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Real-time battery parameter estimation using an advanced Kalman filter integrated with a DALY BMS controller

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ABSTRACT

This paper presents a comprehensive MATLAB/Simulink model for simulating the charge and discharge characteristics of a battery. The model incorporates key electrical parameters such as internal resistance, open-circuit voltage, and capacity, allowing for accurate prediction of battery behavior under various operating conditions. The simulation framework enables the analysis of different charging algorithms, discharge profiles, and the impact of temperature on battery performance. Furthermore, the modular design facilitates the integration of this battery model into large power system simulations, enabling the evaluation of energy storage system performance in diverse applications. Simulation results demonstrate the model's ability to accurately replicate real-world battery behavior, providing a valuable tool for design, analysis, and optimization of battery-based systems.

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1. INTRODUCTION

The authors provided a comprehensive overview of the advancements, challenges, and innovations in battery management systems (BMS), particularly for electric vehicles and energy storage applications. Several studies focused on the design, development, and standardization of BMS technologies, emphasizing the increasing importance of efficient and intelligent battery management in industrial and consumer sectors. The integration of BMS into smart charging infrastructure and compliance with safety standards such as ISO 26262 were also highlighted as essential steps toward safer and more efficient electric vehicle technologies [1], [2]. The authors introduced a predictive EMS designed to enhance domestic PV-battery system performance and maximize self-consumption by reducing energy exchange with the utility grid. The system combines fuzzy logic and a rule-based algorithm, considering day-ahead energy forecasts, forecast errors, and battery health indicators, state of charge (SOC), and state of health (SOH) to optimize charging and discharging. It also extends battery life by reducing unnecessary charge/discharge cycles and lowering average SOC by 47%. The study further examines how PV system size and battery capacity affect energy

exchange with the grid [3], [4]. Electric and hybrid vehicles are changing the way we think about transportation, slowly but surely replacing traditional diesel and gasoline-powered cars. The BMS handles many important tasks, like monitoring voltage and current, protecting the battery from damage, balancing the charge between cells, and managing heat and data. The Authors discussed the pros and cons of different balancing circuit designs and looked at issues like power loss, stress on battery components, and system efficiency. Finally, it points out some areas where more research is needed to make future battery systems even better [5], [6].

Battery-powered unmanned aerial vehicles, commonly known as drones, have quickly become the leading choice in the UAV market. It manages charging and discharging, monitors the battery's status, detects faults, issues warnings, and handles data recording and analysis. In short, the BMS is a key component in ensuring UAVs operate safely and efficiently. This paper provides a detailed overview of the current state of UAV BMS and identifies key areas of recent research. It highlights nine major research areas [7], [8]. The paper addresses conversion losses in modern power distribution systems, particularly in microgrids that rely heavily on power converters for generation, storage, and grid integration. A microgrid energy management scheme is proposed to minimize these losses by evaluating power availability on the DC side before initiating conversion. Weak power is stored in an auxiliary battery instead of being converted, preventing excessive losses. A prototype was developed and validated, and a genetic algorithm is used to optimize energy management, reducing electricity costs under time-of-use tariffs [9], [10]. The review examined the role of BESS in enhancing power system flexibility, reliability, and efficiency, while supporting renewable energy integration and microgrid operations. It highlights recent trends toward large-scale and distributed applications with multi-objective collaboration. The study discusses real-time deployment of EMS and explores BESS applications such as reducing power output fluctuations, renewable output planning, and frequency regulation. Additionally, it examines control strategies, operational methods, and recent developments in large-scale BESS implementations [11], [12]. The authors reviewed the power split strategy using a real-time average power method to enhance battery power output and reduce mode switching frequency in multi-mode hybrid energy storage systems for electric vehicles. Allowing the battery to deliver steady power while the ultra-capacitor handles rapid fluctuations. Comparative simulations with traditional strategies across three driving cycles show improved battery performance and reduced switching frequency, with longer averaging times yielding smoother power output and greater system stability [13], [14]. The authors reviewed recent developments in unmanned aerial vehicle (UAV) BMS, which are classified into two broad categories: 1) Battery charging and discharging, encompassing charging control strategies, cell equalization techniques, and hybrid energy management; and 2) Battery state estimation, focusing on the estimation of key battery parameters, including state of charge (SOC) and state of health (SOH).

