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DESIGN OF A BATTERY MANAGEMENT SYSTEM WITH ACTIVE BALANCING TOPOLOGY

AKTİF DENGELEME TOPOLOJİSİNE SAHİP AKÜ YÖNETİM SİSTEMİ TASARIMI

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ABSTRACT

Batteries are packages that contain and use multiple cells. However, not all cells that make up the battery can charge and discharge equally, and this imbalance leads to a loss of efficiency in the battery. Even if they were produced on the same date, in the same factory, with the same method, for example, one of them is consumed by 40% while the other is consumed by 50%. At this point, battery management systems (BMS) are gaining importance. BMS, which is divided into two main headings as active and passive methods, is the focus of this paper. Both active and passive cell balancing are effective ways to improve system health by monitoring and matching the state of charge (SoC) of each cell. Active cell balancing redistributes the charge during the charge and discharge cycle, unlike passive cell balancing, which simply distributes the charge during the charge cycle. Thus, active cell balancing increases system uptime and can improve charging efficiency. At the same time, it is a method that is more reliable, avoids energy wastage as it sends excess energy to the low-energy cell, and has a faster balancing speed. Active balancing creates a more complex, larger carbon footprint and passive balancing is more cost-effective. Therefore, passive balancing is more preferred in the sector. However, active balancing is more suitable for high-voltage applications and electric vehicle technologies. Considering the disadvantages of active balancing, the main objectives are to develop this method, to provide know-how for the sector, and to increase energy efficiency in many popular areas of technology.

Keywords: Active Battery Management System, Arduino, Battery Efficiency, State of Charge

ÖZET

Piller birden fazla hücre içeren ve kullanan paketlerdir. Ancak pili oluşturan hücrelerin tamamı eşit şekilde şarj ve deşarj olamaz ve bu dengesizlik pilde verim kaybına neden olur. Aynı tarihte, aynı fabrikada, aynı yöntemle üretilmiş olsalar bile mesela biri %40 tüketilirken diğeri %50 tüketiliyor. Bu noktada batarya yönetim sistemleri (BMS) önem kazanmaktadır. Aktif ve pasif yöntemler olarak iki ana başlığa ayrılan BMS bu makalenin odak noktasını oluşturmaktadır. Hem aktif hem de pasif hücre dengeleme, her hücrenin şarj durumunu (SoC) izleyip eşleştirerek sistem sağlığını iyileştirmenin etkili yoludur. Aktif hücre dengeleme, şarj döngüsü sırasında yükü basitçe dağıtan pasif hücre dengelemenin aksine, şarj ve deşarj döngüsü sırasında yükü yeniden dağıtır. Böylece aktif hücre dengeleme, sistemin çalışma süresini artırır ve şarj verimliliğini artırabilir. Aynı zamanda daha güvenilir, fazla enerjiyi düşük enerjili hücreye gönderdiği için enerji israfını önleyen, dengeleme hızı daha hızlı olan bir yöntemdir. Aktif dengeleme daha karmaşık, daha büyük bir karbon ayak izi oluşturur ve pasif dengeleme daha uygun maliyetlidir. Bu nedenle sektörde pasif dengeleme daha çok tercih edilmektedir. Ancak aktif dengeleme, yüksek gerilim uygulamaları ve elektrikli araç teknolojileri için daha uygundur. Aktif dengelemenin dezavantajları göz önüne alındığında, bu yöntemin geliştirilmesi, sektöre bilgi sağlanması ve teknolojinin popüler pek çok alanında enerji verimliliğinin artırılması temel amaçtır.

Anahtar Kelimeler: Aktif Akü Yönetim Sistemi, Akü Verimliliği, Arduino, Şarj Durumu

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1. INTRODUCTION

Today, with the developing technology, electric vehicles, electric scooters, and renewable energy systems have started to take up more space in our lives. Because of this, the batteries which are in charge of providing energy to them also gain importance. Therefore, the service life and efficiency of these batteries are of great importance. Batteries consist of cells within themselves, and the energy consumption rates of these cells are not the same. Even if they are produced at the same date, in the same factory, with the same method. The lowest capacity cell in a battery stack determines how well the stack performs; when that cell runs out, the stack as a whole is essentially empty, and this imbalance leads to a big decrease in efficiency [1]. There are many studies on battery management systems and different methods are described in these studies [2], [3]. BMS has 2 different main methods as active balancing and passive balancing. The primary distinction between the two approaches lies in how they address the balancing of series-connected cells. Passive cell balancing achieves balance by dissipating excess energy from the highly charged cells, while active cell balancing redistributes energy from strong cells to weak cells. Passive cell balancing is extensively employed in industrial applications due to its simplicity, reliability, and cost-effectiveness [4], [5]. On the other hand, active balancing methods involve the redistribution of cell energy, which proves to be more energy-efficient compared to passive balancing methods that dissipate excess cell energy through resistors [6]. Active balancing methods are also well-suited for both charging and discharging operations [7]. In every application where batteries are used, the terms "balancer" and "BMS" come up frequently. In addition to balancing, BMS also monitors and regulates the entire battery at the cell level, disconnects the entire battery in the event of an over- or under-voltage, and extends the life of the expensive battery. All that a balancer does is transfer energy from a higher-voltage cell to a lower-voltage cell to keep batteries balanced. In this study, a battery management system using active balancing topology will be developed. In this system, one switched capacitor method is preferred among other active balancing methods. With this study, it is aimed that the team will gain know-how on the management of batteries to be used in renewable energy and electric vehicle systems, which are popular topics of the last period. It is thought that this study will also make significant contributions to the electric vehicle industry in the near future, when the number of domestic and national electric vehicles will increase.

