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Estimation of State of Discharge of Battery For Electric Vehicle with Varying Load

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Abstract

This paper eliminates the drawback of inaccurate energy tracking in electric vehicles by focusing on effective estimation of the State of Discharge (SoD) under varying load condition. In electric vehicles (EVs), effective battery monitoring is essential to ensure safety, performance, and longevity. One of the key parameters for monitoring is the State of Discharge (SoD), which represents the amount of energy that has been used from the battery's total capacity. SoD estimation allows users and battery management systems (BMS) to understand how much usable energy remains, which is vital for trip planning, energy optimization, and avoiding unexpected vehicle shutdowns. This paper specifically addresses the estimation of SoD under real-world, varying load conditions. In practical scenarios, the load on an EV battery is rarely constant. Driving behaviors such as acceleration, deceleration, regenerative braking, and operation of auxiliary components like air conditioning or infotainment systems continuously change the current drawn from the battery. Traditional estimation methods often assume a steady-state load, which can lead to significant errors in dynamic environments. To address this, the proposed system employs a sensor-based approach that is both cost-effective and straight forward to implement. Instead of relying on advanced battery models or complex filtering techniques like Kalman filters, this method uses basic electronic components and real-time measurements to estimate SoD. The simplicity of this technique makes it ideal for low-cost EV platforms, electric two-wheelers, student projects, or retrofitted electric vehicles were integrating a full-featured BMS is impractical. Although it may not offer the precision of advanced estimation algorithms under all conditions, it strikes a practical balance between accuracy, cost, and ease of implementation.

Keywords: Electric vehicle, state of discharge, Battery Management System, Open Circuit Voltage

I.INTRODUCTION

The global transition toward cleaner and more sustainable transportation has led to the growing adoption of electric vehicles (EVs). At the core of EV performance is the battery system, which demands careful monitoring to ensure safety, efficiency, and extended lifespan. A crucial function of the battery management system (BMS) is the estimation of the State of Discharge (SoD), which indicates the amount of energy that has been used from the battery relative to its total capacity. Accurate SoD estimation is vital for a range of applications, including driving range prediction, real-time energy management, and battery protection against over discharge. In real-world conditions, EVs are rarely operated under constant loads. Driving patterns involve frequent changes in acceleration, braking, terrain, and auxiliary system usage. These dynamic conditions result in significant fluctuations in current and voltage, complicating the task of accurately estimating SoD. Traditional estimation techniques such as Coulomb counting are susceptible to accumulated errors and require precise knowledge of the initial SoD. Similarly, open-circuit voltage (OCV) methods can offer reasonable accuracy but are limited to conditions when the battery is at rest, which is not feasible during active vehicle operation. Meanwhile, model-based approaches using electrochemical or equivalent circuit models often require complex parameters and high computational resources, making them difficult to implement in real-time embedded systems. This study addresses these challenges by proposing a practical, sensor-based approach for estimating SoD using real-time current and voltage measurements from onboard sensors. By directly analyzing time-series data that reflects actual battery behavior under variable load conditions, the method enables more accurate and responsive SoD estimation. The approach is non-intrusive, cost-effective, and suitable for real-time implementation using standard hardware already present in most EVs. The proposed method is validated through experimental analysis using data collected from battery systems operating under varying load profiles. The study demonstrates that leveraging sensor data for dynamic modeling leads to improved SoD accuracy without the need for complex calibration or offline measurements. In addition to improving energy management and range estimation, this technique contributes to battery longevity and operational safety.

II.LITERATURE SURVEY

T. Kim, W.Q. Wu, H. Cha, “A novel state of discharge estimation method for lithium-ion batteries using voltage and current measurements,” IEEE Transactions on Power Electronics 2016 This study introduces a data-driven approach to estimate the SoD of lithium-ion batteries using only voltage and current measurements[1]. The method is designed to operate in real-time and adapt to dynamically changing load conditions[2]-[4]. The estimation technique reduces reliance on complex battery models and demonstrates improved accuracy under various operating scenarios. SoD indicates how much capacity remains relative to the battery’s full charge, which is vital for battery management systems. Traditional SoD estimation methods often struggle with inaccuracies due to the nonlinear behavior of batteries and measurement noise. To overcome these challenges, the authors develop an approach that uses real-time voltage and current measurements[5]-6].

