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Design and analysis of battery management system in electric vehicle

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Abstract

The usage of electric vehicles is gaining momentum in recent time's thus providing support to the growth in sales of electric vehicles. The Battery management system is the most important aspect to ensure the smooth functioning of an electric vehicle. This research highlights some key statements on the background of electric vehicles. The increase in the overall growing importance of electric vehicles has also been explained in this work. Battery management system has an importance in the functioning of electric vehicles, thus presenting the key highlights of this article. The finding presents the importance of batteries and their type used in EVs. The simulation results of the Lithium battery cell – 1 RC, 2 RC equivalent circuit parameters such as charging current, terminal voltage, state of charge, and battery current have been simulated and analysed in Matlab. The future scope of BMS and its development has been discussed.

Keywords: Electric vehicle, Battery Management System, one RC network, Two RC networks, Battery monitoring

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1. Introduction

The electric vehicle industry has been growing in recent days with manufacturing units focusing on vehicles operated by electricity. The history of electric vehicles shows that experimental prototypes emerged in Hungary with gasoline-powered cars in the 1830s. In recent times, fuel prices have surged, making electric vehicles a cleaner mode of transportation, designed this prototype that used electricity in place of steam and gasoline. These EVs have been known for their smooth, quiet rides. In the same year, hybrid versions of mechanical cars were introduced. Thus, this made the demand for EVs fall as they failed to cover long distances. The overall market share was 33% at that period. At the end of the 1960s and 1970s, the demand for EVs started dropping as fuel cars have higher speeds and range. However, at the beginning of the 21st century, increases in fuel prices and environmental concerns again pushed the market of EVs [1], [2].

The electric vehicle market has shown a growing trend based on propulsion (BEV, PHEV), by components (Battery Cells and packs), showing a market of USD 205.58 billion by the end of 2022. The electric vehicle market is considered the future of technology in automobiles as these emit "zero tailpipe emissions" that can reduce carbon emissions. These electric cars can reduce pollution and thus fight global warming and drastic climate change. Consumers are aware of vehicle pollution and this awareness has allowed EV adoption. The sales of EVs have increased globally by 60% in 2022 and a growth rate of $150 million. The revenue in the EV segment is expected to reach $906.7 billion by 2028 at a CAGR of 10.07% from 2023-2028 as illustrated in Figure 1. The growing importance and demand for EVs further bring into focus the battery management system of the vehicles which is the most integral component [3], [4]. The BMS allows monitoring of different parameters such as temperature, input and output current, and voltage flow in different battery packs. This protects the vehicle and battery pack from overcharging, over-discharging, and excessive current. Power optimization and safety are some of the major importance of BMS. The outcome of cell monitoring helps in battery optimization. These cell monitoring functions keep the Safety of Charge (SOC) and Safety of Health (SOH) optimized. The Safety of the Operating Area (SOA) defines the temperature, current and voltage condition. The battery management system optimizes the safety of the battery pack by maintaining thermal management through power optimization in the battery [5].

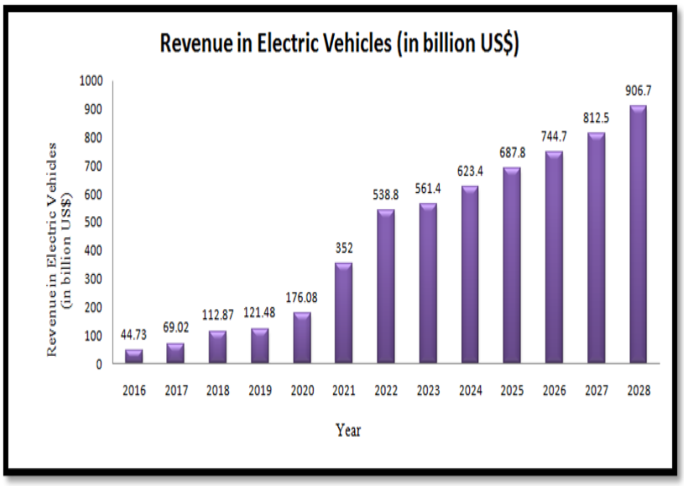

Figure 1. Revenue in electric vehicles (2016-2028)

As electric vehicles have lithium ions in the cell, they get overheated and need to be monitored. This cell monitoring helps in energy power consumption and energy calculation. An electric vehicle refers to a vehicle that can be powered by both battery electricity and electric motors. This vehicle uses a large fraction of electric energy from the charging station. As mentioned in [6], hybrid and plug-in EVs are both powered by electricity and petrol. It is an environment-friendly option, as its emissions are power generated which can be reduced through the use of renewable energy. The purchase of EVs is increasing as it has a lower refuelling cost, lower car tax, and maintenance thus attractive for any exhaust system. EV owners gain momentary value as vehicle-to-grid technology is lower than conventional-powered cars. Based on that, a general configuration of EV has been provided as depicted in Figure 2 [7],[8].

