Internet of Things enabled Automatic Battery Cooling System Using Peltier Effect

Abstract

Electric vehicles (EVs) have developed rapidly and are popular due to their zero emissions and efficiency. However, several factors limit electric car development, including performance, cost, lifetime, and battery safety. Battery management is crucial for achieving maximum performance under various conditions. The battery thermal management system (BTMS) plays an important role in controlling the battery's thermal behavior. A BTMS manages the battery's operating temperature by either dissipating heat when it is too hot or providing heat when it is too cold. Cooling the battery is particularly important as it enhances the battery's efficiency. Various methods of cooling batteries include air cooling systems, liquid cooling systems, refrigerant cooling systems, and phase change material cooling systems. In this study, the battery is cooled using a Peltier module. The cooling system's operation is regulated via Blynk, an Internet of Things (IoT) platform that facilitates remote monitoring and control through a mobile application. The integration of Blynk allows for real-time temperature monitoring, dynamic adjustment of cooling intensity, and automated alerts for temperature anomalies. The system architecture includes temperature sensors, a NodeMCU, and the Peltier module, all interconnected through a wireless network to the Blynk platform. With the Peltier module, the battery temperature is maintained within 35°C to 45°C. Significant improvements in thermal management are observed, showcasing the potential of IoT-enabled Peltier cooling systems in various battery-dependent applications.

Keywords: Thermal management; Battery cooling system; Peltier module; Internet of Things (IoT).

Introduction

Electric Vehicles (EVs) have emerged as a transformative force in the global automotive industry, providing an alternative to traditional internal combustion engines. With increasing environmental concerns and a push to reduce greenhouse gas emissions, EVs present a promising solution due to their lower carbon footprint and reliance on renewable energy sources.

Globally, the adoption of EVs has been accelerating, with significant advancements in battery technology, charging infrastructure, and supportive government policies. Leading markets such as China, the United States, and several European countries have implemented robust incentives and regulations to promote EV adoption. In 2023, the global EV market witnessed remarkable growth, with over 10 million EVs sold, marking a significant milestone in the transition to sustainable transportation. The increasing range, affordability, and performance of EVs have further fueled consumer interest and acceptance[1].

In India also the EV market is gaining momentum, albeit at a different pace. The Indian government has set ambitious targets for EV adoption, aiming to achieve 30% electric vehicle penetration by 2030. Initiatives such as the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme and the National Electric Mobility Mission Plan (NEMMP) have been pivotal in driving the growth of EVs in India. Despite challenges such as high upfront costs, limited charging infrastructure, and low consumer awareness, the Indian EV market is poised for rapid expansion, supported by government policies, incentives, and increasing investment in EV technology and infrastructure.

The battery is a critical component of an electric vehicle (EV) and has a significant impact on its overall performance, range, cost, and environmental footprint. EV batteries face several challenges that can impact their performance. As the adoption of EVs grows, addressing these challenges becomes crucial for enhancing efficiency, safety, and user convenience. Battery thermal management remains a critical challenge, as overheating can lead to reduced battery performance, decreased lifespan, and even potential safety hazards [2]. One significant challenge in the operation of EVs is managing battery temperature. Research indicates that both the calendar life and cycle life of Li-ion batteries degrade rapidly when exposed to elevated temperatures [3]. The ideal operating temperature for most Li-ion batteries ranges from 15°C to 35°C[4].

Thermal management systems are designed to handle situations where batteries operate outside their designated temperature range. Investing in a well-designed battery thermal management system can significantly enhance battery performance, safety, and capacity. Various cooling techniques are employed, including fluid cooling (both indirect and direct, passive and active), air cooling (natural or forced), phase change materials, or combinations of these methods[4]. Natural and forced air cooling methods alone are often insufficient for ensuring uniform temperature distribution across the battery pack. Indirect active fluid cooling is more effective at dissipating heat compared to air cooling methods. Additionally, proper ventilation is necessary to expel hazardous gases generated by batteries. While fluid cooling is effective, it may not be practical for smaller battery packs, where alternative cooling methods might be more suitable[5-6].

