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Solar-Based Smart Charging Station with Wireless Power Transfer (WPT) for Electric Vehicles and Monitoring using IoT

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Abstract: Solar-Powered Smart Charging Station with Wireless power transfer (wpt) for EV and monitoring it by IoT presents a hassle-free EV charging solution by combining solar power with wireless charging technology. The system gets maximized by utilizing solar energy and the grid supply as a backup to provide continuous operation. Wireless charging does away with physical connectors by delivering energy through inductive coupling between coils. It includes RFID-enabled secure payment and access, enabling users to program charging by desired units. It has an LCD front panel that reports real-time data such as output voltage and payment status. Integrated sensors for fault detection and regulated DC-to-DC converters ensure safety through stable energy supply. Automatic switching of sources adds to the reliability. The system brings together energy efficiency, sustainability, and convenience of use, furthering the development of smart and green EV infrastructure.

Index Terms: Solar energy, wireless power transfer, electric vehicles, smart charging, RFID authentication, inductive coupling, IoT, DC-DC converters, fault detection, automated switching.

I. INTRODUCTION

The growing demand for Electric Vehicles (EVs) as environmentally friendly substitutes for internal combustion engine vehicles has greatly increased the need for sophisticated charging infrastructure. Of the solutions becoming prominent, solar power is notable based on its abundance, renewability, and eco-friendly nature. Applying solar power in EV charging responds to the most pressing issues like dependence on fossil fuels and increasing carbon emissions. While governments and industries encourage clean energy shifts, solar technology integrated into transportation systems becomes a strategic and environmental necessity. Evolution of green EV infrastructure is no longer a choice but a necessity to achieve climate objectives and energy efficiency criteria. This has prompted the search for hybrid energy models maximizing both solar and grid-sourced power sources. This project proposes a Solar-Based Smart Charging Station with Wireless Power Transfer (WPT) to upgrade the existing EV charging status quo. It harvests solar power as the main power input with traditional grid electricity as a fallback, providing reliable system operation. Wireless charging based on inductive coupling eliminates physical connectors, which enhance ease of use and system longevity. The design incorporates intelligent features like RFID-based access, real-time user interfaces, and power source switchover while charging automatically. These features, in combination, ensure hassle-free and intelligent charging. The integration of renewable energy, contactless charge, and digital control is the foundation of a revolutionary and efficient solution.

Conventional EV charging points impose a heavy burden on the electrical grid and, as a result, cause inefficiencies and sustainability issues. Solar-powered options notably reduce this burden while providing emission-free power generation. Intelligent integration of energy management and monitoring systems provides optimized function, with greater user interaction and energy savings. In addition, wireless charging introduces a safety and convenience aspect through the removal of cable risk and ease of user interaction. Overall, these developments individually contribute to the development of EV infrastructure towards intelligent, greener, and more robust systems. Thus, the system proposed is in line with international endeavors to implement sustainable, high-performance technology in transportation.

II. LITERATURE SURVEY

The study by M. N. V. S. Aditya, P. V. R. Krishna, and V. V. S. S. Chakravarthy [1] investigates a solar-powered wireless charging station for electric vehicles (EVs) with integrated IoT for real-time monitoring. The system utilizes photovoltaic (PV) panels and resonant inductive charging to provide power efficiently. IoT sensors monitor battery health, solar power, and charging efficiency, with data going to a cloud platform for analysis.

The prototype has an 85% charge efficiency in ideal conditions. The study, though, cites scalability issues arising from the high cost of installation, thus calling for cost-efficient solutions that will facilitate mass adoption.

The study by V. Sharma, A. Kumar, and R. Singh [2] introduces an IoT-enabled solar power monitoring and wireless charging system designed for smart cities. The system incorporates Maximum Power Point Tracking (MPPT) algorithms to optimize solar energy harvesting and employs LoRaWAN for low-power, long-range data communication. It reports a 20% improvement in energy efficiency compared to conventional systems. However, the system faces limitations in IoT network reliability in urban environments with high interference, suggesting a need for enhanced network stability.