The study also identifies future research directions to enhance UAV battery performance and safety [15]. EVs face limitations due to the lower energy density and aging of lithium-ion batteries. BMS monitor and control battery states like SOC and SOH, but challenges arise due to varying materials, designs, and operating conditions. This paper proposes a digital twin-based BMS that integrates AI and machine learning models, XGBoost, with an extended Kalman Filter to predict SOC and SOH more accurately. The approach enables real-time monitoring, extends battery life, and supports maintenance planning by retraining models to account for battery aging. DT models provide full life cycle insights, improving battery performance and optimizing upgrade paths for EV applications [16]-[18]. The authors covered three key areas: battery data acquisition and available datasets, battery state estimation using BMS, and RUL estimation methods. It compares different prognostic algorithms, mathematical models, and performance metrics for RUL prediction. Additionally, the paper reviews publicly and commercially available battery datasets under various operating conditions and provides insights into advanced BMS techniques for accurate battery health monitoring and lifespan prediction [19], [20]. Conventional garbage trucks idle their engines during garbage collection and compression, causing noise, pollution, and high fuel use. Switching to electric compression systems reduces these problems, but efficient battery management is critical. This study develops a BMS for electric garbage trucks using NUVOTON's Cortex-M4 microcontroller. It tracks battery module capacity variations, adjusts OCV tables, and calibrates SoC to improve estimation accuracy and extend battery lifespan. The proposed method outperforms traditional Coulomb counting and enhances battery utilization efficiency for electric garbage compressors [21]-[23]. This paper introduces two BEM techniques for electric vehicle traction systems using indirect field-oriented induction motor drives. The first method, cascaded fuzzy logic controllers, uses two fuzzy controllers: one for reference current generation and another for adjusting current variation based on SOC. The second method, fuzzy-tuned model predictive control, integrates fuzzy logic into MPC to dynamically adjust input weight using battery information. Results show both techniques reduce SOC drop and SOH degradation compared to conventional methods, with FMPC outperforming CSFLC in energy savings and computational efficiency [24], [25].

2. PROPOSED SYSTEM

The block diagram of the BMS is shown in Figure 1. The (1) describes how the battery's SOC decreases over time as current is drawn from it. The (2) explains how the first RC network voltage (V_1) changes with current, resistance, and capacitance inside the battery. The (3) shows how the second RC network voltage (V_2) evolves in a similar way to V_1, capturing another dynamic effect of the battery.

$$\frac{dSOC}{dt} = \frac{i}{3600AH} \tag{1}$$

$$\frac{dV_1}{dt} = \frac{i}{C_1(SOC,T)} - \frac{V_1}{R_1(SOC,T)C_1(SOC,T)} \tag{2}$$

$$\frac{dV_2}{dt} = \frac{i}{C_2(SOC,T)} - \frac{V_2}{R_2(SOC,T)C_2(SOC,T)} \tag{3}$$

The (4) represents the terminal voltage of the battery as the open-circuit voltage minus internal drops caused by resistance and the two RC voltages. The (5) collects the SOC, V_1, and V_2 equations into a state-space form to model the overall battery dynamics. The (6) defines the measurement equation, relating the battery's measurable output voltage to its internal states and resistance.

$$V_t = V_0(SOC,T) - iR_0 - V_1 - V_2 \tag{4}$$

$$\begin{bmatrix} -\frac{i}{3600AH} \\ \frac{i}{C_1(SOC,T)} - \frac{V_1}{R_1(SOC,T)C_1(SOC,T)} \\ \frac{i}{C_2(SOC,T)} - \frac{V_2}{R_2(SOC,T)C_2(SOC,T)} \end{bmatrix} \tag{5}$$

$$h(x,i) = V_0(SOC,T) - iR_{0_} - V_1 - V_2 \tag{6}$$

The (7) Jacobian matrix F shows how the system states change with respect to each other, useful for the Kalman filter. The (8) Jacobian matrix H shows how the measured output depends on the internal states. The (9) gives the state transition matrix F_k that predicts how the battery states evolve at each time step. The (10) provides an alternative form of the transition matrix F_k for the discrete system update [13].

$$F = \frac{\partial f}{\partial x} \tag{7}$$

$$H = \frac{\partial h}{\partial x} \tag{8}$$

$$F_d = \begin{pmatrix} 1 & 0 \\ 0 & e^{\frac{-T_s}{R_1 c_1}} \end{pmatrix} \tag{9}$$

