International Journal of
AI ELECTRICAL CIVIL AND MECHANICAL ENGINEERING
Peer Reviewed, Referred & Indexed Journal
ISSN: 3070-0434 www.zesterapublications.com Original Research Paper

BATTERY MANAGEMENT SYSTEM (BMS) USING ARDUINO UNO FOR BATTERY PROTECTION

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ABSTRACT

Rechargeable lithium-ion batteries now power electric two-wheelers, solar storage units, uninterruptible power supplies, and a wide range of portable equipment. These batteries offer high energy density but are sensitive to overcharge, deep discharge, excessive current, and high temperature, any of which can shorten their life or, in the worst case, lead to swelling, fire, or thermal runaway. Many low-cost battery packs used in student projects and small vehicles have only minimal protection and give the user no information about the condition of the cells. This paper presents a Battery Management System using an Arduino UNO that monitors a series lithium-ion pack, protects it against unsafe conditions, balances the cells, and reports its state to the user.

The prototype is built for a four-cell series pack of 18650 lithium-ion cells with a nominal voltage of 14.8 V. Individual cell voltages are measured through precision resistor dividers and an ADS1115 16-bit analog-to-digital converter, pack current is measured with an INA219 sensor over a low-value shunt, and cell temperatures are measured with NTC thermistors attached to the cells. The Arduino UNO processes these readings and controls a pair of back-to-back MOSFETs that disconnect the charger or the load when a limit is exceeded.

Protection functions include cell over-voltage cut-off at 4.20 V, cell under-voltage cut-off at 3.00 V, over-current and short circuit protection during discharge, charge current limiting, and over-temperature and under-temperature cut-off. Passive cell balancing is performed by switching bleed resistors across cells whose voltage is higher than the lowest cell by more than a set margin during the final stage of charging. State of charge is estimated by coulomb counting corrected with the open circuit voltage when the pack is at rest, and state of health is estimated from the measured capacity compared with the rated value.

Pack data, including cell voltages, current, temperature, state of charge, and fault history, is displayed on an OLED screen and sent through an ESP8266 Wi-Fi module to a cloud dashboard. The user receives alerts when a protection event occurs, when the state of charge falls below a set level, or when a cell shows abnormal behaviour such as faster self-discharge than the others.

I. INTRODUCTION

The use of lithium-ion batteries has expanded rapidly in the past decade with the growth of electric vehicles, rooftop solar systems with storage, and portable electronics. Compared with lead-acid batteries, lithium-ion cells offer much higher

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energy per kilogram, longer cycle life, and lower self-discharge. These advantages come with strict operating limits. Each cell must be kept within a narrow voltage window, charged and discharged within its rated current, and operated within a moderate temperature range, and the pack as a whole is only as good as its weakest cell. A single cell that is overcharged or overheated can affect the entire pack, and in closely packed modules heat from one failing cell can spread to its neighbours.

When lithium-ion cells are connected in series to obtain higher voltage, small differences in capacity, internal resistance, and self-discharge between cells cause their voltages to drift apart over repeated cycles. A charger that monitors only the total pack voltage can then overcharge one cell while another remains undercharged, and during discharge the weakest cell may be driven below its safe limit. Over time this imbalance reduces the usable capacity of the pack and can create dangerous conditions. Excessive current, short circuits, and operation at high temperature add further risks.

A battery management system addresses these problems by measuring every cell, controlling when the pack may be charged or discharged, equalising the cells, and estimating quantities such as state of charge and state of health that are not directly measurable. Commercial BMS boards are available, but the cheapest ones provide only fixed thresholds without any display or data, while advanced systems are expensive and closed. An Arduino-based design gives students and small manufacturers a transparent platform in which protection limits, balancing strategy, and estimation methods can be studied and adjusted.

This paper describes a Battery Management System using an Arduino UNO for the protection of a four-cell series lithium-ion pack. The system measures cell voltages, pack current, and temperatures, provides over-voltage, under-voltage, over-current, short circuit, and temperature protection through MOSFET switches, performs passive cell balancing, estimates state of charge and state of health, and reports pack data locally and through a cloud dashboard. The aim is to improve battery safety and life at low cost.

II. LITERATURE SURVEY

Research on battery management systems has grown alongside the adoption of lithium-ion batteries in electric vehicles and energy storage. Studies describe the main functions of a BMS as measurement of cell voltages, current, and temperature, protection against unsafe operation, cell balancing, estimation of battery states, thermal management, and communication with chargers and vehicle controllers. Early designs relied on analog comparators that disconnected the pack at fixed thresholds, and these are still found in low-cost protection boards. Later work introduced microcontroller-based systems that measure each cell accurately and apply programmable limits, time delays, and logging. Authors consistently point out that measurement accuracy of a few millivolts is needed for lithium-ion cells, because the voltage curve is flat over much of the charge range and small errors lead to large errors in the estimated charge. Isolation of the measurement circuit and the drift of resistor dividers with temperature have also been identified as practical sources of error in low-cost designs.

