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Design and Implementation of IoT Based Wireless Battery Management System for Electric Vehicles

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Abstract: The Battery Management System is essential for managing and monitoring battery performance, ensuring optimal performance and extending battery life. A potential way to get around these restrictions and improve the precision and dependability of SOC estimation is through the integration of wireless technologies and IoT in BMS. The use of a Wireless Battery Management System (WBMS) for the efficient management of battery cells in Electric Vehicles (EVs) is discussed in this paper. IoT devices with voltage sensors are deployed on the battery cells as part of the experimental setup. As part of the experimental setup, IoT devices with voltage sensors are installed on the battery cells. These sensors continuously monitor the voltage levels and wirelessly transmit the data to a central monitoring station. The outcomes show that the suggested wireless BMS system is efficient and accurate at calculating SOC from voltage measurements. According to the experimental findings, the cell temperature is higher during a 1C discharge rate compared to a 0.5C discharge rate.

Keywords: *Battery Management System (BMS), Electric Vehicles, State-of-Charge (SOC), Internet of Things (IoT).*

1. Introduction

Concerns about the environment getting worse, bad air quality, and the fast depletion of fossil fuels are making the world pay more attention to finding alternative, green, and eco-friendly sources of energy. Global problems like pollution, climate change, and the running out of fossil fuels have made it clear that electric vehicles (EVs) are needed as an alternative way to get around. EVs help make energy more diverse and less reliant on fossil fuels [1-3]. EVs can be powered by clean and sustainable energy by using electricity from sources like solar and wind power. The use of electric vehicles (EVs) creates chances for technological progress and economic growth. Electric vehicles (EVs) and the infrastructure that goes with them, like charging stations, create jobs and spur innovation in the auto and clean energy industries. Battery Management Systems (BMS) systems are important because they improve battery safety, boost performance, check the health of the battery, balance the cells, manage energy efficiency, and give the user a better experience. Battery Management Systems (BMS) are needed because rechargeable batteries are being used more and more in places like electric cars, renewable energy systems, portable electronics, and grid energy storage [4]. Wire-based Battery Management Systems (BMS) have been used in many systems that run on batteries. They do have some problems that have led people to look for other solutions, such as wireless BMS. Wire-based BMS needs a lot of wiring to collect data from sensors and send it to the master controller. There can be problems with the reliability of wired connections. Vibrations and mechanical stress can break physical connections, making it hard or impossible for the BMS parts to talk to each other. To get around the problems with wired-BMS, researchers have been working on wireless topologies that can send information and control commands between sensors and controllers. This has led to the development of Wireless Battery Management Systems (WBMS), which are better than traditional wired systems in many ways. WBMS also saves money and weight by getting rid of the need for a complicated wiring infrastructure [5-7]. WBMS also gives you the freedom to put sensors wherever you want. With wireless communication, sensors can be put in different parts of the battery pack. This makes data collection more accurate and efficient. The development of Wireless Battery Management Systems (WBMS) is a solution to the problems with wired-BMS. WBMS offer better system reliability, lower weight and cost, flexibility in sensor placement, fault tolerance, scalability, and the ability to replace individual components. The development of Wireless Battery Management Systems (WBMS) has been a big step forward for battery management technology, especially when it comes to estimating the State of Charge (SOC). Since electric cars are becoming more popular quickly, people are paying more attention to how well their battery systems work [8]. State of Charge (SOC) estimation, which measures the energy in the battery, is needed for EVs to work. Accurately estimating SOC helps drivers plan trips, get the most out of their vehicle's range, and make the best use of the battery. It also stops the battery from getting too low, which hurts its performance and

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makes it last less long. Voltage-based methods were used in traditional battery management systems to estimate SOC. These methods are often wrong because of how batteries are made, how they are used, and how they age. So, advanced SOC estimation methods are needed to make EV batteries work and last as long as possible [9]. The Internet of Things has made battery management systems more flexible. IoT-based BMS allows for monitoring in real time, management from afar, and better connectivity. With sensors, advanced estimation algorithms, and IoT technology, a BMS that is based on IoT can better estimate the EV SOC.

