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Development of Thermoelectric Power Generation with Safety System for Electric Vehicles using IOT Technology

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Abstract: Electric Vehicles (EVs) have emerged as a sustainable alternative to conventional transportation, but battery safety and energy efficiency remain critical challenges. This project presents the development of a Smart Safety System for EVs using Internet of Things (IoT) technology integrated with Thermoelectric Generator (TEG) modules. The system continuously monitors key battery parameters such as temperature, voltage, and current using sensors connected to an IoT-enabled microcontroller. Real-time data is transmitted to a cloud platform, allowing remote monitoring and instant alerts in case of abnormal conditions. When the battery temperature exceeds a predefined limit, automatic safety measures such as cooling activation and vehicle shutdown are triggered to prevent thermal runaway and fire hazards. Additionally, the TEG module converts waste heat generated from the battery into electrical energy, which is stored in a secondary battery to improve overall efficiency and extend vehicle range. This integrated approach enhances safety, optimizes energy utilization, and increases reliability, making it a cost-effective and scalable solution for modern electric vehicles.
Keywords: Electric Vehicle (EV), Internet of Things (IoT), Thermoelectric Generator (TEG), Battery Safety, Energy Efficiency etc.

I. INTRODUCTION

Electric Vehicles (EVs) are rapidly gaining importance as a sustainable and environmentally friendly mode of transportation. With increasing concerns over fossil fuel depletion and environmental pollution, EVs offer a cleaner alternative by reducing greenhouse gas emissions and dependence on conventional fuels [1]. However, despite these advantages, EVs face several technical challenges, particularly related to battery safety, thermal management, and energy efficiency. Lithium-ion batteries, commonly used in EVs, are highly sensitive to temperature variations and can pose serious risks such as overheating, thermal runaway, and even fire hazards under extreme conditions [2].

Effective battery management is therefore crucial to ensure the safe and reliable operation of electric vehicles. Traditional battery management systems primarily focus on monitoring parameters such as voltage and current but lack advanced capabilities like real-time remote monitoring and automatic safety response [3]. This limitation creates the need for intelligent systems that can continuously monitor battery health and take immediate corrective actions when abnormal conditions arise. The integration of Internet of Things (IoT) technology provides a promising solution by enabling real-time data acquisition, communication, and remote monitoring of EV battery systems [4].

IoT-based systems utilize sensors and microcontrollers to collect data and transmit it to cloud platforms, allowing users to monitor vehicle performance from anywhere. Such systems can provide early warnings and alerts in case of temperature rise or electrical faults, significantly reducing the risk of accidents [5]. Furthermore, IoT enables predictive maintenance by analyzing historical data and identifying potential issues before they become critical, thereby improving the lifespan and reliability of EV batteries [6].

Another major challenge in EV systems is the loss of energy in the form of heat generated during battery operation. A significant portion of electrical energy is dissipated as thermal energy, which is typically wasted and not utilized effectively [7]. Recovering this waste heat can improve overall energy efficiency and extend the driving range of electric vehicles. Thermoelectric Generators (TEGs) provide an effective method for converting heat energy into electrical energy based on the Seebeck effect [8]. When there is a temperature difference across the TEG module, it generates voltage that can be used to power auxiliary systems or recharge batteries.

Recent research has shown that integrating TEG modules into EV systems can enhance energy utilization and reduce heat-related losses [9].

However, most existing systems treat safety monitoring and energy recovery as separate functions, lacking a unified approach that combines both aspects. Additionally, there is limited research on systems that integrate IoT-based monitoring with thermoelectric energy generation in a compact and efficient design [10].

This project aims to address these challenges by developing a Smart Safety System for Electric Vehicles that integrates IoT-based monitoring with thermoelectric power generation. The proposed system continuously monitors battery parameters using sensors and processes the data through an IoT-enabled microcontroller. In case of abnormal conditions, automatic safety measures such as cooling activation and vehicle shutdown are triggered to prevent damage. Simultaneously, TEG modules capture waste heat from the battery and convert it into electrical energy, which is stored and reused.