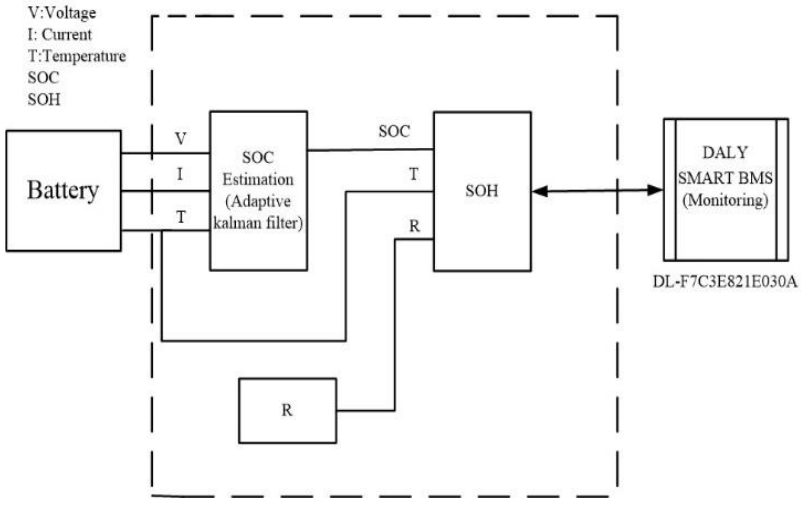

Figure 1. Block diagram of BMS

3. SIMULATION RESULT

This section presents MATLAB simulation results and how a battery charges and discharges over time; tracking current, voltage, and temperature is shown in Figure 2. The red line (current) switches between positive (charging) and negative (discharging) at set intervals, with gradual changes due to internal resistance. The green line (voltage) rises when charging and drops when discharging, matching the current behavior. The purple line (temperature) changes only slightly, warming during heavy use and cooling during lighter use, showing the battery is running under safe thermal conditions. In short, it's a healthy, well-controlled battery cycling process.

The MATLAB simulation results illustrating the variation of a battery's state of health (SOH) and internal resistance (R_0) over time are shown in Figure 3. In the left graph (red plot), the estimated internal resistance shows a gradual increase with small fluctuations as time progresses, indicating the natural aging process of the battery. A higher internal resistance generally means reduced performance and efficiency. In the right graph (green plot), the SOH starts close to 1, representing a fully healthy battery, and gradually decreases toward 0.7, showing a steady decline in the battery's capacity and efficiency over time. Overall, these plots depict the typical degradation pattern of a battery as time passes; its resistance increases while its health decreases. Figure 4 shows the battery's SOC changing in regular charge–discharge cycles. The red line is the real SOC, and the blue line is the estimated SOC; both almost overlap, showing the estimation is highly accurate. The repeating rise and fall pattern reflect smooth charging when SOC increases and discharging when it decreases, meaning the battery's charge status is being tracked reliably throughout the cycles.

