# Simulation based Single cell and Multi Cell Monitoring Management with SOC & SOH Control for Continuous working of Electric Vehicle/ Grid Connected System

**Kandaswamy K V** (kvksamys@gmail.com)
Velammal Engineering College
**Raj Narain B**
Velammal Engineering College

**Research Article**

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Kandaswamy K V[1], Raj Narain B[2]
[1]Velammal Engineering College, Ambattur Red Hills Road, Chennai 600 066, India
kvksamys@gmail.com, https://orcid.org/0000-0002-7468-6426

**ABSTRACT**
Electric vehicles (EVs) and smart grids are two examples of high-power applications that frequently use lithium-ion pack and a battery management system (BMS). Battery status estimation, defect detection, monitoring, and control functions are required for BMS implementations, which require both software and hardware. Predicting battery life aids in the consistent and efficient operation of battery-powered equipment. The proposed method uses Portable and continuous monitoring of the battery life to prevent from sudden discharge, High temperature with frequent charging and discharging system. Voltage, current, and temperature sensors are used to detect the voltage, current, and temperature of the cells. The controller receives the data from each sensor connected at different node gives the update continuously to the monitor. Similarly, the controller prevents the battery from over discharge and under discharge of each cell. Apart from regular monitoring and controlling of each cell, a novel method is proposed in the existing circuit for partial or full charging during idling condition. Monitoring the battery state continuously allows for balanced charging of the battery cells and overcharge prevention. The suggested concept includes a Graphical User Interface (GUI), a method for training a model, and test results for the BMS.

***Keywords:*** Control, Idling, Monitoring, Over voltage, SOC (State of Charge), SOH (State of Health), Under Voltage

## 1. INTRODUCTION

The ecology has been harmed and the quality of the world's air has significantly degraded as a result of coal-fired power plants with inadequate after-treatment. Internal combustion engine (ICE) automobiles and industrial gas emissions have made urban air pollution much worse. Recent years invention of electrical vehicle and usage of smart grid increases drastically [1]. Electrical Vehicle have fewer moving parts to maintain and lower running costs. They may also be highly environmentally beneficial because they use very little fossil fuel (petrol or diesel). Due to its excellent durability, efficiency, power and energy density, extended lifespan, and low discharge rate, Li-ion batteries outperform conventional batteries in many sectors of use [2].

A system control component known as a battery management system (BMS) is used to verify the operational safety of the system battery pack. A BMS's main function is to protect the battery. Even if a battery pack's cooling system is good, each cell in the pack has a distinct temperature. Cell balance is necessary for safety reasons. Monitoring of each cell is essential because to ageing concerns. To avoid over-charge and over-discharge circumstances, which happen when the battery is connected to a load, the BMS measures the voltage, current, and associated temperature of the battery cells [3]. Li-ion battery states, such as the State of Available Power (SOP), State of Charge (SOC), State of Life (SOL), and State of Health, are estimated using these measurable data (SOH).

Timely maintenance of battery systems is made possible by early diagnosis of mediocre performance. This lowers operating expenses and avoids mishaps and malfunctions. Lithium batteries must be accurately and consistently monitored in order to determine their state, especially the amount of residual energy, as indicated by the SOC [4]. Range anxiety and other psychological issues are lessened by precise and trustworthy understanding about the SOC. A critical and direct consideration when constructing a BMS is accurate [5] SOC calculations. Estimates that are accurate and exact can not only assess the battery's dependability but also provide information on the amount of untapped energy and the duration of its useful life [6]. The value of the SOC cannot be determined directly; instead, it may only be inferred from measurements of other battery characteristics, including as current, voltage, internal resistance, and temperature.

In this [7] the study discusses issues and difficulties with the present BMSs. A crucial role for a BMS is to evaluate a battery's condition, including its charge, health, and life. Future problems for BMSs are discussed, along with potential answers, by analyzing the most recent methods for battery condition evaluation.

