Development of the High Voltage EIS Instrument for the Evaluation of the Residual Useful Life of the Batteries

배터리의 잔여 수명 평가를 위한 고압 임피던스 분광장치의 개발.

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Abstract

The battery powered electric vehicle (EV) is one of most promising technologies in 21st century. Though the lithium batteries are playing an important role in the EVs, they are only applicable until their capacities reach 80%, the end of its useful first life. Yet, these batteries can live a second life such as Energy Storage Systems (ESS). In order to utilize the Residual Useful Life (RUL) of the batteries the State of Health (SOH) of them needs to be estimated by a nondestructive test such as Electrochemical Impedance Spectroscopy (EIS) technique. Though many kinds of different EIS instruments are commercially available, most of them can only test a battery module less than 10V and the price of the instrument is very high. In this paper a low-cost EIS instrument suitable for measuring the impedance spectrum of the high voltage battery module is proposed and its validity is verified through the experiments. In order to prove the accuracy of the developed EIS instrument its measured impedance spectrum is compared with the results obtained by a commercial instrument. The Chi Square value calculated between two impedance spectrum measured by both developed and commercial instruments are less than 2%, which prove the strong correlation between two results.

1. Introduction

In recent years battery powered Electrical Vehicles (EV) shows a strong uptake in popularity and becomes one of the most promising technologies in 21st century. The battery of these EV`s have their own consumable life which ends at 80% of the designed capacity. Yet, these batteries can live a second life, even when they no longer meet EV performance standards, which typically include maintaining over 80 percent of total usable capacity and achieving a resting self-discharge rate of only about 5 percent over a 24-hour period. After remanufacturing, such batteries are still able to perform sufficiently to serve fewer demanding applications, such as Energy Storage System (ESS), scooters, bikes and etc.

The Electrochemical Impedance Spectroscopy (EIS) has been observed as the most popular technique in the field of electrochemistry to characterize the electrode processes and the complex interfaces. EIS studies the system response to the application of a periodic small amplitude ac signal for which the measurements are carried out at different frequencies [1]. The EIS is the only non-destructive technique carried out to analyze the system response which contains information about the interface, its structure and the reactions taking place inside the electrochemical devices. It is a valuable tool utilized in different areas including applied chemistry, biomedical sciences, physical cells and many other engineering fields. The electrical power sources such as fuel cell, supercapacitor and batteries can be modelled and diagnosed by this useful tool [2]. However, most of the commercially available EIS instruments developed so far are suitable for measuring the impedance of the battery module less than 10V and of very high cost.

In this paper a low-cost electrochemical impedance spectroscopy instrument is proposed, which can measure the impedance spectrum of the battery modules up to 100V without using any external power supply. The system is composed of a commercial data acquisition board (NI-MYDAQ) by National Instrument, signal conditioning and sensing circuits and a GUI software by LabView software. The validity of the proposed system is proved by comparing the measurement results obtained by the developed low-cost impedance spectroscopy system with those by the commercial instrument, BIM2.

2. Development of the system

2.1 Hardware Development

Fig 1 shows the block diagram of the proposed high voltage EIS system. The proposed system is a plug and play device connected to the PC through the USB port. The main PCB board includes signal conditioning and sensing circuits with the feedbacks which send the measured data to the PC. The generated swept sinusoidal signal super-imposed on a dc signal which is half in magnitude to that of generated sinusoidal shown in Eq. (1), is used as reference signals for the current control through a switch. The measured voltage and current signals are acquired by the data acquisition board and converted into digital signals.

$$I_{\max_{P-P}} = I_P \sin(\omega t + \varphi) + I_{dc} \qquad \because I_{dc} = \frac{1}{2} I_{\max_{P-P}} \tag{1}$$

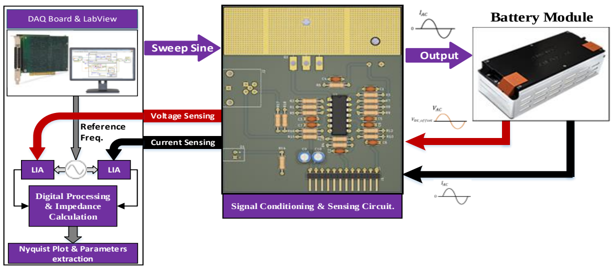

Fig 1 Block diagram of the proposed high voltage EIS system.

