International Journal of Engineering and Advanced Research Technology (IJEART)
ISSN: 2454-9290, Volume-2, Issue-6, June 2016

Device of Rapid Battery Efficiency Check by Coulomb's Law and Voltage Measurement

Jen-yu shieh, Yu-Ting Liu, Cheng Xi Wu

Abstract—**High energy, high power and compact size batteries are demanded on the current market of battery applications. As battery has turned out to be one of the essential components in driving high energy-consuming products, the development of battery is greatly important. Battery Management System (BMS) has become a very important core technology to play the major roles in performing safety monitoring, and effective control and management of the battery pack to improve the service performance and reliability of the vehicle while it is running. In this paper, the Coulomb integral measurement method was adopted as a checking device to compute the battery capacity as it can be implemented on different battery types and has an average current measurement error rate of only 1%. While the general testing devices require the battery to go through a complete charging process, the integrated voltage measurement method has the advantage to effectively save the battery checking time. When a 3000mAh battery is used in checking its performance, the normal checking time of 155 minutes can be reduced to 45 minutes while using the checking method adopted by the method proposed in the paper.**

Index Terms—**Battery Management System, Battery performance, Coulomb's Law, Hall element, Micro-controller**

I. Introduction

As BMS has currently been used extensively, the system has been successfully developed to provide a balanced electrical discharge and battery protection. The BMS is able to record the electric vehicle's battery conditions under the state of charge (SoC) and to monitor the battery status to achieve a protection function [1]. The system utilizes an algorithm to compute the battery aging degree within the reminding charging time. As the state of health (SoH) is an important basis in battery station maintenance and updating[2], so a battery exchange point was set up for managing purpose by using the parameter identification to determine if the batteries in the pack are consistent or not[3]. A portable power management device was designed to test the Ni-ion, nickel-cadmium and nickel-metal hydride batteries [4]-[6]. If the power supply status is unable to maintain within the battery specifications, it will cause the batteries to age rapidly; and the inconsistent aging degrees of batteries that are connected in series will cause the battery power to reduce and its performance to decline due to overcharging or over-discharging. It is vital for the check system to determine the battery aging degree by considering the battery status, including the battery's terminal voltage monitoring, ambient temperature management and uniform charging of the battery pack. A chip was thus designed by the study to serve as a system to measure the remaining battery power, using an open-circuit voltage measurement method to estimate the battery power, and the Coulomb power integral method to check the battery charging status [6]-[8]. As battery charging comes in the form of a non-linear curve, so an integrated voltage measurement method was employed to check and assess the battery health status.

However, the methods mentioned above are used individually; they are unable to yield a high accuracy. To improve the accuracy and reliability of battery power estimation, the battery aging degree is an essential correction parameter. Thus, for the traditional open-circuit voltage estimation method of residual power estimation method accompanied with aging parameter and the Coulomb ampere-hour integral algorithm, the BMS is required to design with a battery aging parameter. Hence, the study on battery performance measurement is a very important issue.

Two major battery aging estimation methods are: (1) the full charge-discharge method which involves predicting the total battery capacity after the battery has finished a charging-discharging cycle and left still until a steady state so we can estimate the total battery capacity, and further calculate the battery performance through the ratio between the total capacity of the battery and its total original capacity. The process may normally take a few hours and cannot be detected instantly; (2) the battery aging status estimation method which involves measuring the battery's internal resistance under different charging-discharging states, i.e., it uses an impedance method to perform a discharge check to achieve the battery monitoring purpose. However, this method must be conducted with a high-precision and expensive internal resistance measuring device.

II. MATERIALS AND METHODS

a. Battery Check Method

The main purpose of the battery check method is to detect the amount of power stored in the battery. It was initially applied in charging-discharging control to prevent material damages within the battery caused by overcharging or over-discharging. Following the popularity of portable products lately, users are enthusiastic about the battery capacity checking technology to help them clearly grasp the battery current working status and its remaining working capacity. Not only can the capacity checking technology find out if the battery has been fully charged or discharged, but can even assist users to master the instantaneously working status of the battery.

The battery capacity checking task is to predict the battery's electrical property changes during the charging and discharging processes. However, as the majority of batteries are composed of different materials and different internal structures, each battery has its own unique battery charging and discharging characteristics; thus, each battery may also have its own special, most suitable and most accurate battery capacity checking method.

To determine the most suitable battery capacity checking method, we must first fully understand the charging and discharging characteristics of each battery so we can decide the most appropriate approach. Even if two batteries are identical, their most appropriate battery capacity checking method may vary depending on their working environment or working manner (for example, one comes in constant current discharge manner, and the other an intermittent current discharge version). In short, we must be fully aware of the battery charging and discharging characteristics and its nature of work so we can decide the most suitable checking method.