The author demonstrated [8] a special test board created to experimentally evaluate a BMS front-end integrated circuits EMI susceptibility using measurements of direct power injection (DPI) and radiated susceptibility. Different EMI-induced failure mechanisms noticed throughout the testing are highlighted in the discussion of the experimental data. The author [9] talked about the hardware principles of battery management systems. It concentrates on the hardware features of battery management systems (BMS) for stationary applications and electric cars. In order to maximize the overall energy efficiency of grid-connected storage systems, the author presented [10] a management technique that takes into account the real link between efficiency and the charging/discharging power of the storage system. A method for calculating pulse power performance based on pulse length is proposed by the author [11]. When energy storage and transportation electrification are used, this technology is applied to power generation systems. The author [12] suggested a unique selective voltage multiplier-based cell voltage equalization. The voltage multiplier-based cell voltage equalizer incorporates selection switches, although there are fewer of them than in typical topologies, resulting in a more compact circuit. Li-ion batteries were used to conduct an equalization test and build a prototype for twelve cells. A regression analysis of the peak point in the incremental capacity (IC) curve from the initial state to a 100-cycle ageing state was provided by the author [13] in this suggested notion. Additionally, a regression analysis model was used to determine the State of Health (SOH) of the studied retired series/parallel battery pack. A satisfactory level of precision is attained since the linear regression analysis model's error in the SOHs of the retired series/parallel battery pack was less than 1%. The thermal behavior of a battery pack under a power demand is the subject of the proposed study [14]. The categories for the proposed thermal prediction model include heat dissipation, reversible heat, and Joules heating with equivalent resistance. Using the hybrid pulse power characterization, the state of charge intervals regulates the equivalent resistances. The author [15] talked about the in-depth simulations of the effects of high-power charging on batteries and their limits. It displays how well the power is distributed from the power sources. It demonstrated [16] an improved bipolar-resonant LC converter-based multicell-to-multicell battery equalization. The rapid balancing speed and great efficiency of this equalizer are demonstrated mathematically and in contrast to conventional equalizers. In order to monitor the battery performance of electric vehicles, the Internet of Things (IoT) is used in this article [17]. Performance deterioration is caused by a progressive decrease in the energy given to the vehicle. The concept of employing IoT technology to directly monitor the performance of the vehicle is put out in this paper. This article [18] describes a battery management and monitoring system for electric cars that is low-cost, Internet of Things-based, real-time, and simple to use. It displays the crucial data regarding the battery's state, such as battery capacity and the charging and consuming current.

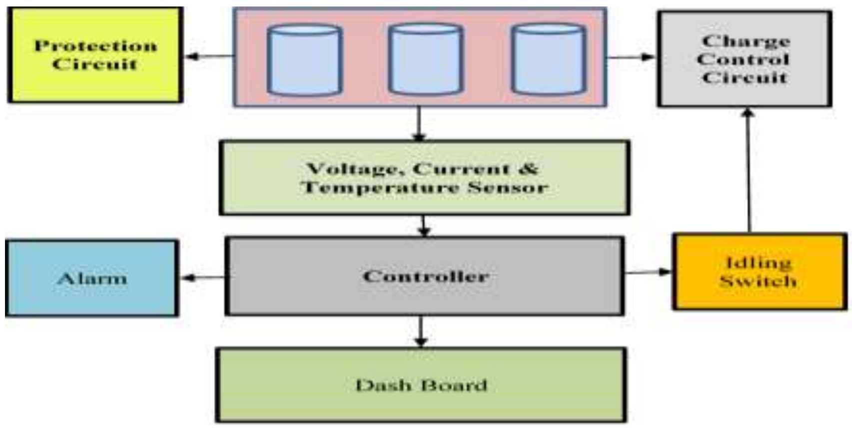


**Figure 1. Proposed System Block Diagram**

## 2. PROPOSED METHOD

A battery management system is used to guarantee the best possible utilization of the battery's energy and to reduce the possibility of battery damage. This is accomplished by keeping an eye on and managing the temperature throughout operation as well as the charging and discharging of the battery. The main job of a BMS is to gather data from the battery and send it to a software programmer for analysis, protection, and charging.[19].

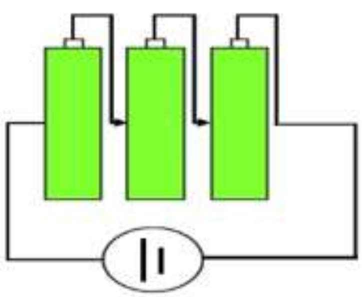

**Figure 2. Balance among cells in the Battery**

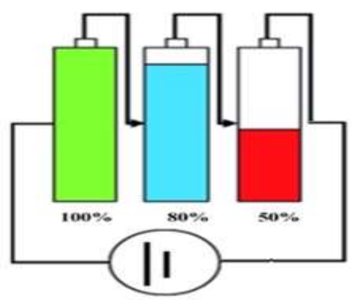


**Figure 3. Unbalance among cells in the battery**

A pack of series Li-ion battery cells is used by the electrical vehicle. During the run-time, the battery cell may act differently [20]. As a result, ongoing battery cell monitoring is required to assess the health of the cells. The findings of the battery cell monitoring may improve system performance by regulating, safeguarding, balancing, and controlling activities. It highlights the need of charge and discharge control, safeguards against overcharged and undercharged cell conditions, temperature and heat control, data acquisition communication and interface, fault diagnosis and assessment, etc.

