"I hereby declare that I have read through this report entitle "*High Accuracy Lithium-ion Electric Vehicle Battery Monitoring System*" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation)"

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Date : 17/06/2014

# HIGH ACCURACY LITHIUM-ION ELECTRIC VEHICLE BATTERY MONITORING SYSTEM

**CHAW PUI LING**

**A report submitted in partial fulfillment of the requirements for the degree of Bachelor in Electrical Engineering (Control, Instrumentations and Instrumentations)**

**Faculty of Electrical Engineering**

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

**2014**

I declare that this report entitle "High Accuracy Lithium-ion Electric Vehicle Battery Monitoring System" is the result of my own research except as cited in references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ...........................................

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## Abstract

Battery that widely used in electric vehicle (EV) and hybrid electric vehicle (HEV) is Lithium-ion (Li-ion) battery. This is because these battery has higher energy density and rechargeable. The objective of this project is to design a Li-ion battery monitoring system for Proton PGMC electric car. The system was designed to measure of thirteen series connected $8V$ Li-ion batteries. The performance of the series batteries requires a monitoring system to measure the individual battery voltage and its charging status. Previously, there are several measurement methods had been used for series battery packs which are resistive divider, relay measurement system, localized data processing and voltage transfer circuit. Hence, voltage transfer circuit measurement system is used for this project. It must be carefully designed such that it able to withstand relatively high voltage with higher accuracy. Furthermore, the circuit is also enhanced with battery temperature measurement, and all the measuring data can be transferred to another device for further manipulation. Due to the nonlinearity voltage-charge characteristic of the Li-Ion battery, this monitoring system requires scanning of the individual battery voltage promptly. The result of measurement of battery voltage needed at least in range of ± 1 % accuracy. This method provides a solution which is high accuracy and low cost.

# Abstrak

Bateri yang digunakan secara meluas bagi kenderaan elektrik dan kenderaan hibrid elektrik ialah bateri litium-ion. Ini disebabkan kedua-dua bateri mempunyai kepadatan tenaga yang tinggi dan boleh dicas semula. Objektif projek ini adalah merekabentuk sistem pemantauan bateri Li-ion untuk Proton PGMC kenderaan elektrik. Sistem ini direka untuk mengukur tiga belas $8V$ bateri Li-ion dipasang secara sesiri. Prestasi bateri sesiri memerlukan sistem pemantauan untuk mengukur voltan bateri individu dan status casnya. Sebelum ini, beberapa kaedah pengukuran telah digunakan untuk bateri pek resiri seperti pembahagi rintangan, sistem pengukuran relay, pemprosesan data setempat dan litar pindah voltan. Oleh itu, system pengukuran litar pindah voltan digunakan untuk projek ini. Ia perlu direka secara berhati-hati supaya ia dapat menahan voltan yang agak tinggi dengan ketepatan yang lebih tinggi. Tambahan pula, litar juga dipertingkatkan dengan pengukuran suhu bateri, dan semua data pengukuran boleh dipindahkan ke peranti lain untuk manipulasi data. System pemantauan memerlukan pengimbasan voltan bateri individu segera dengan keputusan pengukuran voltan bateri yang diperlukan sekurang-kurangnya dalam julat ± 1 % ketepatan. Teknik ini menyediakan penyelesaian yang ketepatan yang tinggi dan kos rendah.

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# Chapter 1

# IINTRODUCTION

## 1.1 Project Background

Battery lifespan is one of the important factors for the EV to function properly. Nowadays, the series battery packs are mostly used in automated application such as EV which has to scan individual battery voltage from time to time[1]. Besides, the performance of the series battery packs in EV is very important. For flexibility and economic reasons, the batteries that are used in EV must be a rechargeable battery.

The primary requirement for the battery packs of EV is high power capability, high energy density, long life, high charging efficiency and light weight. Li-ion battery and lead acid battery consist of same properties which are high energy density and high power. Both of them are secondary batteries which are rechargeable batteries. Li-ion batteries are becoming more commonly used compared to lead acid batteries due to lead plates and acid electrolyte is heavier than lithium or carbon anode and lithium iron phosphate cathode. Li-ion batteries can provide the same voltage as lead-acid batteries. In addition, Li-ion is a rechargeable battery types in which lithium ions move from the anode to the cathode during discharge and back when charging therefore, currently Li-ion battery is the most suitable choice for the EV battery[3].

