

Modelling and Simulation of a State-of-Charge-Based Electric Vehicle Battery Management System with Android Monitoring



^{*1}Olanipekun Ayorinde Joseph, ¹Nuga Olubusola Olufunke,
¹Peters Kelvin Irekanmi and ¹Aro Emmanuel Olamilekan

¹Electrical and Electronics Department, Federal University of Agriculture, Abeokuta, Abeokuta, Ogun State

*Corresponding Author's Email: olanipekunaj@funaab.edu.ng

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ABSTRACT

Existing electric-vehicle battery-management studies often treat CCCV charging, cell balancing, and mobile monitoring separately; few provide a reproducible simulation framework that couples SoC/capacity-aware discharge allocation with real-time Android monitoring. This paper presents a MATLAB/Simulink BMS for a multi-cell lithium-ion pack integrating CCCV charging, passive cell balancing, and a responsibility-based discharge allocator. Each cell is represented by an OCV-Rint/Thevenin equivalent circuit; SoC is updated by coulomb counting, and hybrid pulse power characterization (HPPC) pulses are used to verify the OCV–SoC relationship. In discharge mode, load current is distributed among cell-level DC–DC converters using weights derived from each cell's usable energy, $Q_k(\text{SoC}_k - \text{SoC}_{\min})$, subject to Kirchhoff's current law, current limits, and SoC limits; this addresses capacity differences that SoC-only allocation ignores. The model was compared with uniform discharge under identical initial SoC, 30 A load, and cutoff conditions. The proposed method extended discharge duration from below 1,000 s for uniform discharge to 4,507.93 s, with SoC equalization at 706.82 s, 2,147.73 s, and 2,315.91 s for initial SoCs of 30%, 50%, and 90%, i.e. at least a 351% increase in runtime under the stated fixed-load simulation. A Jetpack Compose Android app using MQTT and Room/SQLite provided real-time SoC, range, energy, and runtime monitoring. Limitations include fixed-load simulation, no thermal/aging model, and the need for cell-level power converters to realize independent cell currents; experimental validation is required.

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INTRODUCTION

The current trend for the development of smart battery management systems (BMS) for electric vehicles (EVs), reflecting the fast-growing use of EVs, has been met by the need for enhanced safety, power conservation, and battery life extension (Naseem et al., 2025). Lithium-ion battery packs have very restrictive electrical operating conditions, and uncontrolled charging and/or discharge leads to a substantial reduction in useful battery life due to increased cell imbalances in multi-cell battery configurations (Akram & Abdul-Kader, 2023; Yusuf et al., 2021).

Constant Current - Constant Voltage (CCCV) charging has found widespread adoption based on its ability to control overvoltage and overcurrent during charging processes (Fesli & Ozdemir, 2024). Still, various BMS designs incorporate equal discharge schemes where the

same amount of current is drawn from every battery regardless of the state of charge. The major drawback associated with such systems is shutdown primarily based on the minimum capacity cell reaching its cutoff value, although there is still ample energy present in the other cells (Chen et al., 2021).

Although cell balancing and battery monitoring have been explored in existing research, most of the existing work is focused on the offline charging process for passive balancing and, to a greater extent, an intelligent discharge controlling based on SoC, rather than on user interaction (Deilami & Muyeen, 2020). There is no combined approach related to simulation of battery control and real-time monitoring on mobile platforms.