2. METHODOLOGY

Active balancing methods are divided into 2 different branches depending on the hardware used as given in Figure 1. These are capacitive and inductive methods. Inductive methods are about using transformers for balancing, and these can be given as examples of switched transformer and shared transformer methods [8] [9] [10]. Although these methods have advantages such as higher balancing speed and less loss, they were not preferred in this study because they use converters as the basic hardware. The fact that the transformers are much more expensive than the capacitors to be used in capacitive methods and the difficulty of supplying them led to the preference of capacitive methods. Capacitive methods use capacitors as the basic equipment and use the method of taking energy from a fuller cell, storing it in the capacitor and then transferring it to the low-energy cell. Examples of these are the multiple switched capacitor and one switched capacitor methods [11].

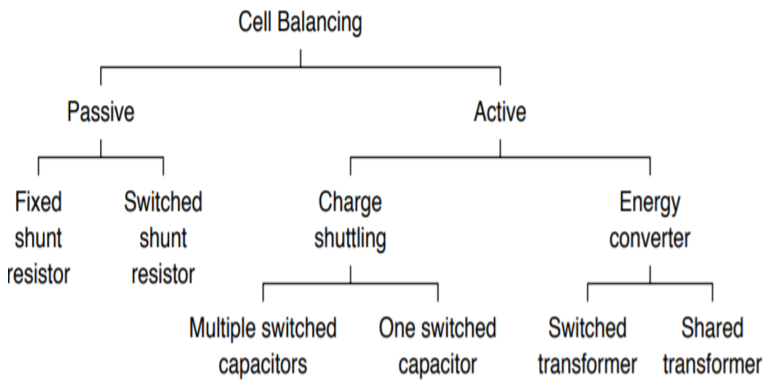
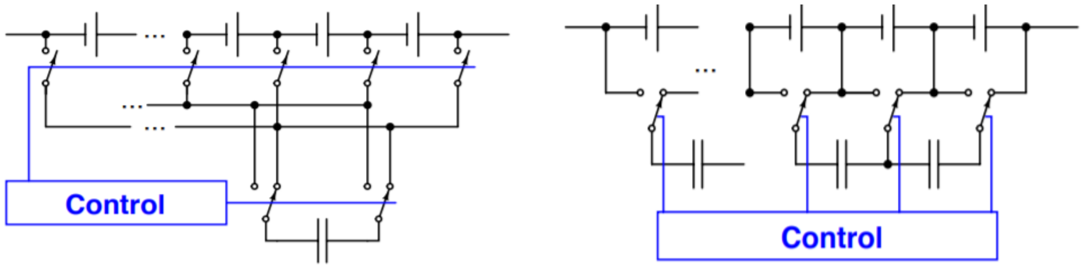


Figure 1. Methods of BMS [12]

In multiple switched capacitor methods, a capacitor is connected for each neighboring cell and balancing is done by providing energy transfer between neighboring cells as given Figure 2a. 2n switches and n-1 capacitors are used to balance n cells. Although this method does not require intelligent control and has advantages such as low switching voltage stress in switches, it requires a long balancing time. In addition, the cost is much higher due to the use of more hardware [13].

In one switched capacitor methods, a capacitor is connected for each neighboring cell and balancing is done by providing energy transfer between neighboring cells as given Figure 2b. The capacitor identifies the high-energy cell, receives and stores the energy, and then transfers it to the low-energy cell it identifies. For this, it is necessary to determine the state of charge of the cells and to use an intelligent control. Balancing N cells requires n+5 switches and a single capacitor. Compared to the first method, it has the advantages of being more reliable, less costly, easy to control and easy to implement. [13].



(a) **(b)**

Figure 2. (a) Multiple switched capacitors, **(b)** one switched capacitor [12]

$$E = \frac{1}{2}C(v_H^2 - v_L^2) \tag{1}$$

$$SOC = E \approx (\Delta z)Qv_{nom} \quad v_{nom} = \frac{V_H + v_L}{2} \tag{2}$$

$$(\Delta z)Q\frac{V_H + v_L}{2} \approx \frac{1}{2}C(v_H + v_L)(v_H - v_L) \quad \Delta z \approx \frac{c}{Q}\Delta v \tag{3}$$

2.1. Topologies of BMS

Battery management systems have a multi-electronic complex structure. The BMS is aimed to be designed voltage and current measurement at cell level, charge level determination (SoC), health level determination (SoH), cell level balancing, continuous control of the voltage and current limits of the cells targeted. For this reason, deciding on the basic features that will form the system is done at the very beginning of the paper. Types of sensors to be used; determined as voltage, current and temperature sensors.

The battery management system may be designed with many different topologies. The advantages and disadvantages of the active BMS methods are given Table 1. The centralized topology offers such solution where cells are directly connected in a single BMS circuit. All measurements, decision mechanisms and parts where balancing operations are performed are all in a single circuit. The disadvantage is the use of excessive cables and thus causing overheating. In the modular topology, there is more than one BMS circuit and one of these circuit boards is the master circuit, but there is difficulty in communication at the cell level. In the Master-Slave topology, the circuit board, which is the manager, has no direct connection with the cells as given Figure 3. In distributed topology, there are analog circuits for each cell. However, these circuits do not have any control function. It consists only of circuit elements related to balancing [14].

In this paper, it is aimed both to balance at the cell level and to make cell measurements using Arduino. Therefore, a synthesis of distributed topology and centralized topology is preferred. In this new synthesis topology, Arduino is planned to be used as the master board as it is suitable for sensor fusion, interface creation and application of different algorithms. Unlike the distributed topology, the current, voltage and temperature data from the cells will be transferred to the Arduino via the sensors and will be processed and interpreted there.

