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Design and Construction of Protection and Monitoring Battery Management System (BMS) on Electric Motorcycle Based on ESP32

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Abstract. Lithium batteries are starting to become a significant commodity in the rapidly growing electric vehicle industry. Along with the increasing number of battery requirements, the use of lithium batteries is also increasingly diverse. The rising number of battery requirements makes the battery must be adapted to various conditions in the field so that the battery life is long and the battery condition is maintained. The safety and battery life will be problematic if these conditions are not supported. A Battery Management System (BMS) exists to overcome this. In this research, BMS has two main features, namely protection and monitoring. Identification in this study is based on the problem of voltage protections in lithium batteries and monitoring the voltage of each battery cell as measured by a multimeter. A BMS nowadays knows that few have added features such as wireless monitoring using Bluetooth in one BMS module. The results of the BMS testing for monitoring the total voltage when charging have an accuracy of 96.63%, and the BMS testing for monitoring the cell voltage when charging has an accuracy of 98.93%. While the results of the BMS testing for monitoring cell voltage when discharging have an accuracy of 95.07%, and BMS testing for monitoring cell voltage when discharging has an accuracy of 96.59%. The protection features function well to overcome overcharge and over-discharge. The results of the BMS testing for monitoring the total voltage when charging have a precision of 0.84%, and the BMS testing for monitoring the cell voltage when charging has a precision of 0.42%. While the results of the BMS testing for monitoring cell voltage when discharging have a precision of 0.7%, and BMS testing for monitoring cell voltage when discharging has a precision of 0.94%. The successful development of this BMS will increase the value of developing the battery industry in Indonesia.

INTRODUCTION

The most severe environmental problem facing human society is global climate change, among which global warming is the most dominant. The main factor causing global warming is Greenhouse gas emissions represented by CO2 [1]. Electric motors are one of the right solutions to address the problem of exhaust emissions. An electric motor uses a battery as a power source. If a battery cannot monitor voltage usage, it will decrease in a lifetime, and damage such as the battery overheats, capacity decreases, and sparks occur [2]. Battery Management System (BMS) is a right system for monitoring and managing the electrical system of electric motor batteries [3].

This research entitled "Design and Monitoring of Battery Management System (BMS) Electric Motor Protection and Monitoring Based on ESP32" is expected to be able to protect batteries from excessive voltage usage. ESP32 was chosen as a microcontroller because it has Bluetooth connection features and low power consumption [4]. This microcontroller is precisely applied to the BMS monitoring feature to make monitoring the battery cell voltage easier.

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METHODOLOGY

The research plan related to this research is listed in Figure 1. The research begins with a literature study to understand the working principle of how to build a battery management system. The references used are in the form of papers, datasheets, research reports on similar topics, and books.