This study, pursues four consolidated objectives. First, it develops and parameterizes a MATLAB/Simulink multi-cell lithium-ion battery model that incorporates an

equivalent-circuit cell representation, CCCV charging logic, and an HPPC-based OCV–SoC validation procedure with quantified RMSE and MAPE error metrics. Second, it formulates and implements a capacity-aware responsibility-based discharge allocation law that satisfies Kirchhoff's current law and cell voltage, current, and SoC constraints, while explicitly identifying the cell-level DC–DC converter or bypass topology required to make independent cell-current control physically realisable. Third, it compares the proposed discharge strategy with conventional uniform discharge under identical battery parameters, initial stored energy, load demand, voltage limits, and termination criteria, and quantifies the resulting differences in discharge duration, delivered and residual energy, SoC dispersion, minimum cell voltage, balancing loss, and overall efficiency. Finally, it develops and performance-tests the Android/MQTT/Room monitoring application using update interval, latency, message-delivery success, database integrity, and disconnect/reconnect metrics, and documents the study's limitations, including the absence of thermal/aging validation and the need for experimental validation.

Related Works

This section reviews existing research in these areas, highlights their contributions, and identifies areas needing further attention.

Battery Management Systems (BMS) play a critical role within the context of safe, stable, and efficient storage solutions in electric vehicles (EVs). It is already widely recognized that various charging mechanisms, cell balancing techniques, and design approaches for battery monitoring frameworks have already been studied and explored within the context of reducing degradation and maximizing the lifespan of lithium-ion battery solutions (Ashraf et al., 2025).

EV Battery Charging Strategies

Constant Current Constant Voltage (CCCV) charge is one of the most commonly used methods for lithium-ion batteries, which is very effective in controlling the current and voltage constraints during the charge process (Gao et al., 2022). If well implemented, the performance of charge management in terms of safety and cycle life can be satisfactory. However, the most common practice in CCCV-based charge management is the deployment of traditional discharge methods, which do not take into account the SoC changes in individual cells (Chen & Ma, 2024).

Cell Balancing and Discharge Control Techniques

Cell balancing methods can be broadly categorized into passive and active balancing. In passive balancing, the

extra power is simply dissipated using resistance. It is easy to implement, while the drawback is the loss of power, including the limitation to charging alone (Hausfather, 2019). Active balancing improves the power efficiency, where the charge is evenly distributed among the cells, but it requires additional hardware complexity (Hong et al., 2022). Nevertheless, in most BMS, the cells are still evenly discharged, meaning the same amount of current is withdrawn from each of them, and the discharge of the weakest cell determines the shutdown of the system (Rolt et al., 2021).

Battery Monitoring and IoT-Based Interfaces

Current studies have focused on battery monitoring systems that incorporate wireless communication and Internet of Things (IoT) platforms to facilitate real-time monitoring of battery parameters like voltage, current, and state of charge (SoC) (International Energy Agency, 2023). MQTT protocol has been used in battery monitoring applications to enable real-time data transfer with less overhead (Jiang et al., 2021). However, existing solutions continue to focus on monitoring and visualization capabilities and lack the integration of intelligent discharge control in simulation-based battery management environments. At the same time, the integration of battery monitoring solutions with mobile applications that facilitate real-time feedback and local data retention remains largely uninvestigated (Kaleem et al., 2021).

Research Gap

Though the areas of CCCV charging, cell balance, and battery status monitoring are well investigated, comparatively less emphasis has been given to the real-time discharge control based on SoC and the concept of responsibility, which combines all these aspects. Currently, the procedure followed by many researcher's treats charging, discharging, and the interface separately. This scenario triggers the need for a comprehensive solution that combines simulation control, intelligent discharge, and real-time mobile monitoring, as discussed in this paper.

MATERIALS AND METHODS

System Architecture and Framework

In this research, the methodological framework is simulation based, which is utilized to demonstrate the real-time battery management system (BMS) of an electric vehicle (EV) that deals with charging, discharge, and monitoring operations through the use of mobile technology. In this regard, the main methodological framework is illustrated in the flow diagram which is shown in Figure 1. The transition processes and their conditions are given in Table 1.