Table 1. Difference between ICEs and EVs

Parameters	ICEs	EVs
Efficiency	20% of the stored gasoline is converted to power	75% of the chemical energy gained from batteries is converted to power
Average Speed	200 km	48-150 kph
Average Acceleration	0-100 kph in 8.4 seconds	0-100 kph in 4-6 seconds
Maintenance	High maintenance due large number of moving parts	Low maintenance due to fewer moving parts
Avg. Mileage	480-500 kilometres before refuelling	120-200 kilometres on one charge
Avg. Cost	0.7-1.1 million INR	1-6 million INR
Emission	Greenhouse and toxic emissions	Zero emissions

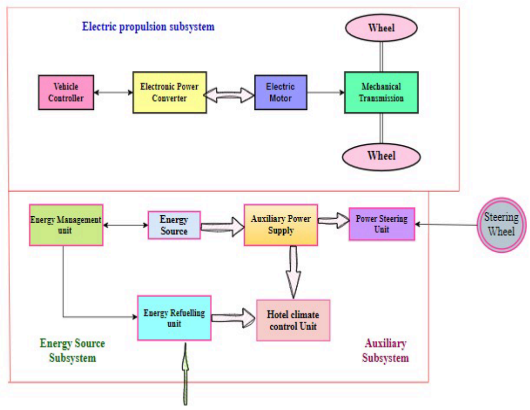

Figure 2. Conceptual illustration of general EV configuration

The EVs can be divided into certain type's like- hybrid, plug-in, and fuel cell. The hybrid electric vehicle operates based on an electric motor that has an internal combustion engine that offers high fuel economy, low tailpipe emission, and a stronger conventional vehicle. The energy stored in the battery pushes power during start and acceleration. It has the power to consume the auxiliary load and reduce engine idling [9],[10]. The difference between ICEs and EVs for different performance parameters is depicted in Table 1.

1.1 Battery and its types

There are currently hybrids and all-electric vehicles available in the market, and the batteries are used based on the type and purpose of the vehicle; the three primary kinds of batteries that are used are lithium, nickel- and lead-acid batteries. The author explains the batteries are incredibly significant for the performance of the vehicle as they provide it with energy and, therefore, a core concept of EVs. Lead-acid batteries were first developed by a French scientist named Gaston Plante, and it makes use of sulfuric acid as the electrolyte within the battery. In contrast, lead and lead oxide are used as an anode and cathode. These kinds of batteries are competent and have been designed to be inexpensive and reliable. Over the years, these kinds of batteries have been highly efficient in providing electrical energy within the automobile sector. To improve their performance, advanced lead-acid batteries are being developed that can provide these electric vehicles with safety [11], [12].

Compared to lead, nickel is a much lighter metal that is also widely available, and due to its high electrochemical properties, it continues to be used within the EV sector to develop batteries. The nickel batteries can further be divided into four different types, these are nickel-iron batteries, nickel-cadmium batteries, nickel-zinc, and Ni-MH. Initially, the nickel-iron batteries emitted a high amount of hydrogen while performing, which made these batteries problematic; however, this was corrected by Thomas Edison to commercialize [13],[14]. Researchers consider this kind of battery to have a complex structure because the water levels within the batteries need to be constantly checked and also to ensure the hydrogen produced is disposed of properly. The nickel-cadmium batteries perform similarly to the nickel-iron ones but combine metallic cadmium negative electrodes. These batteries have long life cycles and can withstand wear and tear, which makes them efficient for use in EVs. The Ni-MH batteries are still relatively new compared to the other nickel battery types. These batteries are known for their specific energy and power capabilities [15], [16].

As lithium is one of the lightest metals that are available in the market, it provides some unique characteristics that make these batteries viable components. In this context, there are two different kinds of lithium batteries; these are Li-P batteries and Li-I batteries [17]. The Li-P batteries make use of lithium metal; the advantages of this type of battery include lower amount of self-discharge rates and safe design, which makes it easy to use for EVs. The Li-I or Lithium-Ion batteries are the ones that are the most used among all of the available battery options. This is particularly because of its ability to provide high-temperature performance and stable recyclable opportunities. The structure of the lithium batteries has been provided below, and they showcase how the energy generation process works by inserting and releasing lithium ions [18],[19]. Researchers have considered this kind of battery to be the most efficient among all of the reachable batteries that are available. Further, a comparison of the different batteries has been given in Table 2.

Table 2. Comparison of various battery types

Parameters	Lead	Nickel	Lithium
Cost	Economic	Expensive	Average
Maintenance	1	0	Medium
Lifetime (estimated)	Small	Lengthy	Moderate
Energy density	60-110 Wh/Kg	45-120 Wh/Kg	110-150 Wh/Kg
Application	Storage of Solar Power	Aircraft Applications	Laptops, Vehicles, Phones
Charging technique	Constant Current-Constant Voltage	Constant Current	Constant Current-Constant Voltage
Hot climate	Severe impact	Moderate impact	Sustainable

2. Battery modelling systems for electric vehicles

The primary function of the BMS is to ensure the safe operation of the battery by controlling the charging and discharging process, cell balancing, estimation of state-of-charge (SoC), and over-temperature protection with effective measurements of the temperature, voltage, and current. The entire condition and health of the battery are controlled by the BMS with effective monitoring of the SoC, DOD, SoH, and operating temperature [20]. However, these states can only be properly deduced with the help of the state estimators which are completely dependent on the battery models. Hence, battery modelling has an important role in the knowledge, prediction, and estimation of the real-time operation of the battery [21]. Different levels of complexity in battery modelling have been created, which are helpful in a variety of application fields. However, the battery models can be classified into three tiers based on the depth of physical insights. The electro chemical model, circuit-oriented model, and artificial neural network [22]. On the other hand, one of the most important factors in battery modelling involves estimating the battery parameters. The modelling is an indispensable part of the BMS in an EV and holds the key to its effective functioning. The mentioned three levels- electrochemical, circuit-oriented, and Artificial Neural Network (ANN) are the ones in which the battery model can be divided. The electrochemical is something that involves the chemical reactions at the molecular level within the battery and some of the examples of the same are Shephard and Unnewehr models [23], [24]. The behaviour of the electrochemical can be described with the help of an ordinary differential equation for the reaction. However, achieving an accurate electrochemical model is difficult because of the electrochemistry involved since it is related to environmental conditions. This further makes the application of the electrochemical modelling quite limited even if an accurate model is developed in the process. The common examples of the circuit-oriented model are- the Rint, RC, PNGV, and Thevenin models. Further, the ANN model makes the required use of non-linear and self-learning behaviour of the ANN with the effective combination of experimental data for establishing the required interaction among the different parameters of the BMS. Some of the common examples of the ANN are the BP network and radial basis network. Hence, based on these three types of modelling, the BMS can be designed for the EVs in the market [25],[26]. Further, one element of the circuit-oriented battery model is shown in Figure 3.