From the literature review on Wireless Battery Management Systems (WBMS) for SOC estimation, certain limitations were encountered that highlight areas for further research and improvement. While, the literature provides valuable insights into the theoretical aspects of WBMS for SOC estimation, there is a need for more empirical studies and field testing to validate the performance of these systems in real-world conditions. Luo et al. [10] proposes an enhanced MC2MC equalizer based on a novel bipolar-resonant LC converter (BRLCC) to improve balancing speed and efficiency. Mathematical analysis and comparison with typical equalizers demonstrate its fast balancing and efficiency. An experimental 8-cell prototype has balancing powers from 1.426 W to 12.559 W and efficiencies from 84.84% to 91.68%. Xia & Qahouq [11] examines equivalent circuit model (ECM) parameter variations under different lithium-ion battery state-of-health (SOH) conditions. This paper fits an ECM to experimental EIS data from 0.01 Hz to 7.928 kHz to characterize battery ageing. As the battery's SOH declines, the ECM's series resistor increases and its capacitance components of CPE decrease. Shrivastava et al. [12] proposes the dual forgetting factor-based adaptive extended Kalman filter (DFFAEKF) for SOC estimation. The combined SOC and SOE estimation method uses the proposed SOC estimation method and the simple SOE estimation approach. The experimental results showed that the combined SOC and SOE estimation method using the proposed DFFAEKF can estimate battery states under dynamic operating conditions with RMSE less than 0.85% and 0.95%. Canilang et al. [13] proposes a modular BMS circuit and testing platform for electric motorcycle battery voltage applications. The BMS platform is evaluated in real time with a total input load voltage of 51.2–67.2 V. BMS voltage accuracy is assessed. With a mean RMSE of 0.0018895, BMS voltage values are verified using actual input load voltage values. Zhang et al. [14] introduces a power/data TDM-based BMS architecture. A common bus transfers power and data in the proposed system, simplifying wiring. MATLAB simulations and a six-node prototype system prove the architecture's correctness and practicality. Huang et al. [15] manages EV battery cells with a Wireless Smart Battery Management System (WSBMS). WSBMS is a wireless cell-level BMS. SOC, SOH, and capacity cells are balanced using a two-step algorithm. Sorted cells SOC value ascending. The maximum-to-minimum SOC deviation is SOC.

A major development in battery management technology is the creation of WBMS for SOC estimation. The available literature mainly concentrates on the technical aspects of WBMS, including sensor technologies, wireless communication protocols, and estimation algorithms. The development of a wireless Battery Management System (BMS) utilizing the Internet of Things (IoT) for State of Charge (SOC) estimation through voltage measurements is the main topic of this research paper. IoT devices with voltage sensors are deployed on the battery cells as part of the experimental setup. These sensors wirelessly transmit the data to a central monitoring unit while continuously measuring the voltage levels. The outcomes show that the suggested wireless BMS system is efficient and accurate at calculating SOC from voltage measurements.

2. Experimental Methodology

Electric Vehicles (EVs) have raised awareness of battery system efficiency. EV range and performance depend on a battery's State of Charge (SOC), which is a percentage of its total capacity. Optimizing battery use, vehicle efficiency, and reliability require accurate SOC estimation. IoT technology has enabled real-time monitoring, remote management, and intelligent decision-making in battery management systems. This thesis develops and implements an IoT-based BMS for electric vehicle SOC estimation. This system uses IoT connectivity, sensors, and advanced estimation algorithms to improve SOC estimation, EV performance, and usability. This research discusses the design, experimental setup, data processing, and performance evaluation of the proposed IoT-based BMS for SOC estimation in electric vehicles.

2.1 Design and hardware of prototype model

Internet of Things (IoT)-based Wireless Battery Management Systems (BMS) use this technology to remotely monitor and control batteries. A network of linked devices that communicate and exchange data online is referred to as the Internet of Things (IoT).

Battery modules in an IoT-based wireless BMS are fitted with IoT-enabled sensors or transceivers that gather information from individual battery cells. The metrics in this data include SOC, voltage, current, and temperature. The battery modules use internet connectivity to wirelessly transfer this data to a central management system or cloud platform. The cloud platform or central management system gets the data from the battery modules and analyzes and tracks battery performance in real-time. Multiple battery packs can be monitored at once, irregularities or problems can be found, and battery operations can be optimized using the data gathered. As well as receiving commands from the central system, the battery modules can also receive control signals from it for tasks like cell balancing or charging/discharging management.