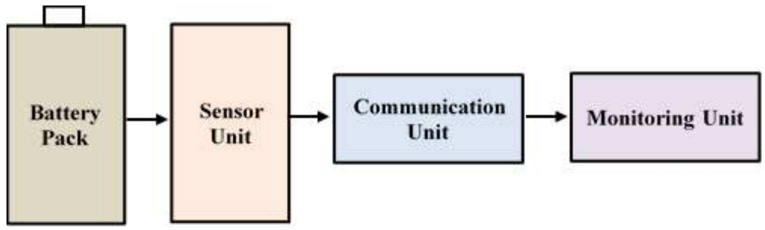


**Figure 4. General diagram of a BMS**

Monitoring of each cell is very important. As the discharge of the battery is irregular during operating condition, the charging of the battery also differ with respect to the remaining portion of each cell [21]. Therefore, a proper control circuit is necessary to maintain each cell voltage in balanced condition. Balanced and Unbalanced Charging level of each cell is shown Figure 2 and 3. The charging and draining of the battery as well as the operating temperature must be monitored and controlled if the objective is to be successful. For users of electrical vehicles, the suggested system is depicted in Figure 1. The system can be implemented using a Controller which allow system monitoring and management. Users can check the SoC (state of charge) and SoH (State of Health) of their EV batteries as well as system temperature. These variables are all updated and shown in real-time.

A battery bank, sensors, a controller, and a display module make up the proposed system shown in Figure 4. Through the computer program, the charging process is tracked, and all information is shown and updated in real-time. Measured Voltage and Temperature send to the microcontroller after necessary condition, the status of the cell monitored continuously.

### 3. BATTERY MANAGEMENT SYSTEM (BMS) AND MONITORING SYSTEM

The two main areas of battery pack protection management are electrical protection and thermal protection [22]. Electrical protection entails preventing the battery from being damaged by usage outside of its SOA and thermal protection involves passive and/or active cooling [23] to maintain or bring the pack into its SOA.

BMS is a system that manages a battery. It monitors constant charging and discharging of the battery and also ensures equal charge on each cell of a battery during charging and discharging mechanism. BMS comprises both, hardware and software. A BMS includes measuring, balancing and protection circuit [24]. The voltage and current measurement section measure the voltage and current values of each cell in the battery pack and that of the whole battery. The temperature control section measures the temperature of each cell of the battery pack and also monitors the cooling system. Balancing circuit ensures even charging and discharging of the battery cells so that they don't get over charged or discharged. Protection circuit provides protection to the battery from different threats.

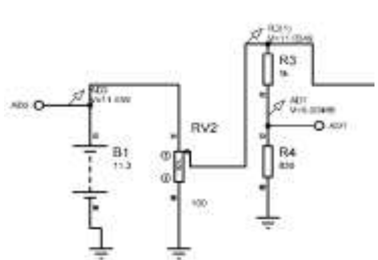


**Figure 5. Voltage Sensor**

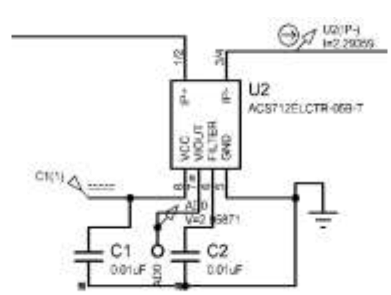


**Figure 6. Current Sensor**

The developed system, which can be realized in a portable device, enables monitoring and administration of the entire system. Users are able to keep track of the SoC (state of charge) of their EV batteries as well as input and output currents. These variables are all updated and shown in real-time. The suggested system is made up of the following components: a microcontroller, Voltage sensor in Figure 5 and Current sensors in Figure 6, a temperature sensor, a lithium-ion battery, and a charger for a lithium-ion battery.

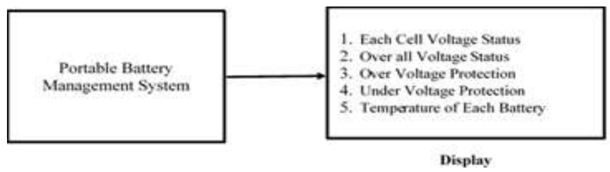


**Figure 7. PBMS Display System**

In order to prevent over-discharge damage to the battery and prolong its life, the system alerts the user to charge the battery when the Battery SoC reaches 90% through a portable display, as illustrated in Figure 7. When the battery is fully charged, the charging process terminates. The Li-Ion Battery Charger uses an internal protected circuit to halt the charging operation.

When the charging voltage goes below 100 mV and the charging current reaches C/10, the cell is said to be completely charged. A typical charging characteristic curve for a lithium battery is shown in Figure 8.

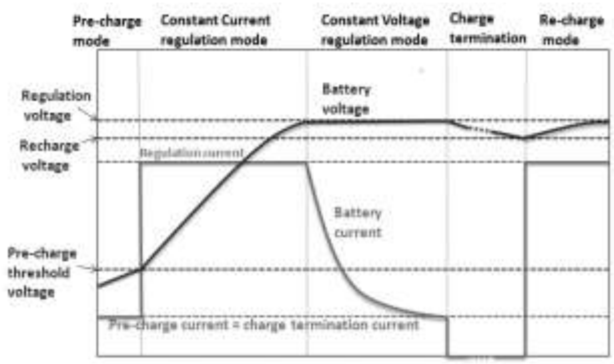


**Figure 8. typical charging characteristic curve for a lithium battery (Courtesy: richtek.com)**

The cut-off discharge voltage at which the state of charge is zero is the minimum discharge voltage. This minimal discharge voltage value varies depending on the load, temperature, age, and other variables.

