Materials Today: Proceedings 45 (2021) 1552–1558

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Experimental analysis on battery based health monitoring system for electric vehicle

D. Selvabharathi *, N. Muruganantham

Department of EEE, Periyar Maniammai Institute of Science & Technology, Vallam, Thanjavur 613403, India

ARTICLE INFO

Article history:
Received 1 August 2020
Received in revised form 7 August 2020
Accepted 9 August 2020
Available online 20 September 2020

Keywords:
Electric vehicle
Battery management system (BMS)
State of charge (SoC)
IoT
Battery capacity (BaCAP)

ABSTRACT

Electric vehicles are the future and the most important part of an electric vehicle is its battery which provides the power to the vehicle and also its weakest part. Batteries are prone to degradation, heating and general age related effects. So a constant monitoring system is required to keep the battery in check and keep the user posted about its various variables. This project provides a management system for a battery by monitoring various factors like main power voltage, cell voltage, etc. It includes monitoring cell condition, states estimation, temperature control and heat management, all aimed at enhancing the overall performance of the system. This data is then acquired and sent to the cloud where it can be remotely accessed by the user or a common access point at any given situation and thus also thereby making removable battery station much more possible and reliable.

1. Introduction

The future of mobility is electric. Almost every major car manufacturer is focusing on electric vehicles as their future plan because of their many advantages over internal combustion vehicles and one of the most crucial part of an electric vehicle or in that matter any electronic gadget we use in our day-to-day life is their battery [1]. In an electric vehicle the battery is one of the weakest part and is prone to heating, performance issues and ageing. So an efficient and accurate battery management system is of utmost importance. This will keep the performance and statistics of the battery in check and let the user know about the various parameters of the battery [2,3].

The battery management system is actually like the brain of the battery. It will help in protecting the battery from wide range of operating conditions and factors by constantly monitoring and measuring crucial information about the battery during its operation [4]. Thus a battery pack built with a built-in BMS system is known as a smart battery pack. A battery management system comprises of hardware and software to observe the battery status and optimize performance or warn the user of any irregularities [5]. It needs to continuously execute algorithms to keep the battery in check at all times. The basic block diagram of a battery management system consists of the battery pack, the sample circuit, the control circuit which will consist of the controller and the display terminal [6–8]. From the battery we will get the data of voltage, current, and temperature of and around the cell which will be sent to the sample circuit. The sample circuit collects the analog data and sends to the control circuit i.e to the controller which an Arduino UNO in this case. The controller will convert the physical data to digital data which can be computed easily. It will calculate the SoC of the battery with the provided information based on an algorithm which will be uploaded to the controller through specific code. In this case the code is written in the Arduino IDE and then uploaded to the Arduino through an USB cable [9]. The data will then be displayed through an LCD display which is connected to the controller. This data is also sent to the Node MCU which is used to get the data from the controller and upload to the cloud to a dedicated server. This server can be accessed by any device from the globe with the appropriate password and login id. This method will come in handy when the user needs to know the battery state of his respective vehicle from his phone when the vehicle is connected to a public charging station [10–12].

1.1. Methods of calculating SoC

There are various methods of calculating soc of a battery. The most notable ones and the ones which are most generally used are

* Corresponding author.
E-mail addresses: dsbsrm@gmail.com (D. Selvabharathi), murugaeee@pmu.edu (N. Muruganantham).

https://doi.org/10.1016/j.matpr.2020.08.303
2214-7853/

- chemical method
- voltage method
- current integration
- Kalman filtering
- pressure

1.1.1. Chemical method

This method is only applicable for a certain type of batteries, the ones where we have access to the liquid electrolyte like non-sealed lead-acid batteries. Here, to determine the SoC, the specific gravity is found out which is done using a device called the hydrometer or by the pH of the electrolyte [13].

1.1.2. Voltage method

The voltage method utilises the voltage vs. SoC curve known as the discharge curve, to convert the reading of the battery voltage to SoC. But the battery current and temperature affects the voltage significantly. The accuracy of this method can be increased by compensating the voltage reading by a variable correction value which will be proportional to the battery current, and by making use of a look-up table of battery's open circuit voltage versus temperature. It is usually the stated goal of battery design to supply a constant voltage without whatever the SoC might be, and this makes it difficult to apply this method [14].