By combining safety, monitoring, and energy recovery into a single system, this project offers a comprehensive solution to improve EV performance and reliability. The proposed design is compact, cost-effective, and scalable, making it suitable for various types of electric vehicles. Ultimately, this system contributes to safer and more efficient electric mobility, supporting the global transition toward sustainable transportation.

II. PROBLEM IDENTIFICATION

1) Electric Vehicle (EV) batteries are prone to overheating and thermal runaway, leading to serious safety risks such as fire and explosion.
2) Existing systems lack real-time monitoring and remote alert mechanisms, reducing the ability to respond quickly to faults.
3) Conventional battery management systems provide limited control actions, with no automatic shutdown or advanced protection features.
4) Significant waste heat generated during battery operation is not utilized, leading to energy loss and reduced efficiency.
5) Absence of integrated systems combining safety monitoring and energy recovery in EVs.
6) Lack of IoT-based intelligent platforms for continuous tracking and predictive maintenance.
7) Limited awareness and user interface systems to inform drivers about battery health conditions.
8) Need for a cost-effective, compact, and scalable solution for improving EV safety and performance.

III. LITERATURE SURVEY

A. Literature Review

Sharma et al. (2023) proposed an IoT-based battery monitoring system for electric vehicles to enhance safety and reliability. The system uses sensors to measure temperature, voltage, and current in real time. Data is transmitted to a cloud platform for analysis and visualization. In case of abnormal conditions such as overheating, the system sends alerts to users, helping prevent thermal runaway. The study highlights the importance of real-time monitoring and remote access in improving battery performance. It also demonstrates that IoT integration can significantly reduce risks associated with EV battery failures and improve maintenance strategies.

Kumar and Singh (2024) developed a smart thermal management system for EV batteries using IoT-based adaptive cooling techniques. The system monitors battery temperature continuously and adjusts cooling mechanisms accordingly. This approach ensures efficient heat dissipation and prevents overheating under varying load conditions. The integration of IoT enables real-time data processing and control, improving battery efficiency and lifespan. The study concludes that intelligent thermal management systems are essential for maintaining optimal battery performance and ensuring safety. Their work provides a scalable solution for enhancing EV reliability through automated temperature control.

Li et al. (2023) investigated thermoelectric energy harvesting from EV battery heat using TEG modules. The study demonstrated that temperature differences across the battery can be effectively utilized to generate electrical energy through the Seebeck effect. This generated energy can support auxiliary loads or recharge batteries, improving overall efficiency. Experimental results showed that integrating TEG modules reduces energy wastage and enhances system performance. The research emphasizes the importance of utilizing waste heat in EVs and highlights thermoelectric generation as a sustainable solution for improving energy utilization and extending vehicle range

Chen and Park (2022) focused on developing fire safety mechanisms for lithium-ion batteries in electric vehicles. The system uses temperature and gas sensors to detect early signs of overheating and potential fire hazards. Upon detection, automatic fire suppression systems are activated to prevent damage. The study highlights the importance of early detection and rapid response in minimizing battery-related risks. Results indicate that integrating fire safety systems significantly improves EV reliability and user safety. Their work contributes to the development of safer EV battery systems through automated protection techniques.

Ahmed et al. (2024) presented an IoT-based safety system for electric vehicles focusing on fault detection and monitoring. The system collects real-time data from multiple sensors and analyzes it using an IoT platform. It provides instant alerts for abnormal conditions such as temperature rise or electrical faults. The system also supports predictive maintenance by identifying potential failures in advance. The study demonstrates that IoT integration improves system efficiency, safety, and reliability. It emphasizes the role of smart technologies in transforming conventional EV safety systems into intelligent and automated solutions.

Patel and Deshmukh (2023) developed a thermoelectric-based waste heat recovery system for electric vehicles. The system uses TEG modules to convert heat generated by batteries into electrical energy. This recovered energy is utilized to power auxiliary systems, improving overall energy efficiency. The study analyzed different configurations to maximize output and found significant improvement in energy utilization. The authors concluded that integrating TEG systems can reduce energy loss and enhance EV performance. Their research supports the use of thermoelectric technology as a sustainable solution for energy recovery in EV applications.

