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13S Battery Pack and Battery Management System Design and Implementation for Electric Bicycles

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Abstract

In this study, the battery pack and ESP32 microcontroller-based battery management system (BMS) design for the electric bicycle have been carried out. The software updates were realized when the battery pack was in the box, thanks to the built-in Wi-Fi feature of the ESP32. The voltage values were read precisely, and a stable BMS was created with a 12-bit ADC-based ESP32 controller. The battery had temperature control from 7 different points. The temperature data were received from DS18B20 digital temperature sensors, and the charging current was cut off when the threshold value was exceeded. At the same time, the ACS712 5A current sensor was used to determine and prevent the excessive current draw. The charging current was defined as 2A. BMS cuts off the charging current to protect the battery pack when the charging current exceeds 3A. The resistor used for passive balancing in BMS was isolated from the ESP module with the KPS2801 optocoupler. The voltage of the battery pack was charged from 3.7 V to 3.85 V in the real-time test. The charging process continued for one hour, and the voltage changes of each cell were obtained in 10-minute periods. It was observed that all cells were charged in a balanced way at the end of the charging process. The temperature measurements were carried out for each dual battery group from seven points. The required updates and wireless data sending process can be made designed BMS. A different method was applied in the balancing process. Thus, the charging process of the designed battery pack was carried out successfully through the designed BMS.

Keywords: BMS; Battery pack; Electric bike; ESP32; Passive balancing;

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1. Introduction

Today, the number of electric vehicles is increasing day by day. Electric vehicles of different sizes and types are produced and used according to the needs. In the field of transportation, electric cars, motorcycles, scooters, balance wheels, trucks, tractors, airplanes, and boats can be given as examples of this field [1]. In addition to transportation, electric vehicles or systems play an active role in our lives in many areas. Electric vehicles are increasing in household appliances, mobile machines, and systems in the business area, and various products are offered to users every day. Rechargeable vacuums, robot vacuums, mixers for home use, and robotic-based systems that can carry loads in the business area are some of these applications [2].

The need to constantly go from one point to another in our daily life is essential. For this reason, various products are produced and offered to the market with different approaches to make life easier in transportation. Electric bicycles are one of these products and have become frequently preferred by users in recent years [3]. Thanks to the electric motor and battery system placed on it, users can easily reach the point they want. Their range may differ according to the size of the battery packs on them [4]. BMS is needed to charge the existing battery pack and maximize its life in many battery-based systems, such as electric bicycles. Battery packs are charged in an ideal way using BMSs to prevent the disadvantageous situations created by overcharging in the system [5]. BMS systems generally consist of microcontrollers and sensors-based electronic structures. Active and passive balancing methods are used, and charging processes are carried out according to these methods. Passive-based methods are frequently preferred in applications due to their low cost and ease of application [6].

Simulation and application-based studies have been carried out in BMS related to electric bicycles [7-10]. However, due to the novelty of these products, a limited number of studies were found in this area [11-12]. The features of the BMS system can be changed according to the system. In electric bicycles, the charge rate of the battery should be actively controlled by the user while in motion. On a global scale, there are systems and applications where the user can access information about the battery using an application on his phone [13]. Relevant information can be transmitted to the user via Bluetooth or internet-based controllers with wireless communication in BMS systems [14]. These products are available in the global market, but they may need help accessing them due to high costs. The number of products related to this field is limited in the local market, and the battery pack and BMS system prices are high.

In this study, a 48 V, 750-Watt battery pack was created for electric bicycles, and an ESP32-based BMS system was designed and implemented. The made battery pack and BMS system have been developed for a bike with a 750-Watt 48 Volt motor. The battery pack is designed and manufactured to consist of 13 series batteries and two parallel arms. 18650-type lithium-ion batteries are used in the battery pack, and the number of used batteries is 39. The passive balancing method is used in BMS, designed based on ESP32. The temperature value of the battery pack was measured with DS18B20 digital temperature sensors from seven different points. An infrastructure has been created where the battery pack can be charged safely. The charging current is determined as 2A, and additional safety measures have been taken to cut the charging current in case it exceeds this value. The charging process was carried out until the voltage value of the 13S battery pack was charged from 3.7 V to 3.85 V, which continued for 60 minutes. During this process, the voltage values of each cell were obtained at the end of every 10 minutes. At the end of 60 minutes, it was observed that all cells had equal voltage values. As a result, the BMS was developed in terms of hardware and software. Improvements and contributions to the BMS were expressed in hardware and software, respectively. The power and control sections were isolated from each other by means of using KPS2801 optocouplers. The required updates and wireless data sending process can be made designed BMS. The different method was applied in the balancing process algorithm. Balancing times were adjusted according to the mathematical proportion created in the algorithm. The balancing process was carried out quickly thanks to the applied method. Thus, the application of BMS was successfully carried out with the designed battery pack.