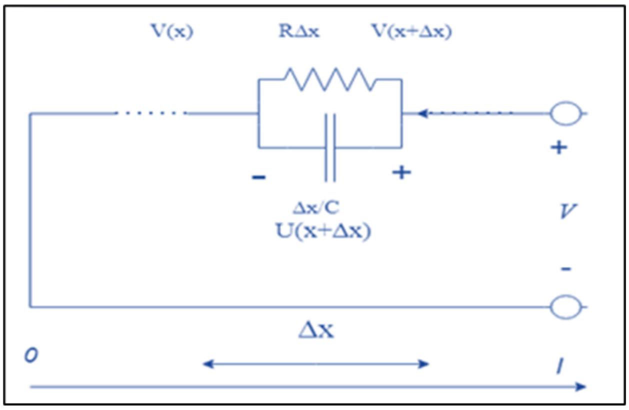

Figure 3. Element of a battery model

The total current across the model is the summation of current flows across an elemental capacitor (I_c) and resistor current (I_r) which has been shown by the below equation,

$$I = I_r(x) + I_c(x) \tag{1}$$

The current in each of the elements of the resistive path is described by the below equations,

$$I_r(x) = \frac{V(x+\Delta x) - V(x)}{R\Delta x} \tag{2}$$

$$I_r(x) = \frac{1}{R}\frac{V(x+\Delta x) - V(x)}{\Delta x} \tag{3}$$

Next, the current in the element of the capacitor is described as follows,

$$I_c(x) = \frac{C}{\Delta x}\frac{\partial\left(V(x+\Delta x) - V(x)\right)}{\partial t} \tag{4}$$

$$I_c(x) = C\frac{\partial}{\partial t}\frac{V(x+\Delta x) - V(x)}{\Delta x} \tag{5}$$

With the elements' length getting small enough, there are infinite elements which further means that Δx is close to zero and then the below equation is generated,

$$\frac{V(x+\Delta x) - V(x)}{\Delta x} = \frac{\partial V}{\partial x} \tag{6}$$

Hence, after substituting the above equations in $I_c$and I_r and then eventually in the first equation for total current (I), we get the below characteristics equation (partial differential equation of second order) that describes the above-suggested battery model.

$$I(t) = \frac{1}{R(x)}\frac{\partial V(x,t)}{\partial x} + C(x)\frac{\partial^2 V(x,t)}{\partial t\,\partial x} \tag{7}$$

Further, the explicit solution to the above equation can be provided by considering the current to be constant. Hence, as Δx tends to be zero, the U (elemental voltage) becomes the partial derivate of the voltage concerning x,

$$U(x,t) = \frac{\partial V(x,t)}{\partial x} \tag{8}$$

Hence, the generated second-order differential equation can further be simplified to the first ODE in time at any x.

$$I(t) = \frac{1}{R(x)}U(x,t) + C(x)\frac{\partial U(x,t)}{\partial t}$$

(9)

Next, the initial voltage distribution for the above-suggested battery model has been provided below, where V_c is the total voltage,

$$U(x,0) = U_{0c} = \frac{V_c}{\int_0^1 R(x)dx}R(x) \tag{10}$$

The equation for an exponential distribution further becomes,

$$U_{0c}(x) = \frac{V_c r_d}{1-e^{-rd}} \tag{11}$$

Hence, the initial voltage distribution becomes as shown in the below equation,

$$(x) = \int U_{0c} d_x = \frac{-V_c}{1-e^{-}\ _d} e^{-r_d x} + k \tag{12}$$

With, k = V (1, 0) with the constraint, an integral constant can be discovered, that $V_{oc}(1) = V_c$ as

$$k = V_c + \frac{V_c}{1-e^{-r_d}} e^{-r_d} \tag{13}$$

This further leads to the initial voltage distribution becoming as shown in the below equation,

$$(x) = V_c\left(1 - \frac{e^{-r_d x} - e^{-r_d}}{1-e^{-r_d}}\right) \tag{14}$$

On the other hand, the explicit solution of the first ODE can provide insights into the behaviour of the battery. Hence, transforming the first ODE in the Laplace domain gives us the below equation,

$$\frac{1}{s}I = \frac{1}{R}U + C(sU - U_{0c}) \tag{15}$$

Putting the above equation in the first ODE further leads to the equation for the elemental voltage of the suggested battery model and the same has been provided below,

$$U = \frac{\frac{1}{c_0 e^{-c_d x}}}{s + \frac{1}{c_0 r_0 e^{-(c_d + r_d)^x}}}\left(\frac{1}{s}I + V_c\frac{c_0 r_d}{1-e^{-r_d}}e^{-(c_d+r_d)^x}\right) \tag{16}$$

Zhang et al. (2022) also developed an electric circuit model, and the composition of that particular circuit model has been provided in the below image. The 1-RC circuit model provided below consists of a voltage source (V_{IOC}), an RC branch, and a resistor R_{10} in series as shown in Figure 4.