The current control is achieved by a precision current sink [3], which controls the gate voltage of the switch by taking the feedback from a shunt resistor as shown in Fig 2. The battery is connected in parallel with the switch. The voltage across the battery is measured by the differential active low pass filter, thereby blocking the DC and allowing only AC to be acquired by the DAQ. The current is also sensed by Rs and amplified through the op-amp. With the acquired current and voltage data, only the required frequency component is extracted and the impedance at a certain frequency is calculated by Digital Lock-In Amplifier (DLIA). The process is detailed in the next section.

2.2 Software development

The software for the proposed system is developed by LabView and Fig 3 shows the front panel of the developed software. When the run button is pressed the system starts to generate swept sinusoidal signals with desired magnitude and frequency range. The

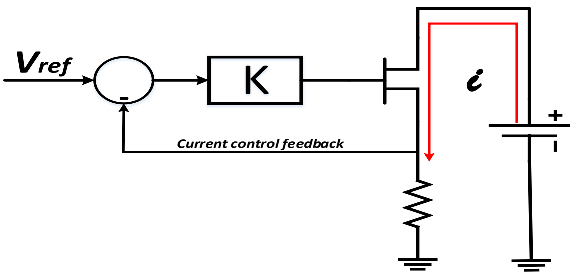

Fig. 2 Control logic of current by Precision current sink.

battery is perturbed and the resulting current and voltage waveforms are acquired by DAQ. The desired frequency component is extracted through DLIA and impedance of that specific frequency is plotted in real time. The DLIA outputs the magnitude and phase information of both current and voltage waveforms and Eq. (2) and Eq. (3) are used to calculate the impedance as shown in Fig. 4.

The measured Nyquist impedance plot is then curve fitted with the model of the Lithium-Ion battery shown in Fig 5. The Complex Non-Linear Least Square Method (CNLS) is used to perform the curve fitting to extract the parameters of the equivalent circuit. The goodness of fit can be evaluated by the chi-square error calculation shown in Eq (4).

$$R=\sqrt{X^2+Y^2} \qquad \theta=\tan^{-1}\frac{Y}{X} \tag{2}$$

$$Z\angle\theta=\frac{V\angle\theta}{I\angle\theta} \tag{3}$$

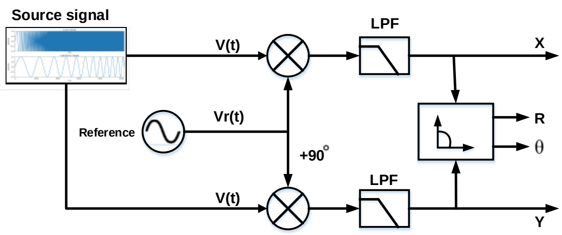

Fig. 4 Block diagram of the DLIA to calculate the impedance

$$\frac{x^2}{v}=\frac{\sum_{i=1}^{n}[(Z_{im}-Z_{ibm})/Z_{im}]^2}{v\sigma^2}\ , \quad Error_{\%}=\sqrt{\frac{x^2}{v}}*100 \tag{4}$$

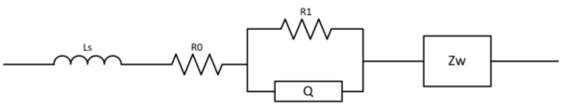

Fig. 5 Equivalent circuit model for the Li-ion battery module

3. Experimental Results

The validity of the proposed system is proven by comparing the Nyquist spectrum measured by the proposed system to that measured by the commercially available instrument BIM2 by BRS Messtechnik with two kinds of battery modules. As shown in Fig. 6 the measured impedance spectrum of the 18650 battery module by the proposed system and BIM2 are well matched each other and shows the chi-square of 0.627%. Fig. 7 shows the results with pouch module and the chi-square is 1.675%. It can be verified from both tests that the results obtained by two instruments show good agreements, thereby proving the measurement accuracy of the developed high voltage EIS instrument. Table I shows the Specifications of tested battery modules.

