor battery parameters and prevent overly discharging of the cell. Much research has been done to determine battery failure modes by measuring capacity of a battery[4]. One of the most well-known techniques for measuring the capacity, use methods measuring parameters such as impedance, conductance, or internal resistance. these techniques are best suited for identifying gross faults, tracking battery age and making battery life time predictions[5].

From the point of view of the electrochemical analysis, the battery dynamics in the frequency range of mHz up to MHz is described[8]. With regard to electronic model of battery, the impedance spectrum is measured with accurate measuring system for lithium and Lead acid-based batteries.

II. IMPEDANCE ESTIMATION TECHNIQUES

A. Overview

The battery is generally divided into two categories. The first type is non-rechargeable and is suitable for consumer electronic products as Zn-Alkaline-MnO2, Zinc-Carbon, Zinc-Air and lithium batteries. In contrast, Secondary batteries are rechargeable. Examples include lead acid, nickel cadmium (NiCd), nickel metal hydride (NiMH) and lithium ion (lithium ion) batteries. For Telecom applications, secondary batteries are candidates as a power source [3].

A cell is defined as an electrochemical unit, while a battery representing multiple cells is configured in series or in parallel.

An important battery characteristic is the rated capacity of the battery expressed in Ah (Amper-hour), is defined for discharging in operating conditions.

Battery capacity is dependent on factors as environmental temperature, discharge rate, age, service history (i.e. characteristics of the batteries last charge), discharge depth and etc. The capacity of a battery is a non-linear function of these parameters[6].

The battery monitoring system is essential to determine three specific modes, including state-of-charge (SOC), state-of-health (SOH), and state of-function (SOF).

For different types of batteries, impedance-based methods are suggested to estimate SOC.

The impedance of the battery is one of the important parameters can help detect trouble spots hidden in the battery system and used to detect faults in battery packs[7].

B. The Electrical Model Structure

The battery can be equivalent to a voltage source with Impedance[8]. The voltage, current and the internal resistance is the important electrical parameter of the battery which indicates the performance of the battery. A battery cell consists of two ohmic and polarization resistance. Ohmic resistance is composed of electrode materials and contact resistance of each part. Polarization resistance is at the interface between electrode and electrolyte. Fig. 1 shows the common equivalent circuit of batteries include of ohmic internal resistance (Ro), the polarized internal resistance (Rp), and the polarized capacitance (Cp), terminal voltage of the battery (Ut), open circuit voltage of the battery (E).

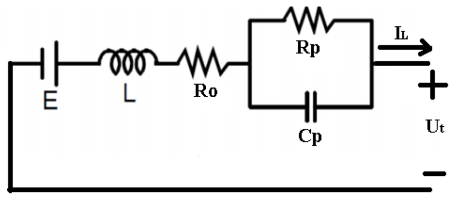

Figure 1. Common equivalent circuit of batteries[8]

According to equation 1 can measure the battery impedance.

$$Z = Ro + \frac{Rp}{1+\omega^2 Cp^2 Rp^2} + jL\omega - j\frac{\omega Cp Rp^2}{1+\omega^2 Cp^2 Rp^2} \qquad (1)$$

Equation shows imaginary part is almost zero when ω is smaller, as in real part "ωCpRp" is equivalent to zero and capacitance effect is removed. At small frequency, the pure impedance value be approximating to (Ro+Rp). At big frequency, the capacitance C has almost shortened, the polarized resistance value-Rp is disregarded, and the internal resistance value be approximating to ohmic resistance-Ro.

In most cases, internal cell resistance until the battery is not near the end of its useful life is almost constant. the increase of internal resistance will be abnormally rapid[1]. The increase resistance value cause be rapid current discharge and therefore the heating effects from high discharge currents will melt metallic connections in internal battery components, causing the battery circuit to open.

C. Methods to Determine the Impedance and Internal Resistance

There are many techniques to estimate the state of health of the battery based on analyzing internal impedance such as discharge test[9], internal resistance[10], impedance spectra[11], EIS[12], Ac impedance[13]. Typical commercial Methods for the measurement of internal resistance of battery include DC discharge and AC injection method. Table.1 it is compares between two methods.

TABLE 1. Comparison methods to measure battery cell internal resistance

Methods	**Online**	**DC discharge**
Connection	Safe	Connection problems
Result	Accurate and Reliable	Error
Accumulated	Avoid the accumulated damage	High rate discharge
Energy store system	Not effect on performance energy store	Require discharge load
Measuring	Ac injection	Dc discharge
Structure	complex	Simple
Failure detection	Fast	Slow
Status	Real time/dynamic	Static

The basic idea of the online method is to excite the battery with a small ac sinusoidal current/voltage signal at a determined frequency f, as ac signal injection, and then measuring the ac voltage response of the battery to the injected ac current/voltage signal in order to determine the ac impedance[14].