### 3.1 State of Charge (SOC) and State of Health (SOH)

The state of charge (SOC) in (1) of a battery refers to the amount of charge that is currently stored in the battery. This is typically expressed as a percentage of the full charge capacity of the battery. For example, if a battery has an SOC of 50%, this means that it has stored half of the maximum amount of energy that it is capable of storing.

$$SOC = \frac{C_{Current}}{C_{full}} X100 \tag{1}$$

The state of health (SOH) in (2) of a battery, on the other hand, refers to the overall health and performance of the battery. This can be affected by factors such as the number of charge and discharge cycles the battery has undergone, its age, and its operating temperature. The SOH of a battery can be used to predict its remaining lifespan and determine when it should be replaced.

$$SOH = \frac{C_{full}}{C_{nominal}} X100 \quad (2)$$

where $C_{nominal}$ is the nominal capacity of a brand-new battery, $C_{current}$ is the capacity of the battery in its current state, $C_{full}$ is the capacity of the battery after it is completely charged.

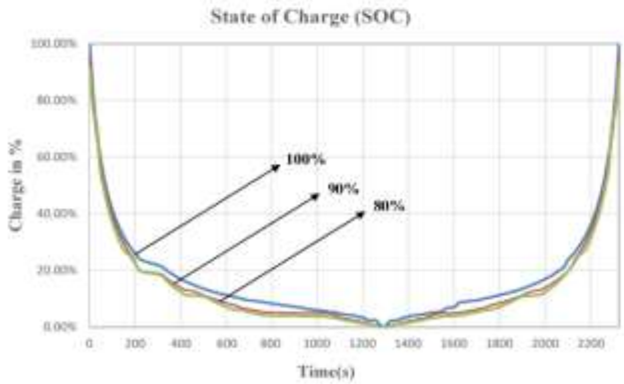


**Figure 9. State of Charge (SOC) for Uncontrolled Charging of Cell**

Any rechargeable battery that is 100% healthy will drain proportionally based on the load state and charge promptly. A 100% healthy battery will typically drain gradually toward 0% before being taken for recharge when it reaches 0%. Similar battery is displayed in Figure 9 for different health conditions of battery. This can occasionally make the load's working conditions worse and degrade its performance. In the suggested procedure, the battery is not allowed to completely discharge; instead, it is charged automatically once it drops 15% below the operational voltage and continues to operate under stable conditions. This can be done by human interaction, idleness, or the load shutdown condition depicted in Figure 10. If the suggested approach is used, the above-mentioned balanced condition for each cell voltage will be maintained. Battery life and continuous load operation can both be enhanced.

The exact formulas for calculating the state of charge (SOC) and state of health (SOH) of a battery can vary depending on the specific type of battery and the information that is available. In general, however, the SOC of a battery can be calculated by dividing the current amount of charge in the battery by the maximum capacity of the battery. For example, if a battery has a current charge of 100 Ah and a maximum capacity of 200 Ah, its SOC would be 50%.

The formula for calculating the SOH of a battery is more complex, as it involves factors such as the number of charge and discharge cycles, the battery's operating temperature, and its age. In general, however, the SOH of a battery can be estimated by measuring its capacity and comparing it to its original factory specifications. For example, if a battery has lost 20% of its capacity over its lifetime, its SOH would be 80%.

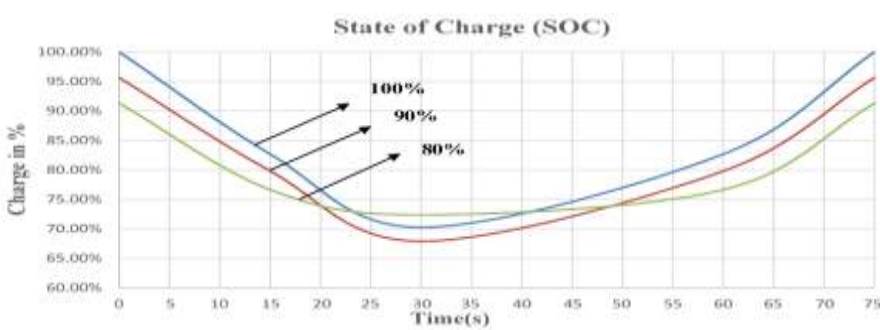


**Figure 10. State of Charge (SOC) for Controlled Charging of Cell**

It's important to note that these formulas are just general guidelines and the accuracy of the SOC and SOH calculations can vary depending on the specific battery and the information that is available. It's always best to consult the manufacturer's specifications or a qualified professional for more accurate information.