2. Material and Method

The battery cells can be charged and discharged unbalanced when batteries connected in series are kept under direct charge voltage. This situation causes the cells to be higher than 4.2 V, and the lifespan of the fast-charging batteries is reduced due to the high voltage. During the discharge usage, the total voltage drops quickly due to the premature discharge of the incomplete cell. Therefore, the battery pack does not operate at full capacity. With passive balancing-based BMS, the voltages of the overcharged cells are reduced.

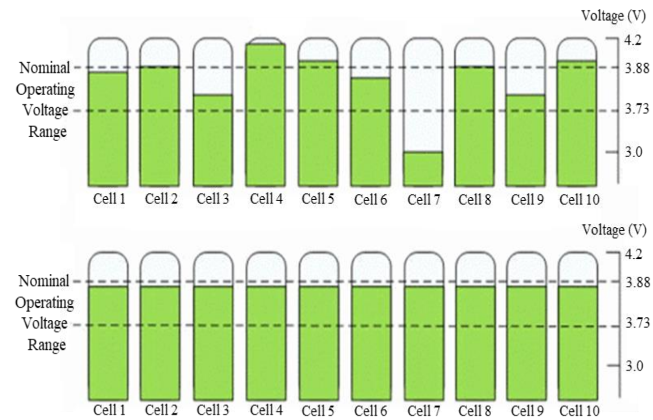

Fig. 1. BMS effect on the battery cells

The charging process is ensured by bringing the voltages of all cells to the same level. The BMS effect on the battery cells can be seen in Fig. 1. In the designed BMS, a passive balancing system based on connecting a parallel resistor is applied under the control of the ESP32 processor module.

2.1 Design and Creation of 13S BMS Circuit

Many BMS designs are under the literature's headings of active and passive balancing. Due to its stable and simple structure, the passive balancing structure using the resistor connection method in parallel with the cell is preferred. In this method, battery cell voltages are continuously measured. The parallel resistor connected to the cell with the highest voltage is switched. The excess voltage value is reduced by the resistor connected to the cell. As all cells are charged at the same rate, the battery cells are evenly charged.

Since the design is for the application, the BMS circuit board must be positioned in the battery box and the battery pack. For this reason, the need to design the BMS circuit as small as possible has arisen. An ESP32 processor module was used in the BMS board, and a 74HC4067 Multiplexer (MUX) IC was used due to the lack of required input and output pins. The ESP32 processor module includes Wi-Fi and Bluetooth modules, as shown in Fig. 2. This way; allows the transfer of battery information to the phone and the program update of BMS, which is in a closed package, via Wi-Fi.

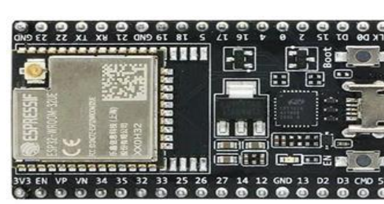
Fig. 2. ESP32 Module

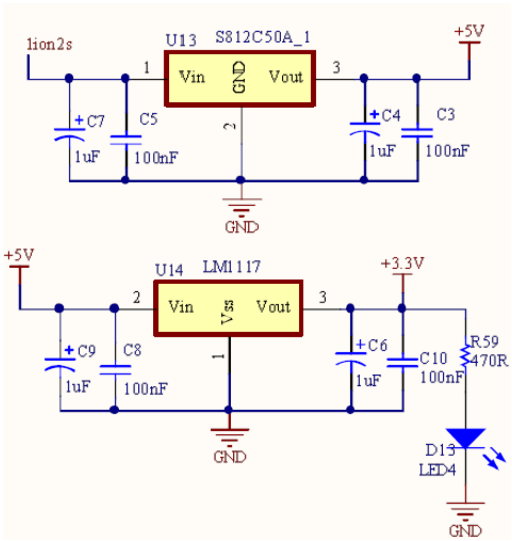

Fig. 3. Regulators in the BMS circuit

There are 13 serial cell groups in the battery system. The required two supply voltages were obtained from the positive pole of the 2nd cell with a 5 V regulator and then with a 3 V regulator. When the battery is fully charged, the 2nd cell is 8.4 V; when it is empty, it is around 6 V. This is sufficient for a 5 V regulator input.

Processor module inputs and outputs are provided with 3 V. Since the voltages of the battery cells go up to 4.2 V, they cannot be directly fed to the ADC input of the processor. The voltage value is adjusted to be below 3 V with the resistor divider. Since there are 13 cells in the design, 13 voltage dividers are used. By design, Cell 1 voltage is expressed with 4096 bits, while Cell 13 is described with 180 bits. The voltage values are set to be displayed at equal intervals with the software. Regulators in the BMS circuit and voltage divider circuit with resistors schemes are given in Fig.3 and Fig. 4. respectively.