There are individual advantages and disadvantages on various types of checking techniques. Take the internal resistance measurement method as an example, as it needs an additional power source to perform the internal resistance measuring, we cannot apply it on portable electrical appliances due to the restraint.

Regarding the total battery capacity estimation method, it has to be performed after the battery has finished a charge-discharge cycle and left still until a steady state so we can calculate the battery performance through the ratio between the total capacity of the battery and its total original capacity. The process may normally take a few hours and cannot be detected instantly.

The relationship between the battery's life cycle frequency and voltage recovery rate after discharging can be done through measuring the battery's voltage recovery rate after discharging, followed by calculating the battery aging status. This is regarded as a rapid measuring and cost-effective method.

While developing the battery capacity check method, we must emphasize to correct the three effects of ambient temperature, output current status and aging because these three variations can significantly affect the battery performance. Only then can we develop a battery check method with high accuracy and high reliability.

Table 1 is an analysis of measurement methods mentioned above and shows their major advantages and disadvantages. A most appropriate measuring method was then adopted by the study for the battery checker to perform the battery check after making the comparison analysis.

Table 1 Advantages and disadvantages of battery capacity check methods.

Methods	Advantages	Disadvantages
Coulomb integral measurement method[9][10]	It is suitable for all types of batteries	It cannot get the initial capacity and has to wait for a cycle discharging.
Open-circuit voltage measurement method[11]	It is simple and accurate to measure the initial capacity	It can only measure the initial capacity.
Load voltage method[12]	It is simple and low-cost	It can only measure one output current
Table look-up method [12]	It is easy-operated and low-cost	The reference data can be only referred to certain conditions.
Inner resistance detective[13]	It does not need to consider a battery's condition and environmental conditions	it needs an additional power source to perform the internal resistance measuring

We will make a brief description on the current major battery capacity check methods. The accuracy of some methods may not be high if used individually; but if two or more check methods are used simultaneously, they may make up for each other's deficiencies to yield a battery capacity check method with high accuracy. There are currently two methods to estimate the battery capacity. One method utilizes the voltage sizes to determine the battery storage capacity, and the other method uses the current output and input to calculate. We know that when a battery voltage is at 10% to 90% of storage capacity, its voltage changes are not obvious and the remaining battery use time is hard to predict. In the experiment, the Li-ion battery was chosen as the measurement target to perform a series of battery capacity checks as to develop a highly accurate and cost-efficient battery capacity check system.

b. The Hall element

The Hall element used in the study is capable of calculating positive and reverse current flow values. If the current output values come in the form of a positive current, the output signal voltages are found to be 2.5V ~ 5.0V, and if the current output values are in reverse curent version, the output signal voltages are 0V ~ 2.5V (as shown in figure 1).

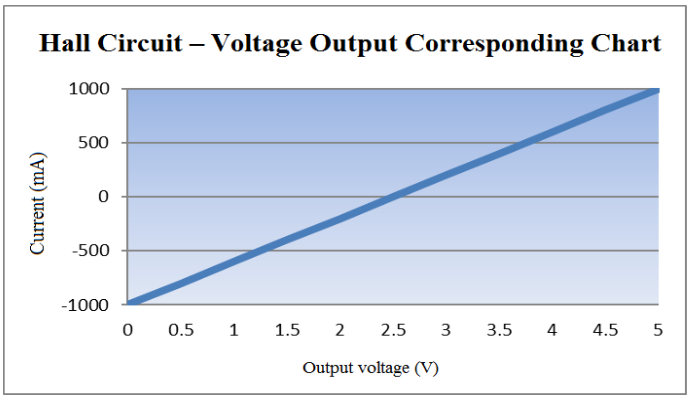

Fig.1 Hall Circuit – Voltage Output Corresponding Chart

After the calculation, the current values of Hall element were compared with the measured values of ammeter to check if they are consistent. The test range was 0mA ~ 1000mA. The test was conducted at room temperature, with current passing through the Hall element and then through the load.

Table 2 Output current values and error rates

Output current	Displayed current	Error rate
0mA	0 mA	0%
100 mA	102mA	2%
200 mA	204mA	2%
300 mA	295mA	1.77%
400 mA	403mA	0.75%
500 mA	489mA	0.22%
600 mA	602mA	0.3%
700 mA	701mA	0.14%
800 mA	797mA	0.375%
900 mA	907mA	0.78%
1000 mA	990mA	0.99%
	Average error rate	1%

The precision measuring error rate of the checking device was found to be 1.5%, and the maximum measuring error rate conducted by the study on current 0mA ~ 1000mA was 2%, with an average error rate of 1% (as shown in figure 2). So this checking device was selected to calculate the battery capacity in conjunction with the Coulomb measuring method.