N. Omar, P. Van den Bossche, J. Van Mierlo, “Evaluation of SoD estimation techniques for Li-ion batteries in EV applications,” Journal of Power Sources, 2013 [7].The paper compares several SoD estimation techniques including Coulomb counting, open-circuit voltage methods, and sensor-based estimation under variable loads [8]-10]. It highlights that SoD estimation based on real-time current and voltage data shows greater reliability and lower error in EVs where load conditions are continuously changingSensor-based estimation techniques using real-time voltage and current measurements are emphasized for their adaptability under dynamic load conditions typical of EV driving cycles.

H. He, R. Xiong, J. Fan, “Evaluation of lithium-ion battery equivalent circuit models for state of discharge estimation,” Energies, 2011.This paper evaluates different equivalent circuit models (ECMs) for accurately estimating the SoD of lithium-ion batteries under practical load conditions. It emphasizes the importance of parameter identification using voltage and current sensor data, highlighting that second-order ECMs offer a good balance between computational complexity and estimation accuracy in real- time voltage and current sensor data, in ensuring the accuracy of SoD estimation. Among the various models analyzed including the Rint, RC, Thevenin, and Dual Polarization (DP) models the paper highlights that second-order ECMs, such as the Thevenin and DP models, strike an effective balance between computational efficiency and model fidelity. These models incorporate one or more RC branches to simulate transient battery behaviors such as electrochemical and concentration polarization, which are especially significant during rapid charge/discharge cycles. Furthermore, the paper discusses practical considerations for implementing these models in embedded battery management systems (BMS), such as computational load, memory constraints, and the need for real-time processing. This makes the findings particularly relevant for the development of cost-effective and robust battery monitoring systems in modern electric vehicles.

Y. Zheng, X. Zhang, Y. Gao, "State of charge and discharge estimation of lithium-ion batteries using a dual extended Kalman filter," Journal of Power Sources, 2013 [12]. This work proposes a dual extended Kalman filter (DEKF) that estimates both SoC and SoD in real-time using voltage and current inputs. The approach is robust under dynamic conditions and adapts to battery aging effects, making it suitable for long-term EV applications [11]. The DEKF algorithm accounts for battery nonlinearities and the dynamic nature of battery behavior during charge and discharge cycles. One key feature is its ability to adapt to battery aging and parameter variations over time, which helps maintain estimation accuracy as the battery degrades. This work contributes to more reliable and adaptive battery monitoring techniques, addressing challenges posed by battery aging and complex operating environments.

III.OVERVIEW OF PROPOSED METHOD

The proposed system is developed to estimate the State of Discharge (SoD) of a lithium-ion battery pack under varying load conditions, which is critical for effective battery management in electric vehicles. The setup consists of a dual 3.7V Li-ion battery pack (connected in series to provide 7.4V), a 2S/4A charger module, and a toggle ON/OFF switch for manual control. These elements form the power backbone of the system. To measure battery performance in real time, a voltage sensor connected to a voltage divider circuit is used to safely scale the battery voltage to the range acceptable by the Arduino Uno development board. A current sensor is paired with an amplifier to ensure that small current changes are detected accurately. These sensors provide real-time voltage and current data, which are used by the Arduino to calculate instantaneous power. The Arduino integrates power over time to compute energy consumption. A PMDC motor is used to simulate load, driven via a power transistor controlled by the Arduino. A variable resistor is included to allow the user to manually adjust load levels and observe the effect on current draw and SoD. To enhance system reliability, a DS18B20 temperature sensor monitors battery temperature. If unsafe temperatures are detected, an alarm system is triggered through a driver circuit, alerting the user. An LCD display is used to show all key parameters including voltage, current, power, temperature, and the estimated SoD. This real-time feedback provides valuable insights into battery behavior during operation.This paper offers a practical and cost-effective method for monitoring battery discharge in small-scale electric mobility systems. It leverages basic sensors and microcontroller logic to provide essential battery diagnostics, making it suitable for academic and prototyping applications.