During operation, the battery must be charged and discharged for many times. The battery will be damaged if there is mishandling over them. To handle battery perfectly, one should know its condition accurately. Overcharging or over-discharging will reduce battery lifespan[2]. Furthermore, Li-ion batteries easily to explode when overcharge occur. Therefore, a battery monitoring system (BMS) is required to monitor and measure the individual batteries in order to prevent damage and identify defective segments. The battery monitoring system is designed to scan and measure the individual battery voltage in a fast and accurate manner. Fast measurement is needed to minimize the voltage measurement skew that occurs when large variation in battery before the scan is completed.

Most BMS systems incorporate some form of communications between the battery and test equipment. Some have links to other systems interfacing with the battery for monitoring its condition or its history. Communications interfaces are also needed to allow the user access to the battery for modifying the BMS control parameters or for diagnostics and test.

## 1.2 Problem Statement

Reducing the impact of road transportation on the environment is a mandatory task for the automotive industry all over the world. With no exhaust fumes, the EV is an optimum solution for urban transportation. Currently, more and more electric car and hybrid car can be seen on the road throughout the world. Most of the car implements Li-ion battery. Considering this, it is important to design a fast and accurate battery monitoring system.

In this project, battery monitoring system is made to monitor the cells in 13 series Li-ion battery. Li-ion battery has high power density and high energy density than other types of battery. However, Li-ion battery cannot withstand overcharge. When overcharge occur, it will have a high risk for explosion[3]. Besides, when over discharge occur, it will shorten the battery life.

The voltage of the battery sometimes will be losing charge due to catastrophic factors such as length of usage, length of storage and temperature[1]. However, repetition of battery charging and discharging may cause variation battery voltages due to different characteristics. The voltage life and storage capacity of the batteries will be affected by the imbalance voltage. When the batteries have different voltage level, voltage will not charge or discharged uniformly. Hence, some batteries may occur overcharged or excessively discharged.

The battery monitoring system is required to scan and measure individual battery with very fast and very accurate. This is because there may have large changes of battery voltage occur during the scanning process. Hence, the accuracy of the BMS will be directly affected also.

## 1.3 Objective

The main objectives of this project are:

1. To measure the voltage level of series connected Li-ion batteries with rapid and high accuracy.
2. To design a voltage monitoring system for EV using Proteus 7.1.

## 1.4 Scope

This project will discuss on the performance of the serially connected Li-ion batteries for EV. 13 stacks of 8 *V* battery connected in series are designed for battery monitoring system with low cost, light weight and at least ± 1 % accuracy. The voltage of individual Li-ion batteries that used in EV will be measured and compared. The battery monitoring circuit is simulated by using software, Proteus. The hardware of the battery monitoring system will be implemented and tested. The environmental factors that affect the battery monitoring system will be examined.

## 1.5 Outlines

The design of battery monitoring system may be arbitrarily classified in the following four categories which is operation of Li-ion battery monitoring system for EV, measured the individual battery rapidly, accuracy of the battery monitoring system by design the proper way of measurement and environment factors such as temperature that affect the battery monitoring system.

# Chapter 2

# LITERATURE REVIEW

## 2.1 Basic Principles

As battery in EV facing a repetition charging and discharging, it can causes the individual battery have variation voltage. The battery life will be reduced due to high or low level of voltage. The range of the charging voltage limit (CVL) and discharging voltage limit (DVL) for series connected battery packs shows in Figure 2.1[4].