Studies on thermoelectric cooling for electric vehicle applications began in the early 21st century. In these designs, the cold sides of the thermoelectric coolers are connected to the heat sink, and the maximum temperature was kept below 55°C[7]. Cold air was blown into the battery pack and cabin for cooling, incorporating a heatsink-fan set for both cold side cooling and hot side heat dissipation[8]. In another study, the hot side design was replaced with water cooling for improved performance. Additionally, the cold side can be directly attached to the battery surface. Air and water are potential candidates to remove heat from the hot end. All these designs have demonstrated the effectiveness of the thermoelectric cooling (TEC) module used in battery thermal management[9-10]. A battery thermal management system was developed which combines thermoelectric cooling, forced air cooling, and liquid cooling. The liquid coolant has indirect contact with the battery and acts as the medium to remove the heat generated during operation. Forced air assists in heat removal from the condenser side of the thermoelectric liquid casing[11]. Most studies take air as the medium of heat transportation from the cold end to the battery[12].

Thermal exchange through a double-layered mini-channel heat sink used as a cooling system for electronic components was developed. Different factors influencing heat exchange enhancement were investigated using ANSYS-Fluent software. The evaluation of thermal exchange between the cold fluid and heated solid with high thermal dissipation has been accurately analyzed under the effect of system geometry, fluid nature and cooling system material. The numerical outcomes demonstrated that the heat transfer quality significantly increases with the variation of the system shape, where the cooling system presented a significant reduction of average temperature by around 62%–65%. Using copper as a cooling material improves the overall performance of a cooling system, delivering higher efficiency and performance[13].

ANN based robust bidirectional charger for electric vehicles was developed. The charger setup consists of a rectifier (AC/DC) in front end and a converter (DC/DC) at the back end, with a DC link capacitor separating converter and rectifier. The simulation results verify the effectiveness of ANN-based charger in grid voltage regulation in various modes of charging and discharging operations of Electric Vehicles (EV's). (14).Although several research has been conducted on effective battery cooling system, there is no work reported on automated effective cooling system The present work aims at developing an automated battery cooling system working on Peltier effect integrated with IOT.

Experimental setup

A view of the experimental setup is shown in Fig. 1. The experimental setup consists of a Peltier module, also known as a TEC, a microcontroller, temperature sensors, and a battery.

The Peltier module is the core component responsible for active cooling. It is strategically placed in contact with the battery pack to facilitate efficient heat transfer. The hot side of the Peltier module is equipped with a heat sink and a fan to dissipate the absorbed heat into the environment[15-18].

Temperature sensors (DS18B20) are used to continuously monitor the temperature of the battery pack. The specifications of the DS18B20 sensor are Power supply range: 3.0V to 5.5V, Operating temperature range: -55ºC to +125ºC and accuracy: ±0.5ºC The output resolution of the DS18B20 sensor is programmable from 9-bit to 12-bit. These sensors are placed at critical points on the battery pack to ensure accurate and representative temperature readings. The data from these sensors is essential for controlling the Peltier module and ensuring optimal cooling performance.

A microcontroller (NodeMCU) serves as the central processing unit of the system. It collects temperature data from the sensors, processes the information, and controls the Peltier module based on predefined algorithms. The microcontroller is also responsible for establishing a wireless connection to the Blynk IoT platform[19]. A stable power supply is crucial for the operation of both the Peltier module and the microcontroller. Power is supplied through a 12V lead-acid battery, which must provide sufficient current and voltage to drive the Peltier module effectively. Blynk is an IoT platform that facilitates remote monitoring and control of the cooling system. The microcontroller communicates with the Blynk server over a wireless network, sending temperature data and receiving control commands.

The Blynk mobile application is used to visualize real-time temperature data, adjust cooling parameters, and set up automated alerts for temperature anomalies. Temperature data collected from the sensors is sent to the microcontroller, which processes the data and controls the Peltier module accordingly. The microcontroller also sends temperature data to the Blynk server, where it is visualized on the Blynk mobile application[19-21]. Control commands from the Blynk app are received by the microcontroller to dynamically adjust the cooling parameters.

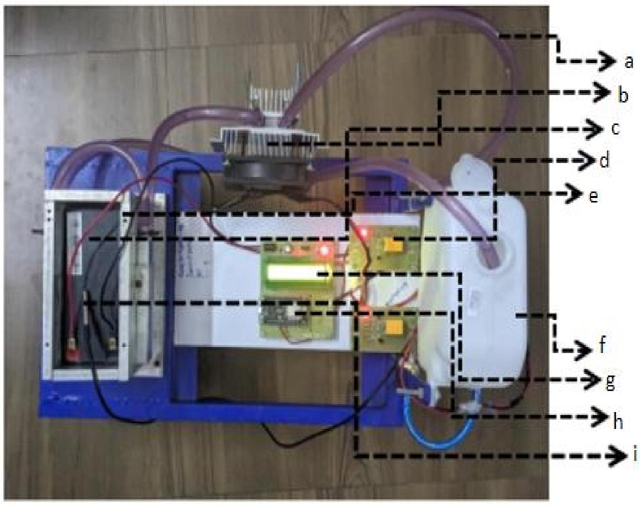
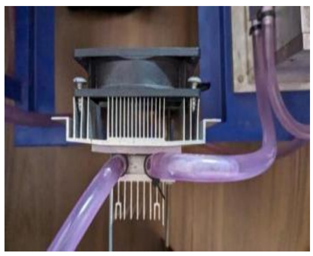