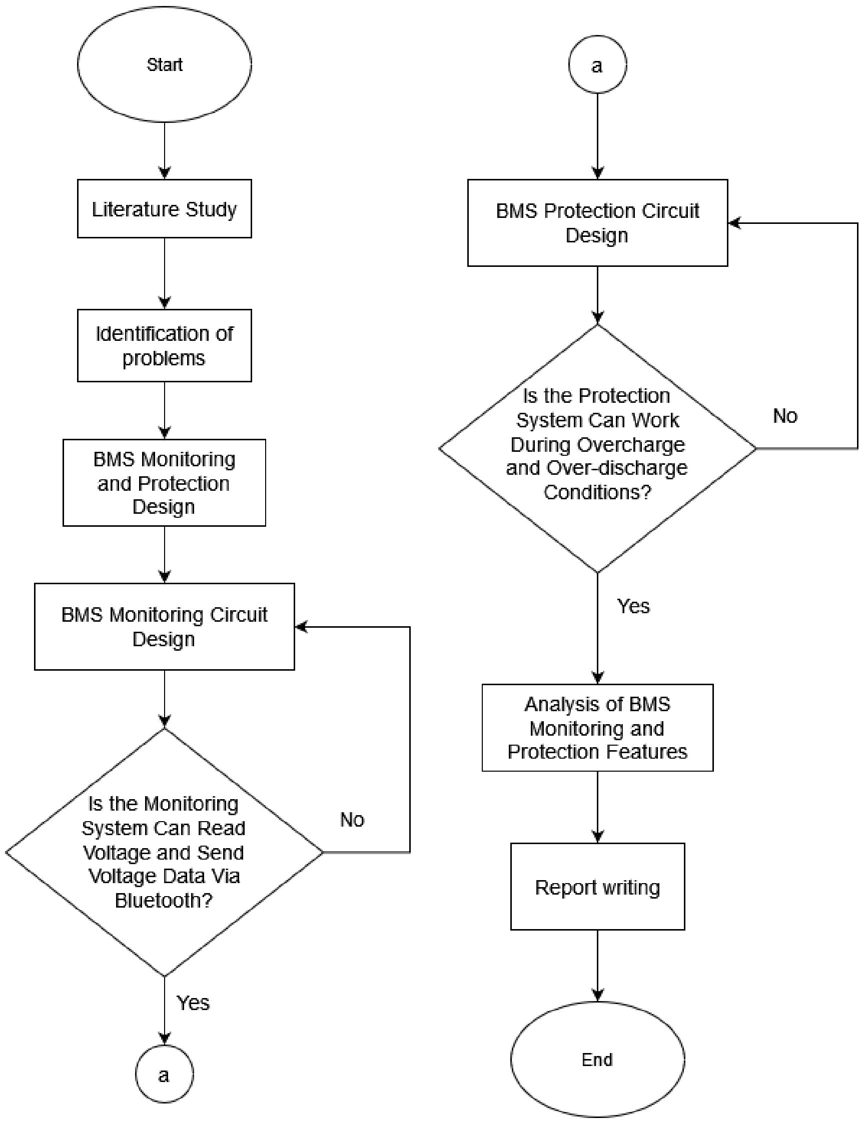


FIGURE 1. Research Flowchart.

After understanding the basic knowledge, this research continues with system design. The software used to design was Proteus 8 Professional. The next step was manufacturing battery management system devices. Device for BMS manufacture including two parts: hardware and software (programs).

Hardware manufacture including to monitoring system design and protection system design. A series of tests determine the overall performance of the circuit, starting from design testing, monitoring testing, and protection testing. Evaluation in this BMS was about whether the circuit can operate optimally. Software for ESP32 was written in Arduino IDE, this program was about monitoring the testing and the output was displayed on Serial Monitor Bluetooth Application in Android. This research ends with analyzing and writing a report.

BMS Monitoring and Protection Circuit Design

BMS in this research, designed two system features, namely the protection and monitoring features. The monitoring and protection system flowchart describe in Figure 2.