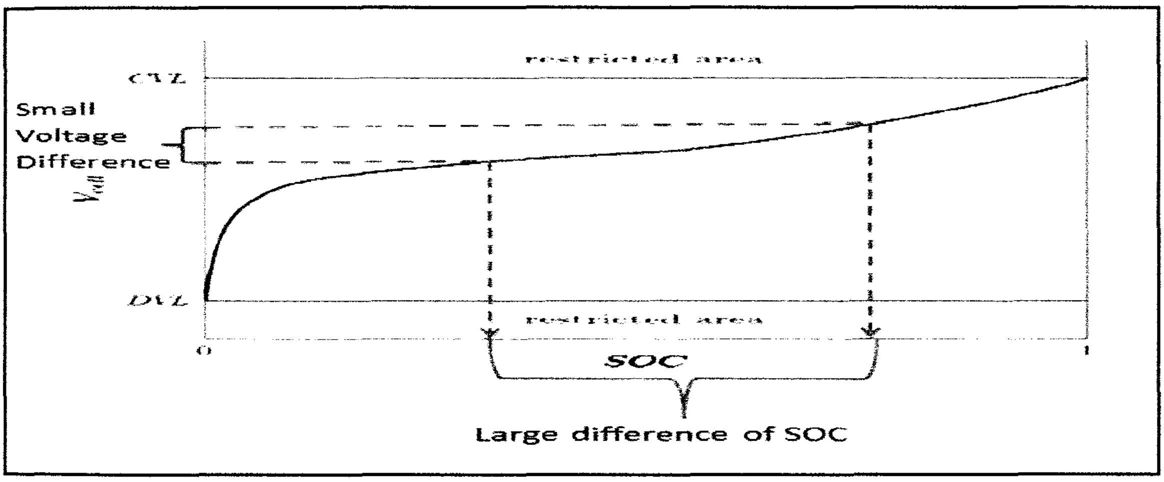


Figure 2.1: Typical Battery Voltage of a Li-ion Battery during Charging or Discharging

From the Figure 2.1, it can be seen that when there is a small voltage difference in the charging process, it can cause a big difference of state of charge (SOC). There are many factors that can affect the SOC such as temperature, battery capacitance and battery internal resistance. During the charging process, as one of the terminal battery voltages has exceeded the CVL limit, the process required to stop immediately. This is to prevent

Li-ion cell damage. It is also similar in the discharging process. As one of the terminal battery voltages has exceeded the DVL limit. At this point, the process required to stop immediately. Charging of the battery stack cannot be continued as one cell is completely charged although others are not. When one the cell is totally empty, the process of discharging of battery stack required to stop as well.

The SOC of a battery, which is used to describe its remaining capacity, is a very important parameter for a control strategy. Battery SOC is an important parameter, which reflects the battery performance and capacity. Hence accurate estimation of the SOC not only protects battery, it also prevents over-discharge, and improves the battery life. Besides that, it allows the application to make rational control strategies to save more energy. The units of SOC are in percentage points which 0 % for empty and 100 % for full respectively. An alternate form of the same measure is the depth of discharge (DOD), which is vice versa of SOC. DOD is the percentage of energy withdrawn from a battery compared to its fully charged capacity. The maximum percentage of total capacity that is permitted to be withdrawn from a battery is called operational capacity of the battery.

For the large Lithium batteries, SOC is particularly important. This is because Lithium is the most chemically reactive of all the common cell chemistries. Hence Lithium batteries require electronic BMS to keep the battery within a safe operating window and to ensure a long cycle life. The major function of the BMS is to control the SOC. Furthermore, most of the automotive applications uses of large number of Lithium batteries. Hence, it needs very precise control of the SOC for efficient and safe management of the energy flows. In EV applications, the SOC is used to determine range of battery capacity.

The performance of a battery stack with different single-cell capacities can significantly be increased when the charge from the cells is equalized with an electronic circuit. This technique called cell balancing. Cell balancing is a technique used to maintain equal or near equal voltage-levels on all cells in a battery pack. This only can be applied for that connected in series, as cells connected in parallel will be self-balancing. The main reason for keeping cells in balance is to keep the batteries capacity as high as possible throughout its lifespan. The battery monitoring system is a protocol for which a battery system can communicate to human being. It can display the cell number and voltage values of the highest and lowest cells.

## 2.2 Research Studies

The general concept of voltage measurement for series battery pack is to measure the voltage of individual battery. Each measurement from the battery packs requires transfer circuit to transfer individual battery voltage to the ground reference such that the measurement voltage safe to operational amplifier and multiplexer, and furthermore it can be used by the data processing system and displays the battery voltage[2]. The actual values of battery SOC can be predicted using voltage data combined with the voltage-charge characteristic. The measured values of the cell voltages can be obtained from the battery monitoring system. The BMS is a protocol for which a battery system can communicate to human being. It can display the cell number and voltage values of the highest and lowest cells. There are several methods used in voltage measurement system of series battery packs. The operation, advantage and disadvantage of each method will be discussed as below. The environment factors such as temperature that affect the performance of the battery monitoring system will be analyzed.