Fig.1. Experimental Setup (a)Tubes (b) Peltier Module (c) Lead-Acid Battery , (d) Relay (e) Cooling block (f) Coolant tank, (g) LCD display (h) Microcontroller (NodeMCU) (i)Temperature Sensor

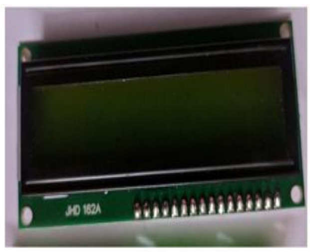
Microcontroller (NodeMCU)

Temperature Sensor



Peltier module

Lead-Acid Battery



LCD Display

Relay

Working

Temperature sensors continuously measure the temperature of the battery pack, and these readings are sent to the microcontroller. The microcontroller processes the temperature data and determines whether the Peltier module needs to be activated or adjusted. If the battery temperature exceeds the predefined threshold, the microcontroller activates the Peltier module to initiate cooling. When activated, the Peltier module absorbs heat from the battery pack (cold side) and dissipates it into the environment (hot side) using heat sinks attached to a fan.

The relay acts as an electronic switch that controls the power supply to the Peltier module. It enables or disables the current flow to the cooling elements based on signals received from the microcontroller. The microcontroller processes real-time temperature data from sensors attached to the battery. When the temperature exceeds the predefined threshold, the microcontroller activates the relay. Once the battery temperature drops to a safe level, the microcontroller deactivates the relay, cutting off the power to the Peltier module. This automated control minimizes energy consumption and prevents overcooling.

The cooling effect reduces the battery temperature to within the desired range. The microcontroller communicates with the Blynk server over a wireless network, sending temperature data to the Blynk app, where it is displayed in real-time. Users can monitor the temperature and manually adjust the cooling parameters if necessary[4]. Automated alerts can be set up in the Blynk app to notify users if the battery temperature exceeds safe levels. The power supply ensures that the Peltier module and microcontroller receive consistent power, while voltage regulators maintain stable voltage levels to prevent fluctuations that could affect the system's performance.

Transfer unit

The transfer unit is responsible for collecting data from the battery and controlling the Peltier cooling modules. It includes temperature sensors, specifically DS18B20, which measure the battery temperature and send data to the microcontroller. The microcontroller (NodeMCU) processes the data from the temperature sensors and controls the relay that powers the Peltier module. The relay module acts as a switch to control the power supply to the Peltier module based on signals from the microcontroller, providing electrical isolation between the low-power control circuit and the high-power cooling circuit. The communication module, such as the Wi-Fi module built into the NodeMCU, enables wireless data transmission between the transfer unit and the receiving unit[19].

Receiving unit

The receiving unit receives data from the transfer unit, displays it to the user, and allows remote control of the cooling system. It includes an IoT platform, such as the Blynk app, which provides a user-friendly interface for real-time monitoring and control of the battery cooling system. Features of the app include temperature displays, control buttons, notifications, and alerts. A mobile device runs the IoT platform app, displaying data and controls and facilitating remote monitoring and control over the internet. [21].

The communication flow begins with sensors measuring the battery temperature and sending data to the microcontroller. The microcontroller processes the data and determines if the Peltier module needs to be activated or deactivated. If the temperature exceeds the threshold, the relay is activated to power the Peltier module. The microcontroller then sends the processed data to the receiving unit via the communication module. The receiving unit, such as the Blynk app, receives the data and displays it on the user interface. Users can send control commands from the Blynk app to the microcontroller to manually operate the relay and control the Peltier module.