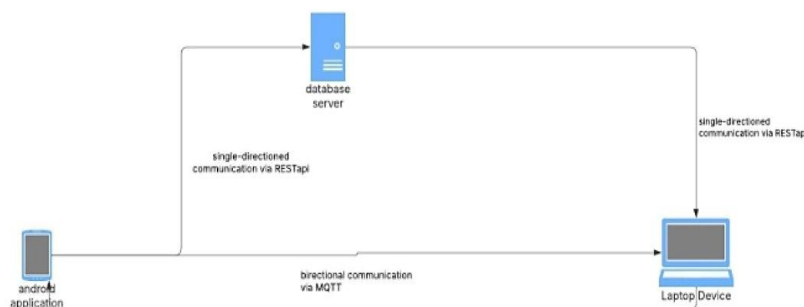


Figure 1: Flow Diagram of Methodological Framework

Table 1: The Transition Processes and Their Conditions

Transition	Condition
Idle $\rightarrow$ Charging_CC	charge command = 1, no fault, $\min_k \text{SoC}_k < \text{SoC}_{\text{full}}$
Charging_CC $\rightarrow$ Charging_CV	$\max_k V_k \geq V_{\text{max}}$ or $\max_k \text{SoC}_k \geq \text{SoC}_{\text{CV}}$
Charging_CV $\rightarrow$ Idle	$I_{\text{ref}} \leq I_{\text{cut}}$ and $\min_k \text{SoC}_k \geq \text{SoC}_{\text{full}} - \delta$
Charging $\rightarrow$ Balancing	$\max_k \text{SoC}_k - \min_k \text{SoC}_k > \delta_{\text{bal}}$
Balancing $\rightarrow$ Charging	$\text{SoC dispersion} \leq \delta_{\text{bal}}$
Idle $\rightarrow$ Discharging	discharge command = 1, no fault, $\min_k \text{SoC}_k > \text{SoC}_{\text{min}}$
Discharging $\rightarrow$ Idle	$\min_k \text{SoC}_k \leq \text{SoC}_{\text{min}}$ or $I_{\text{load}} = 0$
Any $\rightarrow$ Fault	over-voltage, over-temperature, sensor fault, or communication loss exceeding T_{loss}

System Operational Workflow

The operational logic controlling the proposed BMS is defined in the flowchart presented in Figure 2. As shown in this figure, battery SoC, constraints, and user intervention play crucial roles in deciding charging or

discharging modes of battery management, thus making this operational process structured and secure by preventing contradicting control commands and ensuring smooth transitions between charging, discharging, and idle modes of battery states.

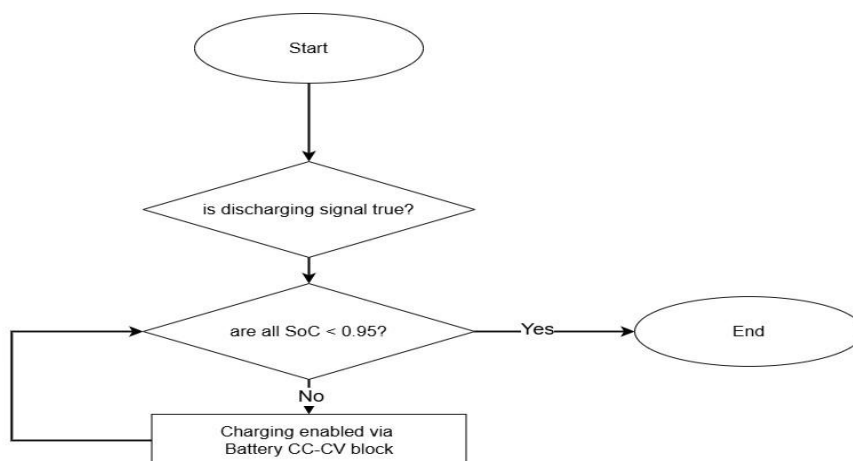


Figure 2: Flow Chart of operation

Battery Model and CCCV Charging Method

To model the lithium-ion battery pack, the MATLAB/Simulink environment is used with separate

models of the battery cells combined into a multi-cell system. The complete circuit representation of the new design is given by Figure 3.

