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# Optimal Thermal Design for Battery Charging System

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***Abstract:*** ***The rapid growth of electric vehicle (EV) usage has increased the need for advanced and dependable battery management systems. Lithium-ion batteries are commonly used in EVs due to their high energy density and efficiency; however, they are very sensitive to temperature changes.***
***Operating these batteries under unsuitable thermal conditions can decrease performance, shorten lifespan, and even create safety hazards such as overheating. Hence, maintaining a controlled temperature range during the charging process is critical for improving efficiency and ensuring safe operation.***
***This study proposes an optimized thermal management design for a battery charging system that combines real-time monitoring, intelligent control, and effective cooling techniques. An Arduino Uno microcontroller acts as the main control unit, continuously tracking key battery parameters like voltage and current through dedicated sensors. A Wi-Fi module is incorporated to transmit data to a remote platform, enabling users to monitor battery conditions and system behaviour in real time. Based on the sensed data, the system automatically regulates thermal control components such as relays, a pump motor, and a Peltier cooling module.***
***The pump motor circulates coolant around the battery pack to remove excess heat, while the Peltier device actively transfers heat away from the battery surface. This integrated cooling strategy ensures stable temperature control during charging, enhancing both performance and safety.***
***Keywords: Electric Vehicles (EVs), Lithium-ion Battery, Battery Management System (BMS), Thermal Management, Arduino Uno, Peltier Module, Cooling System, IoT Monitoring, Temperature Control, Energy Efficiency.***

## I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has significantly increased the need for efficient and dependable energy storage solutions. Lithium-ion batteries serve as the primary energy source in these systems due to their high energy density, extended lifespan, and reliable performance [1]-[3].

Despite these advantages, their operation is highly influenced by temperature conditions, making thermal regulation an essential factor [4]-[6].

During charging and discharging cycles, heat is generated within the battery, and inadequate heat dissipation can result in performance degradation, faster wear, and serious safety concerns such as thermal runaway [7]-[8]. To maintain battery health and ensure safe operation, it is crucial to keep the temperature within an optimal range. Traditional cooling techniques may not be effective under demanding conditions like rapid charging or heavy load usage [9]-[10]. As a result, there is a growing need for advanced thermal management approaches that integrate real-time monitoring with active cooling mechanisms. Such systems help in improving efficiency, enhancing safety, and prolonging battery life [11]-[12].

This project presents the development of an optimized thermal management system specifically designed for battery charging applications. An Arduino Uno microcontroller is used to continuously monitor important battery parameters, including voltage and current [13]-[14].

Based on these measurements, the system automatically regulates cooling devices such as a coolant pump and a Peltier module. Furthermore, the integration of a Wi-Fi module allows remote monitoring of battery conditions, making the system intelligent, responsive, and suitable for modern electric vehicle applications [15].

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## II. FLOW CHART

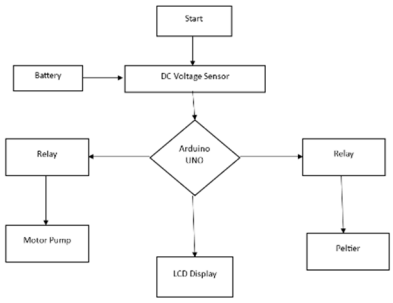



Fig.1. Flow Chart

1) System Start: The system is powered on, and all components are initialized for operation.
2) Battery Supply: The battery provides power to the entire setup and is continuously monitored as the primary source.
3) Voltage Measurement: A DC voltage sensor constantly measures the battery voltage levels.
4) Data Transmission: The measured values are sent to the Arduino Uno for processing.
5) Analysis and Control: The controller evaluates the incoming data to determine whether the battery is operating within safe limits or requires cooling.
6) Relay Control: If the voltage or temperature exceeds the predefined threshold, the controller triggers the relay modules.
7) Cooling Process:
    - One relay activates the motor pump to circulate coolant around the battery pack.
    - Another relay switches on the Peltier module to provide active cooling.
8) Display Monitoring: An LCD screen shows the current battery voltage and system status in real time.
9) Continuous Operation: The system repeatedly performs these steps to ensure the battery remains within safe operating conditions.

## III. PROBLEM STATEMENT

The efficiency, safety, and durability of lithium-ion batteries in electric vehicles (EVs) are highly influenced by temperature changes that occur during charging and discharging. High temperatures, particularly during fast charging or heavy load conditions, can create thermal stress within the battery, leading to decreased performance, faster aging, and serious risks such as thermal runaway. Similarly, operating at low temperatures can reduce the battery's capacity and negatively impact charging efficiency. Therefore, maintaining a stable and optimal temperature range remains a critical challenge in battery management.