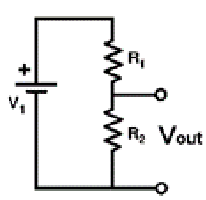

Fig. 4. Voltage divider with resistor

The voltage divider circuit designed with MUX for 13S BMS is given in Fig. 5. In this circuit structure, a voltage reading circuit is formed with voltage divider resistors to measure the voltage of each cell. The voltage values read are connected to the relevant pins of the MUX IC. This way, the voltage values of 13 different cells can be read by the analog pin of the ESP32.

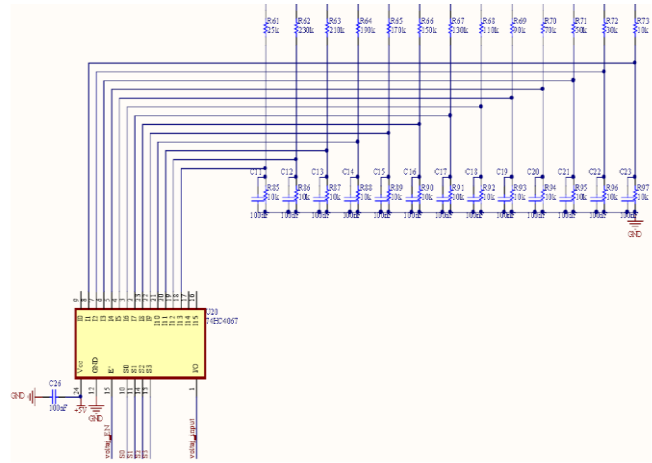

Fig. 5. Voltage divider circuit in 13S battery BMS

The values of the connected parallel resistors vary since there are 13 serial cells in the system. The voltage values to which the MOSFET switching elements are connected are different. For this reason, the optocoupler has been added to the design so that the processor outputs are not damaged, as shown in Fig. 6.

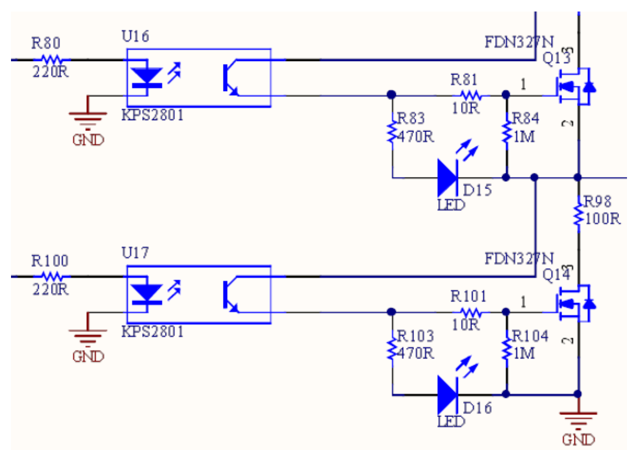

Fig. 6. MOSFET based BMS switching circuit

If the batteries in the cells fail, they overheat and burn out. Temperature sensors have been added between both cells to prevent this situation. In addition, the overcurrent operation was tested by measuring the input current. In the case of one of these two situations, the circuit connection with the MOSFET connected to the main charging arm is cut off. BSS138 N channel SOT-23 package MOSFET, which has low cost was used in the circuit. Four 100ohm, 0.25W SMD resistors were connected in parallel with the battery cell to increase the discharge current of the cell. At the same time, it was aimed to prevent heating on the resistor. Four 100ohm resistors were connected in parallel, and these balancing resistances acted as 25ohm, 1W resistors. MOSFET had a 3.5ohm internal resistor. So, the equivalent resistance value was obtained as 28.5ohm. For this reason, the BSS138 was preferred to limit the balance current easily. The equivalent resistance kept the balancing current within the specified limits. Balance speed was obtained as the determined range. The circuit design was completed in 2 layers and printed with the chemical printing method. The design and implementation of the 13S BMS circuit board are shown in Fig. 7 and Fig. 8.