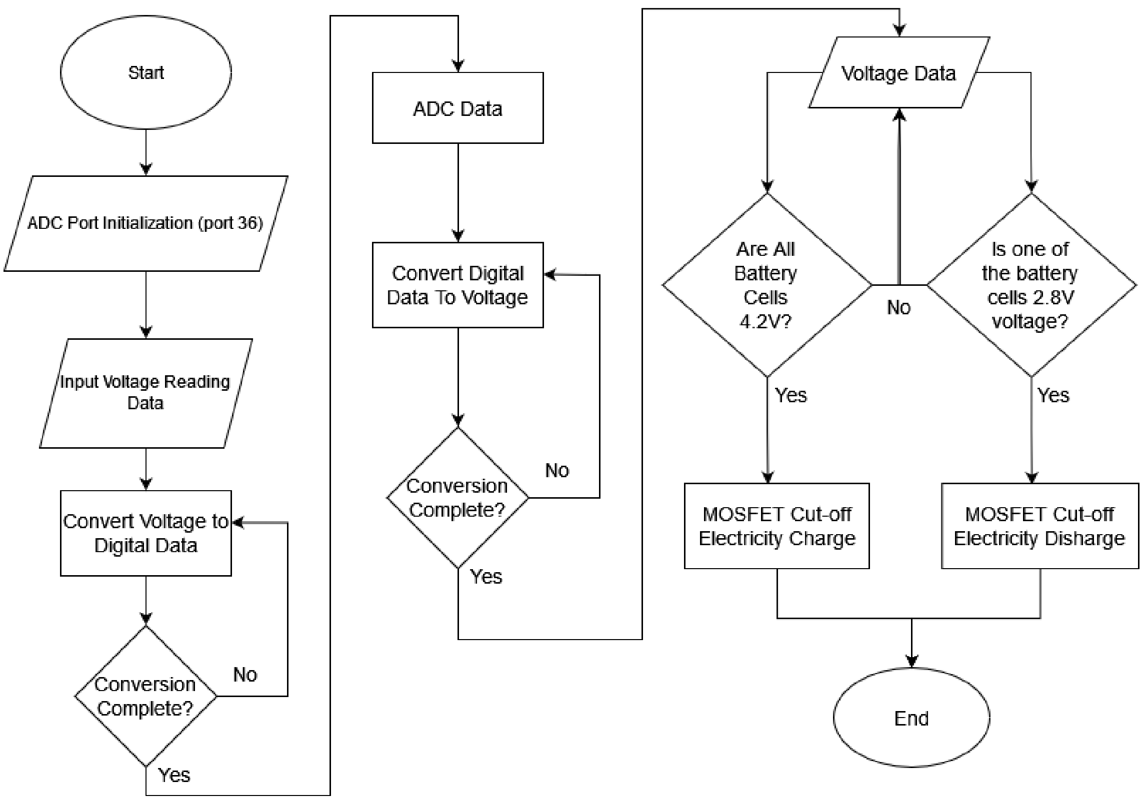


FIGURE 2. Monitoring and Protection System Flowchart.

The monitoring system flowchart describes in Figure 2 and the monitoring system schematic design describes in Figure 3. In the battery pack monitoring test, the measured value is the total battery voltage value and the voltage value for each battery series. The tests carried out on the battery pack are in the form of accuracy and precision testing—this testing uses a 21700 NMC 811 Li-ion 52V 15Ah battery pack. For Li-ion battery, upper threshold voltage is 4.25V and lower threshold is 2.5V [5]. For this research, upper threshold voltage is 4.2V and lower threshold is 2.8V. The voltage divider circuit is a simple electronic circuit that can convert a large voltage to a smaller voltage [6]. The voltage dividers used in the total battery voltage monitoring system are 220k(R1) and 12k(R1) resistors. This resistor value is from Equations 1, so the output voltage value is 3.103V. While in the voltage monitoring system for each battery cell, the voltage divider used is 100k and 200k resistors, so the output voltage value is 2.8V.

$$V_{out} = V_{in} \, x \, \frac{R_2}{(R_1 + R_2)} \quad (1)$$

In reading the total battery voltage, the positive point of the battery pack connects to the voltage divider. The positive voltage output pin will connect to the GPIO pin four, and the negative voltage output pin connects to the ESP32 GND pin. After the ESP32 receives the analog voltage data from the voltage divider circuit, then the ESP32 converts the analog value into a digital value. The digital value will later be processed into voltage data and sent to the Bluetooth Serial Monitor application.

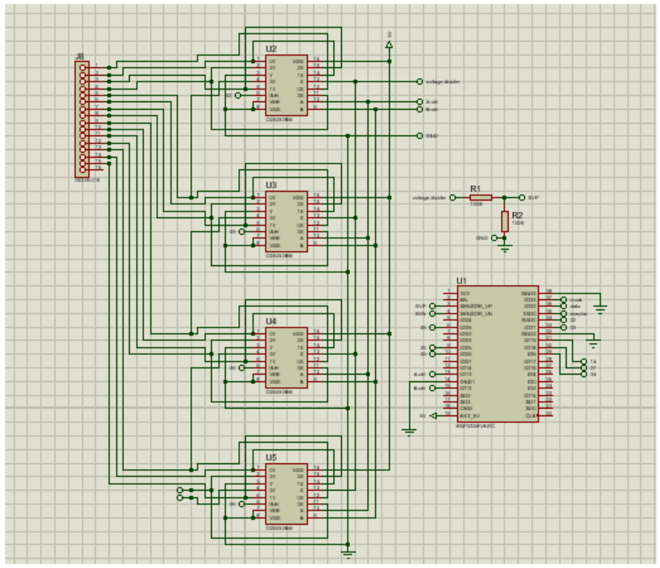


FIGURE 3. Monitoring System Schematic Design.