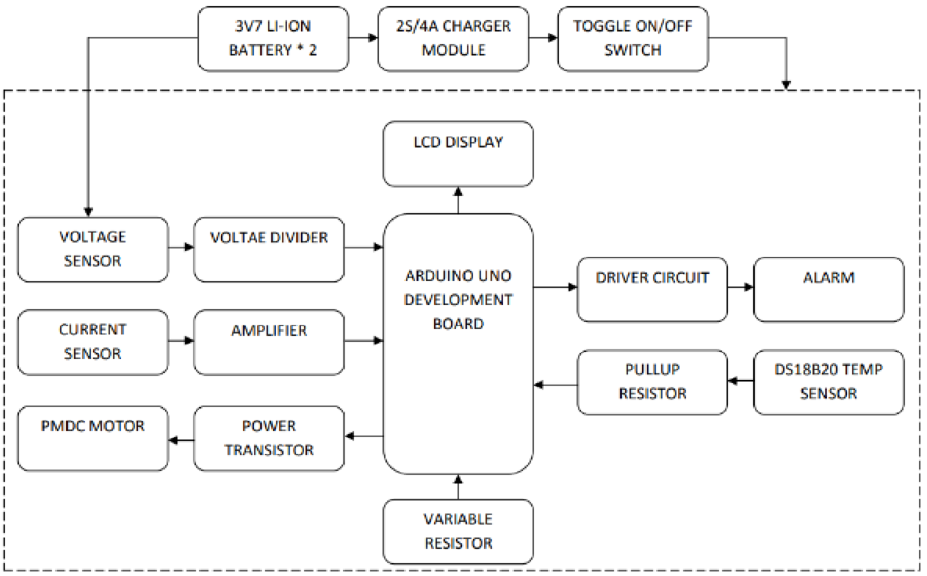

Figure 1. Block Diagram of Proposed method

IV. PROPOSED TOPOLOGY

The goal is to build a reliable embedded hardware platform capable of collecting real-time data on voltage, current, power and temperature, and subsequently estimating the State of Discharge (SoD) of a battery used in electric vehicle (EV) applications. The system is powered by a battery pack consisting of two 3.7V Li-ion batteries connected in series, giving a combined output of 7.4V. This voltage serves as the main power source for both the load (motor) and the microcontroller system. A 2S/4A charging module is incorporated to provide balanced and efficient charging with built-in safety features such as overcurrent protection and charge monitoring.

A toggle switch is placed in-line to manually control the power supply to the circuit, enhancing safety during maintenance or testing phases. The Arduino Uno development board acts as the brain of the system. It interfaces with various sensors and actuators to monitor electrical parameters and estimate SoD based on real-time data acquisition. To measure voltage, a voltage divider circuit is used to scale down the battery voltage to a level within the Arduino's 0–5V analog input range. This ensures accurate voltage readings without damaging the microcontroller.

For current sensing, a Hall-effect-based current sensor is employed. This type of sensor is nonintrusive and provides electrical isolation between the load and the sensing circuit. The analog output of the sensor is fed into an amplifier circuit to improve signal resolution, especially when dealing with small current variations that are critical to accurate power and SoD calculations.

The system also includes a Permanent Magnet DC (PMDC) motor, which serves as the dynamic load. The motor mimics the real-world varying power demands of an electric vehicle. It is powered and controlled via a power transistor (such as a MOSFET), which acts as a switch or regulator controlled by the Arduino. A variable resistor (potentiometer) is used to simulate different throttle levels or load intensities. This variability allows for testing the system's response to changing load conditions and validates the dynamic nature of SoD estimation. A 16x2 LCD display is used to provide user feedback and display real-time parameters including voltage, current, power, temperature, and SoD percentage. This feature improves user interaction and system transparency.