### 3.2 Electric Management: Voltage and Current

Electrical protection can be achieved by monitoring battery pack current and cell or module voltages. Current and voltage are the two factors that determine a battery cell's electrical SOA [25]. Lithium-ion batteries can tolerate larger peak currents in both charging and discharging modes, but for shorter durations of time. In addition to peak charging and discharging current restrictions, battery cell manufacturers often give maximum continuous charging and discharging current limits. The maximum continuous current will undoubtedly be applied by a BMS that offers current protection. However, this might come before to account for a quick change in load circumstances, such the sudden acceleration of an electric car or the sudden drawing of a large load from the grid.

A BMS may include peak current monitoring by integrating the current and, after delta time, choosing to either lower the available current or to stop the pack current entirely. This enables the BMS to have almost immediate sensitivity to extreme current peaks, such as a short-circuit situation that has not been noticed by any resident fuses, while also being tolerant of high peak demands, provided they are not excessive for an extended period of time.

The BMS is aware of these boundaries and will issue instructions according on how close they are to being reached. For instance, a BMS may ask for a progressive reduction in charging current or, if the high voltage limit, which is over 4.2 in the proposed technique, is reached, a complete cessation of charging current.

### 3.3 Protection Circuits

The battery is protected in the following ways by the BMS circuit: a) Over Charge Protection: When the battery's cells are fully charged to the maximum voltage, or 3.7 V, this circuit cuts off the supply. b) Over Discharge Protection - this circuit disconnects the load connection from the battery when one of the cell potentials falls below the minimum voltage, which is 3.2 V. c) Over Voltage Protection - This circuit cuts off the supply if the battery is being charged at a voltage higher than 11.1 V (in the case of a 3-cell battery pack where each cell is charged up to 3.7 V). d) Over Current Protection: Supply is turned off if the current being used to charge the battery exceeds the rated input current. e) Short Circuit Protection - If the load is shut off because the battery's discharge current exceeds the output current's rated value.

### 3.4 Idling Condition

Idling condition used way in the proposed method. Suppose the electrical vehicle is not operated from the battery or during the slope movement. The proposed method will be charged for period of time depend on the load ON condition the cell will be charged, if the load was not operated for long period the cell will be charged for continuously and shut down or charging will be automatically removed from the cells.

### 3.5 Thermal Management: Temperature Protection

Although lithium-ion batteries seem to have a wide temperature range, their total capacity decreases at low temperatures because chemical reaction rates become noticeably slower [26].

To reduce a lithium-ion battery pack's performance loss, cooling is especially important. For instance, if a certain battery performs best at 20°C, its performance efficiency may drop by as much as 20% if the pack temperature rises to 30°C. At 45°C (113°F), the pack must be continually charged and refreshed, or the performance loss might reach a significant 50%. If subjected to extreme heat generation on a regular basis, especially during quick charging and discharging cycles, battery life might also suffer from early ageing and deterioration [27].

Both passive and active cooling methods can be used to attain the same results. Air flow is used in passive cooling to cool the battery. This suggests that an electric car is only travelling along the road in the case of an electric vehicle. Air speed sensors might be added to strategically auto-adjust deflective air dams to optimum air flow, making it more complex than it first looks. The Load of electrical vehicle operated continuously. Therefore, passive cooling will not be applicable all the time. In the proposed method both active and passive cooling method implemented in order to reduced the sudden raise of temperature and avoid accidents.

The temperature of the battery is measured via a thermistor connected to a voltage divider network. Thermistor is a tiny device made of metallic oxide and enclosed in glass or epoxy that provides temperature readings in accordance with changes in resistance. When the temperature rises beyond the set threshold, this circuit disconnects the battery until the temperature returns to normal. By comparing two known temperatures, the temperature sensor is calibrated, and the voltage is then scaled appropriately. The temperature and voltage values are converted to strings and supplied to the controller.

### 3.6 Cooling Unit

The cooling unit of the battery management system enables, whenever the battery temperature goes above the threshold level of the battery. The battery unit disconnected from the circuit, the fan start running to reduce the temperature of the battery. After the temperature reduce the battery once connected to system for regular operation

## 4. METHODOLOGY

In the proposed method, each cell is monitored for over voltage, under voltage and temperature. The Individual cell voltage of the battery is measured continuously [28], whenever the any of the voltage reduced below the threshold the cell disconnected from the battery and connected to charging unit. Similarly, when the cell charged above the limit it disconnected from the cell and connected to the load, this process continuously repeated for entire cycle of the operation till the system shutdown. The flow chart in Figure 11 shows the flow of the proposed battery management system.

The Table1 describes the process of individual cell action. When the battery reactive above or below the threshold level, each cell disconnected from the load/motor and connected to the respective position either to the charging unit or across the load.