Wang et al. (2024) proposed a cloud-based IoT platform for monitoring battery health in electric vehicles. The system collects data on temperature, voltage, and charging cycles and processes it using cloud computing. Machine learning techniques are used to predict battery performance and detect early signs of degradation. The platform allows remote monitoring and real-time visualization for users and manufacturers. The study shows that cloud-IoT integration enhances predictive maintenance and reduces operational risks. It highlights the importance of advanced analytics in improving EV battery management systems.

Gupta and Rao (2023) introduced an IoT-based control system to enhance safety in electric vehicles. The system continuously monitors battery parameters and automatically stops vehicle operation when unsafe conditions are detected. Real-time data transmission enables quick decision-making and improves system response time. The study demonstrates that automated control systems can significantly reduce accidents caused by overheating or electrical faults. It emphasizes the importance of integrating IoT technology for real-time monitoring and safety enhancement. Their work provides a practical approach to improving EV safety using smart control mechanisms.

Kim et al. (2022) developed a hybrid battery system combining self-cooling materials and thermoelectric generators. The system stabilizes battery temperature while simultaneously generating electrical energy from heat. Experimental results showed reduced thermal stress and improved energy efficiency. The integration of cooling and energy harvesting enhances battery performance and lifespan. The study highlights the potential of combining multiple technologies to address both safety and efficiency challenges in EVs. Their research contributes to the development of advanced battery systems with improved thermal management and energy utilization capabilities.

Mehta and Banerjee (2024) proposed an AI and IoT-based safety framework for electric vehicles. The system uses artificial intelligence to analyze sensor data and predict potential faults in battery systems. IoT connectivity enables real-time monitoring and communication. When abnormalities are detected, preventive actions such as cooling activation or system shutdown are triggered. The study demonstrates improved accuracy and response time compared to traditional methods. It highlights the effectiveness of combining AI and IoT for developing intelligent safety systems. Their work supports the advancement of smart and autonomous EV technologies.

B. Literature Summary

The reviewed literature highlights significant advancements in electric vehicle (EV) safety, thermal management, and energy efficiency. Many researchers have focused on IoT-based battery monitoring systems that provide real-time data and alerts to prevent overheating and improve reliability. Studies also emphasize smart thermal management techniques, including adaptive cooling systems to maintain optimal battery temperature. Additionally, research on thermoelectric generators (TEGs) demonstrates the potential to convert waste heat into useful electrical energy, enhancing overall efficiency. Fire detection and suppression mechanisms further contribute to improving EV safety. Integration of cloud computing, AI, and IoT has enabled predictive maintenance and intelligent decision-making. However, most studies address these aspects individually rather than as a unified system. Overall, the literature confirms the importance of combining monitoring, safety, and energy recovery technologies for developing advanced and reliable EV systems.

C. Research Gap

Despite advancements in EV safety and energy systems, several gaps remain in current research. Most existing studies focus on either battery monitoring, thermal management, or energy recovery independently, lacking an integrated approach. Limited work has been done on combining IoT-based real-time monitoring with thermoelectric energy generation in a single system.

Additionally, many systems provide alerts but lack automatic safety actions such as vehicle shutdown or active cooling mechanisms. The efficiency of TEG modules in EV applications is still underexplored, particularly in compact and practical designs. There is also a lack of cost-effective and scalable solutions suitable for commercial implementation. Furthermore, integration of user-friendly interfaces and remote monitoring platforms is insufficient. Therefore, there is a need for a unified system that ensures safety, improves efficiency, and utilizes waste heat effectively in electric vehicles.