2.2 Hardware Implementation

Battery selection

An IoT-based Battery Management System (BMS) for EV SOC estimation must choose a battery. Lithium-ion, Nickel-Metal Hydride (NiMH), and Lead-Acid batteries have different energy densities, voltage ranges, lifespans, and charging/discharging efficiency. Application, energy, weight, and cost determine battery chemistry. Consider the battery's cycle life and aging. Cycle life is the number of charge and discharge cycles a battery can handle while maintaining performance. Age-related capacity fade and impedance increase affect SOC estimation accuracy. SOC estimation requires a battery with a long cycle life and low aging effects.This research develops and implements an IoT-based Battery Management System (BMS) for EV SOC estimation using the MURATA (SONY) 3000mAh (7c) Li-ion battery (details in appendix A). MURATA (SONY) batteries are chosen for their high energy density, voltage range compatibility, and long cycle life. The 3000mAh MURATA (SONY) battery stores enough energy for EVs. Its 7C discharge rate allows high-power output for EV power. Li-ion chemistry maintains efficiency and voltage throughout the discharge cycle. This study examines the MURATA (SONY) battery's charging, discharging, aging, and safety in an IoT-based BMS. The IoT-based BMS using the MURATA (SONY) battery will be evaluated for SOC estimation, cycle life, and operating conditions. This research can improve Li-ion battery management and EV SOC estimation.

Current sensor

The ACS712 current sensor module (figure 3.1) was chosen because it can measure battery system charging and discharging currents. The ACS712 can measure high EV currents with its 30A current sensing range. The sensor module measures current without disrupting the circuit. The IoT-based BMS with the ACS712 current sensor module will be tested for accuracy, linearity, and response time. Analog output pins on the ACS712 current sensor module provide voltage proportional to measured current. The ACS712 module's analog output is connected to the IoT development board or microcontroller's analog input pins to integrate the sensor. Appendix details the module. Calibrating the ACS712 module may improve current measurements. Calibration corrects sensor inaccuracies and non-linearities by adjusting the zero-point offset and sensitivity. The IoT platform or cloud service integrates ACS712 module current data with battery parameters and SOC estimation algorithms.

Fig 1 Photograph of Current Sensor Module ACS712, 30A.

Voltage sensor

The Voltage Detection Sensor Module was chosen because it can measure battery voltage, a key SOC estimation parameter (figure 3.2). The sensor module can accurately measure battery voltage within EVs' operating range with a 25V voltage range. This thesis integrates the Voltage Detection Sensor Module into the IoT-based BMS, configures IoT hardware communication, and processes voltage data for precise SOC estimation algorithms. The 25V Voltage Detection Sensor Module outputs a digital voltage signal. The sensor's digital output is connected to the IoT development board or microcontroller's digital input pins to integrate it with the system. The communication protocol sends processed voltage data to the IoT platform or cloud service. IoT development boards or microcontrollers connect to the network and securely send data.

Fig 2 Photograph of Voltage Detection Sensor Module 25V.

Thermocouple K-type and MAX6675

Figure 3.3: Thermocouple K-type with MAX6675 temperature sensor module. The Thermocouple K-type and MAX6675 module were chosen because they can measure battery temperature, a crucial parameter. The K-type thermocouple-specific MAX6675 module outputs temperature readings digitally. The MAX6675 module is essential for integrating the Thermocouple K-type and the IoT-based Battery Management System (BMS) for accurate State of Charge (SOC) estimation in Electric Vehicles (EVs). The MAX6675 module uses a 12-bit analog-to-digital converter (ADC) to digitize Thermocouple K-type analog temperature readings. SCK, CS, and SO are the MAX6675 module's serial interface pins. The SCK pin synchronizes the MAX6675 module and IoT hardware. The serial data output pin sends digital temperature data from the MAX6675 module to the IoT hardware. Appendix describes module and thermocouple.