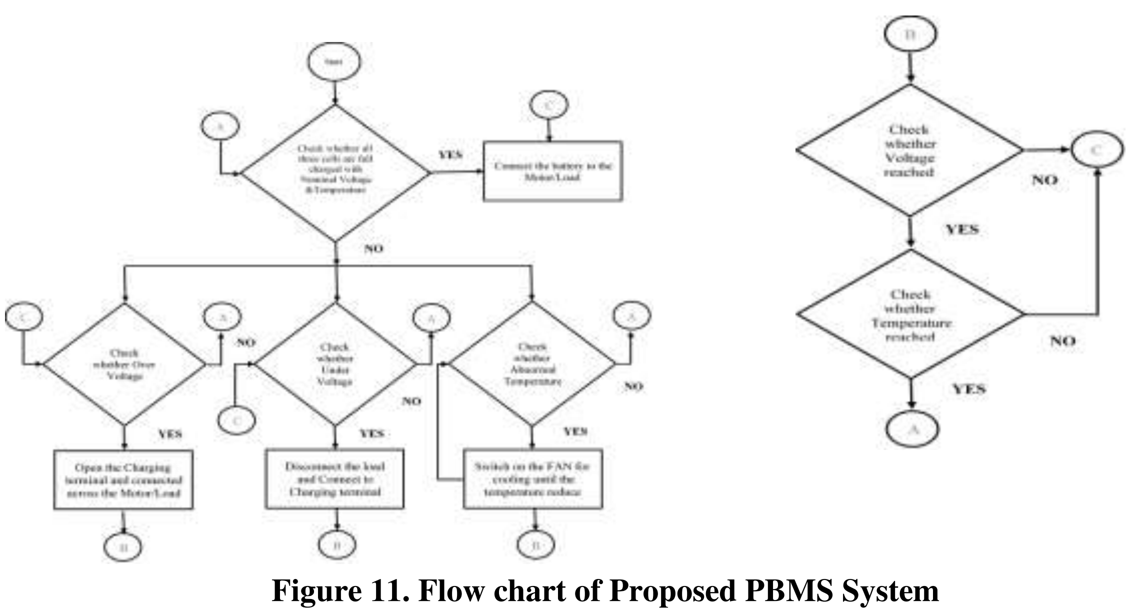


**Figure 11. Flow chart of Proposed PBMS System**

Table 1 Various level of cell voltage and status

| Cell 1 | Cell 2 | Cell 3 | Tot Acc Volt | Over Volt | Under Volt | Status of Each Cell | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Cell 1 | Cell 2 | Cell 3 |
| 3.7 | 3.7 | 3.7 | 11.10 | NO | NO | **CON** | **CON** | **CON** |
| 3.7 | 3.2 | 3.6 | 10.55 | NO | NO | **CON** | DC | **CON** |
| 3.2 | 3.6 | 2.6 | 9.44 | NO | **YES** | DC | **CON** | DC |
| 4.2 | 4.2 | 4.2 | 12.65 | **YES** | NO | DC | DC | DC |
| 0 | 3.7 | 3.7 | 7.44 | NO | **YES** | DC | **CON** | **CON** |

**CON** - Connected
**DC** - Disconnected

In short, each cell will be connected in series during balanced condition [29] [30], whenever abnormal condition such as over temperature under voltage detects the cell disconnected from the load and connected to respective position. When the temperature of the system reaches above threshold value either during working condition or charging condition, each cell will be isolated from the load or charging point [31].
In Table 1 the various level of cell status is shown. In this proposed method few levels of cell percentage are taken for testing such as Nominal Voltage, Over Voltage and Under Voltage (100%,95%,85%,114%,67%). The voltage obtained by each level is shown in the following section.

## 5. RESULTS AND DISCUSSION

The various simulation circuits and results will be detailed in the section that follows. Since the suggested approach employed a controller to manage the relays based on the battery's state, the vehicle's operating or idling condition, temperature, and other factors.

### 5.1 Over Voltage Detection and Protection

Over voltage protection is one of the crucial considerations that must be taken into account. Three 3.7V voltage cells are utilized in the suggested technique; if the real voltage climbs by 15% of the nominal value, or 4.2V, the higher voltage cell will be disconnected from the charge and connected to the load or Vehicle. As a result, the cell will be shielded from over charging. When each cell is charged above 15% of the nominal voltage, the circuit below will be switched to the load position. The Figure 12 keeps track of the cell's condition constantly. Based on the battery's state, the user will control the load or vehicle.