Traditional cooling techniques, including passive air cooling, are often not sufficient to manage sudden temperature rises or uneven heat distribution inside battery packs. Moreover, many existing thermal management systems do not incorporate real-time sensing or smart control strategies, which limits their ability to respond effectively to changing conditions. The lack of remote monitoring features further reduces user awareness, making it difficult to take timely action to prevent overheating or excessive cooling.

## IV. PROPOSED SYSTEM

The proposed work aims to develop an integrated Battery Thermal Management System (BTMS) designed for lithium-ion battery packs used in electric vehicles. In such applications, the battery is a vital and temperature-sensitive component, and its performance is directly affected by thermal conditions. Both high and low temperatures can negatively impact efficiency, shorten battery lifespan, and pose safety concerns. To address these issues, the system integrates sensing, cooling, and real-time monitoring to maintain the battery within a safe and stable temperature range. The system consists of essential components including a lithium-ion battery pack, an Arduino Uno microcontroller, voltage and current sensing units, a relay module, a pump motor, a Peltier cooling module, and a Wi-Fi communication unit. The Arduino Uno functions as the main control unit, continuously gathering data from the sensors to track battery parameters. Based on this data, it decides when cooling actions need to be activated. A combined cooling strategy is implemented to enhance effectiveness. The pump motor circulates coolant around the battery pack to dissipate heat, while the Peltier module offers active thermoelectric cooling for improved temperature control. Both cooling elements are automatically managed through relays, ensuring efficient and reliable system operation.

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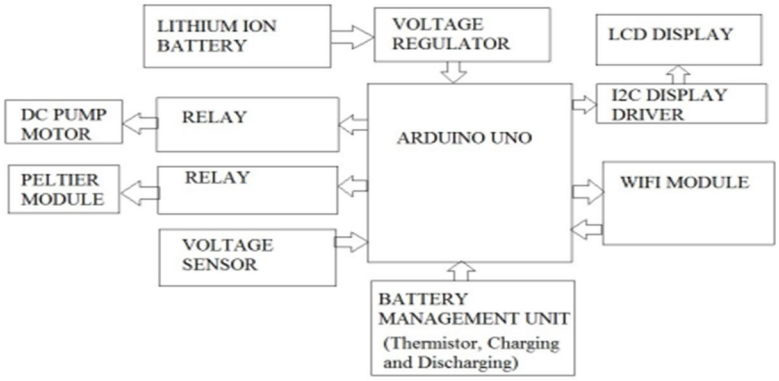



Fig.2. Block Diagram

## V. HARDWARE IMPLEMENTATION

### *A. Arduino UNO*

The Arduino Uno is a widely used open-source microcontroller platform designed for building electronic and embedded systems. It is built around the ATmega328P microcontroller and is capable of receiving input signals from sensors and controlling output devices such as LEDs, relays, and motors. Operating at 5V, the board provides 14 digital input/output pins and 6 analog input pins, enabling easy connection with a variety of external components. Due to its affordability, ease of use, and adaptability,



Fig.3. Arduino UNO

### *B. Lithium-ion battery*

A Lithium-ion battery is a commonly used energy storage device recognized for its high energy density, lightweight structure, and long service life, making it suitable for applications such as electric vehicles, mobile phones, and laptops. It operates based on the movement of lithium ions between two electrodes an anode and a cathode through an electrolyte.



Fig.4 Lithium-ion battery

### *C. LCD Display*

An LCD with an I2C interface is widely used in embedded systems to display text information while minimizing the number of required microcontroller pins. It typically combines a standard 16×2 LCD (16 columns and 2 rows) with an I2C communication module, making it easy to interface with development boards such as the ESP32 or Arduino.



Fig.5. LCD Display

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*D. Relay Module*

A relay module is an electrically controlled switching device that allows low-voltage circuits to operate high-voltage or high-current loads. It is commonly used with microcontrollers such as the ESP32 or Arduino to enable safe and efficient control of electrical appliances in automation systems. One of its key advantages is electrical isolation, which protects the control circuit from high-power signals.



Fig.6. Relay Module

A typical relay consists of an electromagnetic coil, a mechanical switching arm, and three terminals known as Common (COM), Normally Open (NO), and Normally Closed (NC).

*E. DC Voltage Sensor*

A DC voltage sensor module is an electronic component designed to measure the voltage level of a direct current (DC) source such as a battery or power supply, and it is widely used in microcontroller-based applications for real-time monitoring. The module operates on the voltage divider principle, reducing higher input voltages to a lower and safer range that can be read by controllers like the Arduino Uno. This makes it possible to measure voltages that exceed the controller's input limit, typically 5V.