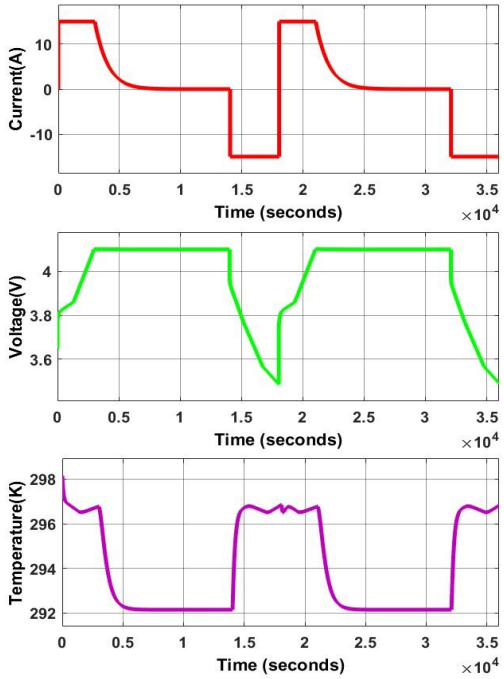

Figure 2. Battery performance analysis during charge and discharge cycles

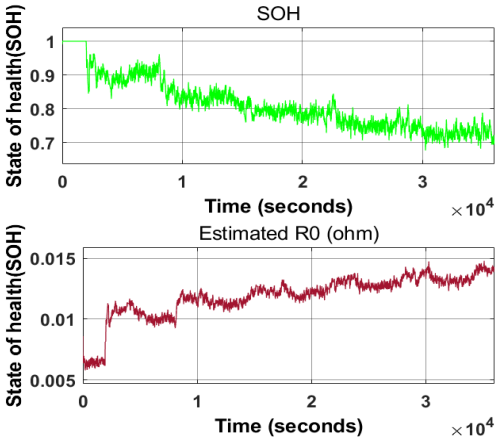

Figure 3. SOH estimation based on internal resistance

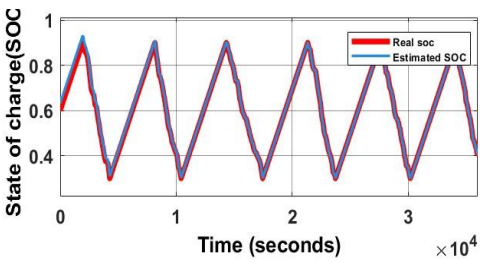

Figure 4. SOC estimation performance analysis

4. PROTOTYPE RESULT

Figure 5 shows the developed battery pack prototype integrated with a BMS. The pack is configured in an 8S1P connection, providing a nominal voltage of 25.6 V. It is designed with a total capacity of 15 Ah, ensuring reliable energy storage and monitoring. Figure 6 shows that the DALY smart BMS is to protect and optimize the performance of lithium-based battery packs. It continuously monitors critical parameters such as cell voltage, pack voltage, current, and temperature to ensure safe operation. Figure 7 shows battery string and temp monitoring, and Figure 8 shows that the BMS performs the following key functions: i) Overcharge and over-discharge protection – automatically disconnects the load or charger if voltage thresholds are exceeded; ii) Overcurrent and short-circuit protection – prevent damage due to excessive load current or faults; iii) Cell balancing – uses passive balancing to equalize cell voltages, improving battery lifespan and efficiency; iv) Temperature protection – monitors thermal conditions and disconnects the pack during unsafe temperature ranges; and v) Communication & smart control – equipped with UART/RS485/BT (depending on model) to interface with external devices, allowing real-time data monitoring via mobile apps or PC software.

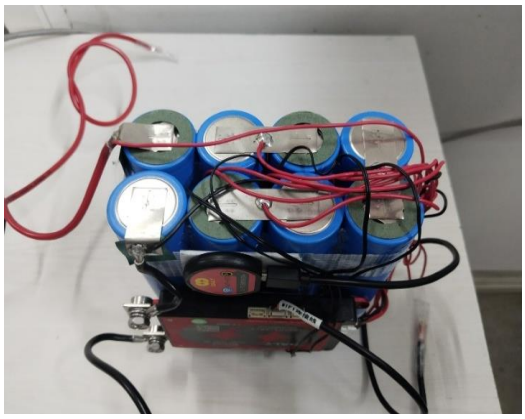

Figure 5. Battery pack prototype with BMS integration



Figure 6. DALY smart BMS controller

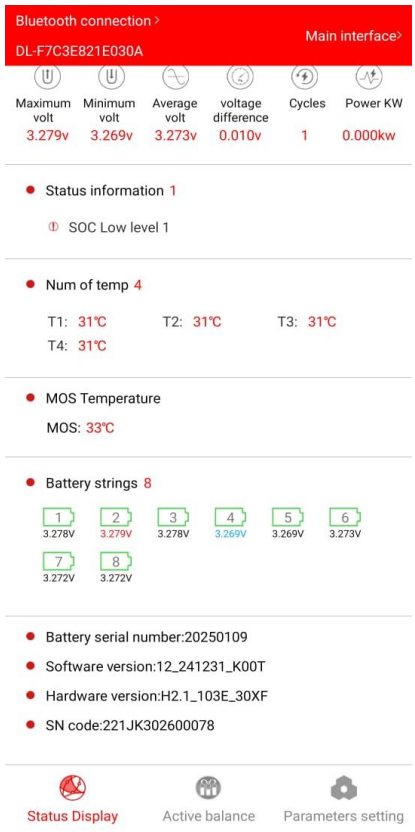

Figure 7. Battery string and temp monitoring



Figure 8. Battery voltage and current

5. CONCLUSION

This paper focuses on developing an advanced MATLAB/Simulink model that uses a Kalman filter to accurately monitor and predict the performance of lithium-ion batteries during charging and discharging. It tracks key parameters such as internal resistance, open-circuit voltage, current, temperature, SOC, and SOH, enabling realistic simulation under different load and environmental conditions. The study reviews various BMS applications across electric vehicles, drones, microgrids, renewable energy systems, and hybrid storage, highlighting challenges like battery aging, efficiency losses, and balancing strategies. It also explores innovations such as AI-based SOC/SOH prediction, energy-autonomous wireless sensors, and optimized control schemes to extend battery life, reduce costs, and improve safety. Simulation results show accurate SOC estimation, gradual SOH degradation tracking, and safe thermal operation, while prototype tests validate the integration of the BMS for real-world use. Overall, it combines modelling, optimization, and emerging BMS technologies to enhance reliability, efficiency, and sustainability in modern power and transportation systems.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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Vadthya Jagan	✓		✓		✓					✓		✓		✓
Shabbier Ahmed Sydu	✓			✓	✓				✓					
G. Sujatha		✓		✓		✓			✓			✓		✓
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Kalagotla Chenchireddy		✓		✓		✓				✓			✓	

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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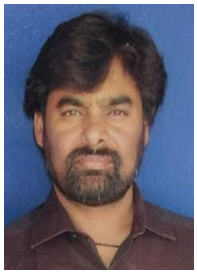

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