1.1.3. Current integration method

Another name for this method is 'Coloumb Counting'. This method takes into account the battery current and integrates it in time to calculate the SoC. But because of lack of a reference point this method suffers from long-term drift and makes this measurement imperfect. To counter this, SoC must be re-calibrated on a regular basis, which can be done by resetting the SoC to 100% when the charger determines that the battery has been charged fully [15].

1.1.4. Kalman filtering

There are various shortcomings of the previous methods and to overcome these Kalman filter can be used. The Kalman filter will be used to predict the over-voltage due to the current if the battery is modelled with an electrical model. If we add Coulomb-Counting to this, it will be able to make an accurate estimation of the state of charge. The main advantage of the Kalman filter is that it's able to adjust the trust of coulomb counting and the battery voltage in real time [16].

1.1.5. Pressure method

Only certain NiMH batteries can be used to apply this method because their internal pressure increases rapidly when the battery is charged. This technique can be enhanced by applying Peukert's Law. Peukert's Law is the function of charge / discharge rate or ampere. In this particular work we are using the voltage method to determine the SoC of the battery of a supposed electric vehicle because it is quite accurate and not as complex as the Kalman filter method. It is the perfect balance of cost effectiveness, complexity and accuracy of a battery management system which will be helpful in using in low-cost consumer friendly future electric vehicles [17].

1.2. Topologies of a BMS

BMS can be used in various different topologies which will vary in complexity, accuracy and performance. A simple passive regulator achieves cell balancing across the cells by bypassing charging current when a cell's voltage level attains a certain level. An active regulator turns on and off a load intelligently when appropriate to maintain cell balancing, a complete system would also suggest the state of the battery to a display and protect the battery.

BMS topologies fall in 3 categories

Centralized: The battery cells are all connected through a slew of wires to a single controller

Distributed: Each cell is equipped with its own BMS board with a single cable for communication between battery and controller

Modular: A small number of controllers, each handling a certain number of cells will be present and all of them will communicate with each other

1.3. Introduction to IoT

The internet of things, or IoT, is a system of interrelated computing devices, mechanical and digital machines, objects, animals or people that are provided with unique identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction [18]. These IoT enabled devices can transmit data and interact with similar others over the internet which also can be controlled and monitored remotely. To make it possible these devices are embedded with suitable electronics, internet connection and other suitable forms of sensors and required hardware.

For connecting the Arduino to the internet we use a NodeMCU. The Arduino send the data and the NodeMCU converts it into ASCII and then to binary which then uploads it to the server. The data gets uploaded every 5 s. This data is then accessed from the phone by logging into the server website using specific login information. The whole transfer process takes place by the UART method. First analog signal is received, then the analog signal is converted to ASCII then to binary signal which is received by the Node MCU. It then converts it back to the format required with the same UART technique and is then sent to the dedicated server. The node MCU connects to the internet through Wi-Fi because a Wi-Fi chip is present in the controller [19]. The basic working of a Node MCU is to connect to the internet and sends data to the cloud. All the analog and digital sensors sends the data to the microprocessor, in this case, the Arduino UNO, to be processed, and then this is then sent to the Node MCU and the process takes place as discussed previously through the UART protocol.

2. Existing technologies

This part discusses about the already existing technologies and methods that exists to find the state of charge of a battery.

2.1. Specific gravity

In this method a Hydrometer is used to get the indication of the SoC. When the battery is discharged, the electrolyte becomes lighter and when it is charged the light electrolyte will float on top and give an approximate reading. This process called electrolyte stratification and can be overcome only by mixing up again by the bubbling action of a good charge. Distilled water in the battery will also act in a similar way. There are other issues with using a hydrometer like a dirty reading scale will hinder and also for an accurate reading the figures needs to be adjusted for temperature compensation. Different battery manufacturers can use different acid strengths in their batteries. So, in conclusion, judging battery SOC from a hydrometer reading also has many difficulties and inherent inaccuracies.