### 2.2.1 Resistive Divider Voltage Measurement System

The resistive divider voltage measurement system is the most common method used to measures battery voltage. This system is the simplest way to scale down a voltage and minimized the high impedances. The voltage of each cell can be measure at each node by using voltage dividers as shown in Figure 2.2. The general formula for resister divider concept is as shown 2.1.

$$V_{B(n+1)} = \frac{R_{(n+1)}}{R_n + R_{(n+1)}} V_{B(n)} \tag{2.1}$$

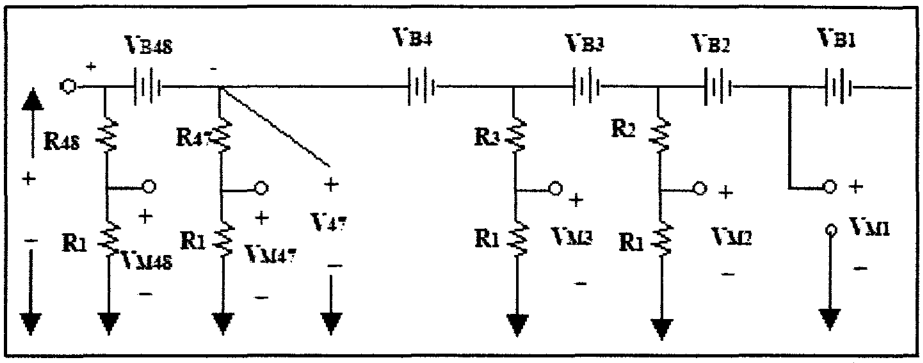


Figure 2.2: Example of Resistive Divider Network

The disadvantage of this method is it must provide switches to prevent the resistors from drawing current from the battery when not in use[1-2]. Besides that, voltages near the top of stack require very accurate divider ratios. For example, consider the top battery contains a stack of n $V_{DC}$ batteries. Then,

$$K_n = \frac{R_1}{R_1+R_n} \qquad ; where\ n = 1,2 \ldots \tag{2.2}$$

If the ideal values of $K_n$ as defined in Figure 2 are

$$K_n = \frac{1}{n} \tag{2.3}$$

$$V_{m(n)} = V_n \times K_n = nV_{DC} \tag{2.4}$$

$$V_n = \frac{nV_{DC}}{K_n} = \frac{nV_{DC}}{\frac{1}{n}} = n^2 V_{DC} \tag{2.5}$$

If the actual of $K_n$ is in error by + 1 %, then it will affect the actual value of $V_n$ by increase + 1 %. Therefore, the accuracy of this system can be directly affected by the divider ratios, $K_n$[1-2].

### 2.2.2 Relay Measurement System

In this system, small electromechanical relay is used to send the signal to the isolation amplifier as shown in Figure 2.3. All the relays are grouped into rows, which in turn divide the stack so that one battery voltage appears as the output of the last row. The isolation amplifier is used to provide galvanic isolation between the batteries and data processing circuitry[2].