Table 1: Comparison of active BMS methods

	Switched transformer	Shared transformer	Multiple switched capacitors	One switched capacitor
Balancing speed	High	High	Low	Middle
Control	-	-	-	High
Cost	High	High	Middle	Low
Ease of supply	Low	Low	High	High
Reliability	High	High	Middle	High

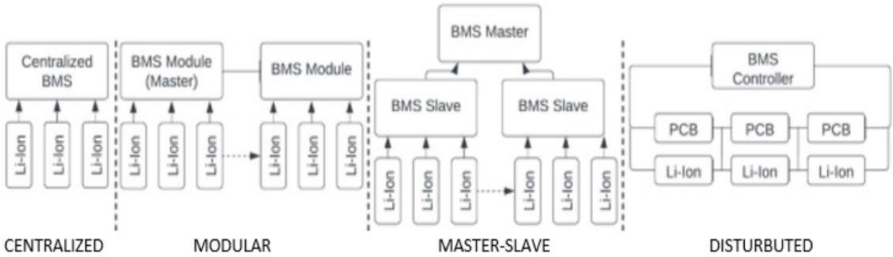


Figure 3. Schematic overview of BMS topologies

2.2 Battery Types and state of charge

Since the discharge voltage curve of Li-Ion batteries is relatively more linear than other battery types, it was decided to use coulomb counting instead of voltage measurement as a method of determining the state of charge. Estimating SoC with only voltage measurement causes high percentages of error. Because Li-Ion batteries have less voltage changes between 80% and 20% during discharge [15]. In addition, the BMS circuit constantly checks that the voltage and current values of the batteries are within the limit values during both charging and discharging. In case of exceeding these values, it controls the relays connecting the battery to the circuit and ensures that the battery is deactivated. The proposed topology is given Figure 4.

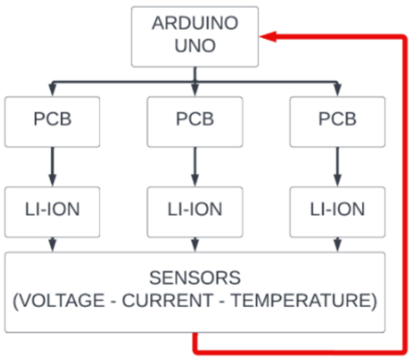


Figure 4. Diagram of the synthesis topology

Calculation of State of Charge (SoC) is aimed to be done in this part. There are different methods for obtaining SoC. The most suitable method for the BMS is chosen according to the battery type. As it is seen in the Figure 5, both charge and discharge curves of Li-Ion batteries does not change linearly. Because of this reason, it would cause great errors to calculate SoC by only using voltage values. Therefore, it is decided to use Coulomb counting method to calculate/estimate SoC with minimum error [16, 17].

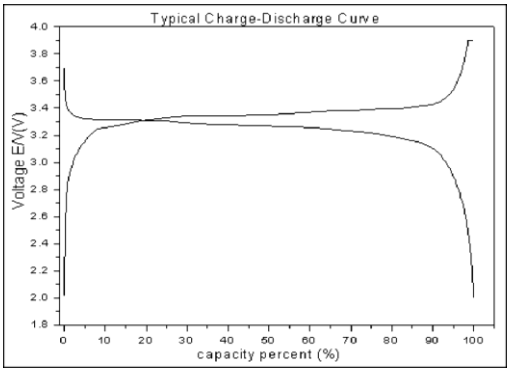


Figure 5. Charge-discharge curve of Li-Ion batteries [18]

Coulomb counting method uses current measurement to calculate how much energy remains in the battery pack using which is done by comparing current values measured separately [19].

$$SoC(t) = SoC(t-1) + \frac{I_{(t)}}{Q_n}\Delta t \quad (4)$$

SoC(t-1) = SoC at previous time step

η = efficiency

t = current time step

t-1 = previous time step

Q = Charge capacity of the battery

Finally, an active balancing BMS with one switched capacitor method within a synthesis topology is implemented using Arduino Uno, 3 18650 Li-ion batteries in series, ACS712 current sensors, DS18B20 temperature sensors, and a 5V relay. Coulomb counting is applied in Arduino to calculate/estimate SoC. Balancing PCBs with one switched capacitor method are designed and implemented to work with digital outputs of Arduino. Then, display is derived to show SoC, voltage, temperature, and current values of all cells.

3. SENSORS

3.1 Temperature Sensor

This part includes the choice of most suitable temperature sensor for this paper and its implementation into the Arduino Uno in both hardware and software context. The implemented circuit is given Figure 6. This is done by making such choice to minimize number of inputs used in Arduino Uno to leave more room for balancing control. Decision of temperature sensor is made in favor of DS18B20. This is because of the possibility of using 3 of DS18B20 sensors with only one digital input of the Arduino Uno with the help of each sensor having its own ID [20].

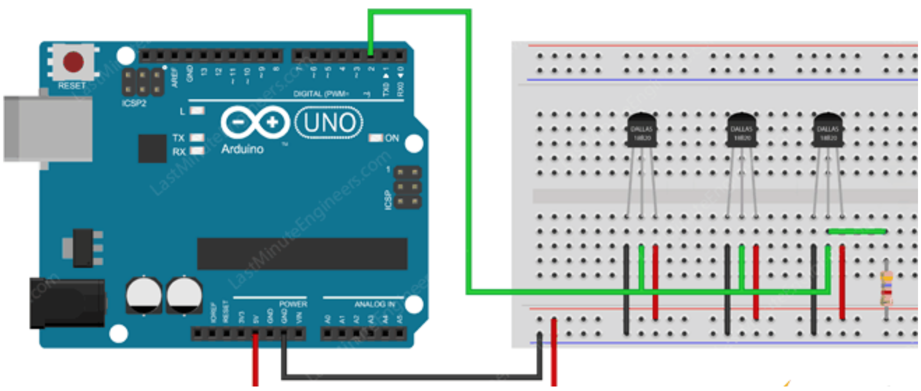


Figure 6. Wiring temperature sensor to Arduino [21]

In addition, DS18BS comes in two variations. There is only one difference between those two which is the casing of sensor. The one with the metal casing is chosen because of the fact that heat transfer is faster compared to the other one with epoxy casing. Number of inputs and connections are the same. Implementation of the DS18B20 temperature sensor is completed. The sensor with minimum number of inputs is obtained, implemented, and integrated into the BMS with required connections along with suitable code.

