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An electromechanical transfer circuit to measure individual battery voltages in series packs

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Abstract

A novel approach has been developed to measure the voltages of individual batteries used in electric vehicle (EV) battery packs using a unique selective battery measurement system. This system consists of a voltage measurement circuit that measures battery voltages using a set of electromechanical relays connected in a matrix formation. A 16-bit microcontroller was used for controlling the operation of the relay matrix circuit. The system was designed for a pack of 12 series connected 12 V_{dc} lead–acid batteries. The proposed approach was found to be compact and is a universal one that can be used for any type of battery. Moreover, the method was very effective and produced good accuracy. In fact, test results over a wide temperature range of −20 to +40 °C indicated that the method is very precise with voltage fluctuations less than ±30 mV.

Keywords: Electric vehicle; Voltage measurement; Lead–acid; Batteries; Relays

1. Introduction

Several applications such as electric vehicles and uninterruptible power supplies require the use of series connected battery packs for adequate power. These packs often need precise and autonomous voltage measuring schemes for accurate battery voltage measurements from time to time. The battery voltage is a good indicator of whether any battery is losing charge due to extraneous factors. Some of the factors that contribute towards reduction in battery life or charge retention include the type of battery cell design, ambient temperature, and length of usage/storage [1,2]. This means that if there are certain subtle differences between individual batteries in a pack, the batteries will not charge/discharge in a uniform manner, resulting in overcharge and excessive discharge in some units.

All batteries must remain within a high and low voltage operating range to prevent damage. During the discharge cycle, batteries which are less efficient tend to go out of voltage balance before the rest. This phenomenon limits the total battery capacity. Also, during the charge cycle, batteries which are more efficient tend to get charged a little higher than the rest, resulting in an overcharge. Batteries such as nickel metal hydride (NiMH) and lead–acid when overcharged are subject to an oxygen recombination cycle at their negative electrodes, and this causes their cycle life to be significantly reduced over a period of time [1,2].

It is possible to obtain a fair idea of the state of health of a battery by keeping track of its terminal voltage. For example, the open circuit voltage (OCV) and state of charge (SOC) for a 12 V_{dc}, 13 ampere-hour (Ah) EnerSys Genesis G13EP lead–acid battery have the following linear relationship for the 10–100% SOC range [16]:

$$\mathrm{SOC} = \frac{\mathrm{OCV} - 11.6}{0.0126} \tag{1}$$

Therefore, the SOC of each battery in series connected packs can easily be predicted by measuring its terminal voltage after some period of time at rest. This information is used to identify weak batteries so that they can receive an additional boost charge to balance the pack. It is therefore imperative that battery voltage monitors be accompanied with some type of equalization scheme to maintain voltage balance [3–8]. In fact, these systems combine to form battery management systems (BMSs) that monitor several critical battery parameters, such as the volt-

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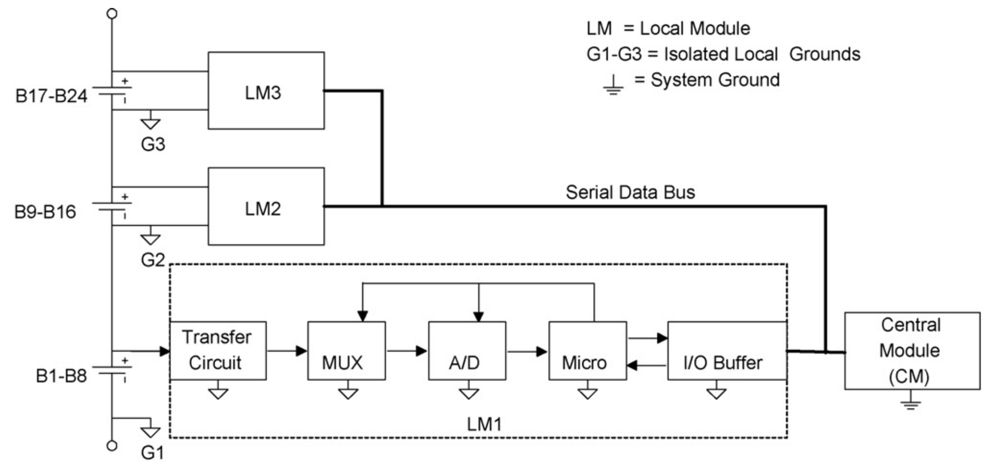