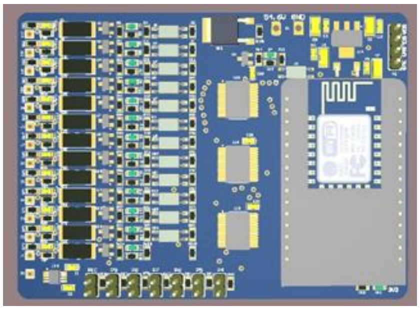

Fig. 7. PCB BMS circuit design

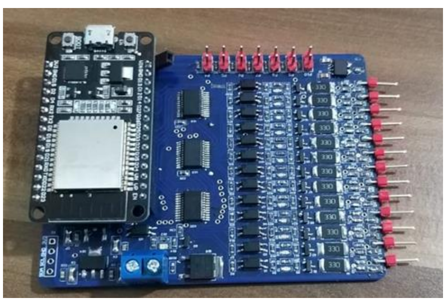

Fig. 8. Real time implemented designed BMS circuit

2.2 Control Algorithm of 13S BMS System

When the working algorithm starts, the processor communicates with the mobile device via Bluetooth modem. Afterward, the connected battery system starts the charging process. Measurements are made continuously in cycles. The first two measurements are made at the beginning as they are safety measures. First, the charging current measurement is performed. If the charging current exceeds the critical level, switching the power MOSFET on the system stops the charging current. Since data are sent to the mobile device simultaneously, a warning is given to check the battery. At the same time, the current measurement continues. Since no current is drawn from the system, the process stops until the problem is resolved. If the current drawn is within the desired range, the following safety measure is temperature measurement. The temperatures of 7 sensors are measured and sent to the mobile device, and the process continues if it is within the desired range. However, if the temperature increases due to the malfunction, the charging process stops. Since the current is cut off, the program flow remains stuck in the previous loop until the problem is fixed. When safety is ensured, charging continues with a parallel resistor connection and passive balancing; in this section, all battery cell voltages are measured and sorted from largest to smallest. If the voltages are very close, they are considered equal. While the charging process is in progress, the first step of the cycle is operated, and the security scan is performed again and continues. If there are differences in voltage levels, parallel resistance is connected to the three cells with the highest voltage with the help of a MOSFET switching circuit. While the voltage of the cells under the charging current increases rapidly, the voltage value of the cells connected in parallel increases slightly. In this way, the difference between the cell voltages is reduced over time; that is, it is balanced. The flow diagram of the control algorithm applied in the designed 13S BMS circuit is shown in Fig 8.

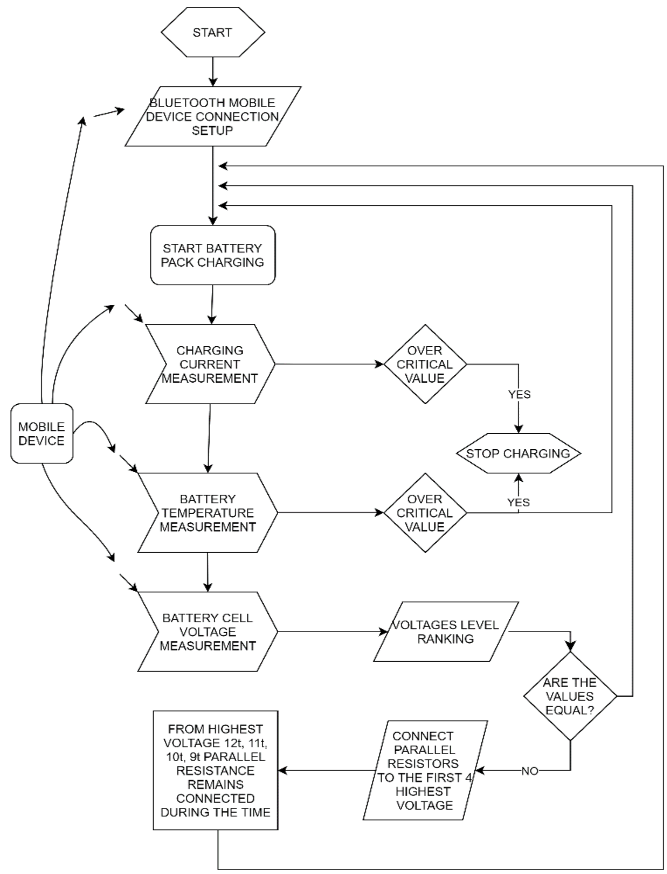

Fig. 9. Real time implemented designed BMS circuit

2.3 13S Battery Group Creation and Temperature Sensors

The battery pack output voltage is 48 V and consists of 13 series cells. The battery pack is designed to contain two parallel battery connections to increase bike range. The batteries are Lithium-ion type and determined as 18650 packs. Each battery has a capacity of 2500 mAh. When calculating the serial connection of the batteries, each battery is calculated as 3.7 V. Since the end of the linear increase in the battery charge graph is 3.7 V, the voltage value is written on the battery as 3.7 V. But when the battery is fully charged, it has a voltage of 4.2 V. Based on these data, it is understood that 13 batteries are needed to obtain 48 V with 3.7 V batteries. When 13 batteries connected in series are fully charged, a voltage value of 54.6 V is obtained. Each li-ion cell had a 2500mAh capacity. 5A current value could be obtained when two parallel arms were created. 13S battery voltage was 54.6V when fully charged. 273Wh battery capacity was calculated when 54.6V and 5Ah current capacity was multiplied. It has a capacity of 273 Wh when fully charged. The bike has a 750 W brushless DC motor.