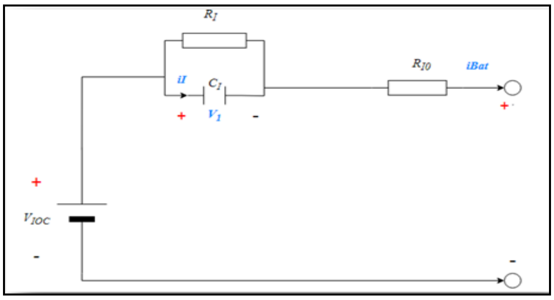

Figure 4. 1-RC circuit model

The electric behaviour of the 1-RC model can be described by the below-given equations, where V_{OC} is the terminal voltage and V_{Bat} is the terminal voltage.

$$v_I = \frac{-1}{R_I * C_I} v_I + \frac{1}{C_I} i_{Bat} \tag{17}$$

$$v_{Bat} = V_{OC} - v_I - R_0 i_{Bat} \tag{18}$$

Further, the terminal voltage over time for the circuit during the relaxation phase for the above circuit can be given as,

$$v_{Bat(t)} = V_{OC}(t_1) - v_1(t_1) e^{\frac{-t}{\tau I}} \tag{19}$$

Similarly, the resistance (R_I) and capacitance (C_I) of the 1-RC branch as derived for the model in Zhang et al. (2022) can be written as,

$$R_I = \frac{v_1(t_1)}{\left(1 - e^{\frac{-T_{discharge}}{\tau I}}\right) I_{discharge}} \tag{20}$$

and, $$C_I = \frac{\tau_I}{R_I} \tag{21}$$

2.1 Basic functions of the battery management system

As batteries are the powerhouse of EVs, having effective battery management systems is necessary for initiative control over the performance. The main purpose of implementing this system is to increase the reliability aspect of the batter. The system comes with an embedded algorithm that collects necessary information about the battery to estimate the output levels of the battery. Xiong (2020), in their research, has highlighted some of the main functions that the BMS plays within the EVs. Data collection is one of the most crucial aspects of the BMS; EVs are an evolving market, and therefore they need to be constantly monitored to help the systems adapt to the changing environments. The terminal voltage levels, the temperature of the vehicle, and the battery need to be monitored to improve the existing algorithm that has been set in place.

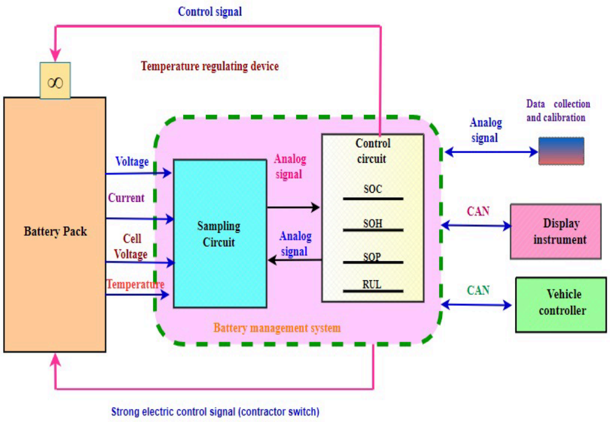

Figure 5. Structure of the battery management system

Safety is another basic function of the BMS; online fault detection and diagnosis options are available for all of the EVs that are being produced so that battery-related problems can be directly assessed. The available safety protections also help identify any form of leakage, over or under voltage that might have occurred within the vehicle**.** BMS also serves the purpose of charging the controls; it helps in regulating the temperatures within the battery and manages the energy within the system. The entire purpose of introducing EVs and replacing traditional fuel-powered vehicles is to reduce energy wastage. Therefore, one of the top priorities is to optimize the batteries so that a reasonable amount of energy gets consumers. The BMS system adopted also helps with equalization management within the battery; it allows the vehicle to adopt active or passive methods, whichever suits the structure of the car, and utilizes it to reduce the inconsistencies that exist with the vehicle. A great deal of heat is produced during the process, and therefore the BMS also helps with the regulation of the thermal cooling of the battery. As can be seen, the BMS houses multiple modules that control the performance of the battery and help ensure a long battery life as illustrated in Figure 5.

2.2 Design and architecture of the BMS

The design and architecture process of the BMS involves several parameters that help the battery maximize its power and improve the overall performance of the vehicle. Xiong, in their research, has argued that the design procedure of the system includes several indicators that help in measuring the performance, the acceleration capability of the battery, and the level of speed that it can help the vehicle to achieve, all elaborated within this section. The author has stressed in their research that the BMS utilizes EMC systems to run simulations. The root problems with the system are identified with the help of this process; other factors affect the design procedure of the BMS. Different kinds of EVs appear in the market, and the cost, reliability, and convenience of the system also need to be considered while measuring the performance levels. To fully understand the Battery Monitoring Control (BMC), understanding the control unit of the battery is also significant. Ramkumar*et al.*, in their work, elaborated on how within a centralized BMS, there exists a single board with a controller and a small circuit that controls all the operations.