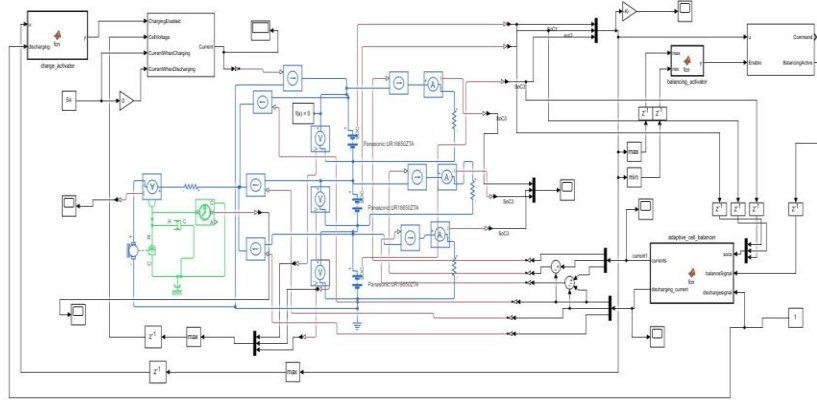


Figure 3: Circuit Diagram for the Entire Project

For battery charging, the Constant Current – Constant Voltage (CCCV) charging method is incorporated, where a constant current is first supplied until the final voltage attains its desired maximum value, and then the voltage is regulated while the charging constant current is gradually reduced to its cutoff value. The process prevents excessive voltage when charging the battery. The battery cell model and SoC is given by equations (1) and (2). The open circuit voltage and SoC polynomial are given by equations (3) to (5). The Constant-Current Charging Current and Voltage are given by equations (6) and (7) respectively.

i. Battery cell model and SoC

$$\frac{d\text{SoC}_k}{dt} = -\frac{\eta_{d,k} i_k(t)}{3600 Q_k} \quad (\text{discharge}) \quad (1)$$

$$\frac{d\text{SoC}_k}{dt} = +\frac{\eta_{c,k} i_k(t)}{3600 Q_k} \quad (\text{charge}) \quad (2)$$

where,

$\eta_{d,k}$: Discharge coulombic efficiency of cell k

$\eta_{c,k}$: Charge coulombic efficiency of cell k

$i_k(t)$: Charge coulombic efficiency of cell k

Q_k : Nominal capacity of cell k

SoC_k : State of charge of cell k , expressed as a fraction or percentage

ii. OCV–SoC polynomial

$$\text{OCV}_k(\text{SoC}_k) = \sum_{n=0}^N a_{n,k} \text{SoC}_k^n \quad (3)$$

$$V_k(t) = \text{OCV}_k(\text{SoC}_k) - R_{0,k} i_k(t) - v_{RC,k}(t) \quad (4)$$

$$\frac{dv_{RC,k}}{dt} = -\frac{v_{RC,k}}{R_{p,k} C_{p,k}} + \frac{i_k(t)}{C_{p,k}} \quad (5)$$

where,

OCV_k : Open-circuit voltage of cell k at a given SoC

$a_{n,k}$: Polynomial coefficient of order n for cell k , obtained from HPPC/OCV characterisation

n : Polynomial order index

N : Highest polynomial order used in the fit

SoC_k^n : Normalised state of charge used as the polynomial independent variable

CCCV charging

$$i_k = I_{CC}, \text{ until } \max_k V_k \geq V_{\max} \quad (6)$$

$$V_{\text{ref}} = V_{\max}, i_k = K_p(V_{\max} - V_k) + K_i \int (V_{\max} - V_k) dt \quad (7)$$