Speed and torque can be adjusted with the engine gear transmission. In this way, it can reach a rate of 40 km/h. It can travel at a speed of 40 km for approximately 22 minutes. This means a range of about 15 km. The container where the batteries were placed was printed with a 3D printer, and the batteries were placed inside. Zinc alloy strips were used to assemble the batteries as a group. Top and bottom views of the designed battery pack are given in Fig 9 and Fig 10. After the batteries were centered, circuit connections were made by soldering cables to each voltage level. Finally, the temperature sensors were placed between the batteries in their slots on the 3D output. The integrated state of the 13S BMS circuit into the battery pack is seen in Fig. 11. Battery pack and BMS are combined into one package. The mounted version of this system on an electric bicycle is shown in Fig. 12.

Fig. 9. Designed battery pack top view

Fig. 10. Spotted view of batteries

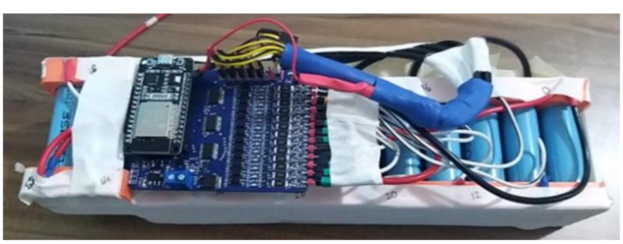

Fig. 11. Integrated BMS circuit to the designed battery pack

Fig. 12. Electric bike with battery pack and BMS

3. Results and Discussion

The behavior of the battery pack for 60 minutes at 10-minute intervals was analyzed. Charge graphs at 20 minutes intervals are shown in Fig.13, Fig.14, Fig.15, and Fig.16. For this purpose; the results are recorded in the table. The "min" meaning in the figures is the smallest initial voltage of the voltage values. It was added to the table for better detection of voltage risings. Parallel resistance was connected to 3 selected batteries at each stage for the calculated durations. It was obtained by sampling every 10 minutes of the system and is given in Table 1. According to the working principle of the circuit, system measurements were made every 1 second, and parallel resistance connection was performed for 1-2 seconds. The measures should take 1 second. This period was determined because it was easier to follow during the experimental test. Performing all operations in 5ms with processor frequency and algorithm is possible. However, this short time was not considered due to the parallel resistor connection time. A parallel resistance was connected to the 1st battery with the highest voltage for 2 seconds, the 2nd battery for 1.1 seconds, the 3rd for 1 second, and the 4th for 0.9 seconds in the prepared system algorithm.

Table 1. Obtained cell voltages data

Cell Number	**Time (Minute)**						
	0 m	10 m	20 m	30 m	40 m	50 m	60 m
S1	3.72	3.74	3.76	3.78	3.81	3.83	3.85
S2	3.71	3.74	3.76	3.79	3.82	3.84	3.85
S3	3.75	3.77	3.79	3.81	3.83	3.85	3.86
S4	3.77	3.79	3.80	3.82	3.84	3.85	3.86
S5	3.77	3.79	3.80	3.82	3.84	3.84	3.85
S6	3.76	3.78	3.81	3.82	3.83	3.85	3.86
S7	3.77	3.78	3.80	3.83	3.84	3.86	3.86
S8	3.76	3.78	3.81	3.82	3.83	3.85	3.86
S9	3.77	3.79	3.80	3.82	3.84	3.84	3.86
S10	3.79	3.79	3.80	3.83	3.83	3.84	3.85
S11	3.78	3.79	3.81	3.82	3.83	3.85	3.86
S12	3.78	3.79	3.81	3.83	3.84	3.86	3.86
S13	3.72	3.75	3.78	3.80	3.83	3.85	3.86