Mega 2560 Dev Board

Figure 3.4 shows the ATmega2560-based Mega 2560 Dev Board. One of the most popular Arduino development boards, it is used in many applications. Different sensors are controlled by Arduino mega 2560. are interfaced using sensor-specific digital input and output pins. Hardware's brain. The microcontroller follows a code that specifies how all sensors work. It connects the sensors, IoT platform, and GSM module.

Here are some **specifications of the Mega 2560 Dev Board**:

Microcontroller: The Mega 2560 Dev Board is based on the ATmega2560 microcontroller, which is a 8-bit AVR microcontroller with 256KB of flash memory, 8KB of SRAM, and 4KB of EEPROM.

Digital I/O Pins: The board has 54 digital I/O pins, including 15 PWM outputs.

Analog Inputs: The board has 16 analog inputs.

UART: The board has 4 UARTs.

SPI & I2C: The board has 1 SPI interface and 1 I2C interface.

Fig 3 Photograph of Mega 2560 Dev Board.

SIM800L Module

In figure 3.5, the SIM800L module transfers data from the IoT system to a mobile app. The SIM800L quad-band GSM/GPRS module is a low-cost IoT wireless communication module. The SIM800L module is used to seamlessly transmit sensor data to a mobile application. The module integrates with IoT hardware and uses GSM and GPRS protocols for reliable and efficient data transfer over cellular networks. The SIM800L module connects to

IoT hardware using serial communication protocols like UART to transfer data. After receiving data from IoT hardware, the SIM800L module connects to the mobile application via GSM/GPRS. SMS, GPRS, or other module-supported methods send the data.

The SIM800L module offers a variety of communication features, including SMS messaging, voice call capabilities, and Internet connectivity.

Here are some specifications of the SIM800L Module:

Frequency Bands: The SIM800L Module is a quad-band module that supports

850/900/1800/1900 MHz

Interface: The SIM800L Module has a TTL level serial interface, which allows it to be connected to a microcontroller or other device using UART communication.

Power Supply: The module requires a 3.4V to 4.4V power supply and can consume up to 2A during transmission. Antenna: The module requires an external GSM antenna to be connected. Dimensions: The SIM800L Module is a small module, measuring only 24mm x 24mm. Support for TCP/IP protocols, Integrated TCP/IP stack, Support for HTTP, FTP, and SMTP protocols and Built-in SIM card reader.

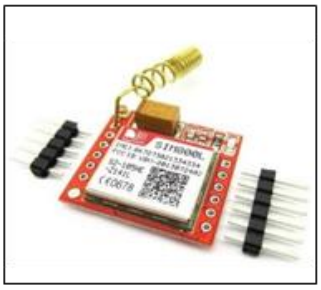

Fig 4 Photograph of SIM800L module.

2.3 Software Integration

Integration of hardware and software in an IoT-based EV Battery Management System (BMS). Hardware integration involves seamlessly integrating sensors, microcontrollers, communication modules, and other physical components into the BMS system, while software integration involves developing and implementing software modules, algorithms, and interfaces to control, monitor, and analyze hardware components. Software integration of an IoT-based Battery Management System (BMS) for State of Charge (SOC) estimation in Electric Vehicles (EVs) using a MQTT broker is the focus. IoT applications use MQTT for efficient and reliable device-to-system communication. MQTT broker integration in BMS software streamlines data transmission and improves system functionality and connectivity. The thesis examines MQTT broker integration into BMS software architecture. To estimate SOC, the software collects data from current, voltage, temperature, and other sensors. The software processes data and implements SOC estimation algorithms.