2.2. Plasmatronics PL regulator

An amp-hour counter is a counter which maintains a balance of ampere hours in with comparison to ampere hours out. This amp hour counter method is used to use the estimate. The display which shows the SoC will actually show the balance as a percentage of the battery size [20]. This battery size has to be entered separately by the user with a battery capacity (BCAP) setting which will make the SoC meaningful. But as time elapses, the amp hour balance counter will slowly be traversing out of line with the actual battery SoC.

The disadvantages with this method

(i) The PL does not inherently have knowledge of the entire system and thus it at all times must be measuring all charge and discharge of the battery.
(ii) Since there will be variations in charge efficiency, the SoC needs to be a bit more on the positive side.
(iii) Battery capacity in older batteries need to be reduced to keep up with the ageing of the batteries
(iv) Inaccuracy is also caused by variations in temperature and self-discharges.

It is when the SoC reaches 100% the inefficiency of the battery and losses due to self-discharge show up. So the SoC counter to show values like 12% is quite normal in this technique when the battery reaches into float. That 12% extra in the SoC reading is due to the extra power the charging sources had to put up for making up for the battery losses. When the SoC display shows the percentage at 12% state of charge of the battery, then it is expected for it to drop to 99% when amp-hour is discharged. If we suppose it will decrease upto 80% and then in the following davit increases to 90% but that 10% which has gone in does not take into consideration the losses in charging the battery. This irregularity multiplies and stockpiles when this goes on for a long time. So with every next charge on a different day, the error gap gap will keep on increasing and become an error of a significant amount. As the battery becomes discharged the charging inefficiency decreases.

3. Proposed system

The proposed system is shown in Fig. 1; the battery management system is tested in a simulated environment using Matlab Simulink.

3.1. Li-ion block

To explain the simulink model is shown in Fig. 2; the li-ion block is based on the equivalent circuit of a li-ion cell. Internal resistance R1 and capacitance of the cell C1 is connected in parallel and the resistance across the terminals R2 is connected in series with it.

3.2. Thermal block

A thermal block is used in the model because the SoC of a battery depends very much on the temperature of the battery and the ambient temperature around the battery. This is done by taking into account the external temperature and the heat generated due to the power developed from the battery. The circuit of the thermal block is shown in Fig. 3; As we see here, the inputs to the thermal block consists of one from external temperature sensor which compares it with the battery mass and the second input is the heat generated due to the power from the battery. The output from the thermal block is used as a feedback for the current source which implements the cell's main branch voltage source, and determines values for capacity (C) and state of charge (SOC). The defining equations depend on cell temperature, T. Li-Ion cells are connected in series and parallel to form a stack of cell is shown in Fig. 4. There is a convective heat transfer block connected between each cell so that the heat generated due to the power from each cell can be taken into consideration. We use 10 of such stack of cells which consists of 8 individual Li-Ion cells. The 10 stacks are again connected in series and again we have used convective heat transfer between each stack of cell and also the output thermal data from each stack is also into account such that the temperature data is as accurate as possible.