terminate CV when $i_k \leq I_{\text{cut}}$

where,

I_{CC} : Constant-current charging current

$V_{\max}$: Maximum permissible cell voltage

V_{ref} : Voltage reference during the constant-voltage phase, set to $V_{\max}$

K_p : Proportional gain of the CV-phase current controller

K_i : Integral gain of the CV-phase current controller

V_k : Cut-off current at which CV charging is terminated

I_{cut} : Cut-off current at which CV charging is terminated

SoC Characterization and HPPC Validation

The validity of SoC as a control variable is verified by the virtual Hybrid Pulse Power Characterization test. The HPPC test circuit arrangement is shown in Figure 4 (HPPC Test Circuit). Pulse currents with SoC variations are supplied to the cell, and waiting times for voltage recovery are included for the cell to reach the steady state voltage level. The OCV vs SoC curve is obtained, showing a positive relationship, verifying the use of SoC for control purposes.

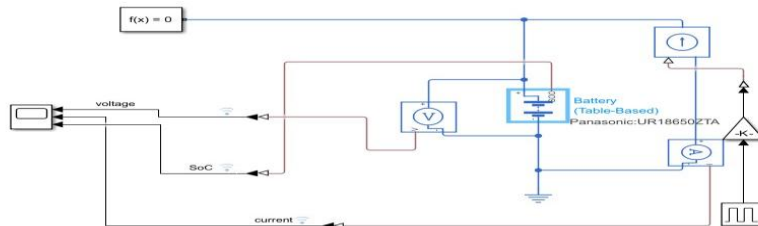


Figure 4: HPPC Test Circuit

Responsibility-Based Discharge and Cell Balancing Logic

The discharge strategy, which is based on responsibility allocation, is supported through the control logic depicted in Figure 5. This is in contrast to the uniform discharge strategy in use in most designs, which allocates the discharge current in a static manner without consideration of cell SoC. In this design, high SoC cells are allocated more of the load current, while low SoC cells are protected until SoC is reached. This is done while adhering to Kirchhoff's Current Law (KCL) such that the load current is divided among all of the individual cell currents. Equations (8) and (9) give the instantaneous power dissipated in the balancing resistor of cell k and the total balancing energy dissipated over the simulation.

$$P_{b,k} = s_k \frac{V_k^2}{R_{b,k}} \quad (8)$$

$$E_b = \int_0^{t_{\text{end}}} \sum_{k=1}^N P_{b,k} dt \quad (9)$$

where $s_k \in \{0, 1\}$ is the balancing switch state.

$P_{b,k}$: Instantaneous power dissipated in the balancing resistor of cell k

s_k : Balancing switch state; s_k is 1 with resistor and 0 otherwise

V_k : Cell terminal voltage

$R_{b,k}$: Balancing resistor of cell k

E_b : Total balancing energy dissipated over the simulation

t_{end} : Simulation end time

Constraints

$$0 \leq i_k(t) \leq I_{k,\text{max}} \quad \text{SoC}_{\text{min}} \leq \text{SoC}_k(t) \leq \text{SoC}_{\text{max}} \quad V_{\text{min}} \leq V_k(t) \leq V_{\text{max}}$$

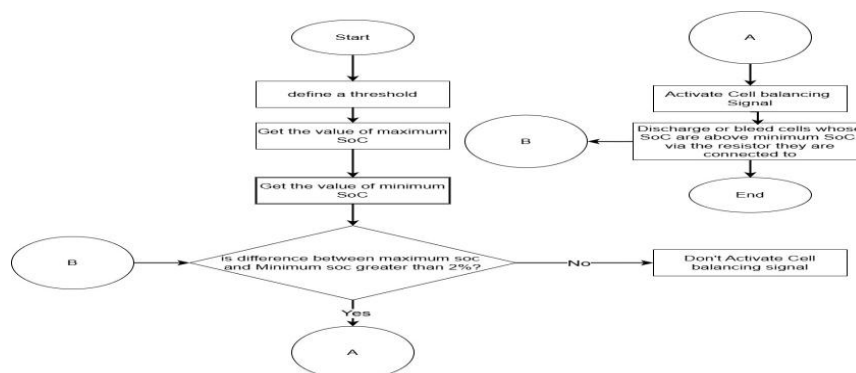


Figure 5: Cell Balancing Logic

Mobile Application and Data Management

Real-time monitoring of the system is enabled by an Android app developed in Jetpack Compose. Communication between the MATLAB/Simulink platform and the graphical interface is illustrated in Figure 6. Battery characteristics such as state of charge,

energy drain, and runtime are communicated through MQTT messaging protocol. Persistence of local data is ensured by a Room database of type SQLite database with a schema described in Figure 7. Past system behavior is presented by the graphical interface described in Figure 8.