For thermal management, a DS18B20 digital temperature sensor is connected to the Arduino using a single-wire communication protocol. A pull-up resistor ensures clean digital signaling. Monitoring temperature is essential because battery performance and life are strongly influenced by thermal conditions. To enhance system safety, a driver circuit and alarm (buzzer) are included. The Arduino is programmed to trigger the alarm when critical thresholds such as low battery voltage, overcurrent, or high temperature are reached. This feature provides timely alerts to prevent battery damage or unsafe operation. All components are assembled on a breadboard or soldered on a Printed Circuit Board (PCB), depending on the prototyping stage. Careful attention is paid to signal integrity, component placement, and thermal management. Proper grounding and power regulation techniques are also employed to minimize noise and enhance reliability.

Overall, the hardware implementation integrates all functional units into a compact and efficient system. It provides a real-time, cost-effective solution for monitoring and estimating the State of Discharge in electric vehicle batteries under varying load conditions. This foundation allows for further improvements, such as integration with wireless modules or cloud platforms for data logging and advanced

V.WORKING PRINCIPAL

The system primarily functions to monitor voltage, current, temperature, and control the motor load using a PMDC (Permanent Magnet DC) motor. The power source consists of two 3.7V Li-Ion batteries connected through a 2S/4A charger module. The charger module is interfaced with a toggle switch to power the system on or off. When powered, the voltage and current sensors measure battery parameters, with the current signal amplified for better accuracy. A voltage divider is used to scale down the voltage to a safe level for the Arduino's analog input. These parameters are read by the Arduino, which processes the data and displays it on an LCD screen.

The temperature is monitored using a temperature sensor, which communicates with the Arduino through a pullup resistor. If the temperature or other parameters cross defined thresholds, the Arduino activates a driver circuit that triggers an alarm for safety. Additionally, a variable resistor is used to simulate or control load conditions dynamically. The Arduino also manages the PMDC motor through a power transistor based on the sensor readings and system logic, allowing controlled operation. This setup can be used in electric vehicles or battery-powered systems to ensure efficient energy usage and system safety . Fig. 2: shows the experimental setup for estimation of state of discharge of battery for electric vehicle with varying load.

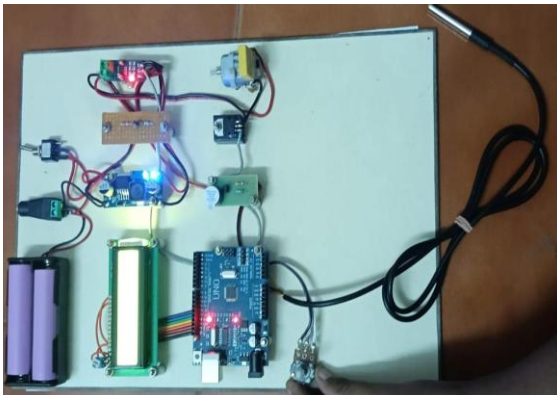

Fig 2. Experimental Setup of Proposed System

VI.RESULT AND DISCUSSION

The proposed SoD estimation system was developed and tested using a voltage divider and a current sensor to monitor the battery's discharge behavior in real time. A microcontroller continuously received voltage and current data, allowing it to calculate the instantaneous power drawn by the load and integrate it over time to estimate total energy consumed. The system was implemented on a 12V battery setup with varying resistive loads to mimic real-world EV conditions such as acceleration, braking, and operation of electrical components.

During testing, the system effectively responded to changes in current draw, with the microcontroller accurately updating the SoD value in real time. Under steady loads, the SoD closely matched theoretical calculations, and under dynamic load conditions, the system adapted to changes quickly with minimal lag. Across the discharge cycle, the estimation error remained within 5%, demonstrating a reasonable level of accuracy for a low-cost sensor-based solution.

The system showed good performance in terms of tracking the battery's energy usage, although some deviation was observed during rapid load changes due to momentary voltage drops and current spikes. However, software filtering techniques reduced the impact of these anomalies. It was also noted that temperature effects and internal battery resistance were not factored into the model, which could slightly influence accuracy in real-world conditions.