The work by S. Patil, P. Desai, and K. Patel [3] is on a solar-powered wireless charging system for IoT devices with blockchain for secure trading of energy. The system is based on the utilization of solar panels to charge a wireless charging pad, while IoT sensors regulate energy use. Blockchain provides secure energy transactions with a 90% efficiency in the transfer of energy. The work presents challenges in scalabilty using blockchain and excessive computation costs for IoT devices as areas for further optimization.

The paper by R. Gupta, S. Mishra, and A. Jain [4] is a real-time monitoring system for solar-powered wireless power transfer via IoT and machine learning (ML). It uses ML algorithms to forecast solar output and charge schedules optimization, and IoT sensors record data on environmental conditions and power transfer efficiency. It realizes a 15% increase in energy utilization but demands high internet connectivity, which is challenging in remote locations with limited network coverage.

A. K. Yadav, P. K. Singh, and M. Kumar [5] describe a solar-powered wireless charging facility for EVs with remote monitoring using IoT-based monitoring. The system uses solar panels and battery storage for power supply, while the power is made accessible through IoT modules to access it remotely through a mobile app. It saves energy loss up to 10% but has a high cost of maintenance, for which cost-effective maintenance approaches are needed.

The study by N. Reddy, S. K. Sharma, and V. Kumar [6] suggests an IoT-based solar wireless charging station energy management system. IoT sensors and cloud-based analytics optimize power distribution, resulting in a 12% boost in energy efficiency with dynamic load balancing. Areas of difficulty are integrating various IoT protocols and maintaining data security, indicating the necessity for standardized protocols and strong security systems.

P. S. Rao, A. Sharma, and R. K. Gupta [7] discuss a solar-powered wireless charging system for IoT-enabled smart homes. The system charges wireless charging pads for home devices, with IoT monitoring of energy consumption and system health, with an 88% charging efficiency. It has limitations in solar panel output during conditions of low sunlight levels, suggesting the need for better energy storage solutions.

The study by K. S. Lee, J. H. Park, and S. H. Kim [8] outlines a cloud-monitoring solar-powered IoT device wireless power transfer system. The system minimizes energy wastage by 25% via resonant coupling. Stabilized cloud connectivity in rural areas is still an issue, which highlights the need for robust network infrastructure.

A. V. Nair, S. Thomas, and P. R. Menon's research [9] discusses a solar-powered wireless charging system with IoT and AI for predictive maintenance. AI is utilized to predict the failures of components, decreasing downtime by 30%, with IoT sensors tracking solar panel performance and the efficiency of charging. High upfront costs and extensive AI training data requirements are cited as weaknesses, recommending cost-cutting and efficiency in data.

The paper by S. M. Ali, F. Ahmad, and M. A. Khan [10] suggests an IoT-based solar wireless charging system with energy harvesting optimized. With the help of advanced MPPT technology and IoT for real-time monitoring, the system is able to ensure a 22% higher energy efficiency. Drawbacks are hardware compatibility and cost, which suggest standardized components and low-cost designs.

The work of R. K. Mishra, A. K. Singh, and P. Sharma [11] introduces a solar-powered wireless charging station with IoT-based fault detection. The system detects faults in real-time using sensors, enhancing reliability by 15%. Scalability is constrained by the high cost of deploying sensors, and affordable sensor technologies are thus needed.

III. PROBLEM IDENTIFICATION

Unsustainable and Inconvenient Charging Infrastructure: Traditional grid-dependent EV charging stations contribute to carbon emissions, strain power grids, and lack user-friendly features like wireless charging and renewable energy integration, limiting sustainability, scalability, and convenience.

IV. OBJECTIVES

1) Design a charging station that prioritizes solar energy with mains electricity as a reliable backup.
2) Enable seamless, cable-free charging using advanced WPT technology.
3) Implement RFID-based payment and customizable charging options for user convenience.

4) Provide an LCD interface for monitoring charging data and integrate sensors for fault detection and battery safety.
5) Send Battery Temperature, Number of vehicles charged per day information to cloud.