Three appropriate methods for measuring internal impedance of battery based on the online method are presented. In the first method, one ac signal is injected to the two ends of each battery. Therefore ac voltage is appeared at the terminals of each of the batteries[16]. The second method, the shunt resistor is placed in series anywhere in the battery string (all the batteries connected together in series). A current is fed to all of the batteries in the string or strings simultaneously. The current is measured through a voltage drop of each battery. This method generally provides cost-effective but path noise is added to current signal and unreliable result follow-up[1]. The third method, the weak ac signal is injected from battery charger to the battery strings. The both Ac Signal and pulse add together and apply to gate of switching transistors at section of DC-DC converter. Design of Output filter is related to frequency ac signal. Measuring the Impedance of a battery is dependence to battery charger system and has not design separately[14].

The first method is preferred at this work. It is considered to produce reliable and accurate results. However, the present method represent a relatively complex and high price.

The measurement module chooses 100Hz-1 kHz as the frequency of the AC signal injected into the battery to internal resistance measurement[15].

III. AC RESISTANCE METHOD

The battery's internal resistance is equal to the change in voltage divided by the change in current at same frequency[16].

A known AC current Forced through the battery terminals. A small AC voltage appears at two end of battery. AC signal can pass through to the next while large dc component is blocked by a coupling capacitor or band pass filter. Then AC voltage is amplified, filtered and measured[16].

Impedance measurement is determined by applying an AC current signal, measuring the voltage drop across the battery and

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calculating the impedance using ohm's Law. That's better, both AC voltage drop and current is measured each cell, and then impedance is calculated, displayed and stored. According to Fig. 2 the block diagram of the proposed internal cell measurement system is shown.

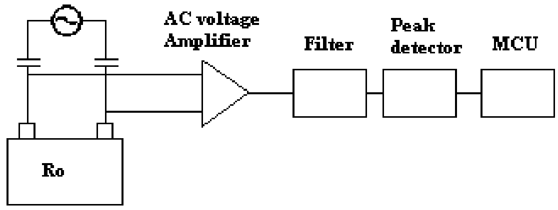


Figure 2. The Block diagram of the readout circuit

The procedure of measuring the internal resistance of a battery includes in the six stages:

- Generate Alternative voltage and then current signal at constant frequency
- The Injection of current signal to two side of the battery
- Readout of the voltage response of battery terminals
- Amplifying and filtering AC voltage signal
- A peak detector Circuit to detect Peak value of the applied AC signal
- Measuring of resistor value by microcontroller unit

The resistive value of a battery to an AC current expressed according to equations 2-4. The resistance inside a battery which creates a voltage drop proportion to current.
Equations related to measuring the internal resistance, to calculate the resistor, injected AC current and voltage response relations in order to determine the final resistor, of a battery:

$$I = Imax \sin(2\pi ft) \qquad (2)$$

$$Vbattery(t) = Vbattery_{dc} + Vac.\sin(2\pi fst + \emptyset i) \qquad (3)$$

$$R(f) = \frac{Vac\_pp}{Iac\_pp} \qquad (4)$$

IV. DESIGN AND SIMULATION

A. Design a battery internal resistance measurment circuit

An impedance meter circuit for measure internal resistance of battery is introduced. The impedance meter circuit comprises an AC current injection and read out circuit.

The impedance meter circuit of this paper permits injection of AC signal current at fix point of frequency to the battery terminal and measuring the corresponding voltage variation of the battery.

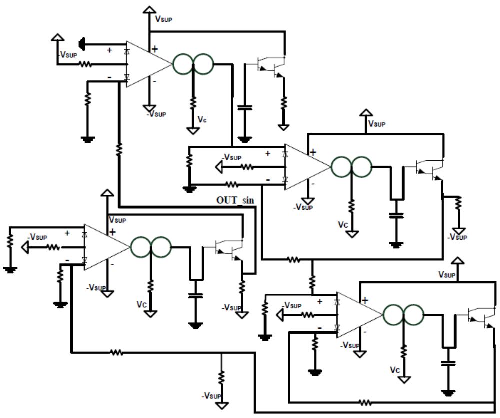
The Fig. 3 shows a schematic representation of the impedance meter. The entire apparatus consists of an AC current source (wave shaper and current injection), a voltage meter (v), a filter, pick detector, and a microcontroller unit (MCU).

The waveform generator circuit as shown in figure 3.A can be operated either from a single power supply or a dual power supply. This circuit is an oscillator with capabilities Frequency and Amplitude Adjustable. The oscillating amplitude range is controlled by Vc voltage. By adjusting the output capacitors and the number of stages, the frequency can be adjusted.