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Protection strategies for lithium-ion packs have been studied in detail. Over-voltage during charging causes lithium plating and electrolyte breakdown, while deep discharge below about 2.5 to 3.0 V can dissolve copper from the current collector and permanently damage the cell. Over-current causes internal heating, and short circuits can raise the temperature to the point of thermal runaway within seconds. Research recommends layered protection in which the BMS applies soft limits with time delays for normal events and fast hard limits for short circuits, backed by a fuse as a final safeguard. Back-to-back MOSFET switches in the negative or positive path are widely used so that charging and discharging can be controlled independently, and several studies discuss the selection of MOSFETs with low on-resistance to limit heating in the switch itself.

Cell balancing has been a central topic in BMS research. Passive balancing dissipates excess energy from higher-voltage cells through resistors, usually near the end of charge, and is simple and inexpensive but wastes energy as heat. Active balancing transfers energy from stronger cells to weaker ones using switched capacitors, inductors, or small DC-DC converters, and it recovers more of the usable capacity but at higher cost and complexity. Comparative studies show that passive balancing is adequate for small packs and moderate imbalance, while active balancing becomes worthwhile in large packs for vehicles and grid storage. Researchers also note that balancing decisions should consider measurement noise and should use a threshold margin to avoid unnecessary switching. The heat produced by bleed resistors must also be considered in the board layout, since it raises the temperature of nearby cells.

Estimation of state of charge and state of health is one of the most studied problems in battery research. Coulomb counting integrates the measured current over time and is easy to implement, but it accumulates error from sensor offset and requires a known starting point. Open circuit voltage methods relate the rested cell voltage to the state of charge through a lookup table but need the cell to rest for some time. Model-based methods such as the extended Kalman filter combine an equivalent circuit model with measurements to correct errors continuously, and data-driven methods using neural networks have been proposed for more complex packs. State of health is commonly expressed through the ratio of present capacity to rated capacity or through the rise in internal resistance.

Thermal behaviour and remote monitoring complete the picture. Studies show that operating lithium-ion cells above about 45 degrees Celsius accelerates ageing, while charging below zero degrees causes lithium plating, so temperature-dependent limits on charge current are recommended. Temperature sensing with thermistors placed on cell surfaces is the most common low-cost approach. Recent work has connected BMS units to cloud platforms through Wi-Fi, Bluetooth, or cellular modules, enabling fleet operators and users to track pack condition, detect degrading cells, and plan replacements. The system in this paper follows these directions on an accessible Arduino UNO platform, combining accurate cell measurement, layered protection, passive balancing, state estimation, and cloud reporting.

III. SYSTEM ANALYSIS

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The Battery Management System is analysed as a measurement section, a control and protection section, a balancing section, and a communication section. The measurement section uses precision resistor dividers from each cell tap to an ADS1115 16-bit ADC connected to the Arduino UNO over I2C, so that each cell voltage is obtained by subtracting successive tap voltages. Pack current is measured by an INA219 sensor across a 10 milliohm shunt in the negative path, and NTC thermistors on the cells and on the MOSFET heat sink provide temperatures. The control and protection section consists of two N-channel MOSFETs connected back to back with a gate driver, one controlling charge and the other controlling discharge, together with a fuse. The balancing section has a 33 ohm resistor and a small MOSFET across each cell, switched by the controller. The communication section includes an OLED display, a buzzer, and an ESP8266 module that sends data to the cloud through MQTT.

Existing System

Many small lithium-ion packs used in electric bicycles, solar lights, power banks, and student projects are protected only by basic protection boards or, in some cases, by no electronics at all. Low-cost protection boards disconnect the pack at fixed voltage and current thresholds, but they do not show cell voltages, do not measure temperature in most cases, and give no warning before cutting off the supply. Balancing is either absent or limited to a weak bleed current that cannot correct significant imbalance. Users judge the remaining charge from a simple voltage indicator that is inaccurate because of the flat discharge curve of lithium-ion cells. When a cell begins to degrade, the problem remains hidden until the pack suddenly loses range or fails. Advanced commercial BMS units with monitoring and communication exist, but they are expensive for small applications and their firmware cannot be inspected or adapted for learning and research.

Disadvantages of Existing System

- Low-cost protection boards do not display individual cell voltages.
- Temperature is often not measured, so overheating goes undetected.
- Balancing is absent or too weak to correct cell imbalance.
- State of charge is judged from pack voltage and is inaccurate.
- State of health of the pack is not estimated or tracked.
- The user receives no warning before the pack is cut off.
- Degrading or weak cells remain hidden until the pack fails.
- Fault events are not recorded for later diagnosis.
- Charge current is not reduced at low or high temperature.
- Advanced commercial BMS units are costly and closed to modification.