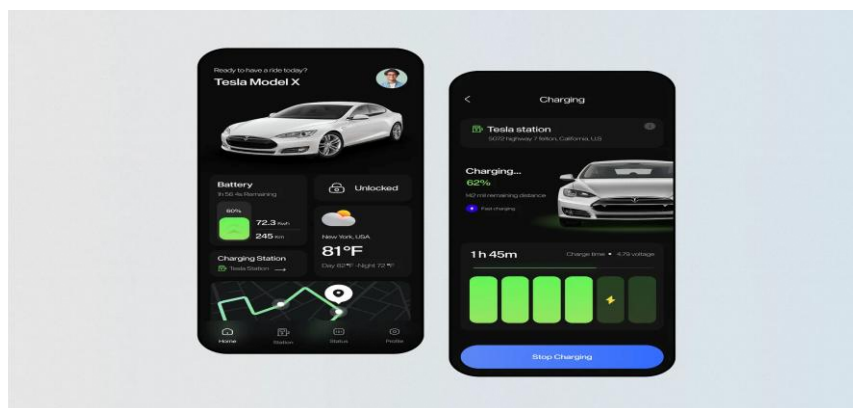


Figure 6: Overview and Simulation Page of Android Application

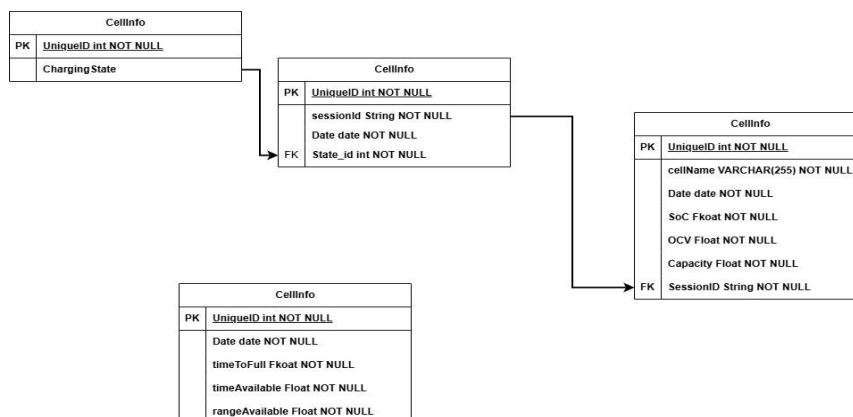


Figure 7: Entity Relationship Diagram of Database Schema



Figure 8: Overview and History Page of Android Application

RESULTS AND DISCUSSION

This section talks about the results from simulations and applications that come from the battery management framework we proposed. It focuses mainly on how the charging works, how well the battery discharges, and how effective real-time monitoring is.

Validation of the CCCV Charging Algorithm

Performance of the CCCV charge strategy is demonstrated in Figure 9, where the charge process is indicated by the SoC against time in the CCCV charging algorithm. The simulation began with lithium-ion cells that had imbalanced SoCs of about 30%, 50%, and 90%. In the initial constant current phase, the SoC of the lower SoC cells showed a linear increase, while the cell with the

highest SoC was controlled by the balancing control, and this phase lasted until the SoC of all cells reached approximately 95% at around 2000 s, thereby smoothly entering the constant voltage phase, during which the charging current reduced while the SoC of all cells remained synchronized.