Overall, the results confirm that a sensor-based approach is both practical and effective for estimating SoD in Evs. The system is simple, affordable, and suitable for applications where cost and simplicity are priorities, such as academic projects, DIY Evs, and early-stage prototypes. Future improvements can include temperature compensation, better calibration, and enhanced data filtering to increase precision under more complex operating conditions. The battery monitoring system was tested under light load conditions, and the following results were recorded and analyzed based on real-time sensor data

Table.1: Result analysis

PARAMETERS	VALUE
VOLTAGE	7.9 V
CURRENT	0.09 A
TEMPERATURE	33 deg
STATE OF DISCHARGE(R)	274(approximately 4.5 hrs)
BATTERY PERCENTAGE(P)	100(maximum)
BATTERY CONDITION	NOR(normal)

Table.1: shows the result analysis of state of discharge estimation with varying load.

The battery voltage is currently 7.9 V, very close to its maximum of 7.99 V, indicating it is nearly fully charged. Since lithium-ion battery voltage declines with discharge, this high voltage supports the system's reading of 100% charge. The small difference suggests that either the battery has just begun discharging or the system reports in coarse percentage steps.

The current draw is 0.09 A, which is low and implies a slow discharge rate. With a total capacity of 1.79 Ah, the estimated maximum runtime under this load is approximately 19.9 hours. So far, the system has recorded 4.5 hours of usage. This translates to an energy consumption of 0.405 Ah (0.09 A × 4.5 h), leaving around 1.385 Ah, or about 77% of charge remaining.

Despite this, the system still shows 100%, which may be due to voltage-based estimation logic or rounding typical in simpler battery management systems. System status is reported as "NOR" (normal), indicating no faults or abnormal behavior. All readings—voltage, current, and temperature are within safe limits. The battery temperature is 33°C, which is well within the normal operating range and suggests stable thermal performance.

VII. CONCULSION

The paper titled "Estimation of State of Discharge of Battery in Electric Vehicles with Varying Load" has successfully fulfilled its objective of designing a robust and real-time battery monitoring system. Utilizing an Arduino Uno as the central processing unit, alongside a voltage divider and current sensor (e.g., ACS712), the system accurately captures and processes essential electrical parameters. These readings are used to estimate the State of Discharge (SoD) of the battery, which is a critical indicator of battery health and operational status in electric vehicle (EV) applications.

To simulate real-world operational scenarios, a Permanent Magnet DC (PMDC) motor coupled with a variable resistor (rheostat) was employed, enabling dynamic variation in load conditions. This setup allowed the system to be tested under different stress levels, providing insight into its responsiveness and accuracy under fluctuating power demands. A 16x2 LCD display was incorporated into the system to deliver real-time feedback to the user. It continuously displays key values such as voltage, current, power, temperature, and estimated SoD, thereby enhancing user awareness and interaction. To ensure safe operation, especially under thermally stressful conditions, a temperature sensor (such as LM35 or DHT11) was integrated. This component monitors the battery's temperature and ensures it remains within the recommended range. A buzzer alarm system is triggered in the event of critical failures, such as over-temperature, overcurrent, or low voltage, adding a layer of safety and alert for users. To ensure signal clarity and effective load management, an amplifier circuit and power transistor (such as TIP120) were employed. These components help in boosting weak signals and managing higher currents required to control the PMDC motor reliably. From a design standpoint, the entire system was successfully integrated into a compact, modular, and scalable prototype, demonstrating not only technical reliability but also potential for real-world application.

The cost effective nature of the components used makes the system ideal for educational labs, academic research, and prototype EV development. Furthermore, the modularity of the system allows it to be expanded with advanced features such as wireless monitoring, data logging via SD card, or integration with IoT platforms for remote diagnostics and control. In conclusion, this project stands as a promising step toward affordable and effective battery management systems, particularly suited for entry-level EVs and research-grade development kits. The design approach emphasizes practicality, safety, and real-time monitoring, making it a valuable contribution to the field of electric vehicle energy management.

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