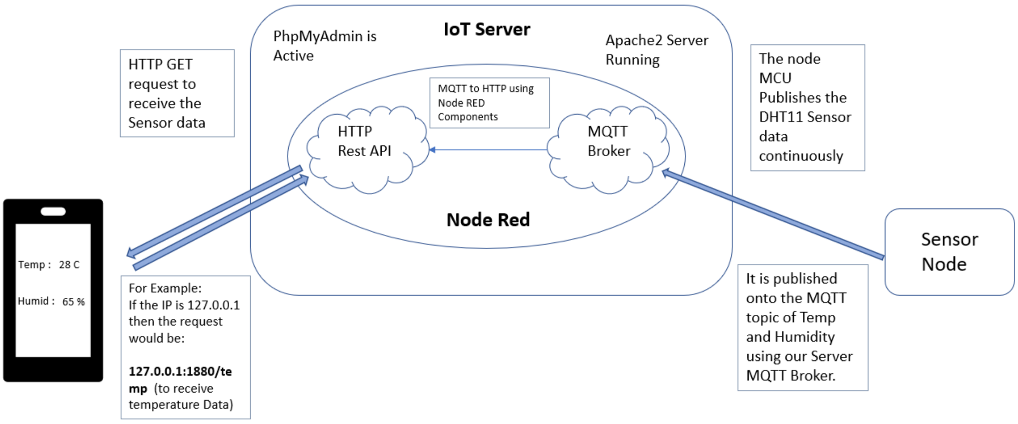

Fig 5 Flow diagram of From Controller to Mobile App.

Integration of MQTT broker and web application

The incorporation of a Message Queuing Telemetry Transport (MQTT) broker into a web application in order to facilitate the effective communication of data and its visualization within the context of the Internet of Things (IoT). Because of its low bandwidth and power requirements, MQTT is a lightweight messaging protocol that is widely used in Internet of Things applications. The combination of a web application and a MQTT broker enables seamless communication in both directions between Internet of Things devices and the web interface, which in turn enables the transmission of real-time data and visualization of that data.

To connect an MQTT broker with a web app, you can follow these general steps:

Set up an MQTT broker:

Create a MQTT broker by selecting one that meets your needs. A few well- known MQTT brokers include RabbitMQ, HiveMQ, and Mosquitto. The broker should be installed and configured on a server or cloud platform.

Pick a framework or programming language. Choose a programming language or framework that supports web development and MQTT communication. Some well-liked choices are Python with the Paho MQTT library, JavaScript (Node.js) for the server-side, and the MQTT.js library.

Install the MQTT library:

Install the MQTT library for the coding language or framework of your choice. For example, if you are using JavaScript with Node.js, you can install MQTT.js using npm:

shell Copy code

```
npm install mqtt –save
```

Include the MQTT library in your web app:s

Include or import the MQTT library into the code of your web application.

Establish a connection to the MQTT broker:

Create a client instance in your web app's code to connect to the MQTT broker. Give the relevant connection information, including the broker's URL, port, username, and password (if necessary).

Subscribe to MQTT topics:

The MQTT topics that you want to receive messages from can be subscribed to. To process incoming messages and carry out actions in your web app depending on the received data, call back functions may be specified.

Publish MQTT messages:

Implement MQTT message publishing capabilities in your web application. Assign the proper topic and payload to your particular use case.

- IoT Device Publish Message
    - Format: UserID/DeviceID/S1/<Data>
        - Data: S1_Value, S2_Value, S3_Value, S4_Value, TimeStamp
    - This is Subscribed by Application Server and Mobile Apps

Handle MQTT messages in your web app:

In your web application, process incoming MQTT messages by using the call- back methods of the MQTT library. Based on the data obtained, modify the user interface or carry out any desired actions.

Test and deploy:

Check that the MQTT connection and message handling function as intended by testing your web application locally. Deploy your web application to a server or hosting platform as soon as you are pleased with the functionality. It's vital to remember that depending on the MQTT library, programming language, and framework you use, the particular implementation details may change. For more detailed guidelines and examples, consult the library's documentation shown in figure 6.

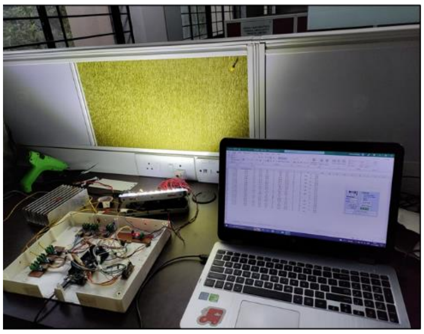

Fig 6 hardware connection with system and testing.