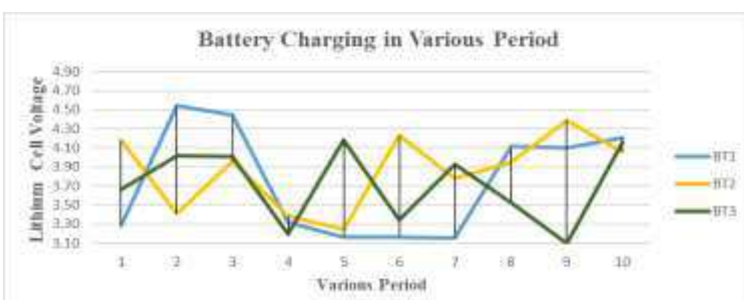


**Figure 12. Over Voltage and Under Voltage Display**

### 5.2 Under Voltage Detection and Charging

Each cell will be shielded from the excess voltage, as can be shown in the section above. Similar to this, each cell needs under voltage protection since the charge in the cell will discharge instantly it exceeds a specified threshold value. Therefore, the cell will quickly shift to the charging point when the voltage drops below 15% of the normal voltage, or 3.2V. The display device Figure 12 monitors each cell's level while it is operating. The user will therefore be aware of the overall time spent operating the load or vehicle. The circuit Figure 13 illustrates the suggested procedure for charging the cell when the voltage drops below the designated threshold.

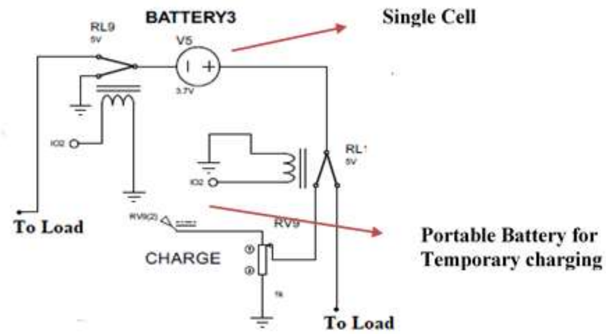


**Figure 13. Circuit Connection between load and Charging point**

### 5.3 High temperature Detection and Protection

One of the keys to ensuring the dependability, efficiency, and durability of electric cars is temperature regulation. The ability to operate electric motors at or near their performance limits, achieve high charging and discharging currents, and prolong battery life all depend on accurate temperature measurement.

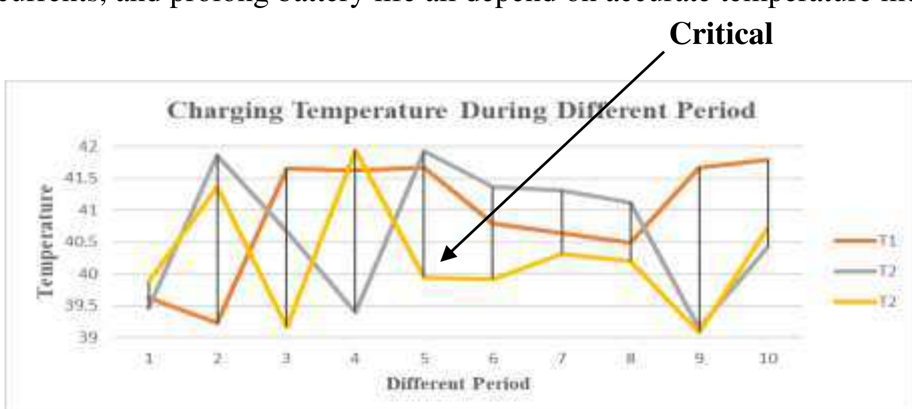


**Figure 14. High Temperature indication and Cooling Fan Status**

Battery Temperature is one of the important facts has to considered, while the load is working or battery charging. Monitoring the battery helps the user to protect the load and devices. When the battery is charged above the nominal level or continuous operation of load the battery leads to high temperature sometimes. The proposed method helps to protect the battery from high temperature. When the temperature of any of the cell is goes above the nominal temperature, the load detached completely and the battery will become open circuited. At the same time the fan connected to the system start operating and cools down the battery temperature shown in Figure 14.

### 5.4 Idling time detection and recharging

Idling is the practice of leaving a car's engine running while it is stationary. This frequently happens when the driver stops the car at a red light, waits outside a building or home, or is otherwise motionless with the engine running. The engine runs idle with no loads other than the accessories.

This idling time helps the battery to retain the loss voltage below the nominal level. In the proposed method separate switch is provided to regain the battery voltage for short or long period of time. This helps the system maintains stable voltage for single or multi cell.

### 5.5 State of Charge (SOC) & State of Health (SOH)

As mentioned in the above discussion SOC & SOH indicate the status of the battery. The performance of SOC and SOH can be improved in the proposed method by continuous monitoring and maintaining the voltage in stable operating condition. The SOC & SOH of each cell continuously monitored shown in Figure 15 and controlled using the proposed system gives Satisfactory results for different operating condition of load. The graph obtained in the above section show the proof of evidence. All the parameter mentioned in the above section continuously displayed in the monitor helps the user for health and charging position of the cell/battery [32] [33].