IV. METHODOLOGY

A. *Proposed System*

1) *Sensing and Monitoring:* Temperature, voltage, and current sensors are placed across the EV battery pack to continuously monitor its thermal and electrical status.
2) IoT Connectivity: All sensor data is transmitted in real-time to an IoT-enabled microcontroller (ESP32), which logs and analyzes parameters through an IoT dashboard or mobile app.
3) Thermoelectric Power Generation: When the battery heats up during charging or operation, the Thermoelectric Generator (TEG) module absorbs this heat energy. Through the Seebeck effect, it converts the temperature difference into electrical voltage

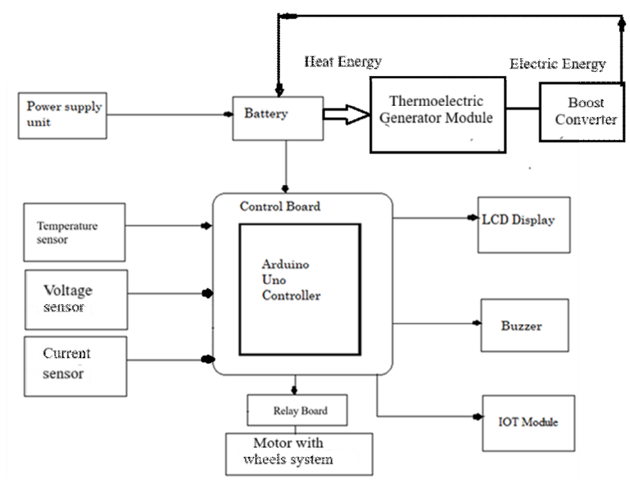

Figure 1. Proposed System

4) Energy Storage: The generated electrical energy from the TEG module is stored in a secondary lithium battery, which can support the EV's main battery, enhancing overall vehicle efficiency and driving range.
5) Automatic Safety Response: If the temperature crosses the critical limit, the system automatically activates high-speed cooling fans or fire suppression mechanisms. The vehicle is halted, and the driver receives an alert through IoT notifications and display messages.
6) System Recovery: Once the temperature stabilizes, the system resumes normal operation, ensuring both thermal management and safety with improved energy recovery

B. *Main Features*

1) Real-Time Monitoring: Continuously tracks battery parameters such as temperature, voltage, and current for accurate system analysis.
2) IoT Connectivity: Enables remote monitoring and control through mobile or web-based applications using Wi-Fi-enabled microcontroller.
3) Automatic Safety Mechanism: Activates cooling fans and triggers vehicle shutdown when temperature exceeds safe limits to prevent thermal runaway.
4) Fire Hazard Prevention: Detects abnormal thermal conditions early and provides alerts to avoid battery fire risks.
5) Thermoelectric Power Generation: Utilizes TEG modules to convert waste heat from the battery into electrical energy.
6) Energy Recovery System: Stores generated energy in a secondary battery to enhance overall efficiency and vehicle range.
7) User Alerts and Notifications: Sends real-time alerts and warnings through IoT platforms and buzzer systems.

8) LCD Display Interface: Displays live system data including temperature, voltage, and safety status.
9) Compact and Scalable Design: Easily integrates into different types of electric vehicles without affecting performance.
10) Low Maintenance System: Requires minimal servicing due to automated operation and robust component design.

C. Hardware Used

1) Microcontroller (Arduino uno 328p): Acts as the main control unit with built-in Wi-Fi for IoT connectivity and real-time data processing.
2) Temperature Sensors (LM35): Measure battery temperature continuously to detect overheating conditions.
3) Voltage Sensor Module: Monitors battery voltage levels to ensure proper operation and detect abnormalities.
4) Current Sensor (ACS712): Measures current flow in the battery system for performance and safety analysis.
5) Thermoelectric Generator (TEG Module): Converts waste heat from the battery into electrical energy using the Seebeck effect.
6) Cooling Fan: Automatically activated to dissipate excess heat when temperature exceeds safe limits.
7) Relay Module: Controls switching operations such as activating cooling systems or stopping the vehicle during critical conditions.
8) Lithium-Ion Battery: Stores generated electrical energy and powers the system.
9) LCD Display (16x2): Displays real-time system parameters such as temperature, voltage, and alerts.
10) Buzzer/Alarm: Provides audible warning signals during unsafe conditions.
11) Power Supply Unit: Supplies regulated power to all system components.