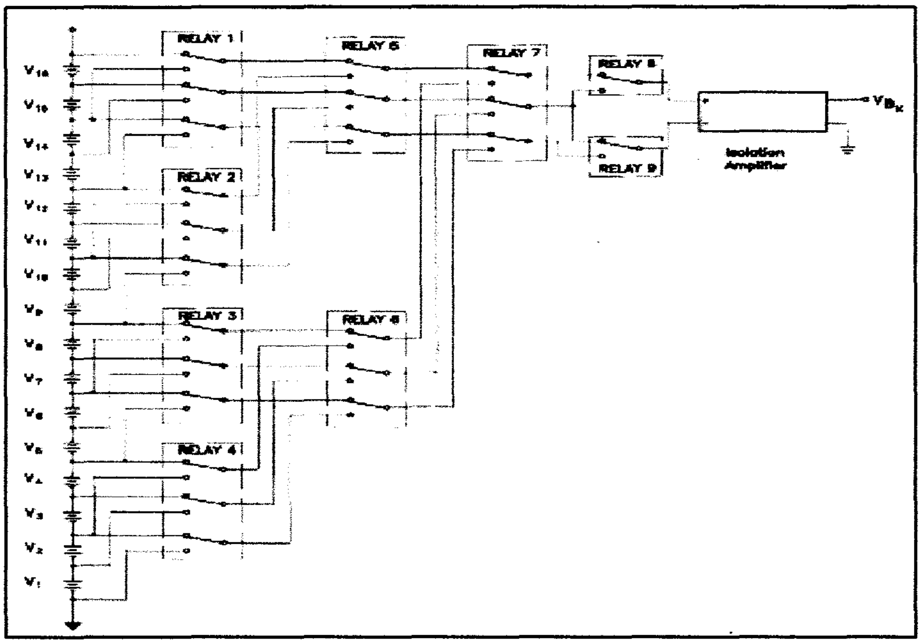


Figure 2.3: Relay Measurement System

The disadvantage of the relay measurement system is high cost and slow response. The signal that sent to the isolation amplifier takes longer time to transfer the battery voltage level. This is due to it requires time to energize or de-energize the relay. When the current flowing through the contactor coil, the electromagnet started to energize. Thus, the contactor will closed causing short circuit for the power to load. Once, the electromagnet de-energized, the contactor will opened. No current will flowing through the load. Hence, delay occurs in this system. From the previous experiment result, Table 2.1 shows the accuracy of the relay measurement system[2].

Table 2.1: Battery Voltage Measurement

| Battery | Measured Value ($V$) | Actual Value ($V$) | Accuracy (%) |
|---|---|---|---|
| B1 | 12.62 | 12.59 | 76 |
| B2 | 12.65 | 12.62 | 76 |
| B3 | 12.56 | 12.60 | 68 |
| B4 | 12.60 | 12.63 | 76 |
| B5 | 12.58 | 12.61 | 76 |
| B6 | 12.57 | 12.60 | 76 |
| B7 | 12.56 | 12.60 | 68 |
| B8 | 12.59 | 12.63 | 68 |
| B9 | 12.60 | 12.63 | 76 |
| B10 | 12.59 | 12.62 | 76 |
| B11 | 12.57 | 12.61 | 68 |
| B12 | 12.51 | 12.55 | 68 |

By using the Equation (2.6) and (2.7), the accuracy of each cell can be calculated.

$$error = \left|\frac{actual\ value - meausred\ value}{actual\ value}\right| \tag{2.6}$$

$$Accuracy\ of\ each\ battery(\%) = (1 - error) \times 100\% \tag{2.7}$$

Figure 2.4 shows the accuracy of the relay measurement system. The accuracy of the whole system is 72.67 % and it can be calculated by using Equation (2.8). Therefore, the accuracy of this system is average.