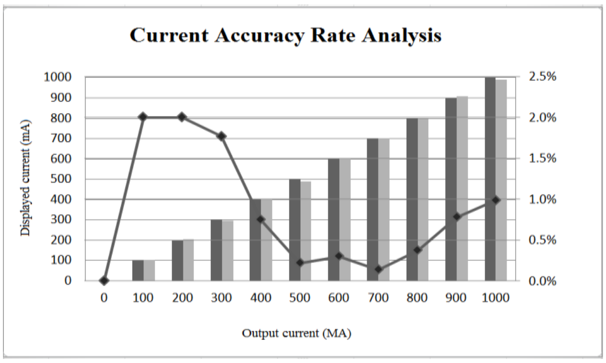

Fig. 2 Current Accuracy Rate Analysis

III. RESULTS

a.Analysis of 3000 mAh battery

While analyzing whenever each charging capacity has reached the total capacity of 5%, the voltages were measured to find out the corresponding voltage values. If the battery performance test results were set to comply with the performance test standard (i.e. voltage ≦ performance test voltage), then we can determine that the battery performance measurement is able to maintain in a sound state.

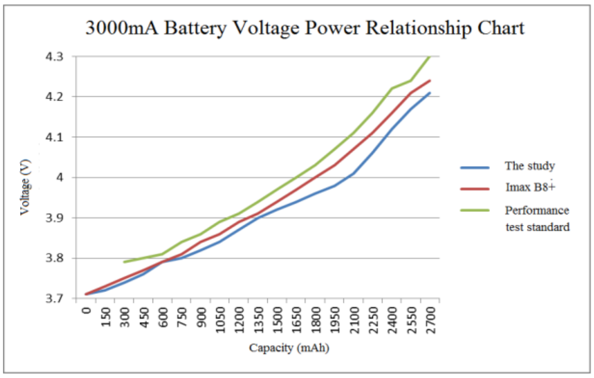

Fig.3 Chart for the performance comparison of 3000mA battery

As the performance comparison chart shows that the measured battery capacities is in figure 3. The corresponding voltage values of measured capacities done by Imax B8+ have not exceeded the detected standard line; we can understand that the performance of this battery has remained good. As compared to a full charge that may consume two hours, this checking device has only charged 20% of power to achieve 600mAh capacity, i.e. about 45 minutes to determine if the battery is appropriate to be used further or not.

While analyzing whenever each charging capacity has reached 100mAh capacity, the voltages were measured to find out the corresponding voltage values. If the battery performance test results were set to comply with the performance test standard (i.e. voltage ≦ performance test voltage), we can then determine that the battery performance measurement is able to maintain in a proper state.

b. Analysis of 3000mAh Low-Performance Battery

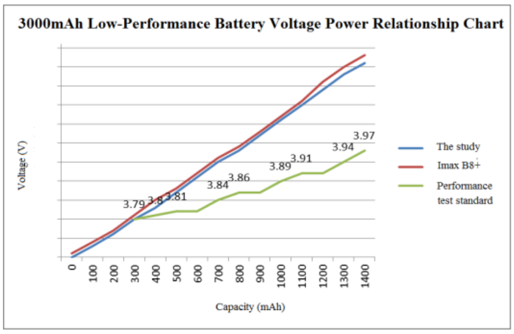

Fig.4 Chart for the performance comparison of 3000mA Low-Performance battery

The performance comparison chart shows measured capacities conducted by the study in figure 4. The corresponding voltage values of measured capacities have been done by Imax B8+. It is found that when the battery was charged to 300mAh capacity by the study, the voltage was 3.79V to reach 10% of performance test standard. It is determined as poor performance by the study. When the battery was further charged approximately 5%, of about 150mAh to reach 450mAh capacity, it is noted that the battery voltage is higher than the performance test voltage. Within half an hour of charging time, it is found that the power variances of battery voltages and standard voltage values have become greater and greater, and the battery performance has eventually been discovered to be far lower than the indicated capacity. Therefore, it is not recommended to use this battery further.

IV. DISCUSSION

The future trend of battery applications should not be overlooked. The Coulomb integral measurement method was used by this paper to detect the battery power, which has the advantages being applicable to all types of batteries and a current error rate of only 1% to deem as having higher capacity accuracy. After comparing with Imax B8+ charger sold on the market, it is noted to have a capacity check performance error rate of less than 2%. Furthermore, Imax B8+ can only determine the result after the battery has gone through a charging-discharging cycle, but the integrated voltage method adopted by the paper is able to reduce the checking time as compared to Imax B8+. The measuring time on a 5000mAh mobile power pack has reduced from 276 minutes to 67 minutes, and that on a 3000mAh battery from 155 minutes to 45 minutes, which is shown in figure 5. In other words, only about 30% of checking time is sufficient to determine if the battery is appropriate to be used further or not. Hence, these research findings can be used by users to serve as a valuable reference.