V. METHODOLOGY

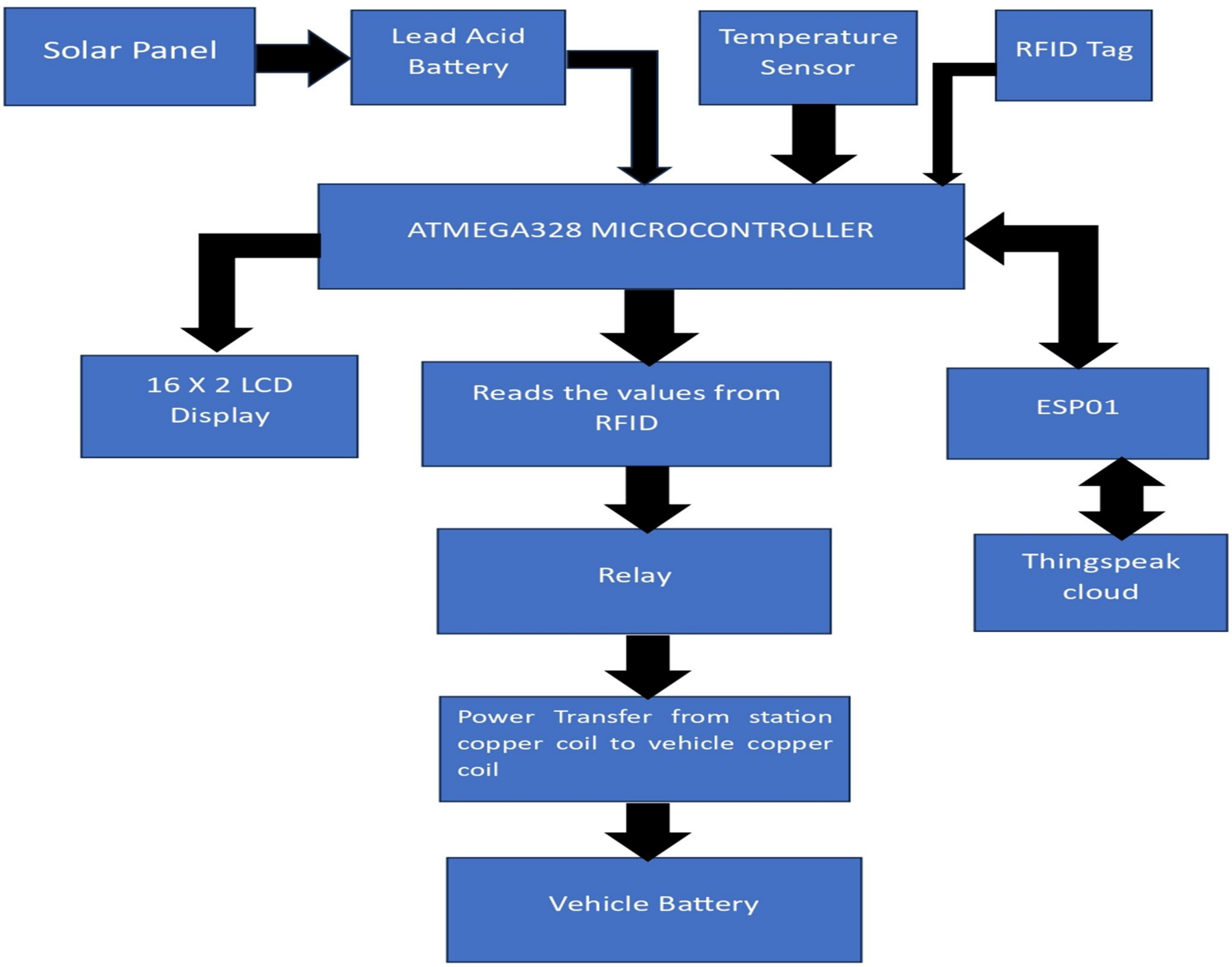

Fig 1: Block Diagram

It is based on the central processing unit represented by the microcontroller ATmega328, which collects data from sensors, controls relays, processes user authentication, interacts with the display, and communicates over the cloud. In this work, solar panels are used as the primary energy source, whose voltages are continuously monitored through the microcontroller's ADC channels. A lead-acid battery acts as a repository of excess solar energy and supplies power during periods of low sunlight. Voltage levels from both solar and battery sources are processed to determine the appropriate charging mode.