$$Accuracy\ of\ whole\ system = \frac{\sum B_n}{n} \tag{2.8}$$

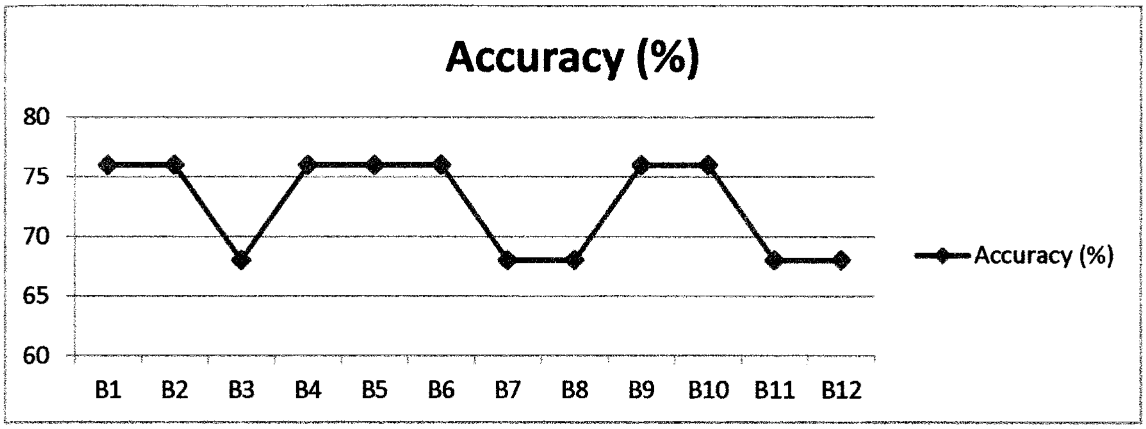


Figure 2.4: Accuracy of the Relay Measurement System

### 2.2.3 Localized Data Processing Measurement System

For this system, it is an expensive system due to it is using one microcontroller for one cell as shown in the Figure 2.5[1]. Besides that, it also consists of analog-to-digital converter and a galvanic isolated serial port. Galvanic isolation is a principle of isolating functional sections of electrical systems to prevent current flow; no direct conduction path is permitted for example fibre optic. For the communication of microcontroller and central processing unit (CPU), a serial data link is used in this system. All the commands in the microcontroller will be recorded in the CPU[1].

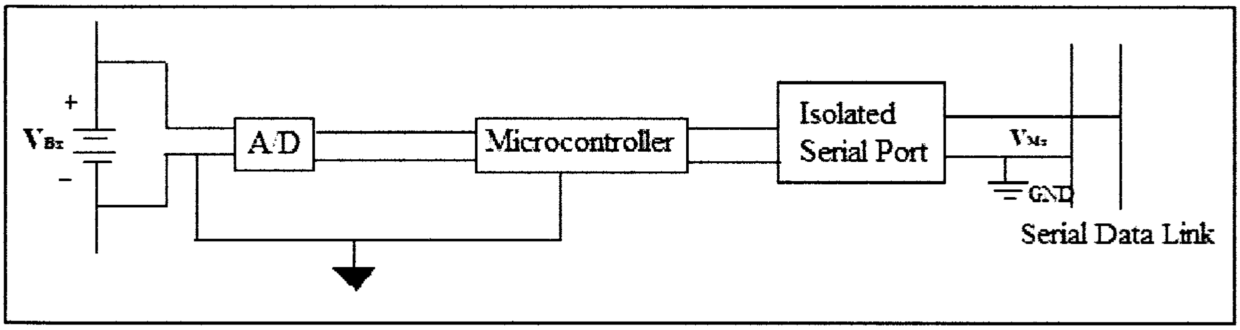


Figure 2.5: Localized Data Processing Measurement System

### 2.2.4 Voltage Transfer Circuit Measurement System

Operational amplifier (Op-amps) and bipolar junction transistor (BJT) is used to designed the voltage transfer circuit measurement system[1-2]. The block diagram of voltage transfer circuit measurement system is shown in Figure 2.6.

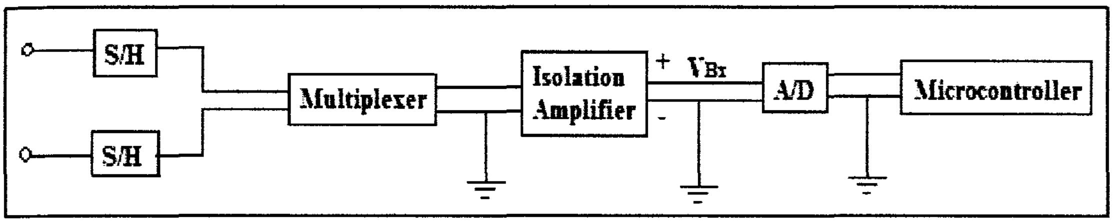


Figure 2.6: Block Diagram of Transfer Circuit Measurement System

The transfer circuit measurement system is shown in Figure 2.7. These circuits require a lot of discrete components such as MOSFET, BJT, resistor, Op-amps, analog-to-digital converter (ADC) and microcontroller. The function of the MOSFET and BJT is to prevent current leakage when the system not in use[1-2]. Voltage signal will send to the ADC, it can convert the analog signal to digital signal. The digital signal is then sent to the microcontroller to process. Then the microcontroller will display all the voltage on the PC monitor. To improve the system, sample and hold function can be added in the transfer circuit. The function of sample and hold is to prevent voltage skew problem caused by rapid variation in battery current[1-2]. It also acts as measurement scan. The initial tolerance can be reduced to a very low level.