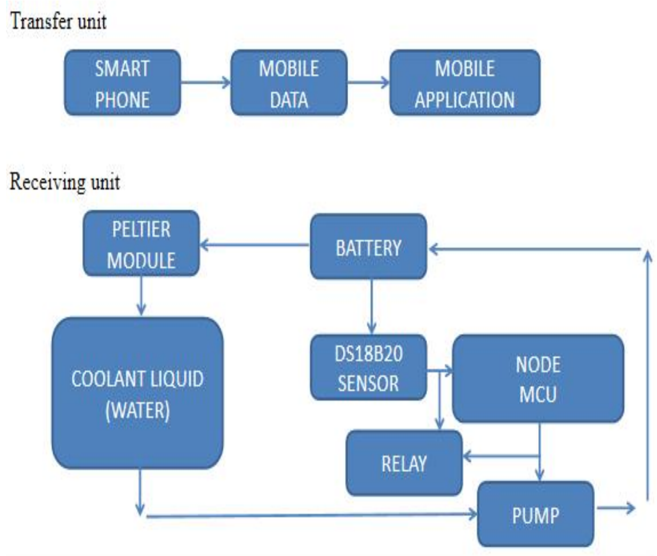


Fig.2. Functional block diagram For IoT based automatic battery cooling system

Results and Discussion

The experiments were conducted at an ambient temperature of 35°C for 20 minutes (1200 seconds). Temperature variations were measured every 2 minutes based on the following observations:

1) Temperature variation without Peltier cooling
2) Temperature variation with Peltier cooling

The temperature of the battery raises during discharging and also charging.

Temperature variation with and without Peltier cooling

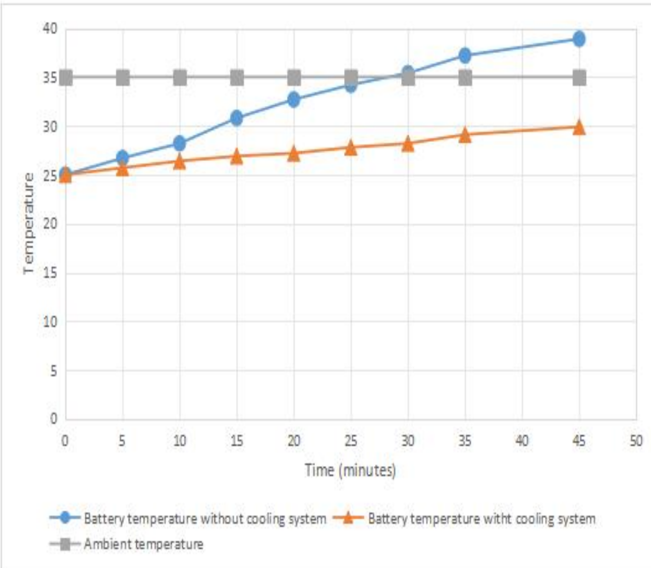


Fig.3. Temperature variation with and without Peltier cooling

Fig.3 shows the temperature variation of the battery with and without Peltier cooling. The temperature variation was observed over 45 minutes, starting from an initial temperature of 25°C. Without the cooling system, the battery temperature increased steadily from 25°C to a maximum of 39°C. This continuous rise in temperature was due to ambient heat. In contrast, with the Peltier cooling system activated, the temperature rise of the battery was significantly mitigated. The temperature remained between 25°C and a maximum of 30°C over the 45 minutes, which is expected to improve the battery's lifespan.

Voltage and Current Measurements Test

Time (minutes)	Battery Voltage(V)	Battery Current(A)
0	12.6	0
5	12.5	1
10	12.4	1.5
15	12.2	2
20	12.0	2.5
25	11.8	3
30	11.6	3.5
35	11.4	4
40	11.2	4.5
45	11	5

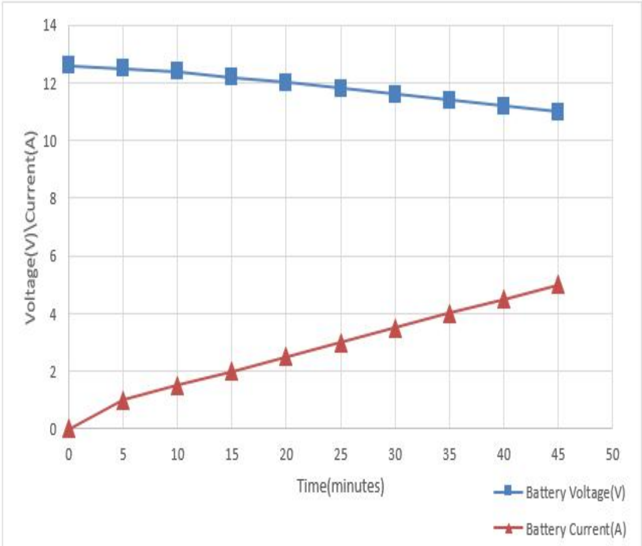


Fig.4. Voltage and Current Measurements Test chart

The voltage and current measurements test provides critical data on the electrical performance of the Peltier cooling system. Understanding power consumption and maintaining stable voltage levels are essential for optimizing the efficiency and effectiveness of the cooling solution.