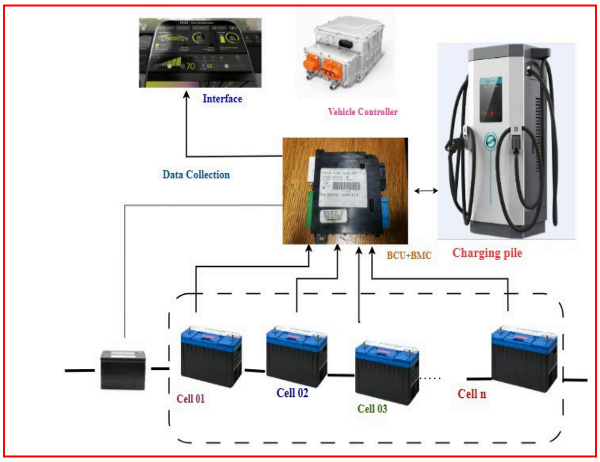

Figure 6. Centralized BMS design

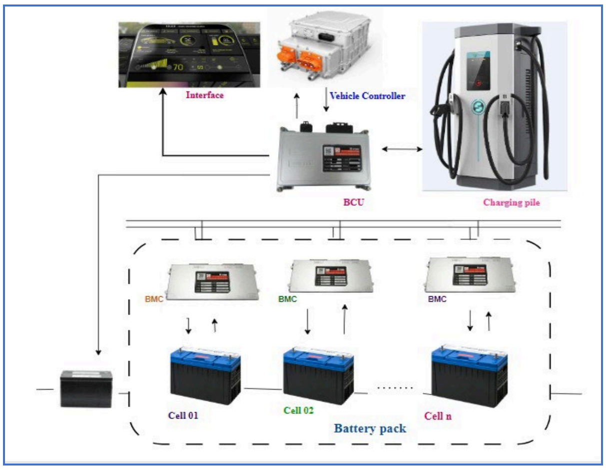

Figure 7. Distributed BMS Structure

The image showcases how both the BMC and the control unit have been integrated on a circuit board to collect valuable information on the battery that will help in facilitating the data collection and safety procedures within the system. There are many different kinds of advantages to the centralized BMS design, it not only helps with data collection, but the compact structure prevents outside interference. As the cost of producing and maintaining this kind of structure is relatively low, it continues to be used in EVs. The second design that will be observed in this research is the BMS with a distributed structure. The image below presents how a distributed BMS works, and the Battery Control Unit (BCU) is responsible for the detection of any kind of fault within the system. It is also utilized to scan the voltage and temperature of the system as depicted in figure 6. The CAN bus establishes a connection between the BCU and BMC and allows them to communicate (Xiong, 2020). The advantage of having a distributed BMS structure involves fault detection. As the process is divided into two parts, separating and checking different areas within the system becomes easier. The layouts are simplified, unlike centralized BMS structures; the flexibility of this system allows more batteries to be placed within the system as depicted in Figure 7.

2.3 Development process of the BMS

Each EV that is developed is different from the other, and therefore the vehicles have specific needs to perform well; the requirement of the vehicles helps in dictating the developmental procedure of the BMS. Identifying the type of battery that is utilized within the system is a crucial step toward developing the BMS (Xiong, 2020). The flowchart that has been incorporated within this section has identified the need to carry out different forms of tests to determine the characteristics of the battery. Focus needs to be drawn on the battery grouping method, the number of batteries used, and the arrangements within the system. The design used for the BMS keeps the functions and indicators of the EV and the battery system in consideration. The developmental process of the BMS also includes the mechanical details and the installation procedure (Xiong, 2020). The algorithm used for the BMS also needs to be configured during the procedure to ensure all of the underlying details are working properly. The development process includes several kinds of tests that help in evaluating the integrity and security of the system and the reliability of the design as given in Figure 8.

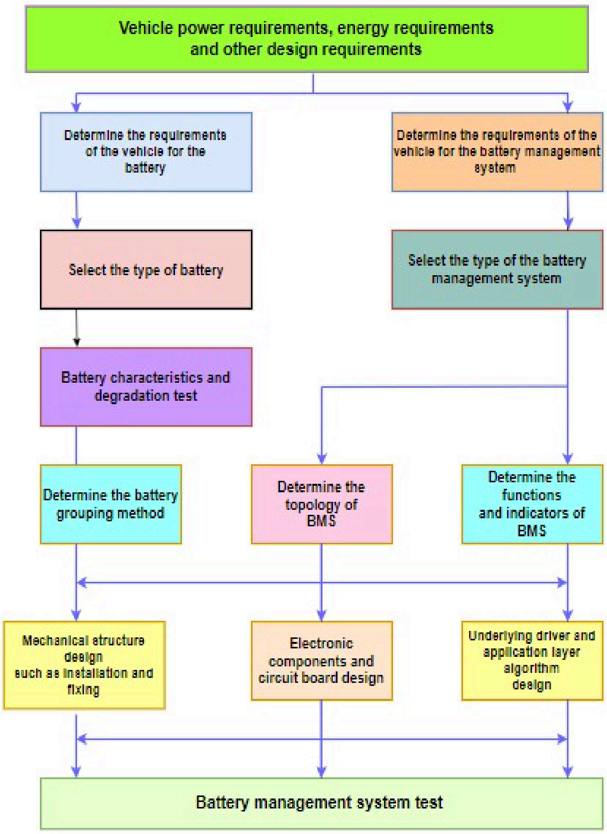

Figure 8. Development process of BMS

Table 3. Advantages and disadvantages of BMS, battery types

Battery type	Advantages	Disadvantages
Lead	1.Advanced technology 2. Material cost is low 3. The capital required is also low 4. Production at the global level	1. Life-cycle is short 2. Reliability is low 3. The output generated is sensitive to temperature 4. Safety issues and long charging time
Lithium	1. Life-cycle is long 2. Fast charging 3. Global efforts in R&D 4. High reliability 5. High energy density	1. Capital cost is high 2. Certain safety issues 3. Recyclability is low 4. Advanced BMS is required
Nickel	1. The capital required is low 2. Highly reliable 3. Safety is high 4. Fast charging 5. Acceptable energy density	1. Short life cycle 2. Poor recycling/recovery 3. The self-discharge rate is high

.