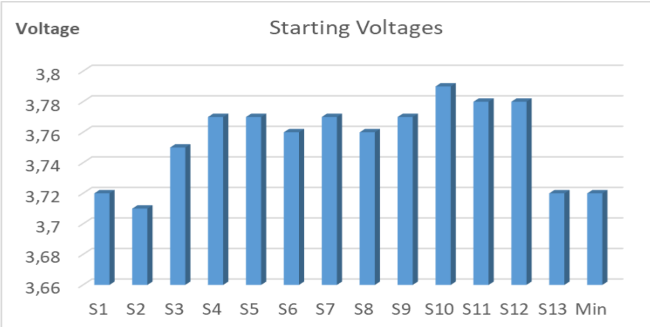

Fig. 13. Graphs of starting cell voltages

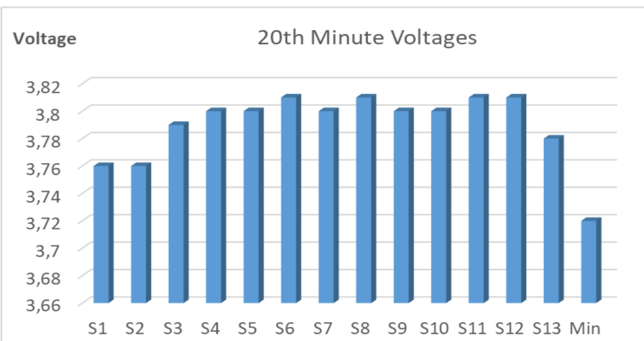

Fig. 14. Graphs of cell voltages between 0-20.min

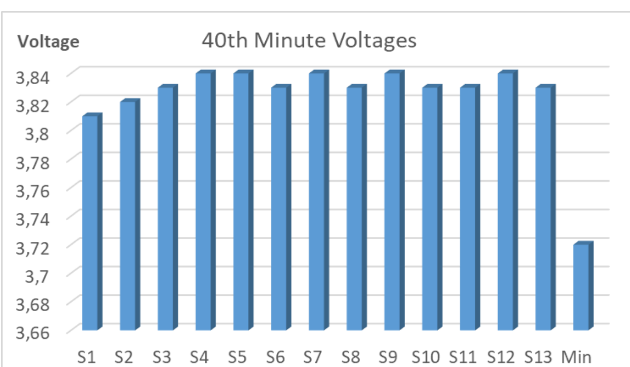

Fig. 15. Graphs of cell voltages between 0-40.min

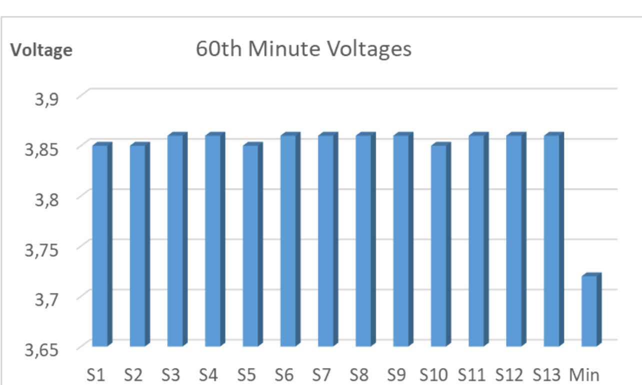

Fig. 16. Graphs of cell voltages at the end of 60 minutes

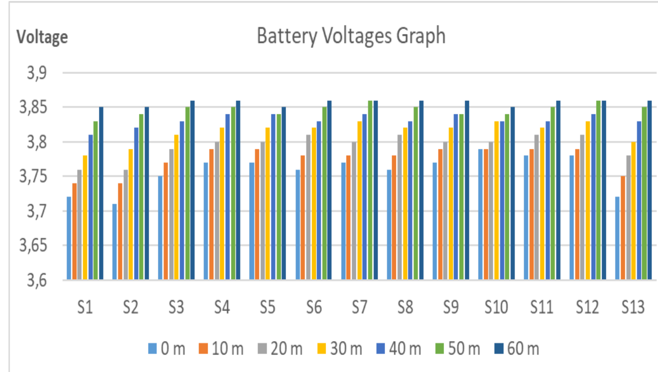

Fig. 17. Cell voltages during 60 minutes of charging

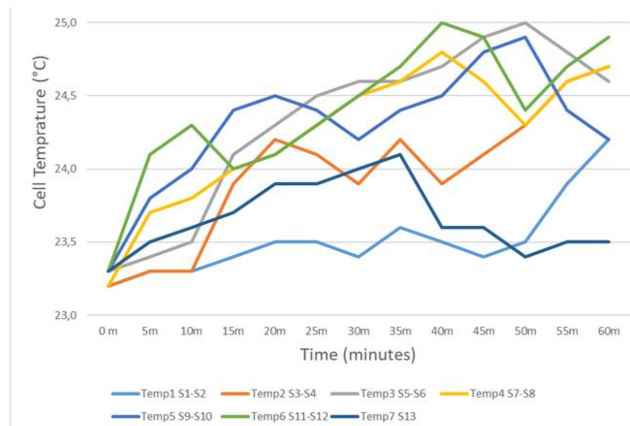

Fig. 18. Cell temperatures during 60 minutes of charging

The voltage differences between the batteries were high initially, as seen from the graphs above. A parallel resistor was connected to the batteries with the three highest voltages during charging. The voltage levels came very close to each other within 60 minutes, as shown in Fig. 17. Thus, it has been demonstrated that the system is working successfully. The battery pack was placed in a closed environment. So, the measured battery temperature remained between 23 °C and 25 °C when the ambient temperature was 22 °C. The critical temperature value was determined as 50 °C, and no higher than this temperature was observed during the test. The obtained temperature graph, while the batteries are charging is shown in Fig. 18.