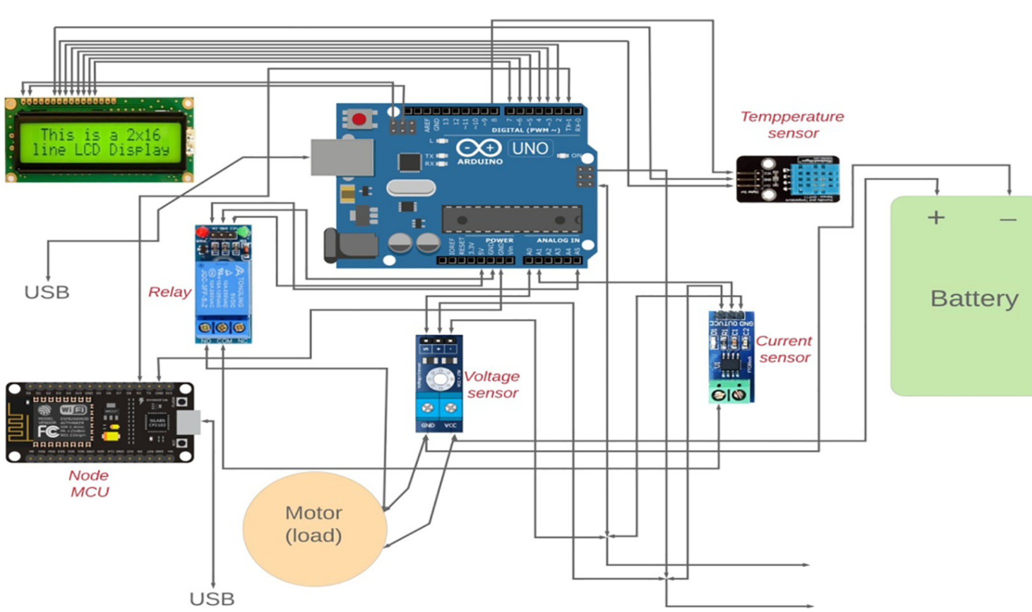

Fig. 1. The Proposed System.

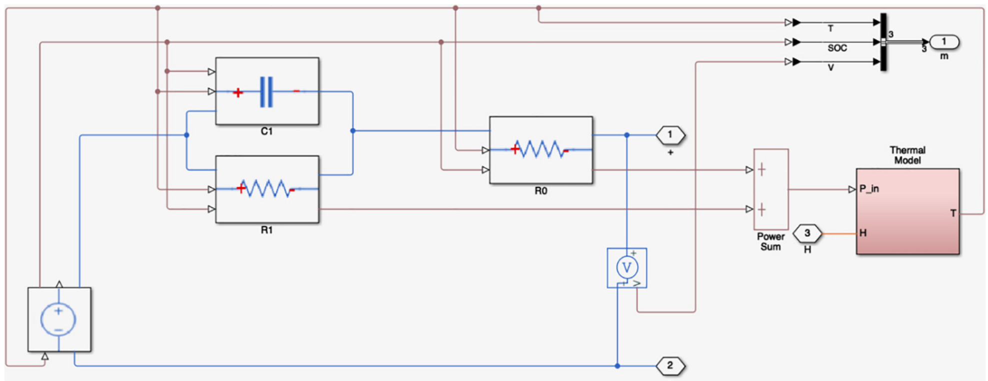

Fig. 2. Li-ion based Simscape Model.

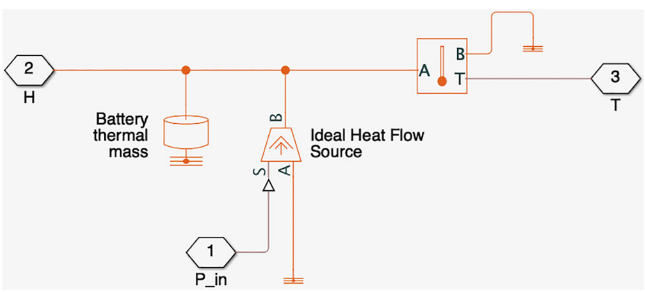

Fig. 3. Thermal lock.

4. Simulation & output

4.1. Simulation

The proposed circuit diagram consists of a pulse generating block, a temperature source block, input current generating block, a voltmeter block, a function block, a sort cell measurement block and 2 scopes.

i. The pulse generating block will be used as an example of the load. It will provide a constant pulsating current which will be considered as the current drawn by the load and it will also set a temperature at which the battery will perform in its optimum condition.
ii. Simulink to physical signal converters because the current and the temperature signals from the generating block are simulink signals which needs to be converted to physical signals for the ammeter and the temperature source.
iii. Ideal temperature source to keep the battery at the optimum temperature which has already been set.
iv. The function block is there such that if there arises any moment when the code forms a loop and starts repeating itself this block will prevent it by ending the loop.
v. The block of 80 cells has already been described extensively previously. Basically it consists of 10 stacks of cells where each cell consists of 8 Li-ion cells.
vi. The sort cell measurement block will calculate the SoC based on the temperature and voltage readings from each individual cell, that is why we can see 240 bus lines because each li-ion cell has a voltage, SoC and temperature readings.
vii. There are 2 scopes, out of which one will show the readings of the overall SoC, voltage output and temperature of the cell. The other scope will show the output from the pulse generator which used in the form of a load.

4.2. Output from the pulse generator

The first graph in Fig. 5 shows the pulse current. The current is in the negative direction of the graph because it is made to resemble a load that is being applied to the battery. The second graph shows a temperature at which the battery will run in its optimum condition, which is set to be at 20 °C. Fig. 6 is obtained from the first scope which shows the graphs of the temperature around the battery, the SoC of the battery and the current from the current.