3.2 Voltage and Current Sensors with Relay

This part includes the choice of most suitable voltage and current sensor along with relay and their implementation into the BMS. Voltage of each Li-Ion cell is going to be measured separately and maximum voltage value of a Li-Ion cell is 4.2 Volts. Arduino Uno can measure voltage values up to 5 Volts. For this reason, it is possible to use Arduino Uno itself along with a passive circuitry for voltage measurement. This process is basically using two resistors as voltage dividers, reading the divided voltage value from an analog input pin, and later scaling this value to obtain measured voltage in the very beginning of the process. For the sake of accuracy, resistor values are measured with a multimeter and included in the code with their measured values. For example, a 10k ohm resistor is measured as 9800 ohm and 100k one is also measured as 97800 ohm and the code is written accordingly to eliminate errors. The voltage measurement circuit generated in this study is given Figure 7.

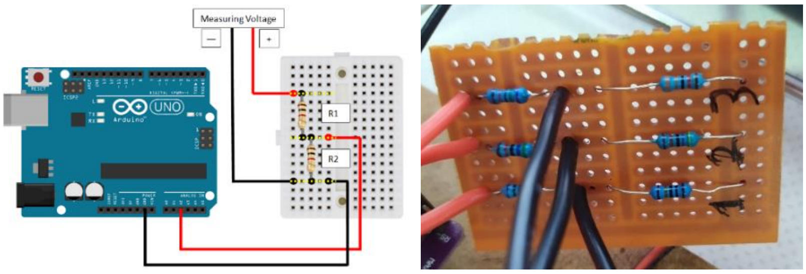


Figure 7. Voltage measurement with Arduino [22]

While adjusting the algorithm for more accurate measurement, such method in the Figure 8 used by measuring the voltage value with a multimeter, a cell meter, and an Arduino Uno. Even though cells are connected in series in designed BMS, current values of each sensor are done separately to track the process in a better manner during balancing. Therefore, it is needed to obtain and implement 3 current sensors. Current sensors that were analyzed for decision are MAX4080, INA169, INA219, INA3221, ACS712, ACS758, and WCS1800. After a long consideration in a wide range of current sensors according to the cost, sensitivity, and range parameters, it is decided to use ACS712. It is currently one of the most reachable current sensor in the market and its specifications are suitable for such BMS. However, some modifications are done to implement ACS712 into the BMS [23, 24]. ACS712 has 3 variations such as ± 5A, ± 20A, and ± 30A. Among other versions, ±5A is chosen due to the reason that it is more sensitive which helps doing more accurate measurements.

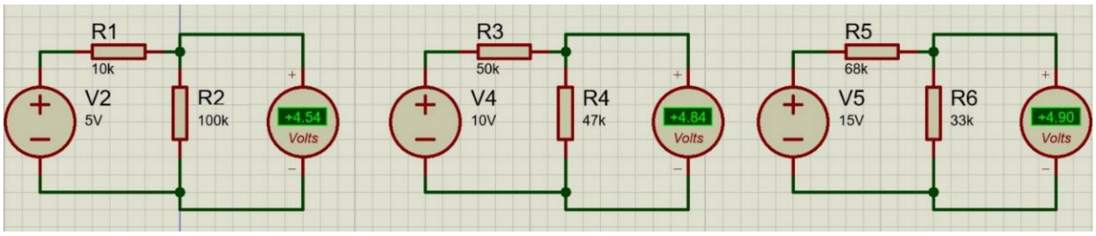


Figure 8. Voltage divider circuit design

The sensor is working with a principle of dividing 5 Volts given into its VCC and GND terminals into 2.5 Volts which is also the output of the sensor in VIOUT terminal connected to an analog input pin of Arduino Uno. However, this 2.5 Volts changes according to measured current value. Such change is calculated by the Arduino Uno with a specific code to obtain current values in Amperes. There are 2 capacitors connected to the sensor. C_{BYP} exists to remove ripples of 5 Volts. C_F stands for filtering and affects both measurement period and accuracy as given Figure 9 [25].

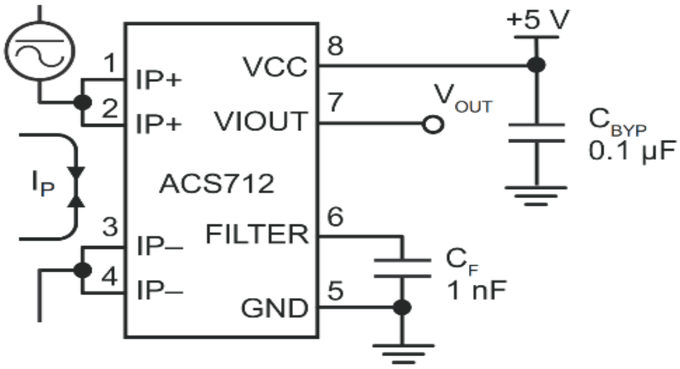
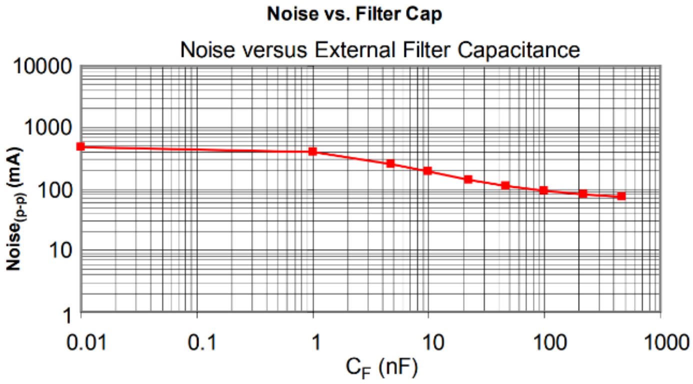