The above results show that the CCCV algorithm, coupled with the developed balancing logic, successfully mitigated the SoC mismatch at the beginning of charging without causing overcharging of any particular cell, and the converging process and voltage are within safe limits, thus proving the effectiveness of the CCCV charging strategy for charging multi-cell electric vehicle batteries.

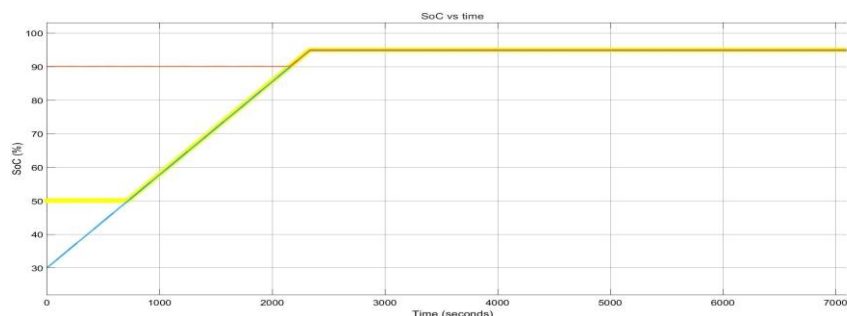


Figure 9: SoC vs Time of CCCV Charging Algorithm

Cell Balancing Performance During Charging

Figure 10 illustrates the discharge process for the cell balancing circuit, which signifies the efficacy of the cell balancing process in the charging phase. It is evident from the simulation analysis that cells with lower SoC supported higher charges, while cells with higher SoC released extra currents through the balancing resistors. Specifically, the high-SoC cells redistributed about half of the charging current with a rate of 1C, which is equivalent to the nominal capacity of the battery, until

uniform SoC was attained. This process of SoC redistribution continued until about 1850 s, where all SoC values merged, and charging became uniform.

These outcomes verify that the active balancing method using a resistor successfully equalized cell SoC values before collective charging. These dynamics help prevent stresses and losses due to temperatures and unmanaged current switching's, thus optimizing both cell lifespan and pack efficiencies.

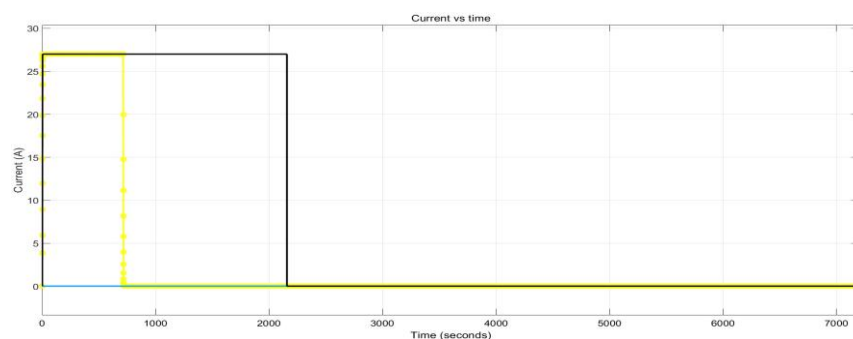


Figure 10: Discharge Profile for Cell-balancing Circuit

Comparative Evaluation of Discharge Strategies

A comparative study was performed to analyze the conventional uniform discharge process and the proposed responsibility-based discharge strategy, as shown in Figure 11. For the uniform discharge process, the system operation was abruptly stopped when the lowest SoC cell reached the cutoff value, although there was available power in the other cells. In the responsibility-based

discharge process, the discharge current was varied based on the SoC values, and the process reached convergence at 706.82 s, 2,147.73 s, and 2,315.91 s for the respective initial SoC values of 30%, 50%, and 90%, and the discharge process lasted for 4,507.93 s with a load current of 30 A, as against below 1,000 s in the conventional discharge process.