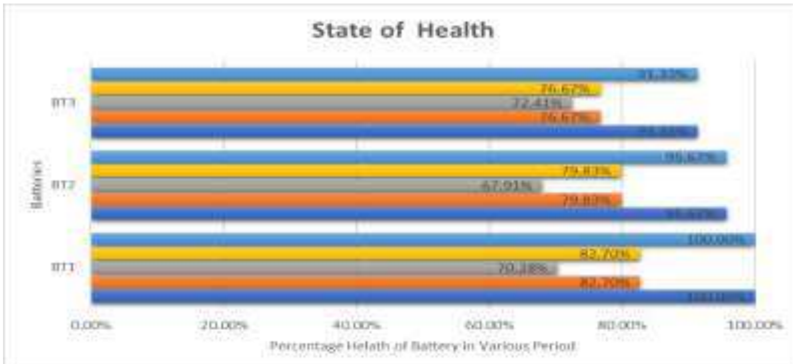


**Figure 15. Different Stage of SOH with the Corresponding SOC**

## 6. PROPOSED METHOD CIRCUIT DESIGN

From the above discussion it is proposed that the battery unit connected in EV/Smart Grid will be protected and maintain stable condition for quick period of time. The drain level of the cell, charging level will be maintained with in the threshold value mentioned in the above section. The proposed method design circuit shown in Fig 16.

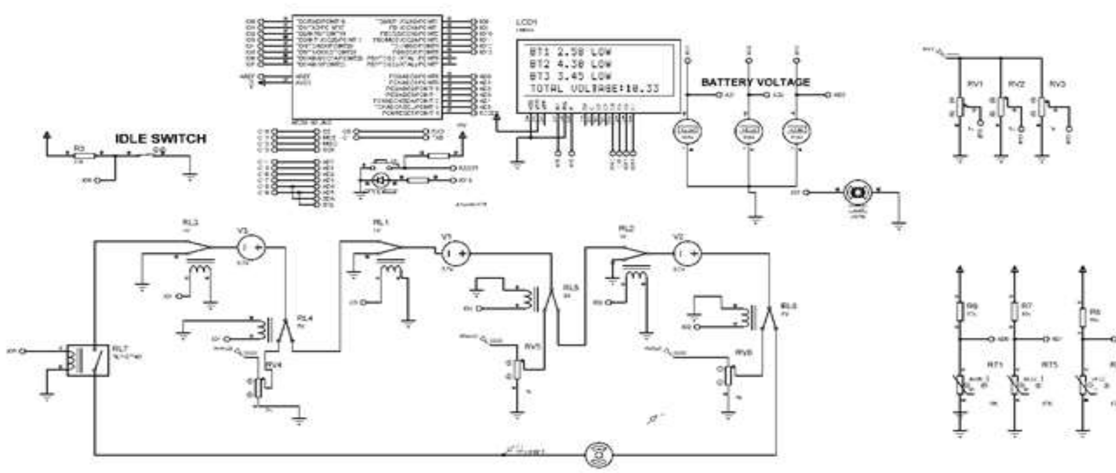


**Figure 16. Circuit Design of Proposed Portable Battery Management System**

## 7. CONCLUSION

The suggested method uses a BMS-optimized charging approach to calculate how long the battery may be utilized, i.e., charged and discharged without degrading performance. the intended over discharge of the battery cells, high temperatures, and uneven charging and discharging. The tiny constructed circuit's functionality was examined using computer assisted software. The BMSs of both systems might emit an alarm signal and notify the problem in the fault response on actual systems whenever they reached the limitation limits of the associated parameters.

The test findings from the aforementioned section demonstrated that lithium iron phosphate systems performed worse than ternary systems in terms of fault detection rate, warning speed, and protection speed, with ternary systems having wider threshold intervals for a variety of characteristics. This fault response and handling method and its effect could make up for the application effect of lithium iron phosphate battery and ternary system battery in actual battery systems due to their performance differences since the lithium iron phosphate battery was more stable than the ternary system battery.

When the thresholds were achieved, the lithium iron phosphate battery's BMS could detect and report overcharging and over discharging issues and take preventative measures. The BMS might identify and notify overcurrent and overtemperature errors on a regular basis. After the thresholds were reached, the ternary system's BMS could detect and notify all failures in a matter of seconds. Additionally, it implemented precautionary measures within 1 second and 5 seconds (depends on Controller frequency) after the overcharging, over discharging, and overtemperature problems reached their thresholds, respectively.

The suggested approach is accomplished using innovative conditions in addition to the usual parameters to keep the cell voltage constant during idling conditions. This study focuses on the BMS response problems of accuracy, timeliness, and reliability evaluation. It chooses four models based on various BMS battery systems using a software loop that is in line with the actual working environment. To accomplish a real and accurate evaluation of BMS fault response performance, the BMS fault response test and evaluation technology platform was developed.

## DECLARATION

- The authors have no relevant financial or non-financial interests to disclose.
- The authors have no conflicts of interest to declare that are relevant to the content of this article.
- All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.
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