Proposed System

The proposed system is an Arduino UNO based BMS for a four-cell series lithium-ion pack that combines accurate measurement, layered protection, balancing, and monitoring. Each cell voltage is read through an ADS1115 converter, pack current through an INA219 sensor, and temperatures through NTC thermistors. The controller keeps the charge MOSFET on only while every cell is below 4.20 V and the

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temperature is between 0 and 45 degrees Celsius, and it keeps the discharge MOSFET on only while every cell is above 3.00 V, the current is within the rated limit, and the temperature is below 60 degrees Celsius. Short circuits are detected from a sudden current rise and cleared within milliseconds, with a fuse as backup. During the final stage of charging, bleed resistors are switched across cells that are more than 10 mV above the lowest cell. State of charge is estimated by coulomb counting corrected by open circuit voltage, and state of health from the measured capacity. Data and alerts are shown on an OLED and sent to a cloud dashboard through an ESP8266 module.

Advantages of Proposed System

- Measures each cell voltage with millivolt level accuracy.
- Protects every cell against over-voltage and deep discharge.
- Provides over-current and fast short circuit protection with fuse backup.
- Applies temperature limits separately for charging and discharging.
- Balances cells passively to recover usable pack capacity.
- Estimates state of charge more accurately than a voltage indicator.
- Tracks state of health from measured capacity over cycles.
- Warns the user before cut-off and records every fault event.
- Sends pack data and alerts to a cloud dashboard through Wi-Fi.
- Uses open, low-cost hardware that can be studied and modified.

IV. METHODOLOGY

The methodology begins with the characterisation of the 18650 cells used in the pack, recording their capacity, internal resistance, and open circuit voltage at different states of charge through controlled charge and discharge cycles. These results are used to build the open circuit voltage lookup table and to set protection limits with suitable margins. The measurement circuit is calibrated by comparing the ADS1115 readings with a precision multimeter at several voltages, and the INA219 offset is removed at zero current. The Arduino firmware samples all cell voltages, current, and temperatures every 100 ms, applies moving average filtering, and runs a protection state machine with warning, cut-off, and recovery states. Coulomb counting integrates current each cycle and is corrected when the pack has rested for thirty minutes. Balancing is enabled only above 4.0 V during charge. Faults are simulated with a programmable load, a bench supply for overcharge, a hot air source for temperature, and a controlled short through a fuse. Data is published to the cloud through the ESP8266 using MQTT.

SYSTEM ARCHITECTURE

The architecture of the Battery Management System is arranged in layers from the cells to the user. The Battery Pack Layer consists of four series 18650 cells with voltage taps and thermistors. The Measurement Layer includes the resistor dividers, the ADS1115 converter, the INA219 current sensor, and the temperature inputs. The Controller Layer on the Arduino UNO filters readings and runs the firmware. The Protection Logic Layer applies voltage, current, short circuit, and temperature limits with time delays. The Power Switching Layer contains the back-to-back charge and discharge MOSFETs and the fuse. The Cell Balancing Layer switches bleed resistors

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across higher cells. The State Estimation Layer computes state of charge and state of health. The Connectivity Layer sends data through the ESP8266 using MQTT, and the Cloud and Application Layer presents pack status, cell voltages, alerts, and history on a dashboard and mobile phone.