3. Results and Discussion

The graph depicting the voltage discharge profile for the 0.5C-1C case in our experiments provides valuable insight into the battery's performance and efficiency. The voltage values range from 0 to 4.2V, and the time values range from 0 to 7000 seconds. This initial voltage drop indicates that the battery is rapidly losing energy as it begins to power the load. This behavior is expected given that the battery provides the necessary current to meet the load's demand. Internal resistance of the battery is responsible for the initial voltage drop. Internal resistance causes a voltage drop across the battery terminals as soon as the load is connected and current begins to flow. This effect is amplified when the battery is discharging more quickly and at higher currents. In the approximately 6500 seconds that follow, the voltage decreases relatively slowly. This steady drop in voltage indicates that the battery is continuously releasing energy to maintain the load. The gradual decrease in voltage indicates a more stable discharge rate and suggests that the battery will maintain a constant level of power for an extended period. After approximately 6500 seconds, there is another abrupt voltage drop. This sudden drop in voltage indicates that the battery's capacity is nearing depletion, which would explain the battery's more rapid voltage decay. When there is one last sharp voltage drop, the battery is close to its cutoff voltage. The minimum voltage at which a battery can discharge without endangering its health or performance is referred to as the cut-off voltage. As the battery voltage approaches this threshold, it decreases rapidly, indicating that the energy supply has essentially run out. Figure 7-8 illustrates the change in cell temperature with respect to time. It can be seen from the graph that the temperature rises significantly during the first 50 seconds. This initial increase in temperature suggests that the battery generates heat rapidly as it begins to discharge energy to power the load. As a battery discharges, the internal resistance causes ohmic heating, resulting in the production of heat within the battery. The slow and gradual increase in temperature over the sustained discharge period indicates the equilibrium between heat production and heat dissipation. The thermal management mechanisms of the battery, such as heat sinks, conduction pathways, and convective cooling, are essential for maintaining a relatively stable temperature rise.

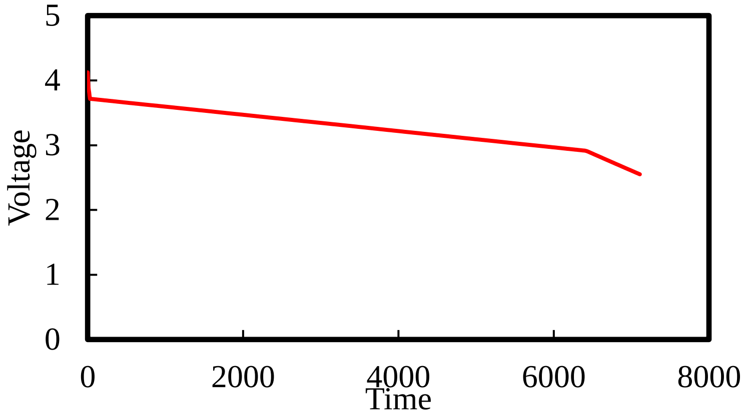

Fig 7 Grapgh of voltage versus time for 0.5C loading conditions.