The flowchart of the protection system describes in Figure 3 and the protection system schematic design describes in Figure 4. MOSFETs were designed as a BMS protection system to protect the battery in the electric motor. MOSFET NCE8580 is a protection system during the charging & discharging process. At the time of charging, when the battery voltage has reached 4.2V in each battery cell, the ESP32 will issue a voltage that will cut off the incoming power from the charger to the battery through the MOSFET. At the same time, during the discharging process, when one of the batteries has touched a voltage of 2.8V, then ESP32 will issue a voltage that will cut off the power coming out of the battery through the MOSFET. A pull-down circuit in the form of a resistor was provided to MOSFET by connecting to the ground to avoid "floating logic" [7].

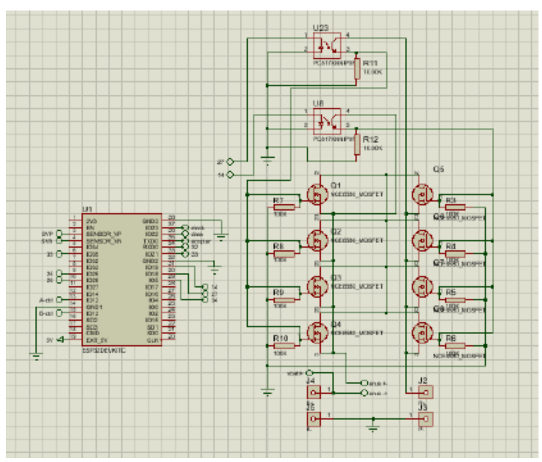


FIGURE 4. Protection System Schematic Design.

RESULTS AND DISCUSSION

The tests carried out are accuracy testing and precision testing. Precision and accuracy tests use to determine the value of precision and accuracy of the BMS monitoring system. Testing the precision and accuracy of the monitoring system is divided into two types of tests, namely, charge testing and discharge testing. Precision testing repeats eight times. The accuracy value is expressed in percentage and described using the formulas of Equations 2 and 3.

$$error_{percentage} = \frac{(actual_{value} - predicted_{value})}{actual_{value}} x\ 100\% \tag{2}$$

$$accuracy_{percentage} = 100\% - error_{percentage} \quad (3)$$

If the battery voltage reading accuracy shows a percentage > 95% during the calculation, the monitoring system is declared successful [8]. Precision testing tests the closeness between the measured values obtained by repeating the same or similar objects under certain conditions [9]. The precision value is expressed in percentage and can be determined using Equations 4-6.

$$\mathrm{s} = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{x_i} - \mathrm{x_{mean}})2}{n-1}} \quad (4)$$

$$\%RSD = \left(\frac{s}{xmean}\right) \times 100\% \quad (5)$$

$$\%Precision = 100\% - \%RSD \quad (6)$$

BMS Manufacturing

The process of making a BMS began with a literature study and the creation of a schematic circuit. The schematic circuit design was applied to a double-layer PCB circuit for printing. The next stage was to install the components to the printed PCB board. Installation of components is done by inserting each component on the PCB, soldering, and connecting each component leg. Figure 5 shows the results of making a BMS which consists of several components.