Fig. 1. Modular battery management system.

ages and temperatures of individual batteries, and take corrective action whenever an imbalance arises in the battery pack [9,10]. Fig. 1 shows a typical modular battery management system that consists of several local modules (LMs) each catering to the need of a well-defined section of the battery pack. In this case, each LM monitors eight batteries and consists of several key components that include a transfer circuit, multiplexer, analog-to-digital (A/D) converter, microcontroller, and an input–output (I/O) buffer. A serial data link provides communication between each LM and a common central module (CM). The CM commands all LMs to simultaneously measure and store their battery voltages locally, and the results are then sequentially transmitted to the CM. It is apparent that the transfer circuit is one of the important elements in each LM and thus, needs special attention in design and development. In fact, these voltage measurements can be quite tricky because each measurement must be transferred from the battery pack to the ground reference used by the data processing system as shown in Fig. 2. Although this might seem to be a simplistic task, the system needs to obtain data quickly to prevent a catastrophic condition from occurring. High performance batteries such as lead–acid, lithium-ion and NiMH have higher energy densities, and therefore, they require precise monitoring to ensure safety and performance.

There are several techniques to measure the battery voltages in series packs, the most evident method being using a resistive divider. Fig. 3 shows such a circuit for 12 series connected batteries. The disadvantages for such a system are fairly clear. Firstly, switches must be provided to prevent the resistors from drawing current from the batteries when not in use. Secondly, the voltages near the top of the stack require very accurate (and expensive) divider ratios. For example, consider the top battery in a stack of 12 12 V_{dc} batteries. Here, $K_{12} = R_1/(R_1 + R_{12})$, $K_{11} = R_1/(R_1 + R_{11})$ and so on. If the ideal values of K_{11} and K_{12} as defined in Fig. 3 are, $K_{11} = 1/11$ and $K_{12}=1/12$

$$V_{M_{11}} = V_{11} \times K_{11} = 12\,V_{dc}, \quad V_{11} = 132\,V_{dc} \tag{2}$$

$$V_{M_{12}} = V_{12} \times K_{12} = 12\,V_{dc}, \quad V_{12} = 144\,V_{dc} \tag{3}$$

$$V_{B_{12}} = V_{12} - V_{11} = 12\,V_{dc} \tag{4}$$

However, if the actual K_{12} is in error by +1% and the actual K_{11} is in error by −1%, the actual $V_{12} = 145.44\,V_{dc}$, and $V_{11} = 130.68\,V_{dc}$. This would mean that the measured $V_{B_{12}}$ equals 14.76 V_{dc}, instead of 12 V_{dc} (an error of 23%).

Another obvious method is to simply provide each battery with its own isolation amplifier [11]. The isolation amplifier shifts the battery voltages to the common reference, and the accuracy problems related to resistive dividers are avoided. A typical circuit is shown in Fig. 4, where the individual V_{B_x} can be multiplexed as in Fig. 3. Sample and hold circuits also can be added to both Figs. 3 and 4 to provide a simultaneous measurement scan. This system meets the necessary accuracy requirements,

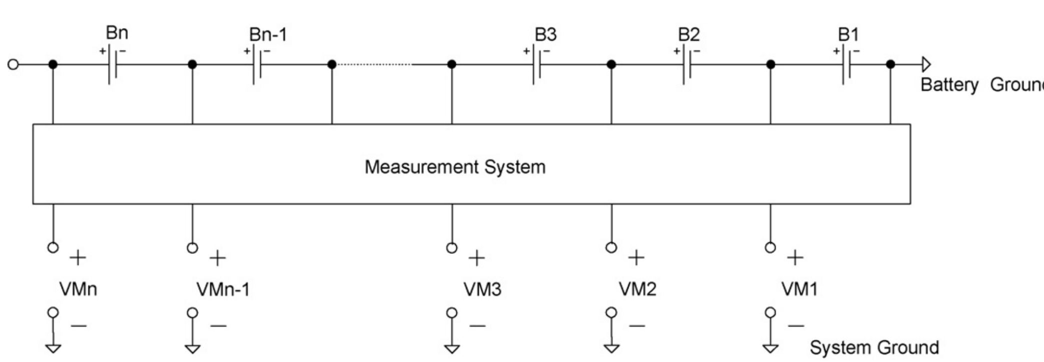

Fig. 2. Typical voltage measurement system.