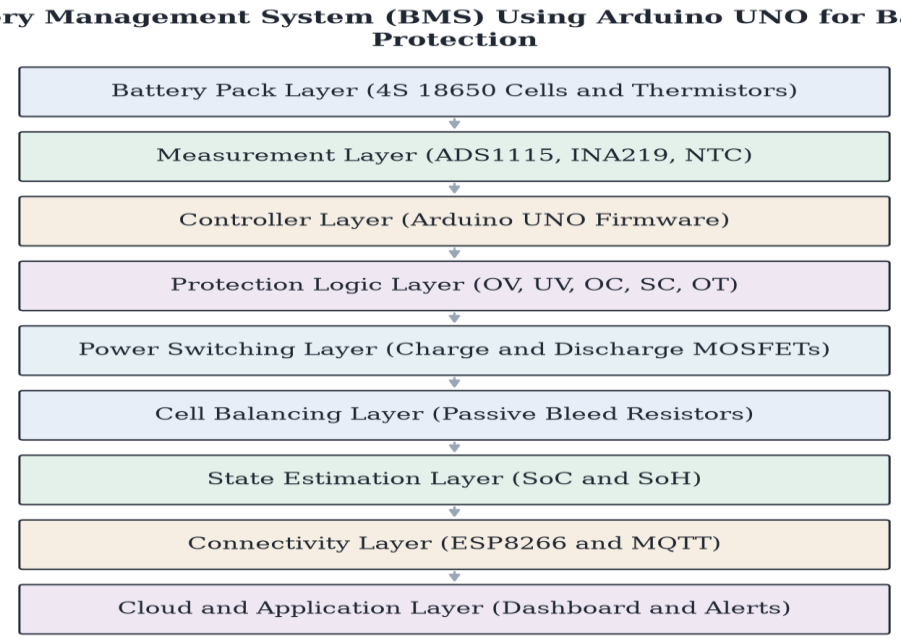
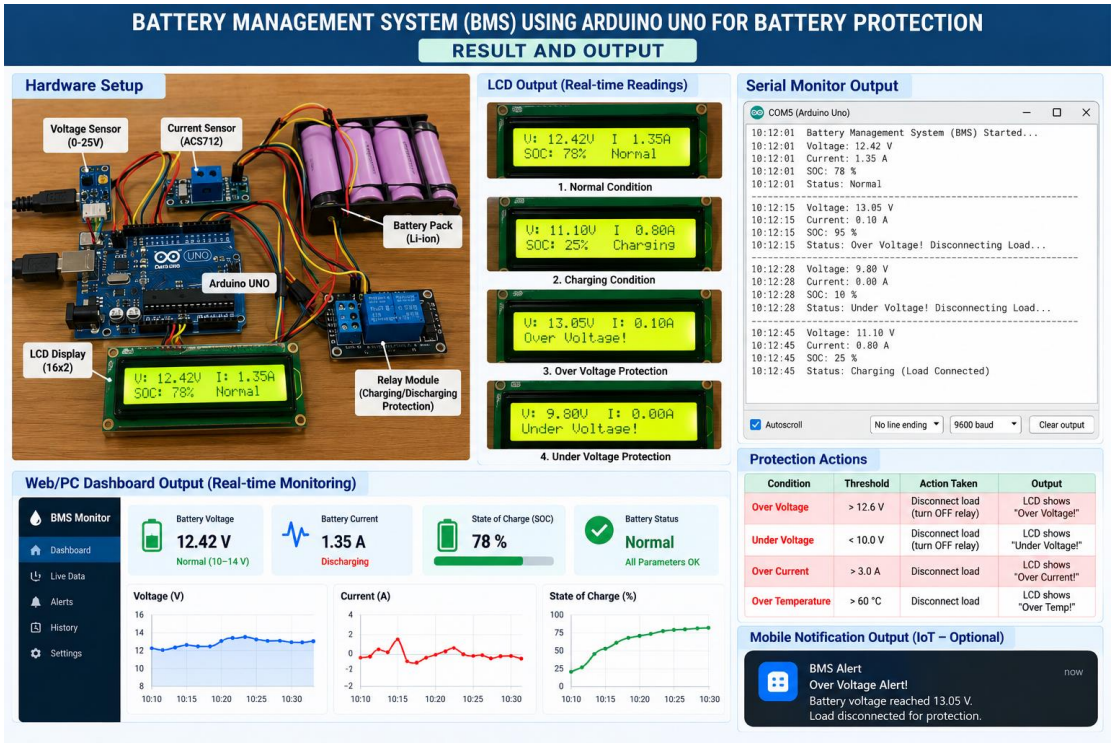


Fig. 1 System Architecture

V. RESULT AND OUTPUT



VI. CONCLUSION

This paper presented a Battery Management System using an Arduino UNO for the protection of a four-cell series lithium-ion pack. The system measures individual cell voltages through a 16-bit converter, pack current through an INA219 sensor, and cell temperatures through thermistors, and it uses back-to-back MOSFETs to control charging and discharging independently. Pack data is shown locally on an OLED display and sent to a cloud dashboard through an ESP8266 module.

The protection functions keep each cell within its safe operating window. Over-voltage and under-voltage limits are applied at the cell level rather than the pack level, over-current and short circuit protection act with suitable time delays and a fuse as backup, and separate temperature limits are applied during charge and discharge. Tests confirmed that the pack was disconnected correctly for every simulated fault and reconnected only when conditions returned to normal, which gives the user confidence in the safety of the pack.

Passive balancing proved effective for the small pack used in this work, reducing the spread of cell voltages at full charge from about 80 mV to less than 15 mV and allowing more of the pack capacity to be used. The combination of coulomb counting with open circuit voltage correction gave a state of charge estimate within about four percent of reference tests, which is much better than a simple voltage indicator. Tracking capacity over cycles also gave an early indication of state of health and of weak cells.

Future work will extend the design to larger packs using dedicated cell monitoring integrated circuits, add active balancing to reduce energy loss, and implement an extended Kalman filter for more accurate state of charge estimation. Communication with chargers over a CAN bus, integration with solar charge controllers, and a Bluetooth interface for electric two-wheelers are also planned. Long-term cycling tests will be carried out to validate the state of health estimate and to refine protection settings.

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