In general, a number of delay cells, which are connected in a positive or regenerative feedback loop for building a basic ring oscillator (R_O), are the main basis of ring-VCO. These delay stages or delay cells are inverting amplifiers. Choosing optimum number of stages for construction of various frequency oscillators are an important part of designing ring-VCO. Thus, for designing the VCO, the 4-stage R_O is chosen to increase the oscillation. Principle operation of the oscillator structure is that if one of the nodes is excited, the wave propagates through all the stages and reverses the polarity of the initially excited node. The connection of the stages is such that input and output have 180 degrees of phase difference to start oscillate. After designing the circuit of the sine generator, it is necessary; the output signal is converted to the current for injection to the battery terminal. The circuit of Figure 3.B of the current source is capable of increasing the signal level of the current.

The sine current with a given frequency, passes through of the battery terminal, and subsequently the sine voltage is appeared proportional to the internal impedance of the battery. The voltage response is readout by sensing circuit according to Fig. 3.C; D. the sensing current includes amplifier, filter, and peak detector circuit.

The value of the battery's resistance is about milliohm. In addition, there is the limitation of the increase in the level of the injected signal; therefore the readout voltage is as small. For this reason, it needs a precise amplifier with the least offset voltage and high input impedance. After amplifying the signal, it is necessary to separate the AC section from the large DC; the Pass band filter is designed as see in figure 3.C. The maximum voltage level of a sine wave is ultimately detected by the peak detector circuit according to figure 3.D.



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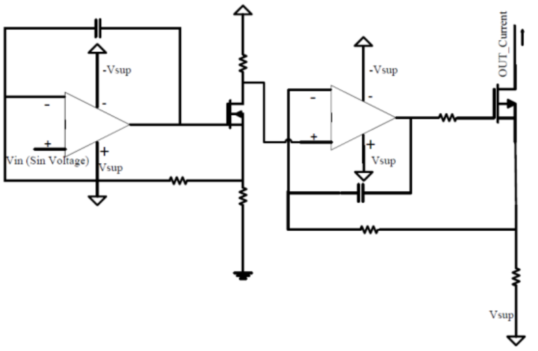

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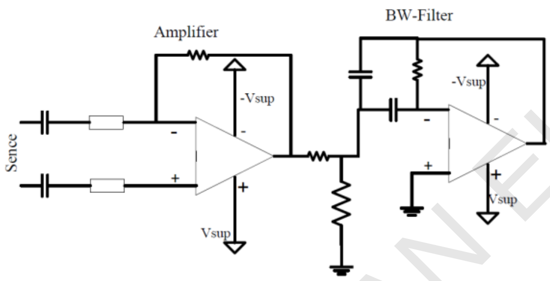

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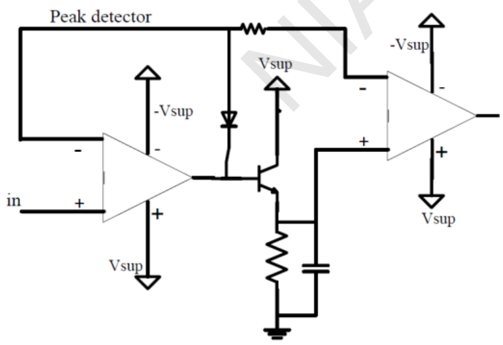
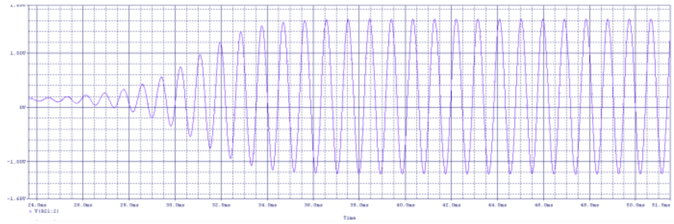


D

Figure 3. Entire system for the internal cell resistance measuring; A) Oscillator circuit; B) Voltage to current converter; C) Amplifier and band pass filter circuit; D) the peak detector circuit.

B. The Simulation Result

The cell used in the experiment was a Nian Battery with a nominal capacity of 200 AH. The MCU is responsible for controlling testing, including the value and frequency of the controllable AC current source, resistor measurement by ohm law. The simulation results of the injection circuit are shown in Fig 4. As shown in Fig. 4.A, the oscillating amplitude is fixed after 30 ms. Results of conversion the voltage signal (Blue line) to current (Red line) as shown in Fig. 4. B



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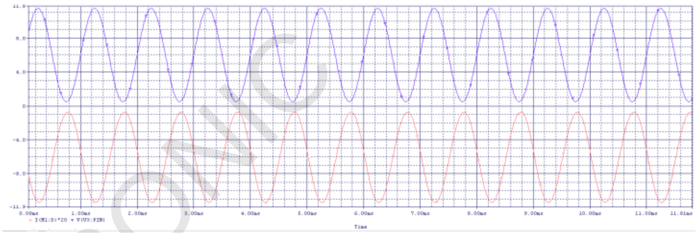

B

Figure 4. The simulation result of the injection circuit. A) Oscillator circuit, B) voltage to current converter

Since the absolute and relative changes in the internal resistance of the battery are small of mohm, it is through precise control that the accurate real-time monitoring of internal resistance can be achieved.