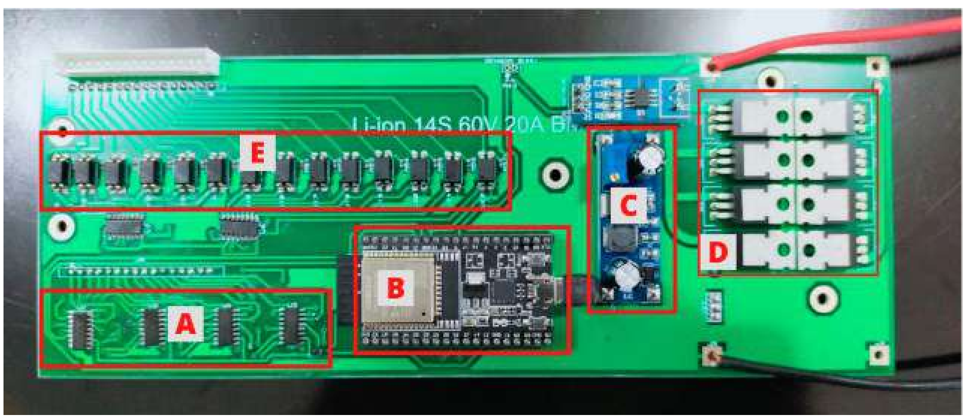


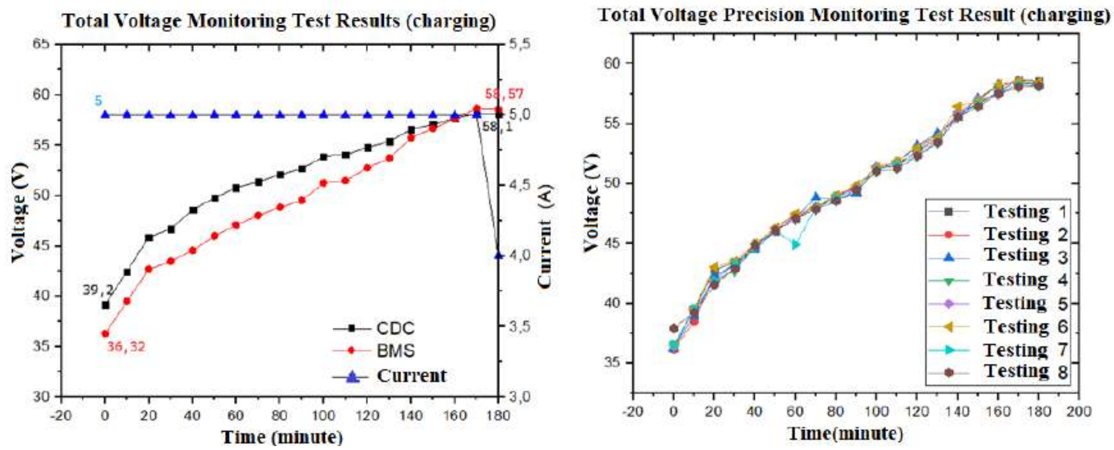
FIGURE 5. Results of Making Battery Management System (BMS).

Description:

A: Multiplexer
B: ESP32 Module
C: Step-down Module
D: Mosfet
E: Optocoupler

Monitoring Testing of Charging Condition

Total Voltage Monitoring of Charging

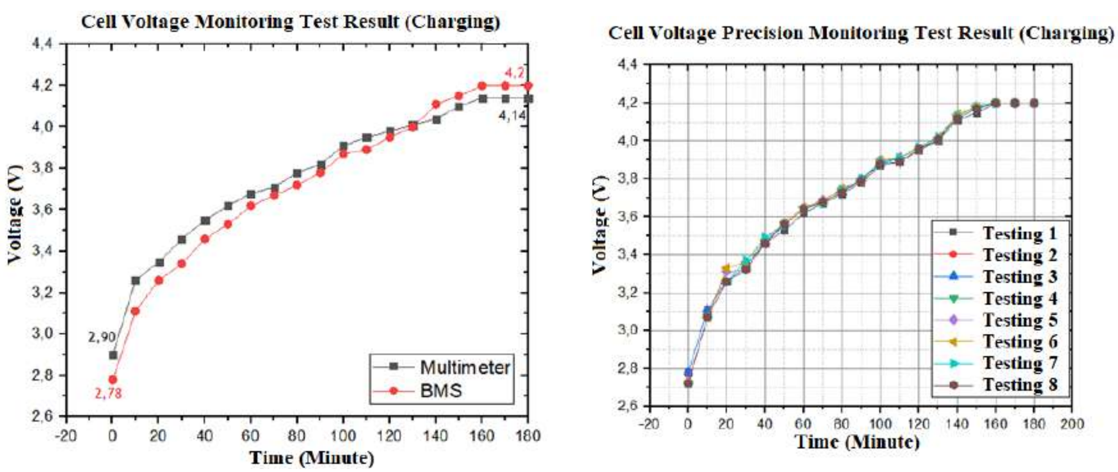


(a) (b)

FIGURE 6. (a) Results of Total Voltage Monitoring; **(b)** Results of Total Voltage Monitoring Precision.