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For secured user access, one EM-18 RFID reader is interfaced with the controller; thus, it authenticates the vehicle for the initiation of charging. The microcontroller triggers the 12 V relay upon the detection of a valid RFID tag. This allows the initiation of wireless power transfer via the transmitter coil. Wireless charging makes use of the principle of inductive coupling that facilitates the wire-free flow of energy to the EV's receiving coil. A 16×2 LCD shows voltage, authentication, and charging information in real time.
An ESP-01 Wi-Fi module, which enables smart monitoring, sends the essential parameters like battery temperature and number of vehicles charged per day to the ThingSpeak cloud for remote supervision. In the microcontroller, sensor readings are constantly matched with threshold values for safe charging and fault detection. The methodology ensures smooth coordination between hardware and software components, resulting in an automated, sustainable, and user-friendly EV charging system.

VI. HARDWARE COMPONENTS

1) ATmega328 Microcontroller
2) Solar Panel
3) 16x2 LCD Display
4) RFID Reader & Tags
5) ESP-01 Wi-Fi Module
6) Temperature Sensor
7) Wireless Charging Unit
8) Relay
9) 12v Battery

VII. SOFTWARE USED

1) Embedded C
2) Arduino IDE
3) Thingspeak Cloud

VIII. RESULT

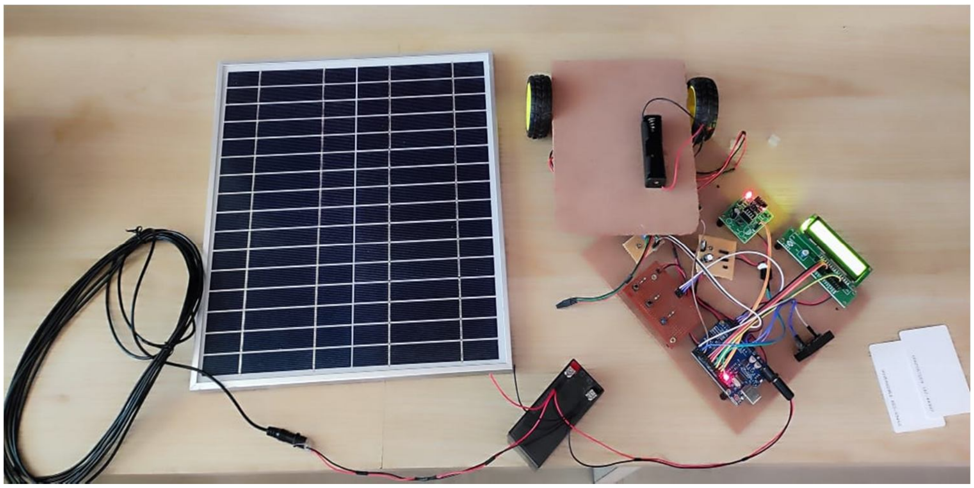

Fig 2: Image of the project

The developed solar-based smart wireless charging for electric vehicles successfully demonstrated the integrated approach toward sustainable and automated EV charging. The prototype worked reliably for different operating conditions, validating the efficacy of each subsystem. The solar panel generates adequate voltage in daylight, while the lead-acid battery provides uninterrupted backup power to ensure continuity in system operation even during low sunlight conditions. Voltage readings from both sources are accurately captured by the ATmega328 and displayed in real time on the 16×2 LCD, confirming stable sensor interfacing and ADC functionality.

The RFID module operates with a high degree of precision, permitting only the authenticated user to trigger the charging. The access, therefore, is secure, and it blocks unauthorized energy utilization. The 12V relay switches over neatly to charging states, while the inductive coil setup delivers wireless power transfer for short-range EV charging and proves the working principle of contactless energy delivery. The buzzer feedback enhances user interaction by signaling valid scans, charging start, and charging completion.

IoT integration is implemented using the ESP-01 module. In this regard, the Battery Temperature, Solar Voltage, and Day Count of Charging have been uploaded without failure to the ThingSpeak cloud. Cloud Dashboard demonstrates data points with proper timestamping, thus assuring reliable Wi-Fi communication and remote monitoring. Overall, it functions as an intelligent charging unit, fusing renewable energy, embedded automation, wireless transfer, and secure authentication in one practical prototype. That also proves the potentiality of the project in real-life modern EV infrastructure.