In recent times, researchers have been in the process of developing a new technology in the BMS called the Wireless Battery Management System. Analog devices are recently transforming towards the use of WBMS which consists of low-power integrated software used in wireless functioning. With the sudden development in the use of WBMS, operation in the wireless management system is operated based on the ADI-developed software specifically designed for the system-on-chip. The microcontroller subsystem has a specifically designed system-on-chip process with a "2.4 GHz ISM radio". These devices are primarily designed to operate "battery cell monitoring", and BMS controllers. However, the adoption of WBMS needs to be operated differently. Different applications can be advantageous, in the use of scalability and automotive applications. The industry that is developing with the usage of WBMS is automotive manufacturers which use the battery packs as a part of building blocks. Moreover, production needs to be maintained through widespread electrification and light powertrain architecture. A similar battery pack design can be a risk factor as the acquisition of Dialog semiconductor can be tougher in the overall process. The proprietary standard has not been as fast in comparison to BLE and there exists some capacity constraints.

3. Results and discussions

3.1 Lithium battery cell - one rc-branch equivalent circuit

The time vs. charging current graph for the lithium battery cell will show a declining curve, reflecting the reduction in the charging current over time as the cell progresses through the constant current and constant voltage charging stages. The slope of the curve will be steeper during the continuous current stage and become flatter during the continuous voltage stage as shown in Figure 9.

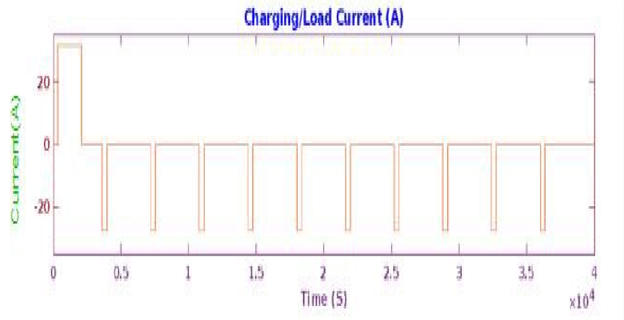

Figure 9. Charging load current for the lithium battery cell

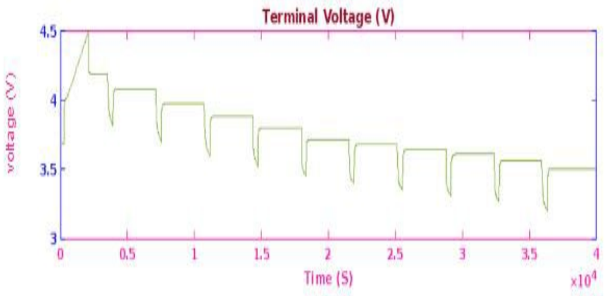

Figure 10. Terminal voltage for the lithium battery cell

The terminal voltage of a battery concerning time is shown in the above graph.”V” represents the terminal voltage and “t” stands for time shows how the voltage of the battery changes over time. Initially, the voltage is 3.7V then rises to the peak value of 4.5V and gradually decreases with an increase in time as depicted in Figure 10.

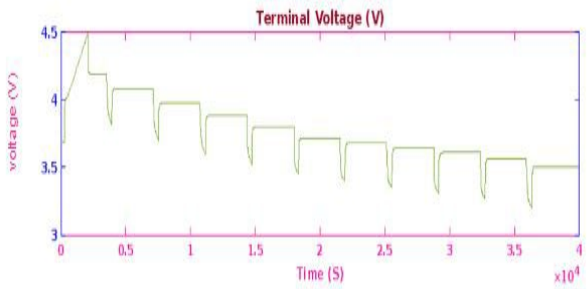

Figure 11. State of charge (soc) for the lithium battery cell

The SOC of a battery concerning time is shown in the above graph. SOC represents the maximum capacity of the battery compared to the amount of energy stored. The variable "t" represents time and allows us to track how the state of charge changes over time as the battery is charged or discharged. Initially, the SOC increases concerning time and -reaches peak value then gradually decreases to zero value with the increase in time as shown in Figure 11.

3.2 lithium battery cell - two RC-branch equivalent circuit

In a Lithium-ion 2RC battery, the battery current vs. current graph also known as the "I-V Curve", represents the relationship between the battery’s applied current (charging or discharging) and the resulting current flowing through the battery, in the x-axis The applied current (I_applied) to the battery, which is the current rate at which the batteries being charged and discharged. The applied positive current when charging and negative when discharging the battery. In the y-axis, the resulting current (I) flows through the battery. It is the actual current measured in the battery's external circuit as illustrated in figure 12.