Testing the voltage reading was done during charging takes place. The data collection was taken every 10 minutes. Figure 6 (a) shows comparison between the BMS readings and the results of the multimeter readings. The CDC voltage reading has increased due to the charging process. It grew slowly from the initial voltage of 39.2V until it stabilized at 58.1V. The voltage sensor readings that have been tested show that the voltage sensor or BMS reading has an average accuracy of 95.23%. While in the precision test, for eight trials in Figure 6 (b), it can be observed that the average standard deviation was 0.16. The relative standard deviation value was 0.003. The measurement of the precision value of the total voltage monitoring system has produced a %Precision value of 99.7%.

Cell Voltage Monitoring of Charging



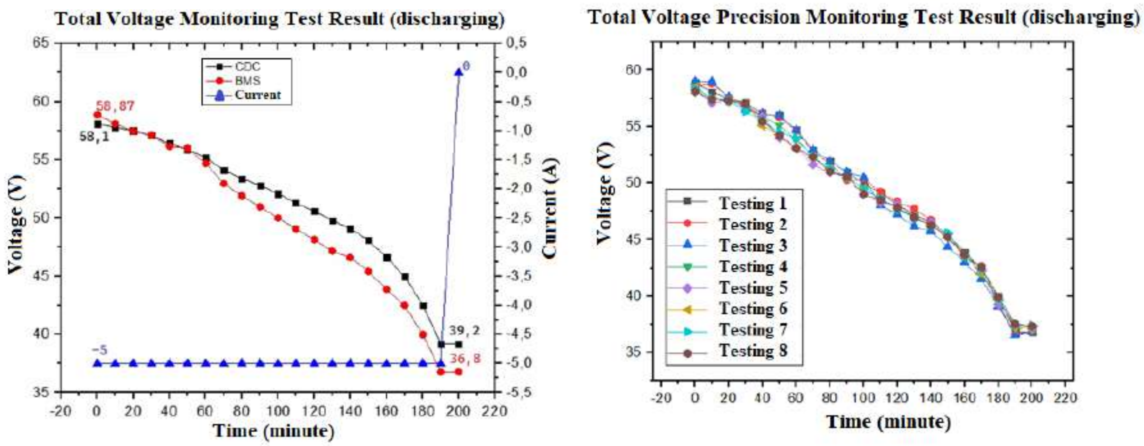
(a) (b)

FIGURE 7. (a) Results of Cell Voltage Monitoring; **(b)** Results of Cell Voltage Monitoring Precision.

Testing the voltage was done during charging takes place. This data collection was taken every 10 minutes. Figure 7 (a) shows comparison between the BMS readings and the results of the multimeter readings. The multimeter voltage reading result has increased due to the charging process. It grew slowly from the initial voltage of 2,9V until it stabilized at 4,14V. The voltage sensor readings that have been tested identifying that the voltage sensor or BMS reading had an average accuracy of 98.09%. While in the precision test, for eight trials in Figure 7 (b), it was observed that the average standard deviation was 0.01. The relative standard deviation value was 0.002. The measurement of the precision value of the total voltage monitoring system produces a %Precision value of 99.8%.