D. Software Used

1) Arduino IDE: For programming microcontroller functions and interfacing sensors.
2) Embedded C: Used as the primary coding language for hardware control.
3) Cloud Platform (Thingspeak): Stores and visualizes patient health data remotely.
4) Mobile server: Provides doctors with real-time access to patient data.
5) Data Analytics Tools: Support trend analysis and report generation for better insights.

V. ADVANTAGES

1) Provides real-time monitoring of EV battery temperature, voltage, and current through IoT integration.
2) Enhances vehicle safety by automatically activating cooling or fire suppression during overheating.
3) Converts waste heat into electrical energy using thermoelectric generator (TEG) modules, improving energy efficiency.
4) Extends battery lifespan by maintaining optimal thermal conditions and preventing thermal runaway.
5) Offers remote alerts and data access through mobile or web-based IoT platforms.
6) Improves vehicle range by supplementing battery charge with recovered energy.
7) Compact, low-maintenance, and cost-effective design suitable for integration into various EV models.

VI. APPLICATION

1) Can be integrated into electric cars, bikes, and buses to improve battery safety and efficiency.
2) Useful for battery research laboratories to test and monitor battery performance under various conditions.
3) Applicable in industrial EV fleets for continuous monitoring and predictive maintenance.
4) Suitable for smart charging stations to analyze and control battery temperature during fast charging.
5) Can be used in hybrid vehicles for waste heat recovery and performance optimization.
6) Supports IoT-based smart transport systems by enabling real-time vehicle health tracking and safety analytics.
7) Ideal for prototype EV development and academic research projects.

VII. RESULTS AND DISCUSSION

The developed Smart Safety System for Electric Vehicles was tested under different operating conditions to evaluate its performance in terms of temperature monitoring, safety response, and thermoelectric power generation. The results demonstrate that the system effectively ensures battery safety while also recovering useful energy from waste heat.

Initially, the system was tested under normal operating conditions. The temperature sensors continuously monitored battery temperature, and the IoT platform displayed real-time data accurately.

The readings remained within safe limits, and no safety mechanism was triggered. At the same time, the Thermoelectric Generator (TEG) module started producing small amounts of electrical energy due to the temperature difference between the battery surface and the surroundings.

As the load on the battery increased, the temperature gradually rose. The system responded efficiently by updating data in real-time on the IoT dashboard. When the temperature approached the threshold limit, the cooling fan was automatically activated. This prevented further temperature rise and maintained system stability.

In critical conditions, when the temperature exceeded the predefined safety limit, the system successfully triggered multiple safety actions, including vehicle shutdown, buzzer alert, and notification through IoT platform. This proves that the system can effectively prevent thermal runaway and fire hazards.

Simultaneously, the TEG module showed improved performance at higher temperatures. The generated voltage increased with temperature difference, demonstrating that waste heat can be converted into useful electrical energy. Although the generated power is relatively small, it contributes to auxiliary power support and improves overall system efficiency.

Table 1: Temperature vs System Response.

Sr. No.	Temperature (°C)	System Status	Cooling Fan	Vehicle Status
1	30	Normal	OFF	Running
2	35	Normal	OFF	Running
3	40	Moderate	ON	Running
4	45	Warning	ON	Running
5	50	Critical	ON	Stopped

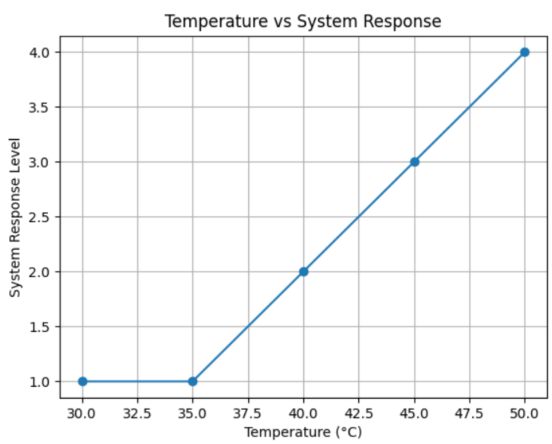

Figure 2. Temperature vs System Response

From Table 1, it is observed that the system operates normally up to 35°C. At 40°C, the cooling fan activates automatically, indicating proactive thermal management. At 50°C, the system enters critical mode and stops the vehicle to prevent damage. This demonstrates the system's automatic safety response capability.