The 1st graph shows the temperature of the cell. As it can be seen from the graph it is constantly increasing and decreasing. It is because the current increases every time the battery receives the current pulse. The 2nd graph shows the SoC of the battery. As it is seen from the graph, the SoC starts to decrease after getting

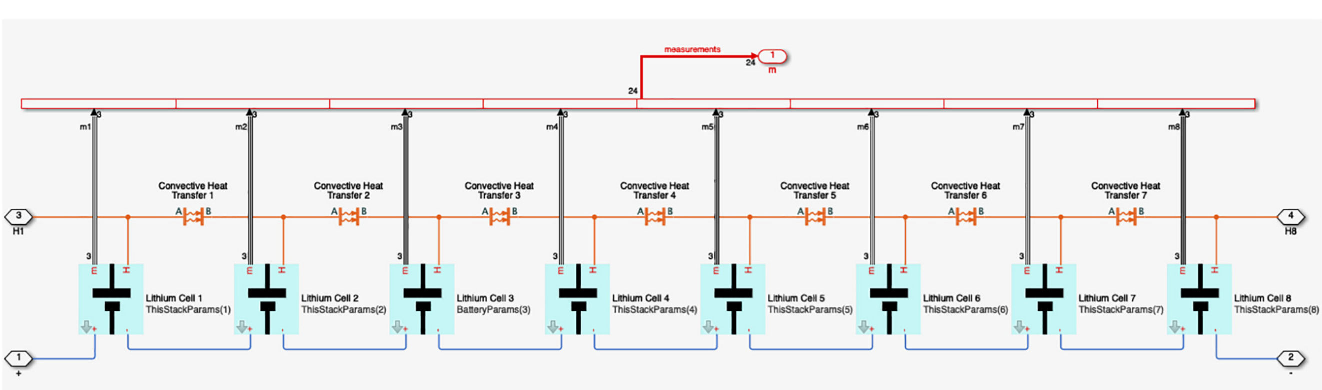

Fig. 4. Stacks of 8 Cells.

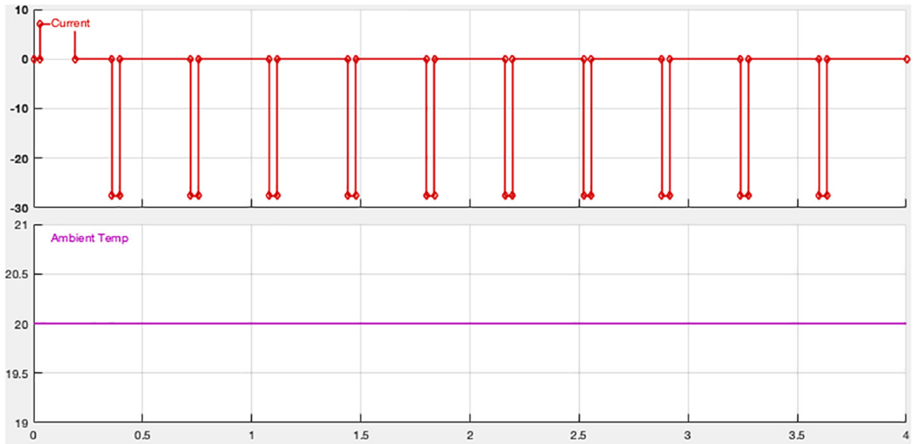

Fig. 5. Output Waveform of Pulse Generator.