Fig.7. DC Voltage Sensor

*F. Motor Pump*

A motor pump is an electromechanical device that uses an electric motor to transfer liquids from one location to another and is widely applied in cooling, irrigation, and fluid circulation systems. It operates by converting electrical energy into mechanical motion; when power is supplied, the motor drives an internal impeller that generates pressure, causing the liquid—such as water or coolant—to flow through connected pipes or channels.



Fig.8. Motor Pump

*G. Peltier*

A Peltier module is a solid-state electronic device that can provide heating or cooling based on the Peltier effect. When an electric current passes through the module, it creates a temperature difference, causing one side to become cold while the opposite side becomes hot. The device is made of semiconductor elements placed between two ceramic plates, allowing heat to be transferred from one surface to the other without any moving parts or refrigerants.




Fig.9. Peltier

This compact and reliable operation makes it suitable for small-scale cooling applications. In battery thermal management systems, the Peltier module is used for active cooling by absorbing heat from the battery surface on its cold side and transferring.

## VI. CIRCUIT DIAGRAM

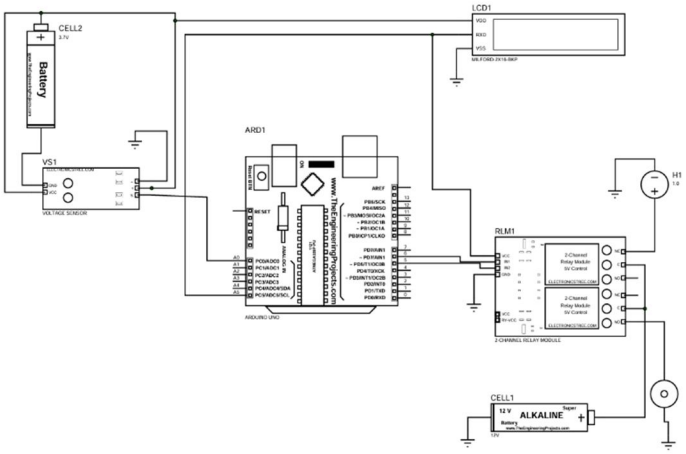



Fig.12. Circuit Diagram

## VII. WORKING METHODOLOGY

1) Battery Monitoring: The system continuously monitors the lithium-ion battery using voltage and current sensors to track its operating condition.
2) Data Processing: The Arduino Uno collects sensor data and processes it to evaluate battery status and heat generation.
3) Automatic Control: The controller activates the relay module to turn ON cooling components when required.
4) Cooling Mechanism:
    - Pump Motor: Circulates coolant around the battery to remove heat.
    - Peltier Module: Provides active thermoelectric cooling to reduce temperature.
5) Real-Time Monitoring: A Wi-Fi module transmits battery parameters (voltage, current, temperature) to a remote dashboard.
6) Display System: LCD shows real-time battery status and system operation.
7) Safety Control: If abnormal conditions are detected, the system ensures immediate cooling to prevent overheating and damage.
8) Continuous Operation: The process repeats continuously to maintain the battery within a safe temperature range.

## VIII. HARDWARE OUTCOME

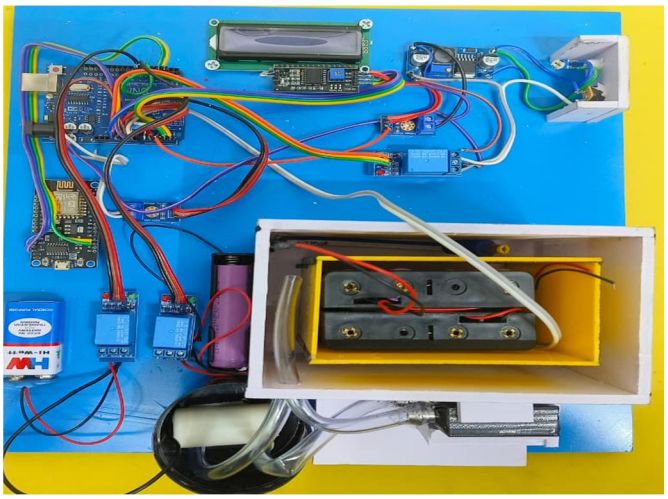


Fig.13. Proto type hardware implementation

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The developed hardware setup effectively demonstrates a reliable and automated Battery Thermal Management System (BTMS) for lithium-ion batteries in electric vehicle applications. The system combines sensing, control, and cooling mechanisms to maintain safe operating conditions and ensure stable battery performance. The Arduino Uno efficiently gathers real-time data from voltage and current sensors and processes this information to monitor battery behavior. Based on the measured values, the controller accurately operates the relay module to manage external components.