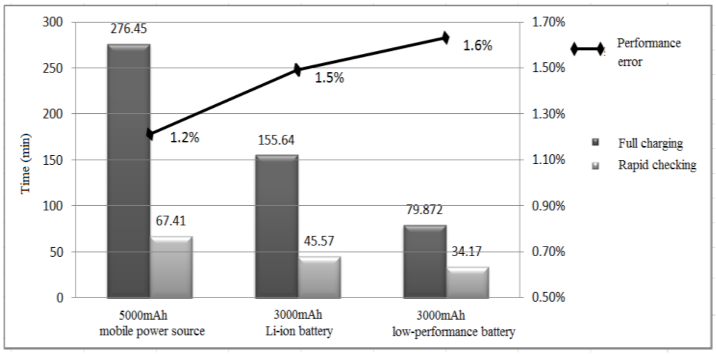

Fig. 5 Charging Time and Performance Error

REFERENCES

[1] R. Kaiser "Optimized battery-management system to improve storage lifetime in renewable energy systems", J. Power Sources, vol. 168, no. 1, pp.58 -65 2007.
[2] L. Maharjan , S. Inoue , H. Akagi and J. Asakura "State-of-charge (SOC)-balancing control of a battery energy storage system based on a cascade PWM converter", IEEE Trans. Power Electron., vol. 24, no. 6, pp.1628 -1636 2009.
[3] E. Meissner and G. Richter, "The challenge to the automotive battery industry: The battery has become an increasingly integrated component within the vehicle electric power system", J. Power Sources, vol. 144, pp.438 -460 2005.
[4]W. Puviwatnangkurn, B. Tanboonjit and N.H. Fuengwarodsakul, "Overcurrent protection scheme of BMS for Li-Ion battery used in electric bicycles", Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2013 10th International Conference on, 2013 , pp. 1- 5.
[5] B. S. Bhangu, P. Bentley and C. M. Bingham, "Nonlinear observers for predicting state-of-charge and state-of-health of lead-acid batteries for hybrid-electric vehicle", IEEE Trans. Veh. Technol., vol. 54, no. 3, pp.783 -794 2005.
[6] A. Manenti, A. Abba, A. Merati, S.M. Savaresi and A. Geraci, "A New BMS Architecture Based on Cell Redundancy", IEEE Trans. Ind. Electron. Vol. 58, Issue: 9. pp. 4314- 4322.
[7] J. Chatzakis , K. Kalaitzakis , N. C. Voulgaris and S. N. Manias "Designing a new generalized battery management system", IEEE Trans. Ind. Electron., vol. 50, no. 5, pp.990 -999 2003.
[8] X. Wang and T. Stuart, "Charge measurement circuit for electric vehicle batteries", IEEE Trans. Aerosp. Electron. Syst., vol. 38, pp.1201 -1209 2002.
[9] K. W. E. Cheng , B. P. Divakar , H. J. Wu , K. Ding and H. F. Ho, "Battery-Management System (BMS) and SOC Development for Electrical Vehicles", IEEE Trans. Veh. Technol., vol. 60, no. 1, pp.76 -88 2011.
[10]Jen-Yu Shieh , Si-Hui Huang ,Cheng-Kai Guo, Performance of Battery Inspection Based on Full Charged and Discharged Method, International Journal of Engineering and Innovative Technology (IJEIT) Volume 5, Issue 11, May 2016. PP 72-75.
[11] V. Coroban, I. Boldea and F. Blaabjerg, "A novel on-line state-of-charge estimation algorithm for valve regulated lead-acid batteries used in hybrid electric vehicles", Electrical Machines and Power Electronics, 2007. ACEMP '07. International Aegean Conference on 2007, P36 – 46.
[12] L. Bowen, R. Zarr, and S. Denton, "A microcontroller-based intelligent battery system", Aerospace and Electronic Systems Magazine, IEEE 1994, pp. 16 – 19.
[13] J.L. Morrison, J.P. Christophersen, and W.H Morrison, "Universal auto-calibration for a rapid battery impedance spectrum measurement device", Aerospace Conference, 2014 IEEE , March 2014, pp. 1 – 8.

Jen-Yu Shieh Professor, Department of Electro-Optics Engineering, National Formosa University, Taiwan.

Yu-Ting Liu Master of Electro-Optics Engineering, National Formosa University, Taiwan.
Cheng Xi Wu, Candidate of Master at Electro-Optics Engineering, National Formosa University, Taiwan.