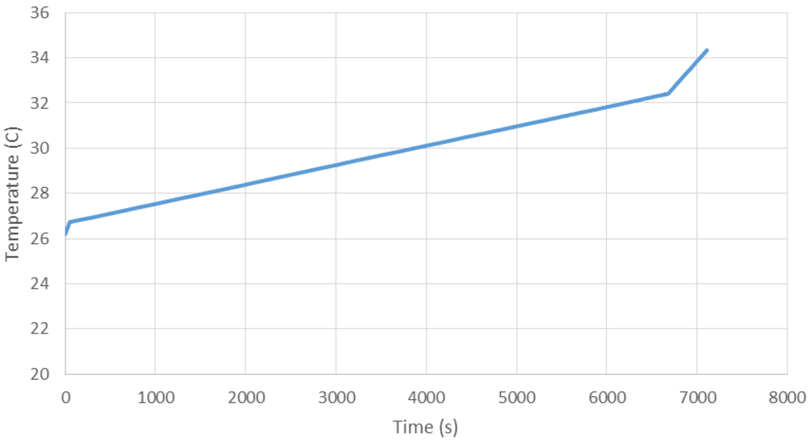

Fig 8 Grapgh of cell temperature versus time for 0.5C loading conditions

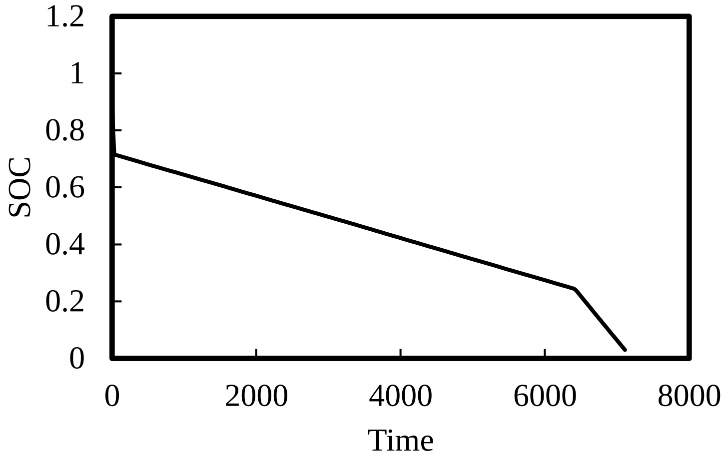

Fig 9 Grapgh of SOC versus time for 0.5C loading conditions

In the same way, figure 10 and 11 shows the behavior of volatilization for a 1C discharge rate. During the first 35 seconds, it is clear that the voltage drops a lot. This quick drop in voltage suggests that the battery is losing power as soon as it starts to power the load. This slow drop in voltage shows that the battery is discharging steadily, giving power to the load at a steady rate. But after about 2900 seconds, the voltage drops quickly again. This sudden drop in voltage suggests that the battery's power is getting low, which makes the voltage drop more quickly. The important thing about these results is what they mean for battery management, optimization, and estimating capacity. Understanding how the voltage drops lets you estimate the State of Charge (SOC) and predict how long the battery will last. Figure 12 shows how the temperature changes when the discharge rate is 1C. The time values range from 0 to 3500 seconds, and the temperature values go from 24 to 37 degrees Celsius. When you figure out what the temperature profiles in the 1C case mean, you can learn a lot about how the battery's temperature changes during discharge. The patterns of temperature rise that have been seen show how heat production and heat loss work together.

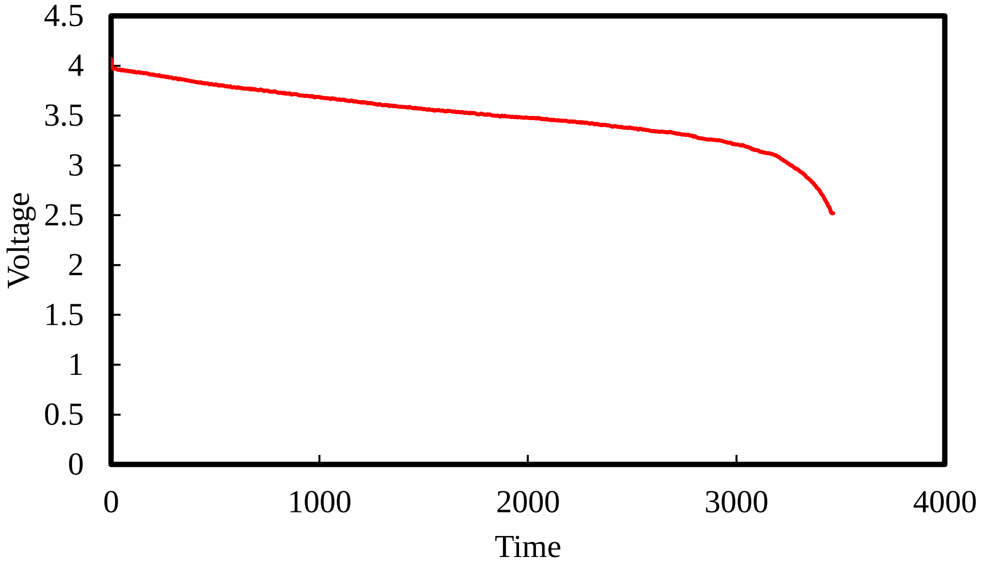

Fig 10 Grapgh of cell voltage versus time for 1C loading conditions.