Table 2: Temperature vs TEG Output Voltage

Sr. No.	Temperature (°C)	TEG Voltage (V)	Power Generation Status
1	30	0.5	Low
2	35	0.8	Moderate
3	40	1.2	Medium
4	45	1.8	High
5	50	2.5	Very High

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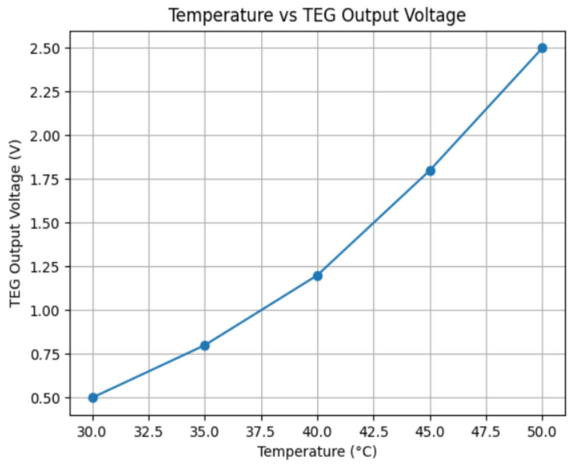

Figure 3. Temperature vs TEG Output Voltage

Table 2 shows that the TEG output voltage increases as battery temperature rises. At 30°C, the voltage is minimal, while at 50°C, it reaches a peak value of 2.5V. This confirms that thermoelectric generation is directly proportional to temperature difference. The recovered energy can be stored and reused, improving efficiency.

The experimental results confirm that the proposed system performs efficiently in both safety enhancement and energy recovery. The IoT-based monitoring ensures real-time tracking of battery conditions, allowing users to access system data remotely. This improves awareness and enables quick action in case of abnormalities.

The automatic cooling mechanism plays a crucial role in maintaining optimal battery temperature. Unlike traditional systems that rely on manual intervention, this system responds instantly, reducing the risk of overheating. The inclusion of vehicle shutdown in critical conditions adds an extra layer of protection, ensuring passenger safety.

Another important aspect of the system is thermoelectric power generation. Although the generated energy is not sufficient to fully charge the battery, it provides supplementary power that can be used for low-power applications or stored for future use. This contributes to improved energy utilization and reduces overall power loss.

The integration of IoT, safety mechanisms, and energy recovery into a single system makes this project unique. Compared to existing systems, which focus only on monitoring or cooling, this system provides a comprehensive solution.

However, there are some limitations. The efficiency of TEG modules is relatively low, and the amount of generated power depends on temperature difference. Additionally, the system requires proper calibration to ensure accurate sensor readings.

Despite these limitations, the system demonstrates significant improvements in EV safety and efficiency. With further enhancements such as AI-based prediction and high-efficiency TEG materials, the system can be made more effective.

The results clearly indicate that the proposed system successfully achieves its objectives of enhancing battery safety, enabling real-time monitoring, and recovering waste heat energy. The system is reliable, efficient, and suitable for practical implementation in modern electric vehicles

VIII. CONCLUSION

The developed Smart Safety System for Electric Vehicles successfully addresses critical challenges related to battery safety, thermal management, and energy efficiency. By integrating IoT technology with advanced sensors, the system enables continuous real-time monitoring of battery parameters such as temperature, voltage, and current. This ensures early detection of abnormal conditions and allows immediate preventive actions, including automatic cooling and vehicle shutdown, thereby reducing the risk of thermal runaway and fire hazards.

Additionally, the incorporation of Thermoelectric Generator (TEG) modules provides an innovative approach to utilizing waste heat energy. The system effectively converts excess battery heat into electrical energy, which can be stored and reused, contributing to improved energy efficiency and extended vehicle range.