Monitoring Testing of Discharging Condition

Total Voltage Monitoring of Discharging

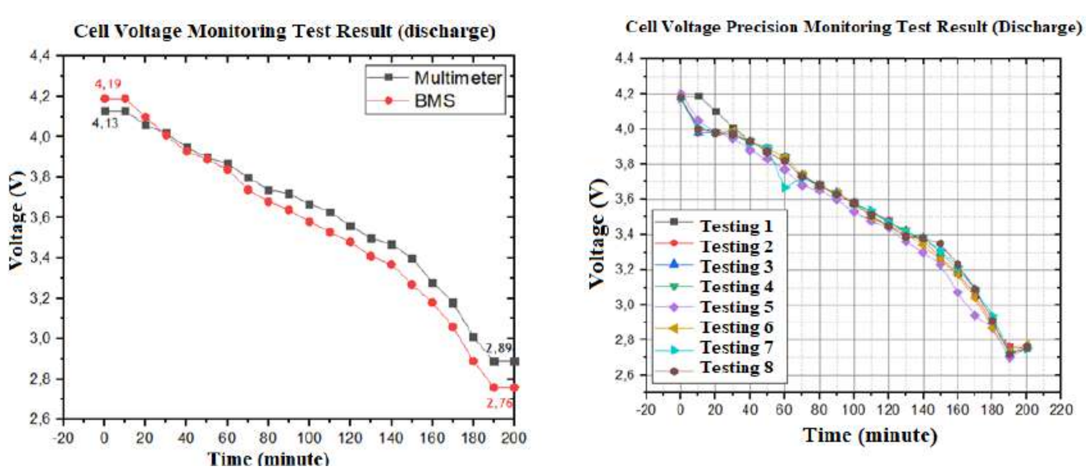


(a) (b)

FIGURE 8. (a) Results of Total Voltage Monitoring; **(b)** Results of Total Voltage Monitoring Precision.

Figure 8 (a) shows the result of the Testing of voltage readings every 10 minutes. The comparison between the BMS readings and the results of the multimeter readings shows that the CDC voltage reading has decreased due to the discharging process. From the initial value of 58.1V, it decreased slowly to become stable at 39.2V. The voltage sensor readings show that the BMS readings have an average accuracy of 96.18%. While in the precision test, for eight trials in Figure 8 (b), it was observed that the average standard deviation is 0.16. The relative standard deviation value was 0.003. The measurement of the precision value of the total voltage monitoring system was produced a %Precision value of 99.7%.

Cell Voltage Monitoring of Discharging



(a) (b)

FIGURE 9. (a) Results of Cell Voltage Monitoring; **(b)** Results of Cell Voltage Monitoring Precision

Figure 9 (a) shows the comparison between the BMS readings and the results of the multimeter readings. The multimeter voltage reading had decreased due to the discharging process; from the initial value of 4.13V, it decreased slowly to become stable at 2.89V. The voltage sensor readings that have been tested show that the voltage sensor or BMS reading had an average accuracy of 97.57%. While in the precision test, for eight trials in Figure 9 (b), it was observed that the average standard deviation was 0.01. The relative standard deviation value was 0.004. The measurement of the precision value of the total voltage monitoring system was produced a %Precision value of 99.6%.

Protection Testing

In the protection test, the measured value is the voltage value of each battery series. There are two samples tested, namely: the overcharge protection test and the over-discharge protection test. The overcharge protection system works when all battery voltages touch 4.2V, while the over-discharge protection system works when one of the battery voltages borders 2.8V. The protection component used in this battery protection system uses 2 NCE8580 MOSFETs, which will act as an overcharge cut-off switch and an over-discharge cut-off switch [10].

Protection Testing System of Overcharge Condition

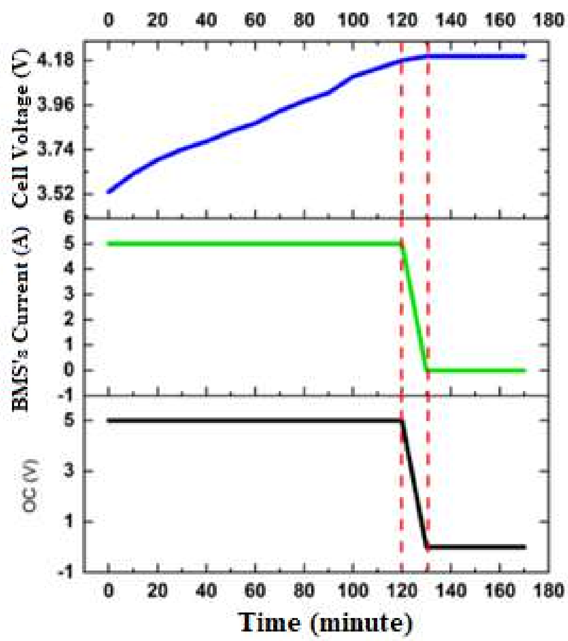


FIGURE 10. Results of Overcharge Protection System.