Figure 9. Diagram of ACS712 [24]

However, ±5A version of ACS712 has 300mA noise because of two reasons. The first one is 0.1 µF capacitor is insufficient to remove ripples in 5 Volts DC output of Arduino Uno. Due to the working principle of the current sensor that is explained earlier in this report, each ripple in 5 Volts cause incalculable changes in measurements. To prevent this, a 220 µF capacitor is connected in parallel to the output of Arduino Uno. The second one is 1 nF capacitor. Because it offers 7.7 µs of rise time with 300mA noise. However, 1120 µs of rise time along with 30mA is a lot more suitable in this BMS. In Figure 10, noise graph and table are given from datasheet of ACS712.



C_F (nF)	t_r (µs)
0	6.6
1	7.7
4.7	17.4
10	32.1
22	68.2
47	88.2
100	291.3
220	623.0
470	1120.0

Figure 10. Noise graph and table of ACS712 [24]

470 nF capacitor is soldered in parallel to 1nF filter capacitor and noise is successfully reduced down to 30mA which decrease the amount of error down to %1 from %10 in a case where 3A is measured during charging process while being able to take samples every 1.12 ms. The connection of the soldered capacitor is given Figure 11.

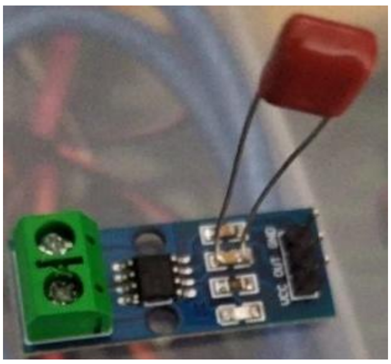


Figure 11. Soldered capacitor that used in the design.

After improvements on accuracy are completed in hardware, some software solutions are derived such as digital filtering. Arduino Uno reads 10 values and takes their average to remove the effects of unexpected peaks from measurements. Then, average values are converted into current values. After all those modifications, noise of the current sensor is successfully reduced to 30mA.

Three types of relays are used in the BMS. A 5V, mechanical and normally closed relay is used to open and close the contact of battery with the system during balancing and in case of an emergency. Such emergency would be batteries overheating, current values increasing more than expected due to a short circuit and measuring unexpected high voltage values in Li-Ion cells during charging or discharging processes. If Arduino Uno detects such emergencies, it sends out a signal from one of its digital output pins to the relay [26].

Other than that, six 5V SPDT relays are used in the balancing part where it is indicated which cells are going to be balanced among three 18650s as given Figure 12. For the last, there are four AQZ205 solid state relays. They form 2 SPDT relays for switching the one switched capacitor between two cells that are chosen to be balanced. Solid state relays are used since they provide significantly high switching speed.

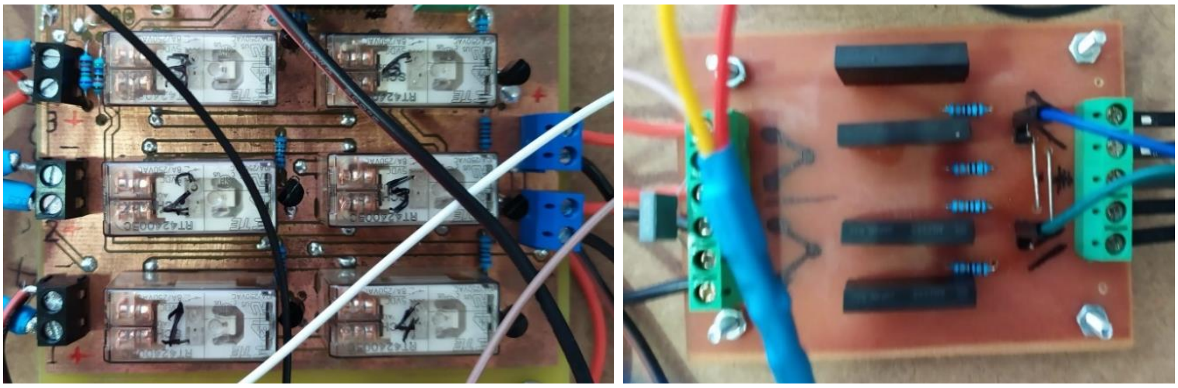


Figure 12. 5V mechanical SPDT Relays 4 solid state SPST relays that are forming two SPDT relays

Since there are many relays used in both balancing and other parts of the circuit, relay driver circuits consist of 2N2222 bipolar junction transistors that are equipped with 1N4002 flyback diodes are implemented as Figure 13. 5V is obtained from the voltage regulator that is connected to plug so that Arduino only provides signal output for all relays.

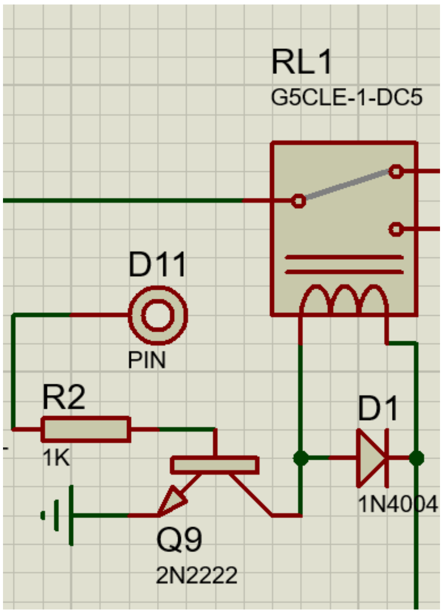


Figure 13. Relay driver circuit

This part of the study is completed by deciding, obtaining, and implementing current, and voltage measurement methods along with the relay. However, digital filtering part is always open for improvement during tests. Because it is quite easy and a lot less concerning to implement changes in the code, it is accepted as finished. After the second part is completed, all codes are put together to form the main loop and overall circuit is configured in Figure 14.