The results demonstrate that the system is reliable, responsive, and capable of enhancing overall EV performance. Its compact design and low maintenance requirements make it suitable for practical implementation. Overall, this project contributes to the development of safer, smarter, and more sustainable electric vehicles, supporting the future of green transportation.

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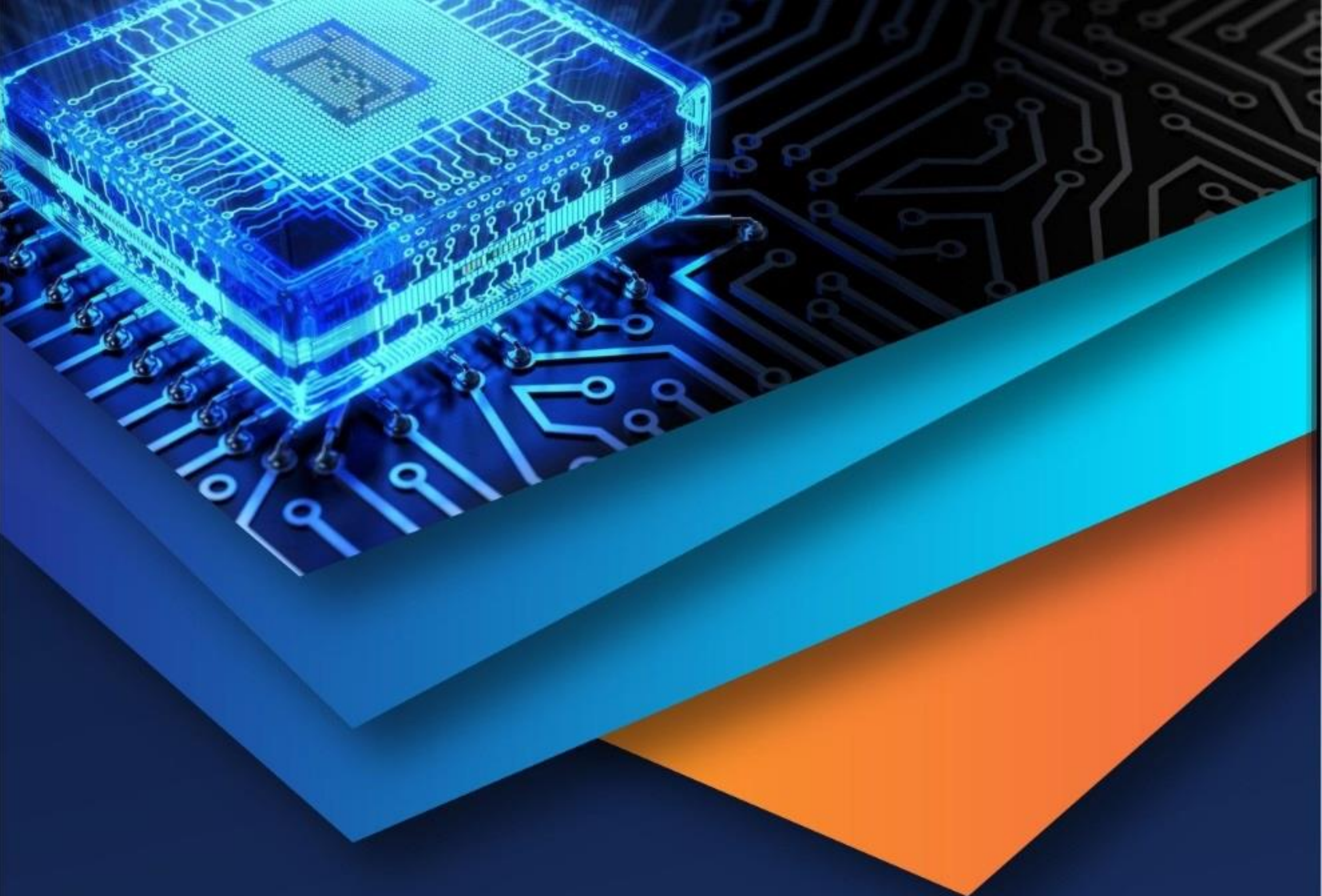

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