Battery packs and BMS design based studies carried out together are limited in the field of electric bicycles in the literature. Generally, BMS and battery design issues have been studied under different headings. In this study, two cases were discussed together, and a comprehensive study was presented.

The 13S3P battery was designed for electric bicycles [15]. Although ESP32 was used in [16] electrical bike studies, the outputs they focused on differed. They developed a mobile application for their work. They used ESP32 to collect data for IOT purposes. The switching operations were performed with relays in the BMS control system. A modular 16S1P BMS for electric bicycles was designed in [17]. BMS was created using the Atmega328P microcontroller and LTC6803 IC. They demonstrated significant improvements in mean relative error about cell voltage monitoring. A 13S1P battery pack was developed in another study. Temperature measurements were made from five different points in the battery pack. They used an STM32F series microcontroller in communication and control processes. They provided data transfer to a mobile system with the Wi-Fi module. The LTC6804 IC was used for the BMS monitoring and control process. Battery balancing processes were performed automatically by means of using this IC [18].

The contribution was made in terms of hardware and software in this study. The isolation was added to the switching circuits by means of using optocouplers with a hardware perspective. Thus, the power and control layers were isolated at the BMS circuit. At the same time, temperature measurements were carried out for each dual battery group from seven different points. Thanks to these contributions in circuit design, an infrastructure was created in which BMS can operate more safely. In addition, wireless control of the system was carried out using an ESP32-based microprocessor in BMS. The required updates can be made easily over Wi-Fi. Thus, a BMS structure that can provide wireless data transfer and control that can be used in IOT-based systems was created.

A different type of balancing algorithm was used in the charging process in terms of software according to other studies [19]. Generally, in BMS circuits, the balancing resistor is connected to the cell with the highest voltage value [20]. In this system, four cells with the highest voltage values were determined, and these cells were balanced altogether. Balancing times were adjusted according to the mathematical proportion created in the algorithm. The cell with the highest voltage value remains in the balancing process. The cell with the lowest voltage performs the balancing process with the least time. The balancing process was carried out quickly thanks to the applied method. Thus, the imbalances between the cells are quickly eliminated, and voltage differences are prevented during the charging process.

4. Conclusion

In this study, a 13S battery pack design with 48V output voltage was carried out to be used in electric bicycles. At the same time, a BMS based on the ESP32 microcontroller module has been developed for the charging process of the designed battery pack. In the designed BMS, the passive balancing method was used by using resistors. Lithium-ion battery technology was used in the battery pack design, taking into account the power/weight ratio. The designed BMS used 18650-pack lithium-ion batteries with a nominal voltage of 3.7 V, a discharge voltage of 3.2 V, and a fully charged 4.2 V. Thanks to the built-in Wi-Fi feature of the ESP32, and the software can be updated over the internet when the battery pack is in the box. It also has an infrastructure to transfer data such as battery voltage, current, and temperature values to a mobile device via Bluetooth. Temperature control was carried out with DS18B20 temperature sensors from 7 different points in the battery. The charging current is cut off when the temperature value exceeds the determined 50 °C. At the same time, the ACS712 5A current sensor is used to protect the system in case of excessive current draw. The battery pack was charged with a current limited power supply with a constant current of 2A. When the charging current exceeds 3A, the BMS cuts off the charging current to protect the battery pack. Each MOSFET switching circuit block required for connecting the parallel resistors is isolated with an optocoupler. A battery pack application for the electric bike has been made, and a stable and safe charging process has been carried out on this battery.

Nomenclature

V	: Voltage
A	: Amper
ADC	: Analog Digital Converter
mAh	: Miliampere Hour
Wh	: Watt Hour
km	: Kilometers
km/h	: Kilometers/Hour
MOSFET	: Metal Oxide Semiconductor Field Effect Tra nsistör

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Yasin Fatih Kurt: Conceptualization, Supervision, Data curation

Tolga Özer: Conceptualization, Writing-original draft, Validation, Formal analysis

References

[1] Özdemir, T., Kiraz, E. D. E., & Yıldırım, B. İklim Değişikliği İle Mücadelede Düşük Karbonlu Ulaşım Sistemlerine Geçiş Uygulamaları. Climate and Health Journal, 2021;1(2): 47-57.

