A Review of Techniques for Measurement of Lithium-Ion Battery Capacity and Efficiency

Tanvi N. Desale[1], Jigisha S. Dhage[2], Sankalp M. Dhule[3], Atharv N. Bhoj[4],
Praveen V. Pol[5], Vikas J. Nandeshwar[6]
[1,2,3,4,5,6]*Department of Instrumentation and Control Engineering, Vishwakarma Institute of Technology, Pune, India*

***Abstract*—This project focuses on developing a practical, cost-effective system that can measure and monitor the performance of lithium-ion batteries. The system records essential parameters such as voltage, current, charge and discharge cycles, capacity (mAh/Wh), and energy efficiency in real time using sensors and a microcontroller setup. Its goal is to assist users in comprehending the present condition and lifespan of both new and used batteries. This is particularly important in areas where reliability and safety matter. Additionally, the solution provides researchers and students with an invaluable platform for studying battery behaviour and energy flow. The system can be expanded for use in research, education, and industry with future enhancements like live displays or online dashboards.**

***Index Terms*—Battery Capacity, Coulomb Counting, Energy Efficiency, Lithium-Ion Battery, Microcontroller, State of Charge.**

I. INTRODUCTION

Lithium-ion Today's technology relies on Lithium-Ion Battery technology for the powering of most of our devices. These batteries are used in everything from cell phones to laptops, to storage of Renewable Energy sources, to Electric Vehicles. The aging of these batteries results in decreased performance by losing energy storage and energy delivery capabilities over time. For this reason, it is important to continually assess battery performance through continuous assessment of key metrics that represent the performance of the batteries. By knowing a battery's Health, we will not only increase the safety and performance of the batteries, but also know when to service or replace them. The goal of this project is to develop a low-cost, reliable, and simple method of continuously collecting and analyzing the key metrics of Lithium-ion Batteries, including voltage, current, overall capacity and efficiency. This involves using basic sensors and a microcontroller-based Data Acquisition System to collect the above information while charging and discharging lithium-ion batteries in real-time. With this data, it will allow for determining the overall condition of the battery(s) as well as the ability to compare and contrast the performance of multiple lithium-ion batteries, and provide a better understanding of how these batteries react to different conditions. Additionally, this project will serve as a tool for academic pursuits and experimentation, making it a great resource for both students and professionals.

II. LITERATURE REVIEW

correct template for your paper size. This template has been tailored for output on the Several Lithium-ion batteries are widely used due to their high energy density and long cycle life, so accurate capacity and efficiency measurement is essential for effective battery management. Recent studies show that low-cost microcontrollers like the ESP32 and Arduino Nano are suitable for such applications because of their low power consumption and easy sensor interfacing [1]. The most popular technique for estimating capacity is Coulomb counting, but because of its drift, it needs reference points from full/empty cycles or voltage-based recalibration [2], [3]. Since the Li-ion OCV curve is flat over most of the SOC range, voltage-only estimation is unreliable, making hybrid current–voltage methods more effective [4].
Precision current sensing using shunt resistors or ICs such as INA219/INA226 is recommended for accurate

measurement [5], while Hall-effect sensors like the ACS712 show lower precision and higher drift [6]. Due to the limited resolution of built-in ADCs in ESP32 and Arduino Nano, external high-resolution ADCs such as the ADS1115 are widely used [7]. Advanced systems also apply Kalman filtering or impedance-tracking models to improve SOC estimation by considering temperature, load variations, and battery aging [8], [9]. Fuel-gauge ICs like MAX17055 and bq27441 offer high accuracy and low drift and are often used as validation references [10], [11]. Most applications use the ESP32 for logging and data processing, while Arduino Nano provides stable real-time sampling [12]. Other works also note that calibration, monitoring temperature, and testing charge/discharge in a controlled manner will provide accurate results in terms of capacity and efficiency [13]. In general, literature supports a hybrid ESP32–Arduino approach using precision sensing, external ADCs, and regular recalibration as a reliable and cost-effective solution for the measurement of Li-ion battery capacity.