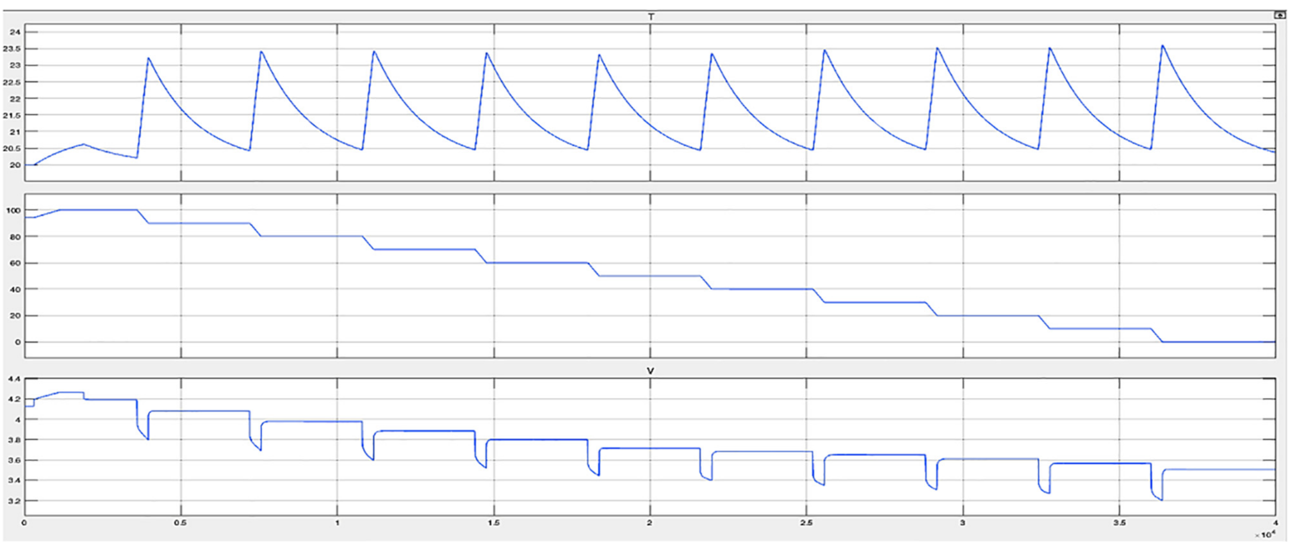

Fig. 6. Output from the first Scope.

fully charged up to 100% to zero percentage. This is evident because this is calculated during the working process of the battery. The 3rd graph shows the variation of current.

4.3. The current, SoC and the temperature variation shown in these graphs is all with respect to time.

Fig. 7 is obtained from the scope which is connected to the voltmeter and battery current. So as it is evident from this, it shows the variation in voltage before supplied to the battery and current from the pulse generator, the top one being the one showing the voltage graph and the bottom one displaying the current graph both with respect to time.

4.4. Working

In Normal mode, the connectors are connected to the battery and hence giving the supply the motor. The Arduino Uno and the ESP8266 NodeMCU are given their respective supply voltages i.e. the micro-controller is given an external supply. The Arduino will first monitor the battery's parameters and check if they are normal i.e. the temperature is below 36 °C and the operating voltage is more than 5 V. It will be then displayed on the 16x2 LCD display. Once everything is normal, the motor will start to operate and the measured values will be hence displayed on the display as well as the server. The server will refresh every 5 s to display the instantaneous values. Since draining a battery takes a lot of time, the battery draining mode will ensure that if such thing happens, the motor will stop. A predetermined voltage value has been set i.e. 5 V. If the voltage sinks below this value, the motor will be turned off. To check if this mode is working, the connectors (previously connected to the battery) are connected to the connection between the Arduino Uno and ESP8266 NodeMCU. By doing this, the motor now has a supply which is less than the predetermined one i.e. 5 V. The Arduino will then send a signal to the relay to cut-off motor's power. This will ensure that the battery is not harmed in any way when there is a low voltage supply.

High temperature safety mechanism for the battery is to prevent the battery from overheating and potentially damaging the whole device. A predetermined value has been set i.e. 36 °C. If the temperature increases this value, the motor will be turned off. To check if this mode is working, a heat source like candle, lighter or burning matchstick is brought near the temperature sensor whilst the motor is running. Before heating, the display and server will display the instantaneous values. Once the temperature goes beyond 36 °C, the Arduino will send a signal to the relay. This