4. Conclusions

In this paper a high voltage EIS instrument that can measure the impedance spectrum of the battery module has been proposed. It is possible to measure the impedance spectrum of the battery module

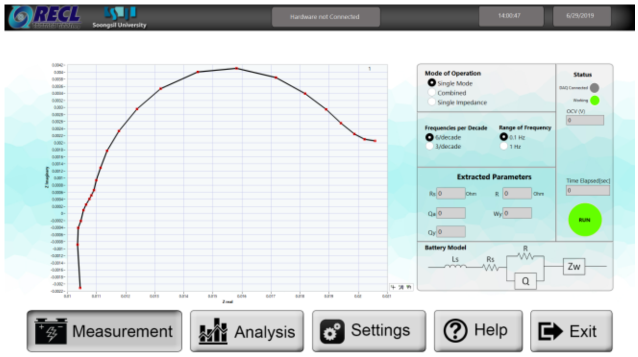

Fig. 3 Front panel of developed GUI.

up to 100V with the developed instrument and it can be utilized to evaluate the RUL of the battery from EV for reuse. Further work is in progress on this instrument to make it compatible for testing a battery pack up to 1KV without using any external power supply.

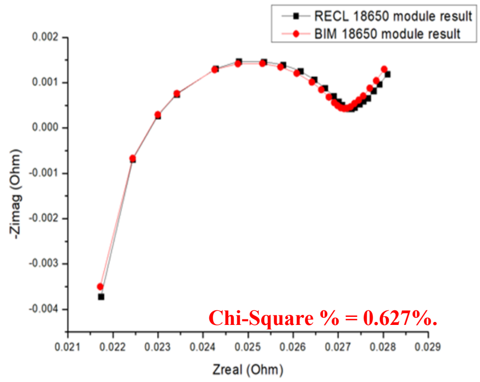

Fig. 6 Comparison of Nyquist impedance plot of 18650 battery module measured by the proposed system and BIM2

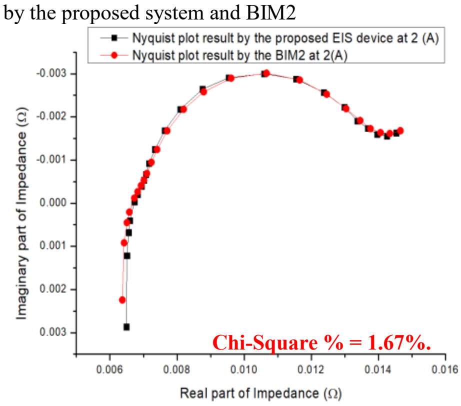

Fig. 7 Comparison of Nyquist impedance plot of pouch battery module measured by the proposed system and BIM2

Table I

Battery Type	Capacity	Nominal Voltage	Connection
Samsung NR 18650 29E module	19.95Ah	14.4 V	4S7P
Bexel 158309 NCM 424 Pouch module	32 Ah	14.8V	4S

References

[1] A. Lasia, Electrochemical Impedance Spectroscopy and Its Applications.

[2] J. Lee and W. Choi, "Development of the low-cost impedance spectroscopy system for modeling the electrochemical power sources," The 7th ICPE, pp. 113-118, Oct. 2007.

[3] Martin Murnane, "Current sources: options and circuits", Application note AN-968 by analog devices.