V. SURVEY ON NOISE OF IMPEDANCE METER SYSTEM

In order to measure resistance in a stable manner, the six problem must be evaluated[18].

Effects of wiring resistance: Resistance values on the order of hundreds of milliohms. The wiring resistance values are added to the cell resistance. Two methods exist for measuring cell resistance as the two-wire and four-wire resistance measurement. There are same path for source and sense of signal at the two-wire measurement. Whereas four-wire method inject signal from two-wire and sense it from other two-wire. The second method not add contact resistance to target resistance and detect offset due to extra resistance.

Effects of electromotive force: At the point of contact between two different metals occurs a potential difference refer to Electromotive force. The magnitude of the electromotive force varies with the temperature of the measurement environment. Methods used to reduce the effects of electromotive force include of increasing the detection voltage by using a large measurement current and using an AC detection signal.

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Effects of thermal noise: The resistance have thermal noise. The thermal noise is added to the detected voltage (relate to 4KTR*BW). Thermal noise can be reduced by increasing the detected voltage (greater than the thermal noise) and by increasing the measurement time (to reduce the bandwidth _BW)

Effects of Leak Current: When measurement cable insulation resistance are low, current flows outside the measurement target, introducing error.

Effects of Friction Noise: Moving a measurement cable cause to friction-induced current.

Delicate measurement targets: The measurement a current detection resistor (shunt resistor) is difficult to obtain an accurate measurement using pin-type leads. Leads may cause measured values to vary depending on the dimension, contact pressure and contact angle (error resistance>0.9mΩ).

To avoid this type of effect, detect voltage at located inside the current injection points. Current distribution will have become uniform at injection points at least 3 times the measurement target's width (W) or thickness (t) (as shown in Figure 5).

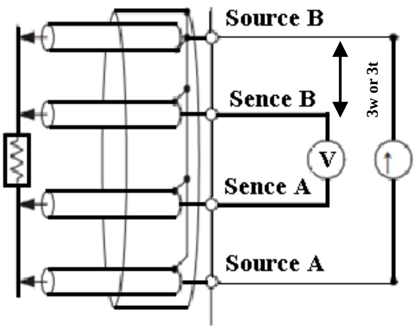

Figure 5. A 4wire cable for injecting of the current and measuring the voltage.

Temperature, External noise, Humidity, effect on measurement value.

VI. The Overall system configuration

Data transmission is also required in the Battery management concept based on DC power. Data transmission is needed for the required performance (voltage, current and battery impedance measuring). One technical solution is Power line carrier (PLC) using the existing power-line infrastructure for communication purposes as see Fig .6. PLC is suitable for slow rate communication and high multipoint systems. The PLC system is connected to power-lines of the DC bus using interfacing circuits. A communication system is built with two main parts, a transmitter and a receiver. the interfacing circuit demodulator and modulator operates to transfer the information to the controller[17].

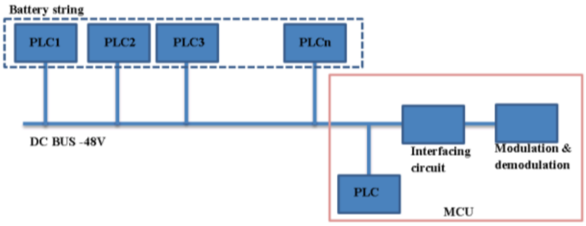

Figure 6. The PLC system for battery meter at the DC power system

VII. CONCLUSIONS

Accurate impedance measurement can be invaluable in the diagnosis of battery health. Important parameters such as SOC, SOH, and temperature affect battery impedance. The aim of this paper is to make an applicable procedure to measure battery's internal impedance. The proposed method is based on the online method. In this method AC signal current at fix point of frequency injects to the battery terminal and measuring the corresponding voltage variation of the battery. The impedance is calculated by the ratio of voltage and current at max point.

A proper structure of an electrical circuit based on ring-VCO circuit, voltage to current converter, Amplifier and band pass filter circuit, the peak detector circuit which could completely simulate the performance of a battery to measure impedance and it is resulted that the proposed method could be a suitable method for engineering design purposes.

In a solution, after measuring the parameters of the battery, transfer data on the DC bus by the power line carrier (PLC) method. The data is transferred to microcontroller unit (MCU) by the power part. The MCU displays each failure in one battery.

ACKNOWLEDGMENT

This research was supported by Mr. Mohammad Ali Chamanian, chief manager of Nian Electronic Company.

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