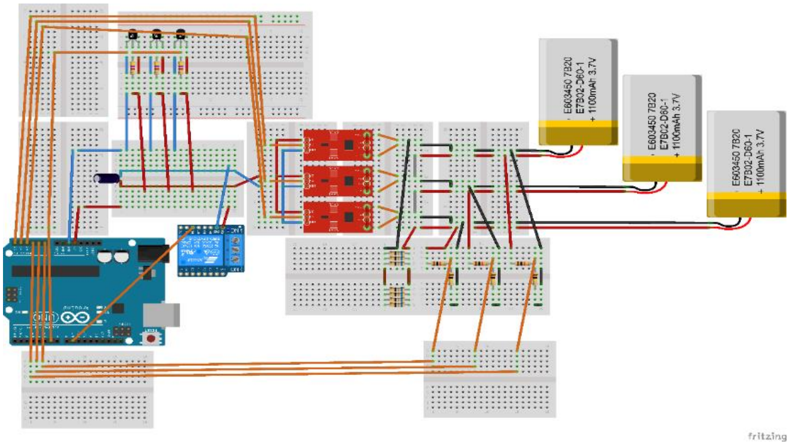


Figure 14. Circuit diagram after the second part is completed

4. BALANCING PCB

In Figure 15, charge and discharge graph of the balancing capacitor is given. By evaluating the voltage and current formulas of a capacitor, required values are determined.

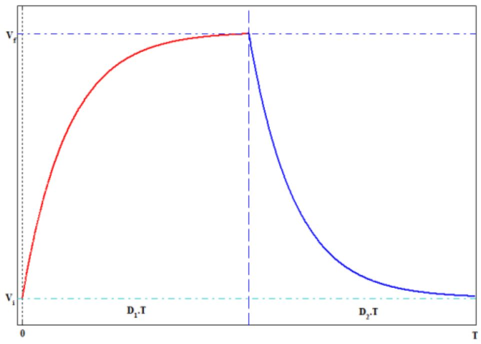


Figure 15. Charge and discharge graph of the balancing capacitor [27].

$$V_{C_{charging}} = (V_f - V_i)\left(1 - e^{\frac{-t}{\tau}}\right) + V_i = V_{diff}\left(1 - e^{\frac{-t}{\tau}}\right) + V_i \quad (5)$$

$$i_c = C\frac{dVc}{dt} = C\frac{1}{\tau}.Vd_{iff}.e^{\frac{-t}{\tau}} = \frac{V\,diff}{Rs}.e^{\frac{-t}{\tau}} \quad (6)$$

$$\text{Energy charging } = C.V_{diff}\left\{\frac{V_{diff}}{2}.e^{\frac{2D}{\tau.F}} - V_f.e^{\frac{-D}{\tau.F}} - \frac{V_{diff}}{2} + V_f\right\} * F \ \ (Wh/h) \quad (7)$$

$$\text{Energy discharging } = C.V_{diff}\left\{\frac{V_{diff}}{2}.e^{\frac{-2D}{\tau.F}} - V_i.e^{\frac{-D}{\tau.F}} - \frac{V_{diff}}{2} - V_i\right\} * F \ \ (Wh/h) \quad (8)$$

Figure 15 and 16 shows the amount of energy capacitor can be charged and discharged on various values of duty cycle. The duty cycle refers to the amount of time a signal is on during a given period. Therefore, decision of providing 0.9 of the periods for the charging process will result leaving only 0.1 for the discharging process which will cause capacitor to not fully discharge its energy into the low voltage cell during balancing. Because of that, even though energy transferred seem to increase with the duty cycle, due to the fundamentals of the term of duty cycle, 0.5 gives the best results for energy transfer during balancing.

Figure 16 also states that increasing switching frequency over 500 Hz does not provide a significant difference in terms of the amount of energy transferred between cells and the capacitor. Therefore, switching frequency is chosen to be 500 Hz.