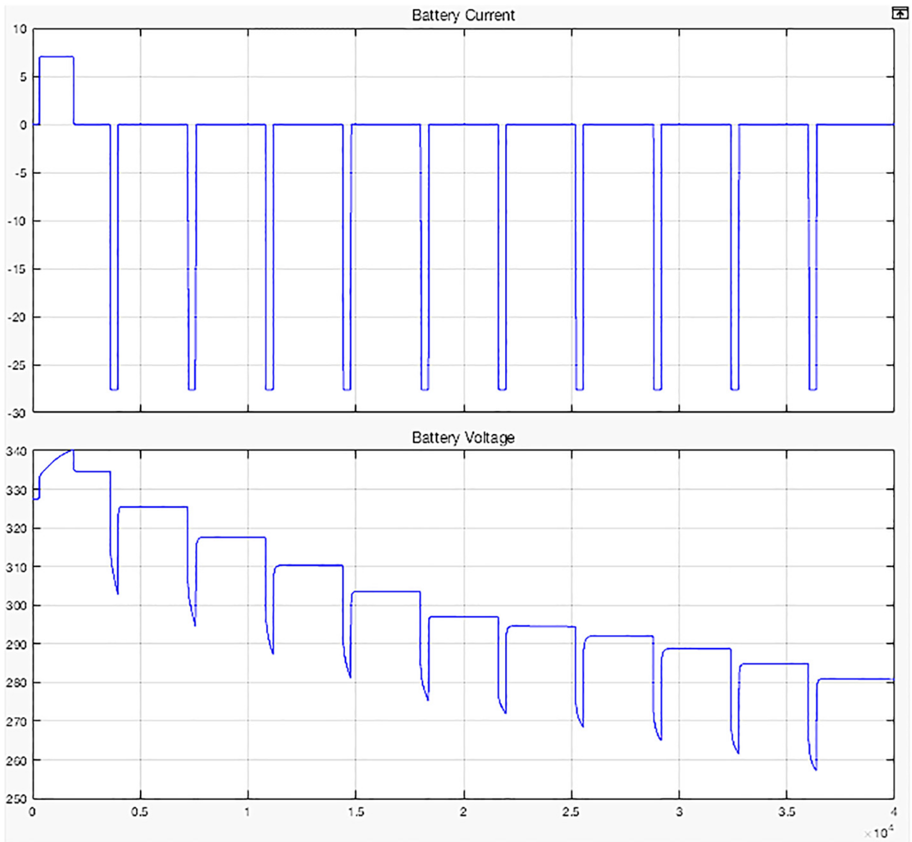

Fig. 7. Outputs from the Second Scope.

will turn off the rotor and hence protecting it from overheating. This mode is to ensure that the device is not harmed when the battery temperature is high.

5. Conclusion

The proposed system of IoT based battery management system will find its application in various electric automobiles and related fields. As the future is moving at a rapid rate towards electric mobility, the BMS will be an integral part of the vehicle and this model being very cheap and accurate and universally usable will be of big demand. With the addition of IoT with the help of which we can access the battery data from anywhere and anyplace, this model can be applied for removable battery technology. Battery Management System and specifically the SoC estimation is a very helpful in Electric Vehicles as it helps in keeping the battery safe from overcharging and thus overheating. Moreover, one major drawback of electric vehicles is range anxiety of people related to electric vehicles. Thus a proper SoC estimation will help in accurately determining the level of charge remaining in the vehicle in real time so as to properly plan journeys.