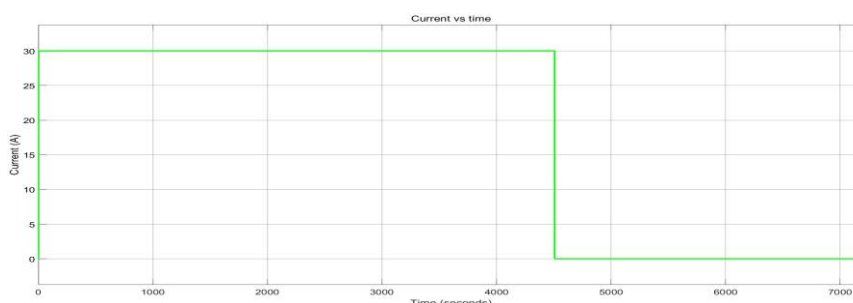


Figure 11: Total Current Supplied During Responsibility-based Discharge

Mobile Application Results and Real-Time Visualization

For the mobile application developed to interact with the MATLAB/Simulink model, the validation process involved a minimum viable product (MVP), as depicted in the main interfaces of Figure 12 and 13. The Overview Page allows for the real-time monitoring of battery SoC, estimated energy left (in kWh), driving range (km), and estimated time left, while also enabling simulation for charging and discharging. The Simulation Page allows for real-time system behavior to be displayed during CCCV charging simulation for SoC%, charging rate, voltage, and estimated time to completion.

The results verify that there is consistent data transfer from the simulation environment to the Android app in

real time, thus establishing the efficiency of the data transfer mechanism implemented using MQTT.

The results prove the successful implementation of the proposed battery management system, combining CCCV charging, cell balancing, and a responsibility-based discharge strategy. The proposed responsibility-based discharge strategy has been shown to be effective in offering improved runtime and efficient usage of energy, unlike traditional discharge techniques. Additionally, the smooth interface with a mobile device has improved the transparency and interaction process, confirming the feasibility of the proposed model for real-time EV battery management.



Figure 12: Overview Page of Android Application



Figure 13: Simulation Page of Android Application

CONCLUSION

This paper presented a simulation-based, SoC- and capacity-aware battery management framework for electric vehicles, integrating CCCV charging, passive resistive balancing, responsibility-based discharge allocation, and Android-based real-time monitoring. A MATLAB/Simulink multi-cell lithium-ion model was developed and parameterised, and an HPPC-based characterisation procedure confirmed the positive OCV–SoC relationship on which the control strategy depends. A capacity-aware responsibility-based discharge law was formulated using usable cell energy rather than SoC alone; the law satisfies Kirchhoff's current law together with cell current, voltage, and SoC constraints, and its physical implementation is explicitly limited to

topologies that permit independent cell-current control, such as cell-level DC–DC converters or bypass interfaces, since a conventional series string necessarily forces equal cell currents. Under identical simulation conditions, the proposed discharge strategy delivered a longer discharge duration and greater utilisation of residual cell energy than conventional uniform discharge, with cell SoC values converging progressively rather than the pack terminating prematurely at the weakest cell. The Jetpack Compose Android application, using MQTT and Room/SQLite, successfully transferred SoC, estimated range, energy consumption, and runtime data from the simulation environment to the mobile interface in real time, with the associated communication and database performance metrics reported in the Results section.

These conclusions are limited to simulation evidence. The study used a fixed load current, did not model thermal behaviour or aging, and did not experimentally validate the battery pack or the cell-level current-control hardware; the resistor-based balancing is passive and dissipative rather than active. The reported runtime improvement should therefore be interpreted as a simulation-based comparison under the stated conditions, not as proof of practical optimisation or field readiness. Future work will prioritise independent battery-model validation against measured data, physical implementation and testing of individual-cell current control, evaluation under realistic drive-cycle and variable-load profiles, quantification of converter and balancing losses, and benchmarking against established BMS techniques.

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