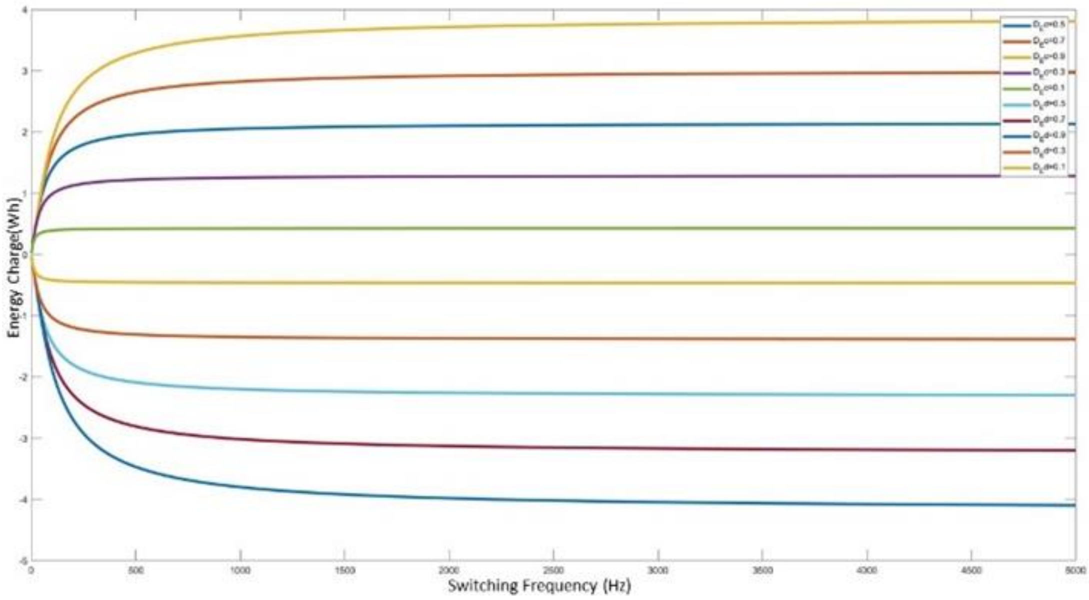


Figure 16. Energy Charge & Discharge Graph Depends on Duty Cycle

Based on the capacitor values already existing on the market, such graphs are drawn by only changing the capacitor value as shown in the Figure 17. Since the duty cycle is determined as 0.5 and switching frequency is 500 Hz, those graphs are obtained to determine the best capacitor value capacitor value as 4.7 µF for the most amount of energy transfer.

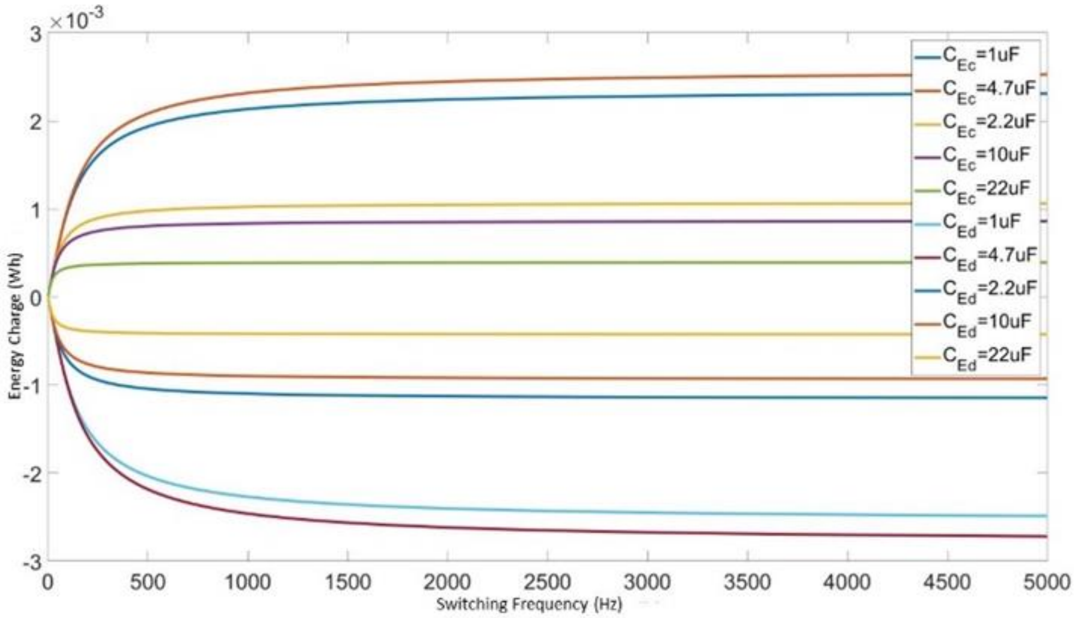


Figure 17. Capacitor Comparison

In Figure 18, charging part of the BMS is shown. This part of the PCB design enables to turn AC input into DC for the charging part of the BMS. It consists of a transformer, a full bridge rectifier, and a capacitor. Transformer decreases voltage while increasing current value of the AC. Full bridge rectifier performs such operation to turn negative half waves into positive. Capacitor enables rectified waves to transform into a DC form. When it is manually switched, the circuit starts charging Li-ion cells. 12.5V and 5V outputs are provided for charging and mechanical relays respectively.

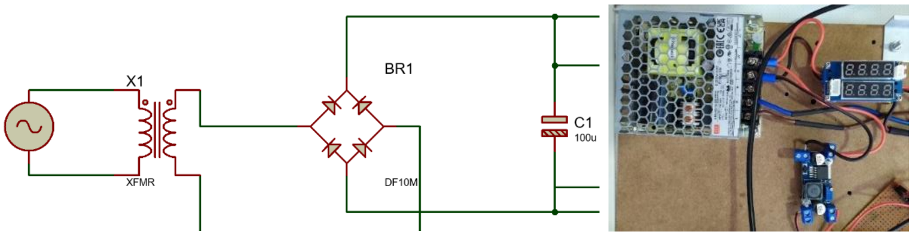


Figure 18. Charging Circuit

To be able to perform balancing operation, it is needed to design such load circuitry that will allow us to discharge Li-ion cells at the most possible current values based on their discharge rates. In Figure 19, such load circuit is given to perform the discharge process. Discharging of 12.6V Li-ion battery that consists of 3 Li-ion cells in series, is done using 8.2 Ω and 50W resistor given in the figure. Even though it is possible to increase current in the designed circuit, 1.43A of current is enough to simulate SoC estimation method using Coulomb counting. Also increasing current causes temperature of the load resistor to increase. Therefore, discharging current is decided to be 1.43A just in case of any accidents which may occur related with the high temperature.

Figure 19. Load Circuit and high watt resistor in discharge circuit

In Figure 20, the main method of the balancing circuit is given. It depends on the MOSFETs that are driven with the digital output pins of the Arduino Uno using a simple gate driving circuit topology. MOSFETs are placed in such way to form one switched capacitor method along with a capacitor. The control of the balancing circuit is done by the Arduino Uno with the help of voltage and current measurements also done and processed with the Arduino itself. When the voltage difference between two cells are higher than the threshold value, balancing starts until they are balanced.

After implementation of the code, Arduino Uno is connected to a personal computer with a USB cable. It sends data using serial monitor. Sent data is a line where V1, V2, V3, I, SoC, T values along with the information whether balancing is happening or not are placed. If microcontroller decides to do balancing it also indicates balancing is done between which cells. The output examples are given in Figure 21.