III. METHODOLOGY

A. Components

1. Arduino Nano: Reads sensors, processes data, and works as the main controller for analog inputs.
2. NodeMCU ESP8266: Enables Wi-Fi communication and sends data to a cloud/server.
3. Voltage Sensor Module: Measures battery voltage and sends readings to the Arduino.
4. Push Button: Manually trigger the alert.
5. Power Supply: To keep it all running with external supply.
6. PCB / Perfboard: For soldering the final version after testing on breadboard.
7. Jumper Wires: For making all necessary electrical connections.

B. Testing

The Arduino Nano works with voltage sensor to read the battery level and handle the analog data. After processing, this information is sent to the NodeMCU ESP8266 through serial communication, which then uploads the data to a cloud server using Wi-Fi. The SIM800L GSM module helps the system send SMS alerts or make calls whenever an alert situation occurs. The entire setup runs on 18650 batteries or an external adapter, with the LM2596 buck converter regulating the voltage so all components receive stable power. A push button is included to manually trigger an emergency alert whenever needed. All parts are neatly arranged on a perfboard and connected with jumper wires to create a stable and reliable final circuit.

Once the device was fully assembled and the code was loaded, testing became a crucial part of the process to ensure everything worked as intended in real-life situations. The team began by checking the GPS module's ability to fetch accurate location data both indoors and outdoors, noting that performance was better in open areas with clear sky access. They also tested the GSM module to confirm that the SMS containing the location was sent quickly and reliably to the predefined contact.

IV. RESULTS AND DISCUSSIONS

A. Review Stage

It involves testing the accuracy of measurements by completing controlled charge and discharge cycles on the system. The prototype captured real-time data and retained consistently accurate measurements over several test cycles. The highly stable performance of the microcontroller and sensors was confirmed by observations during this testing phase, and the measurement errors remained well within an acceptable range (±0.5 V and ±0.1 A). The review phase helped identify minor modifications to the calibration and circuit layout, making the mounted prototype more reliable for tracking parameters and improving the carbon footprint of the circuit.

B. Final Stage

At the final stage of implementation, the designed system provided reliable monitoring of battery parameters (capacity, efficiency and cycle performance) under actual operating conditions. The recorded data provided a unique look at how new versus old lithium-ion cells function, showing clear differences in retention of charge and efficiency. The final results demonstrated that the designed system performs effectively for determining battery health and providing an accurate analysis of data to make informed decisions regarding batteries.

V. FUTURE SCOPE

The new system is intended to be used with new technology, which will greatly expand the features and capabilities of the system as well as make the system much easier to use. It is expected that when the new system becomes available it will include wireless connectivity including Wi-Fi, Bluetooth or IoT modules to allow access to remote monitoring of the system's battery health, storage on cloud servers, and automated reporting of battery health information. Also included will be a mobile and/or web-based app that will present the same data in a much more interactive way (i.e., with the ability to view data in graphical form, receive alerts about issues with the system, view trends over time, etc.). In addition to expanding the features of the existing system, future versions will also include features to monitor temperature, perform advanced SOH calculations and deploy advanced machine learning-based predictive models to determine when to perform diagnostic testing of battery cells. The system can also be expanded to support large battery packs in electric vehicles, solar energy systems and research applications.

VI. CONCLUSION

This project has produced a reliable and low-cost solution for determining the states of charge and discharge of lithium-ion batteries, based on their respective voltage, current, capacity, efficiency, and cycle characteristics. The information created by the battery will enable anyone who uses the battery (from beginners to advanced) to see how much power the battery can deliver over time.

This project can also be used as an excellent teaching tool for hands-on learning about energy storage and batteries. As the system continues to be enhanced with additional features, including connectivity, predictive algorithms, and multi-battery capabilities, this system holds great promise for becoming a complete battery analysis platform for use in academic institutions, industrial applications, and research laboratories

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