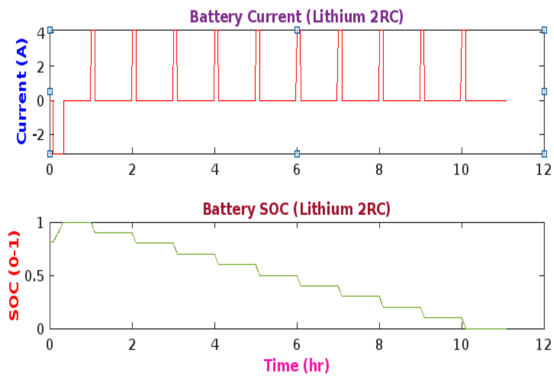

Figure 12. Battery current and soc for lithium-ion 2-rc battery

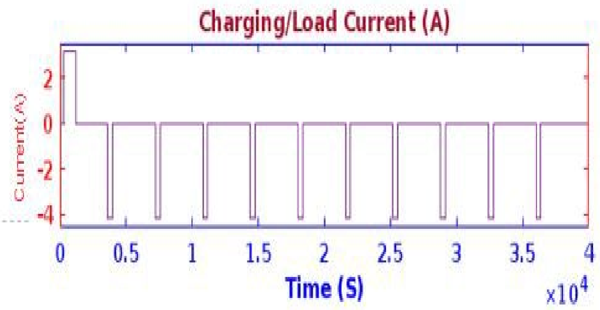

Figure 13. Charging load current for lithium-ion 2-rc battery

The time vs. charging current graph for the lithium battery cell will show a declining curve, reflecting the reduction in the charging current over time as the cell progresses through the continuous current and continuous voltage charging stages. The slope of the curve will be steeper during the constant current stage and become flatter during the constant voltage stage as shown in Figure 13.

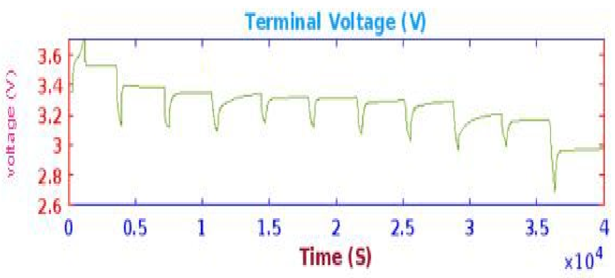

Figure 14. Terminal voltage for lithium-ion 2-rc battery

The terminal voltage of a battery concerning time is shown in the above graph."V" represents the terminal voltage and "t" stands for time shows how the voltage of the battery changes over time. Initially, the voltage is 3.3V then rises to the peak value of 3.8V and gradually decreases with an increase in time as depicted in Figure 14.

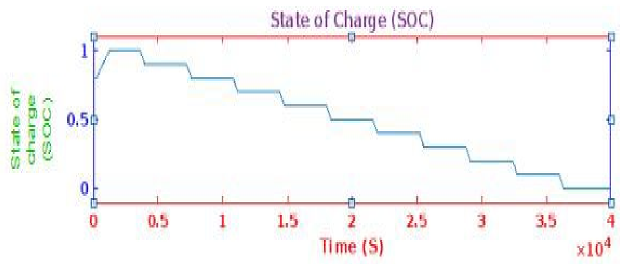

Figure 15. Terminal voltage for lithium-ion 2rc battery

The state of charge (SOC) of a battery concerning time is shown in the above graph. SOC represents the maximum capacity of the battery compared to the amount of energy stored. The variable "t" represents time and allows tracking of how the state of charge changes over time as the battery is charged or discharged. Initially, the SOC increases concerning time and - reaches peak value then gradually decreases to zero value with the increase in time as depicted in Figure 15.

4. Conclusion

The increase in the usage of electric vehicles has helped in the development of the EV market which shows a sale value of USD 205.58 billion. Consumer awareness acts as one of the guiding forces to improve the overall pollution emission and machine faults in the sale of electric vehicles. The major importance of the system for managing batteries in electric vehicles is due to the maintenance of the temperature of the overall battery which can improve the battery performance in the long run. The DBMS provides secured physical management to make the battery optimizer less electric consumption. The concept of electric vehicles arose after the 1990s with the growth in carbon emissions. This work explains the concept of electric vehicles through the SOC, SOH, and SOA. All these are used in maintaining the overall hybrid electric vehicle, fuel cell; plug-in electric, and vehicle movement. Different batteries are used in the operation of electrical vehicles and in a similar this work sheds light on plug-in hybrids and lithium-ion batteries, used in the overall energy storage system. The basic function of BMS is to regulate the temperature in case of overheating. This work showcases that lithium batteries are more significant as they carry a longer period as compared to lead-acid batteries. The simulation results of the Lithium battery cell – 1RC network, and 2RC network parameters have been analysed. These batteries are lighter and allow the chemical reaction to emit less heat thus minimizing the chain of chemical reaction problems. These lithium-used batteries protect the chemical content from excessive heat and cold. This work revolves around the functioning of battery management systems in electrical vehicles. It can be suggested that there is scope to explore the areas of development and testing of power batteries in the BMS control system. Understanding the core of the SOC algorithm is essential in judging the available energy in the battery system. These vehicle control strategies derived from the application of SOC can allow protection to the battery life and limit the damage caused as a result of inadequate power limitation. The MBD-based development process allows safety protection strategies that can be further analysed to understand the concept of BMS in electric vehicles.