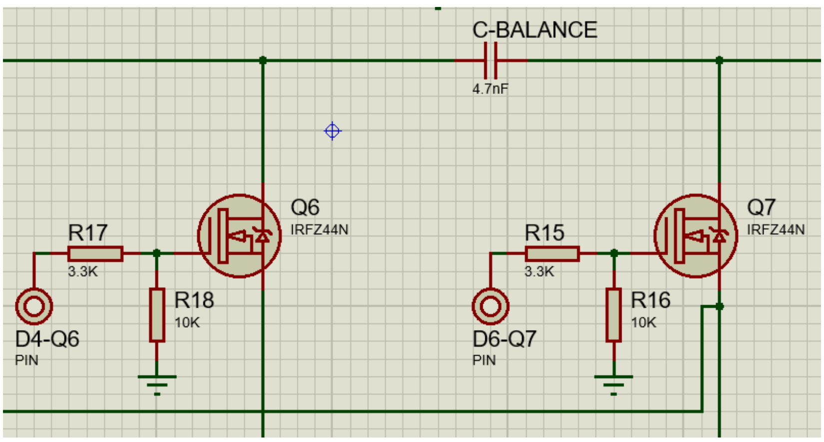


Figure 20. A part of the Balancing Circuit

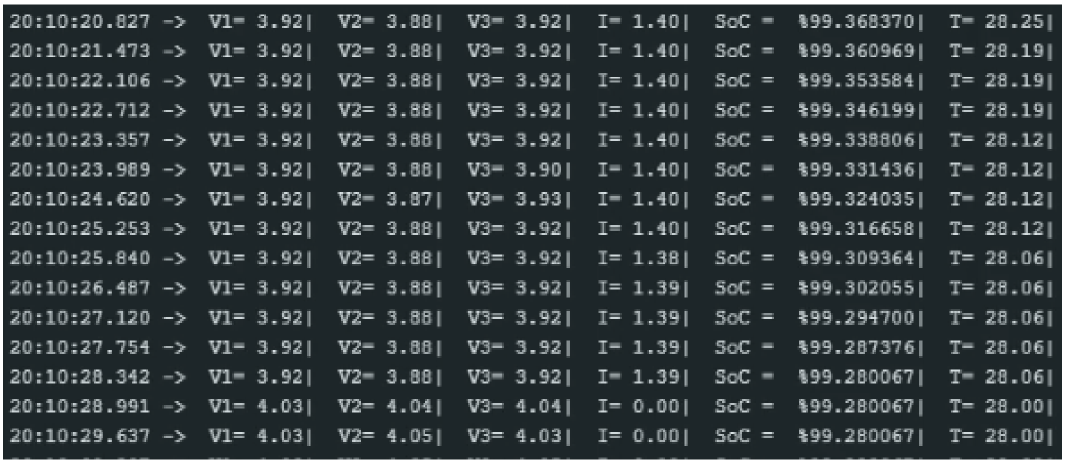


Figure 21. Serial monitor of arduino

5. CONCLUSION

The major subject of this study is BMS, which is subdivided into active and passive techniques. In the sector, passive balancing is more prevalent. However, active balancing is more suitable for high-voltage applications and electric vehicle technologies the main objectives of this paper are to develop this method, to provide know-how for the sector, and to boost energy efficiency in many common technological fields. Active balancing techniques are classified into two groups. Capacitive methods, the ones utilized in this study, use capacitors as the primary equipment while inductive methods focus on using transformers for balance. Additionally, there are various branches for capacitive methods. One switched capacitor technique involves connecting a capacitor to each neighboring cell, and balancing is done by providing energy transfer between neighboring cells. It benefits from being more dependable, less expensive, easy to control, and easy to execute. Numerous topologies may be used in the design of the battery management system. This work aims to balance at the cell level as well as use Arduino to cell measurement. Therefore, a synthesis of distributed topology and centralized topology is preferred. In this new synthesis topology, Arduino is planned to be used as the master board as it is suitable for sensor fusion, interface creation and application of different algorithms. Unlike the distributed topology, the current, voltage and temperature data from the cells will be transferred to the Arduino via the sensors and will be processed and interpreted there. Since the discharge voltage curve of Li-Ion batteries is relatively more linear than other battery types, it was decided to use coulomb counting instead of voltage measurement as a method of determining the state of charge to obtain more reliable SoC data.

For the types of sensors to be used; determined as voltage, current and temperature sensors. Decision of temperature sensor is made in favor of DS18B20. Arduino Uno is able to measure voltage values up to 5 Volts. For this reason, it is possible to use Arduino Uno itself along with a passive circuitry for voltage measurement. For current sensors, after a long consideration, it is decided to use ACS712. It is currently the most reachable current sensor in the market and its specifications are suitable for such BMS. Also, a 5V relay is planned to be used to separate load from the battery in emergencies such as batteries overheating, current values increasing more than expected due to a short circuit and measuring unexpected high voltage values in Li-Ion cells during charging or discharging processes.

The most suitable switching frequency, capacitor and duty cycle values are determined by implementing capacitor charge and discharge equations on MATLAB to obtain better performance in the active balancing part of the BMS circuit. It is aimed to maximize the amount of energy transferred between high and low voltage cells using the capacitor. Later, such values are placed on electrical and electronic components with the aim of designing a BMS with active balancing topology.

Finally, an active balancing BMS with one switched capacitor method within a synthesis topology is implemented using Arduino Uno, ACS712 current sensors, DS18B20 temperature sensors, and multiple relays. Balancing PCBs with one switched capacitor method are designed and implemented to work with digital outputs of Arduino. Then, display is derived to show SoC, voltage, temperature, and current values of all cells.

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