[2] Haq, E. U., Lyu, X., Jia, Y., Hua, M., & Ahmad, F. Forecasting household electric appliances consumption and peak demand based on hybrid machine learning approach. Energy Reports, 2020;6:1099-1105.

[3] Kızıltaş, M. Ç. & Ayözen, Y. E. Yenilikçi Bir Uygulama Olarak Elektrikli Bisiklet Paylaşım Sistemlerinin İncelenmesi. Avrupa Bilim ve Teknoloji Dergisi, 2022;(38):271-275.

[4] Gültek, E., & Altın, S. LiFePO4 Bataryalarda Güncel Çalışmalar Current Studies on LiFePO4 Batteries. Turkish Journal of Engineering Research and Education, 2022;1(2):108-119.

[5] Soeprapto, S., Hasanah, R. N., & Taufik, T. Battery management system on electric bike using Lithium-Ion 18650. International Journal of Power Electronics and Drive Systems, 2019;10(3):1529.

[6] Duraisamy, T., & Kaliyaperumal, D. Adaptive passive balancing in battery management system for e-mobility. International Journal of Energy Research, 2021;45(7):10752-10764.

[7] Puviwatnangkurn, W., Tanboonjit, B., & Fuengwarodsakul, N. H. Overcurrent protection scheme of BMS for Li-Ion battery used in

electric bicycles. In 2013 10th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, 2013:1-5. IEEE.

[8] Morello, R., Di Rienzo, R., Baronti, F., Roncella, R., & Saletti, R. System on chip battery state estimator: E-bike case study. In IECON 2016-42nd Annual Conference of the IEEE Industrial Electronics Society 2016:2129-2134. IEEE.

[9] Taborelli, C., Onori, S., Maes, S., Sveum, P., Al-Hallaj, S., & Al-Khayat, N. Advanced battery management system design for SOC/SOH estimation for e-bikes applications. International Journal of Powertrains, 2016;5(4):325-357.

[10] Suci, W. G. Increasing Electric Bicycle Performance using Lithium Ferro Phospate Batteries with a Battery Management System. Energy Storage Technology and Applications, 2(1), 30-37.

[11] Ekuewa, O. I., Afolabi, B. B., Ajibesin, S. O., Atanda, O. S., Oyegoke, M. A., & Olanrewaju, J. M. Development of Internet of Things-Enabled Smart Battery Management System. European Journal of Electrical Engineering and Computer Science, 2022;6(6):9-15.

[12] Bhukya, R., Nalli, P. K., Kadali, K. S., & Bade, M. C. Designing of Lithium-Ion Battery Pack Rechargeable on a Hybrid System with Battery Management System (BMS) for DC Loads of Low Power Applications–A Prototype Model. In Journal of Physics: Conference Series 2020;1:012017

[13] Anonymous, Electric Bike System Solution, https://www.renesas.com/eu/en/application/power-and-energy/renewable-energy-green-environment/electric-mobility/e-bike-system-solution (Date of access:26.01.2023)

[14] Kulasekara, V. M., Kavalchuk, I., & Smith, A. Smart key system design for electric bike for Vietnam environment. In 2019 International Conference on System Science and Engineering (ICSSE) 2019; 451-455.

[15] Soetrisno, Y. A. A., & Handoyo, E. 48V 15Ah Battery Module Design for Electric Bike Using Li-Ion NMC21700 Bat-tery. International Journal of Research and Analytical Reviews, 2021;8(4).

[16] Cahyono, M. R. A., Mariza, I., & Wirawan, S. Electric Bike Monitoring and Controlling System Based on Internet of Things. Jurnal Nasional Teknik Elektro dan Teknologi Informasi| 2022; 11(1).

[17] Canilang, H. M. O., Caliwag, A. C., & Lim, W. Design of modular bms and real-time practical implementation for electric motorcycle application. IEEE Transactions on Circuits and Systems II: Express Briefs, 2021;69(2), 519-523

[18] Song, C., Shao, Y., Song, S., Peng, S., & Xiao, F. A novel electric bicycle battery monitoring system based on android client. Journal of Engineering, 2017.

[19] Kıvrak, S., Özer, T., Oğuz, Y., & Kelek, M. M. Novel active and passive balancing method-based battery management system design and implementation. Journal of Power Electronics, 2021;21, 1855-1865.

[20] Kıvrak, S., Özer, T., Oğuz, Y., & Erken, E. B. Battery management system implementation with the passive control method using MOSFET as a load. Measurement and Control, 2020;53(1-2), 205-213.