Fig.4 shows the voltage and current measurements of the Peltier cooling system monitored over 45 minutes, starting from an initial temperature of 25°C. This test aims to evaluate the electrical performance and power consumption of the Peltier module during the cooling process. The voltage (V) ranges from 13.5 V to 11 V, indicating how consistently the power supply maintained the required voltage levels for the Peltier module. Significant fluctuations in voltage could affect cooling efficiency. The current (A) ranges from 0 A to 5 A, providing insight into the power drawn by the Peltier module. Monitoring the current helps assess overall energy consumption and identify any potential issues related to power usage.

Benefits of IoT

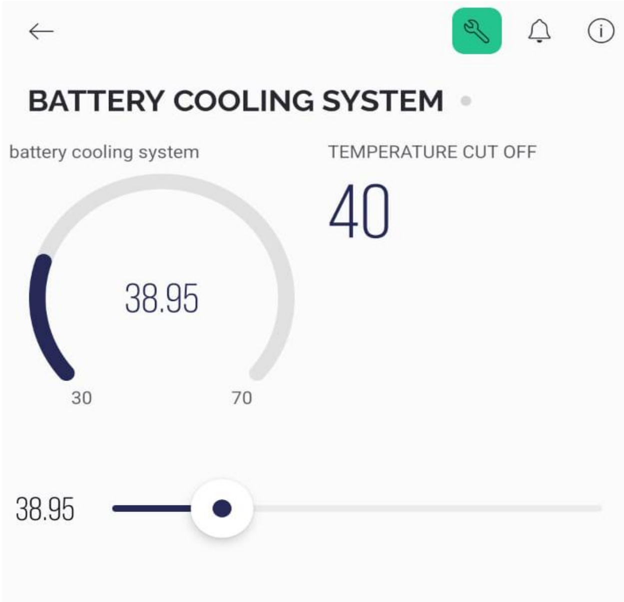


Fig.5. Blynk Software.

The IoT plays a crucial role in enhancing battery cooling systems by providing real-time monitoring, automated control, and advanced data analysis. IoT enables continuous, real-time tracking of battery temperature and other critical parameters through sensors that transmit data to a central platform. This allows for immediate detection of abnormal temperature rises, preventing potential damage or safety risks. The integration of IoT facilitates remote control, allowing users to manage the cooling system from a mobile device or computer, enabling manual adjustments or automated responses based on pre-set thresholds. Additionally, IoT systems collect and analyze historical data to identify trends and predict potential issues, supporting predictive maintenance and optimizing the overall performance and longevity of the battery. By leveraging these capabilities, IoT based battery cooling systems enhance efficiency, safety, and reliability, making them an invaluable component in modern energy management.

Integrating Blynk software into an IoT based automatic battery cooling system significantly enhances its functionality and user experience. Blynk provides a comprehensive and intuitive interface that allows users to monitor and control the cooling system in real-time from mobile devices or web dashboards. This remote accessibility ensures that users can efficiently manage the system, adjusting cooling settings and responding to temperature changes promptly. Blynk also supports automation, enabling the system to perform predefined actions, such as activating cooling mechanisms when temperatures exceed set thresholds. Additionally, Blynk's real-time data monitoring and alert features keep users informed of any anomalies or critical conditions, while data logging facilitates performance analysis and troubleshooting. Overall, Blynk's integration improves system efficiency, optimizes battery performance, and simplifies maintenance, making the battery cooling process more reliable and user-friendly.

Conclusion

The implementation of an IoT-based automatic battery cooling system represents a significant advancement in battery management and energy efficiency. This conclusion explores the benefits and implications of such a system. With IoT sensors continuously monitoring battery temperature and performance metrics, the cooling system can dynamically adjust cooling mechanisms to maintain an optimal operating temperature range. The temperature of the battery was maintained within the limit of 35-45°C. This proactive approach prevents overheating, a major cause of battery degradation, thereby extending battery life span and ensuring consistent performance over time.

The wealth of data provided by the system empowers users to make informed decisions regarding battery maintenance, replacement schedules, and overall system optimization. By precisely regulating battery temperature based on real-time conditions and usage patterns, the IoT-based cooling system minimizes energy consumption and reduces operating costs. Moreover, by preventing premature battery failure, the need for frequent replacements can be eliminated, saving both time and money in the long run.

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