References

[1] Tortorella G.L., Fogliatto F.S., Cauchick-Miguel P.A., Kurnia, S. and Jurburg, D. Integration of industry 4.0 technologies into total productive maintenance practices. Int.J.Prod.Econ. 2021; 240 (2) :108-224.
[2] Baek S.Y., Kim, Y.S., Kim, W.S., Baek S.M. and Kim, Y.J. Development and verification of a simulation model for a 120-kW class electric AWD (all-wheel-drive) tractor during driving operation. Energies. 2020; 13: 24 - 30.
[3] Berecibar M., Garmendia M., Gandiaga I., Crego J. and Villarreal I. State of health estimation algorithm of LiFePO4 battery packs based on differential voltage curves for battery management system application. Energies. 2016; 103: 784-796.
[4] Cipollone R., Di Battista D., Marchionni M. and Villante C. Model-based design and optimization of a fuel cell electric vehicle. Energy Procedia. 2014; 45: 71-80.
[5] Coronado C.R., de CarvalhoJr J.A., Yoshioka J.T. and Silveira J.L. Determination of ecological efficiency in internal combustion engines, The use of biodiesel. Appl.Therm.Eng. 2009; 29: 1887-1892.
[6] Costa C.M., Barbosa J.C., Castro H., Gonçalves R. and Lanceros-Méndez, S. Electric vehicles To what extent are environmentally friendly and cost-effective– Comparative work by European countries. Renew.Sust.Energy.Rev. 2021; 151 :111-548.
[7] Del Pero F., Delogu M. and Pierini M. Life Cycle Assessment in the automotive sector A comparative casework of Internal Combustion Engine (ICE) and electric car. Procedia Struct. Integr. 2018; 12: 521-537.

[8] Landsberg P T, Markvart T. Ideal Efficiencies in Practical Handbook of Photovoltaics. Sustain. Energy Technol. Assess. 2022; 27: 123-134.

[9] Kazem H, A, Khatib A, Sopian K. Sizing of a standalone photovoltaic/battery system at minimum cost for remote housing electrification in Solar. Energies. 2015; 61: 108–115.

[10] Gabbar H.A., Othman A.M. and Abdussami M.R. Review of battery management systems (BMS) development and industrial standards. Technologies. 2021; 9: 28-35.

[11] Gao J., Chen H., Li, Y., Chen J., Zhang Y., Dave K. and Huang Y. Fuel consumption and exhaust emissions of diesel vehicles in worldwide harmonized light vehicles test cycles and their sensitivities to eco-driving factors. Energy convers. Manag. 2019; 196: 605-613.

[12] Jiang C., Wang S., Wu B., Fernandez C., Xiong X. and Coffie-Ken, J. A state-of-charge estimation method of the power lithium-ion battery in complex conditions based on adaptive square root extended Kalman filter. Energy. 2021; 219: 119-603.

[13] Khayamy M., Nasiri, A. and Okoye O. Development of an equivalent circuit for batteries based on a distributed impedance network. IEEE Trans. Veh. Technol. 2020; 69: 6119-6128.

[14] Kumar D., Nema, R.K. and Gupta S. A comparative review on power conversion topologies and energy storage systems for electric vehicles. Int. J. Energy Res. 2020; 44: 7863-7885.

[15] Kumar M.S. and Revankar S.T. Development scheme and key technology of an electric vehicle, An overview. Renew.Sust.Energy.Rev. 2017; 70: 1266-1285.

[16] Lévay P.Z., Drossinos, Y. and Thiel C. The effect of fiscal incentives on market penetration of electric vehicles, A pairwise comparison of total cost of ownership. Energy Policy. 2017; 105: 524-533.

[17] Mekhilef S., Saidur, R. and Safari, A. Comparative work of different fuel cell technologies. Renew. Sust. Energ. Rev. 2012; 16: 981-989.

[18] Qin D., Li J., Wang T. and Zhang D. Modeling and simulating a battery for an electric vehicle based on Modelica. Automot. Innov. 2019; 2: 169-177.

[19] Ramkumar M.S., Reddy C., Ramakrishnan, A., Raja K., Pushpa S., Jose, S. and Jayakumar M. Review on Li-Ion Battery with Battery Management System in Electrical Vehicle. Adv. Mater. Sci. Eng. 2022; 202: 1-8.

[20] Riba J.R., López-Torres C., Romeral L. and Garcia A. Rare-earth-free propulsion motors for electric vehicles A technology review. Renew.Sust.Energy.Rev. 2016; 57: 367-379.

[21] Ruan H., Wei Z., Shang, W., Wang X. and He H. Artificial Intelligence-based health diagnostic of Lithium-ion battery leveraging transient stage of constant current and constant voltage charging. Appl. Energy. 2023; 336: 120-751.

[22] Saldaña G., San Martín J.I., Zamora I., Asensio F.J. and Oñederra O. Analysis of the current electric battery models for electric vehicle simulation. Energies. 2019; 12: 27-50.

[23] Rahmawatie B., Fahma F., Nizam M., Purwanto A., Louhenapessy B.B. and Kadir E.A. A technical review of BMS performance standard for electric vehicle applications in Indonesia.Telkomnika(Telecommunication Computing Electronics and Control). 2021; 16: 54-59.

[24] Albatayneh A., Assaf, M.N., Alterman D. and Jaradat M. Comparison of the overall energy efficiency for internal combustion engine vehicles and electric vehicles. Environmental and Climate Technologies. 2020; 24: 669-680.

[25] Tran M.K., Akinsanya M., Panchal S., Fraser R. and Fowler M. Design of a hybrid electric vehicle powertrain for performance optimization considering various powertrain components and configurations. Vehicles. 2020; 3: 20-32.

[26] Zhang H. Deng C., Zong Y., Zuo Q., Guo H., Song S. and Jiang L. Effect of Sample Interval on the Parameter Identification Results of RC Equivalent Circuit Models of Li-ion Battery. An Investigation Based on HPPC Test Data. Batteries. 2022; 9: 1-10.