CRediT authorship contribution statement

D. Selvabharathi: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Visualization, Writing - original draft, Writing - review & editing. **N. Muruganantham:** Conceptualization, Funding acquisition, Project administration, Supervision, Validation, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] Antonio Affanni, Alberto Bellini, Member, IEEE, Giovanni Franceschini, Paolo Guglielmi, and Carla Tassoni, Senior Member, IEEE, Battery Choice and Management for New-Generation Electric Vehicles, IEEE Transactions on Industrial Electronics, 52, NO. 5, October 2005.
[2] T. Huria, M. Ceraolo, J. Gazzarri, R. Jackey, High fidelity electrical model with thermal dependence for characterization and simulation of high power lithium battery cells, 2012 IEEE International Electric Vehicle Conference, 2012.
[3] Rui Xiong, Jiayi Cao, Quanqing Yu, Hongwen He and Fengchun Sun, Critical Review on the Battery State of Charge Estimation Methods for Electric Vehicles" Received November 11, 2017, accepted December 2, 2017, date of publication December 6, 2017, date of current version February 14, 2018. Digital Object Identifier 10.1109/ACCESS.2017.2780258.
[4] M.A. Hannan, M.H. Hoque, S.E. Peng, M.N. Uddin, Lithium ion battery charge equalisation algorithm for electrical vehicle applications, IEEE Trans Ind. Appl. 53 (3) (Jun. 2017) 25412549.
[5] M.M. Hoque, M.A. Hannan, A. Mohamed, Model development of charge equalisation controller for lithium-ion battery, Adv. Sci. Lett. 23 (Jun. 2017) 52555259.
[6] R. Xiong, J.P. Tian, H. Mu, C. Wang, A systematic model-based degradation behaviour recognition and health monitor method of lithium-ion batteries, Appl. Energy 207 (Dec. 2017) 367378.
[7] B.S. Bhangu, P. Bentley, D.A. Stone, C.M. Bingham, Nonlinear observers for predicting state-of-charge and state-of-health of lead-acid batteries for hybrid-electric vehicles, IEEE Trans. Veh. Technol. 54 (3) (May 2005) 783794.
[8] Y. Xing, E.W.M. Ma, K.L. Tsui, M. Pecht, Battery management systems in electric and hybrid vehicles, Energies 4 (11) (2011) 18401857.
[9] D. Selvabharathi, N. Muruganantham, Battery health and performance monitoring system: A closer look at state of health (SoH) assessment methods of a lead-acid battery, Indones. J. Electr. Eng. Comput. Sci. 18 (1) (2019) 261–267.

[10] K. Selvakumar, N. Sarvesh, B. Shibu, D. Ray, Battery state of charge of a plugged-in hybrid electric vehicle, Int. J. Electr. Eng. Technol. 11 (3) (2020) 105–112.
[11] Linlin Li RuiXiong, JinpengTian,, Towards a smarter battery management system: A critical review on battery state of health monitoring methods, Journal of Power Sources 405 (30) (November 2018) 18–29.
[12] Teodora Murariu, Cristian Morari, Time-dependent analysis of the state-of-health for lead-acid batteries: An EIS study, J. Energy Storage 21 (February 2019) 87–93.
[13] Ross Kerley, Ji Hoon Hyun, Dong Sam Ha, Automotive lead-acid battery state-of-health monitoring system, IECON 2015 - 41st Annual Conference of the IEEE Industrial Electronics Society, 2015.
[14] Laifa Tao, Jian Ma, Yujie Cheng, Azadeh Noktehdan, Jin Chongf, Lu. Chen, A review of stochastic battery models and health management, Renew. Sustain. Energy Rev. 80 (December 2017) 716–732.
[15] Seyed Mohammad Rezvani Zaniani, Zong Chang Liu, Yan Chen, Jay Lee, Review and recent advances in battery health monitoring and prognostics technologies for electric vehicle (EV) safety and mobility, J. Power Sources 256 (15) (2014) 110–124.
[16] G.L. Plett, Dual and joint EKF for simultaneous SOC and OH estimation, in: Proc. 21st Electric Vehicle Symposium (EVS21), 2005, pp. 1–12.
[17] Yingzhi Cui, Pengjian Zuo, Du Chunyu, Yunzhi Gao, Jie Yang, Xinqun Cheng, Yulin Ma, Geping Yin, State of health diagnosis model for lithium ion batteries based on real-time impedance and open circuit voltage parameters identification method, Energy 144 (1) (February 2018) 647–656.
[18] H. Wenzl, I. Baring-Gould, R. Kaiser, B.Y. Liaw, P. Lundsager, et al., Life prediction of batteries for selecting the technically most suitable and cost effective battery, J. Power Sources 144 (2) (2005) 373–384.
[19] Adnan Nuhic, Jonas Bergdolt, Bernd Spier, Michael Buchholz, Klaus Dietmayer, Battery Health Monitoring and Degradation Prognosis in Fleet Management Systems, World Electric Vehicle J. 9 (2018) 39.
[20] Ngoc-Tham Tran, Abdul Basit Khan, Woojin Choi, State of charge and state of health estimation of AGM VRLA batteries by employing a dual extended Kalman filter and an ARX Model for online parameter estimation, Energies 10 (2017) 137.

Further Reading

[1] George Fernandez Savari et al., Optimum Charging and Scheduling of Electric Vehicles in Micro Grid using PSO, Springer, 2019.