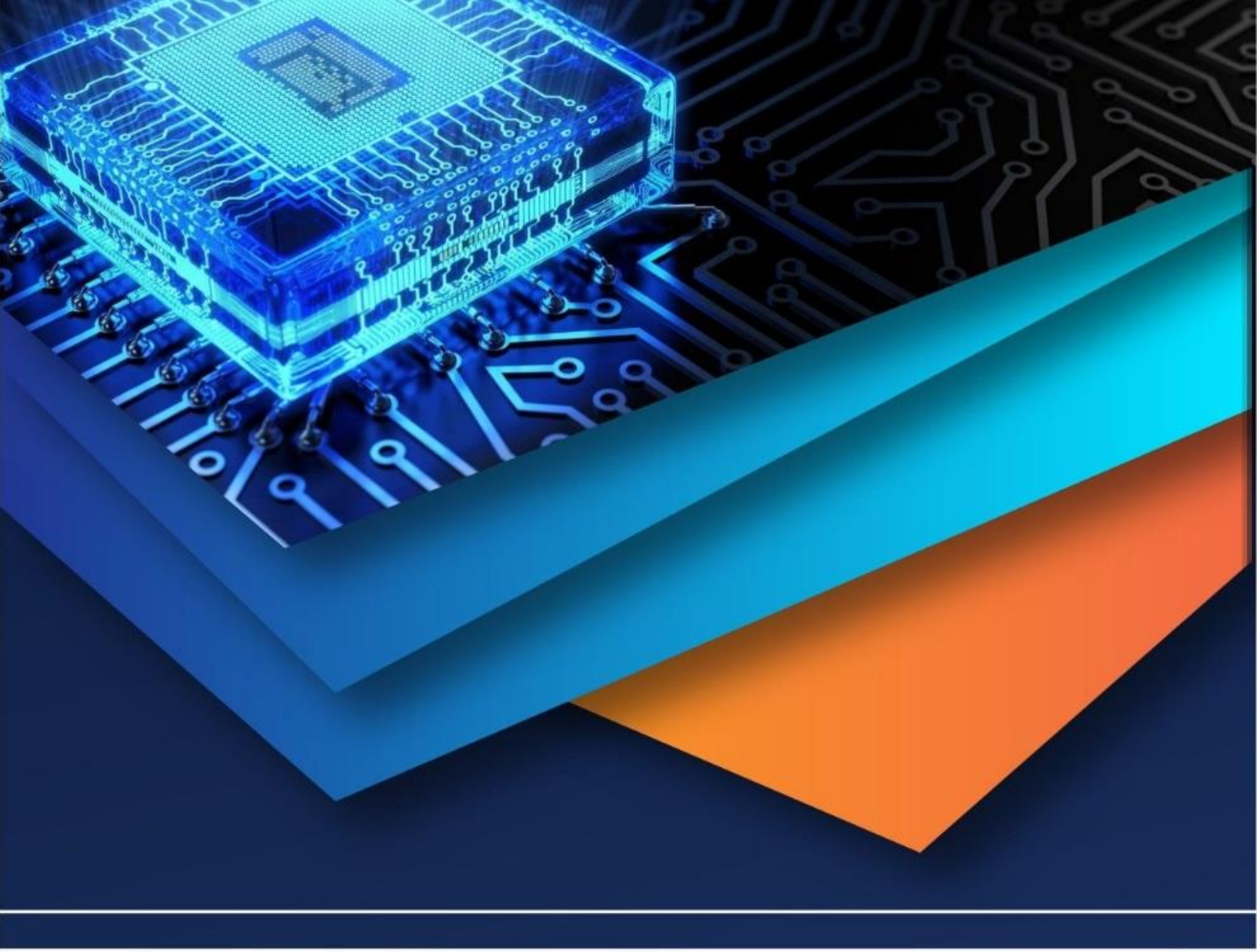
## IX. CONCLUSION

The cooling arrangement functions as intended, where the motor pump provides continuous circulation of coolant around the battery pack, while the Peltier module delivers active cooling to reduce excess heat. This combined approach enhances heat dissipation, especially during charging and high-load conditions. The LCD display presents real-time battery parameters for easy on-site monitoring, and the Wi-Fi module allows remote observation of voltage, current, and system status, thereby improving user awareness and overall system control.

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