Overcharge protection testing is done by charging the battery cells from 3.53V to full (4.2V). From Figure 10, the series voltage of the first battery has increased due to the charging process. During the charging process, the over-discharge cut-off MOSFET is in condition 1 (HIGH), and the overcharge cut-off MOSFET is in condition 1 (HIGH) or ON because the battery voltage is within the voltage tolerance limit, which is 2.8V -4.2V.

At the 130th minute, the series voltage of the first battery has reached 4.2V. The overcharge cut-off MOSFET is in state 0 (LOW), and the over-discharge cut-off MOSFET is in state 1 (HIGH). In this condition, the overcharge protection system has been running. It is declared successful in cutting off electricity from the charger to the battery, as evidenced by the decrease in the value of the current entering the BMS from the initial 5A at 4.18 voltage and then down to 0A when the battery voltage reaches 4.2V.

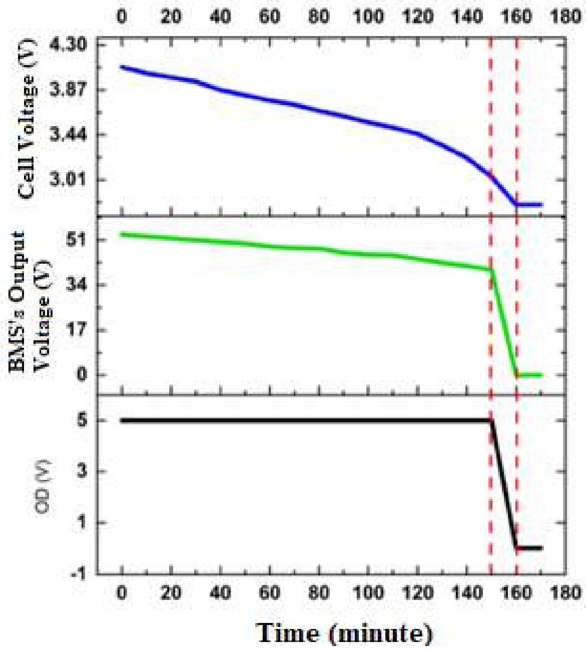


FIGURE 11. Results of Over-discharge Protection System

The over-discharge protection test is carried out by giving the battery load from 4.2V to 2.8V. Figure 11 shows that the voltage (V) per battery series has decreased due to the discharging process. During the discharging process, the over-discharge cut-off MOSFET is in condition 1 (HIGH), and the overcharge cut-off MOSFET is in condition 1 (HIGH) or ON because the battery voltage is within the voltage tolerance limit, which is 2.8V-4, 2V.

At the 160th minute, the series voltage of the first battery has reached <2.8V. The overcharge cut-off MOSFET is in state 1 (HIGH), and the over-discharge cut-off MOSFET is in condition 0 (LOW). In this condition, the over-discharge protection system has been running and was declared successful in cutting off electricity from the battery to the load, as evidenced by the decrease in the value of the voltage coming out of the BMS, which was initially 39.8V at a battery series voltage of 3.04V and then dropped to 0V when battery series voltage reaches <2.8V.

CONCLUSION

The research has successfully designed and manufactured of Battery Management System for protection and monitoring, the total voltage had an accuracy of 95.23% and a precision of 99.7%. Meanwhile, the cell voltage monitoring test had an accuracy of 98.09% and a precision of 99.8%. The discharging test results of monitoring the total voltage have an accuracy of 96.18% and a precision of 99.7%. Meanwhile, the cell voltage monitoring test has an accuracy of 97.57% and a precision of 99.6%. The protection test results show that the BMS performance to cut-off electricity could function appropriately in overcoming overcharge and over-discharge condition.

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