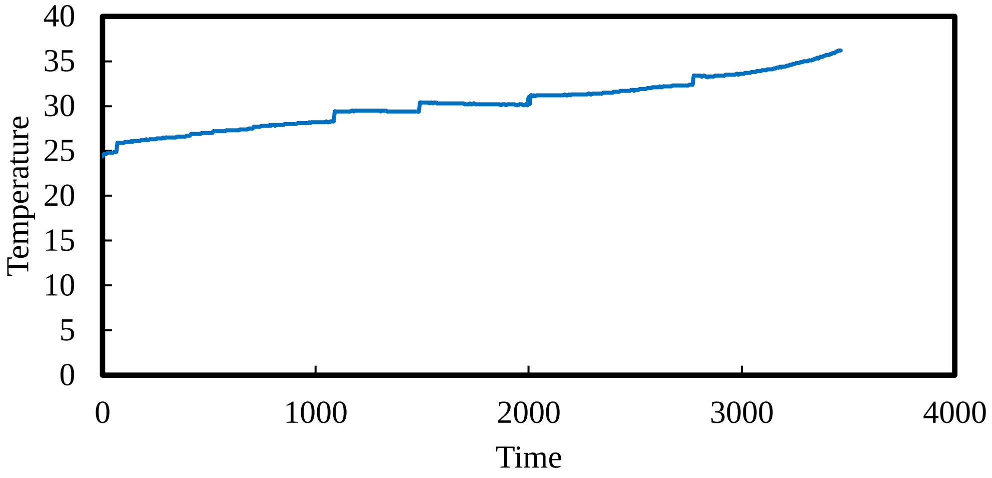

Fig 11 Grapgh of cell temperature versus time for 1C loading conditions.

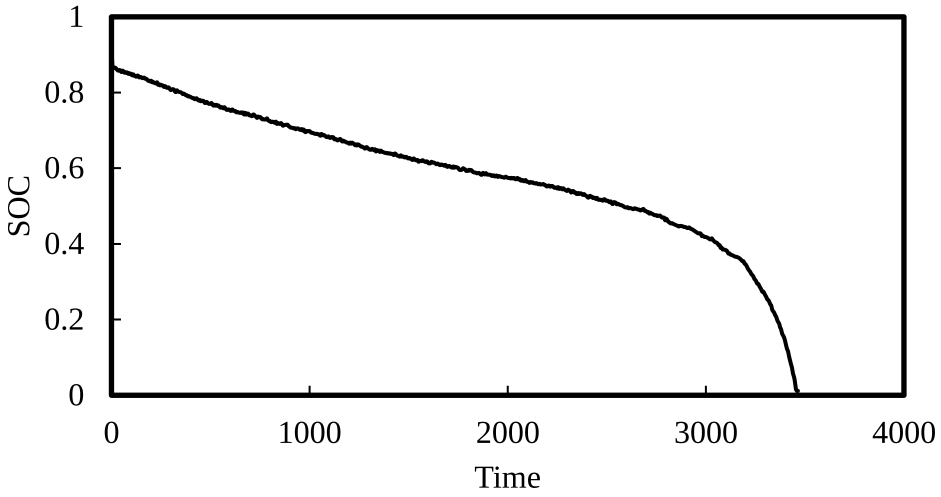

Fig 12 Grapgh of SOC versus time for 1C loading conditions.

4. Conclusion

The implementation of a wireless Battery Management System (BMS) for the purpose of estimating State of Charge (SOC) has demonstrated considerable potential in improving the surveillance and control of battery systems. The utilization of wireless communication facilitates the acquisition and transmission of data in real-time, thereby enabling the estimation of state of charge (SOC) with precision and promptness. The wireless Battery Management System (BMS) enables effortless incorporation with electric vehicles and other battery-operated applications, offering significant observations regarding the energy status and operational efficiency of the battery. The experimental results indicate that the cell temperature during the 1C discharge rate is higher compared to the 0.5C discharge rate. This can be explained by several factors, including increased current demand, higher resistive losses, limited time for heat dissipation, and potential efficiency losses. The evaluation of our wireless Battery Management System (BMS) was conducted using comprehensive simulation and analysis techniques, with a specific emphasis on critical performance metrics including State of Charge (SoC) estimation and fault detection.

Declarations:

- The Authors would like to declare there are conflict of interests.
- No funding has been received for the research work.

Data Availability Statement:

The data that support the findings of this study are available from the corresponding author, [*Ganesh S. Lohar*], upon reasonable request.

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