Fig 3: Demonstration of transaction taking place

User authentication via the EM-18 RFID reader initiates a transaction in the smart wireless EV charging system. Upon the arrival of the vehicle at the charging spot, the user taps the RFID tag near the reader. The ATmega328 microcontroller validates the tag by matching the unique ID against the stored database. If the tag is valid, the system grants permission to charge and switches on the relay powering the wireless charging coils. A buzzer confirms the successful authentication, with the LCD displaying the user status and charging initialization.

Throughout the charging process, the microcontroller continually monitors voltage, battery temperature, and charging time. These parameters enable the calculation of total energy consumed. The controller calculates the final cost of charging when the charging session is complete-either the user removes the vehicle or the system detects a full charge-based on predefined units or time-based rates. This final amount is displayed on the LCD for clarity to the user.

After the amount appears on the display, the user proceeds with his or her payment. As per the proposed model, the payment may be made through a linked RFID account, mobile application, or digital gateway. After successful confirmation of payment, the system updates the usage record, uploads session data to ThingSpeak via ESP-01, and resets itself for the next user. User authentication via the EM-18 RFID reader initiates a transaction in the smart wireless EV charging system. Upon the arrival of the vehicle at the charging spot, the user taps the RFID tag near the reader. The ATmega328 microcontroller validates the tag by matching the unique ID against the stored database. If the tag is valid, the system grants permission to charge and switches on the relay powering the wireless charging coils. A buzzer confirms the successful authentication, with the LCD displaying the user status and charging initialization. Throughout the charging process, the microcontroller continually monitors voltage, battery temperature, and charging time. These parameters enable the calculation of total energy consumed. The controller calculates the final cost of charging when the charging session is complete-either the user removes the vehicle or the system detects a full charge-based on predefined units or time-based rates. This final amount is displayed on the LCD for clarity to the user.

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IX. APPLICATIONS

1) Electric Vehicle Charging in Remote Regions: The system can be installed in rural or off-grid locations where conventional power infrastructure is not present. Solar power provides uninterrupted power, and wireless charging makes it convenient.
2) Smart City Infrastructure: Combined with IoT, it can be a part of smart city infrastructures by facilitating real-time monitoring, fault detection, and usage analytics to manage energy efficiently and plan accordingly.
3) Fleet Management for Government and Private Sectors: Government transport (such as e-buses) or logistics organizations can utilize this system to monitor and control energy consumption, plan maintenance, and remotely monitor the charging status through IoT.
4) Residential and Commercial EV Stations: Can be installed at houses, apartments, offices, and commercial parking lots to offer convenient, green charging to residents or workers.
5) Universities and Tech Parks: Colleges and campuses encouraging green energy can utilize this as a green charging infrastructure for electric bikes, scooters, or cars of employees and students.
6) Disaster Relief and Military Camps: Because it's not dependent on the power grid, this system is well-suited for disaster areas or temporary camps, providing clean power and wireless EV support without having to install much.

X. CONCLUSIONS AND FUTURE SCOPE

The combination of solar power, wireless charging, and IoT monitoring technologies within electric vehicle (EV) charging stations offers a viable and futuristic solution to contemporary transportation needs. The project clearly showcases how clean renewable solar energy can be used to charge EVs without a direct plug-in option, thus simplifying the process for users and improving efficiency. The IoT module provides substantial value through real-time monitoring of system parameters including charging status, voltage levels, and fault detection, enhancing both safety and performance. As a whole, this system minimizes fossil fuel dependence, decreases greenhouse gas emissions, and optimizes energy efficiency, totally in sync with the world's move toward cleaner technologies. In the future, this project may be developed further by installing dynamic wireless charging (charging on the go), AI-driven energy management, and blockchain-based secure payment systems. The addition of fast charging capacities, vehicle-to-grid (V2G) integration, and machine learning algorithms for predictive maintenance can make it even more efficient and smarter. Also, scaling up the design to accommodate multiple EVs in unison and linking the data to a cloud-based centralized dashboard for smart city connectivity will enable large-scale deployment in global public and private infrastructures.

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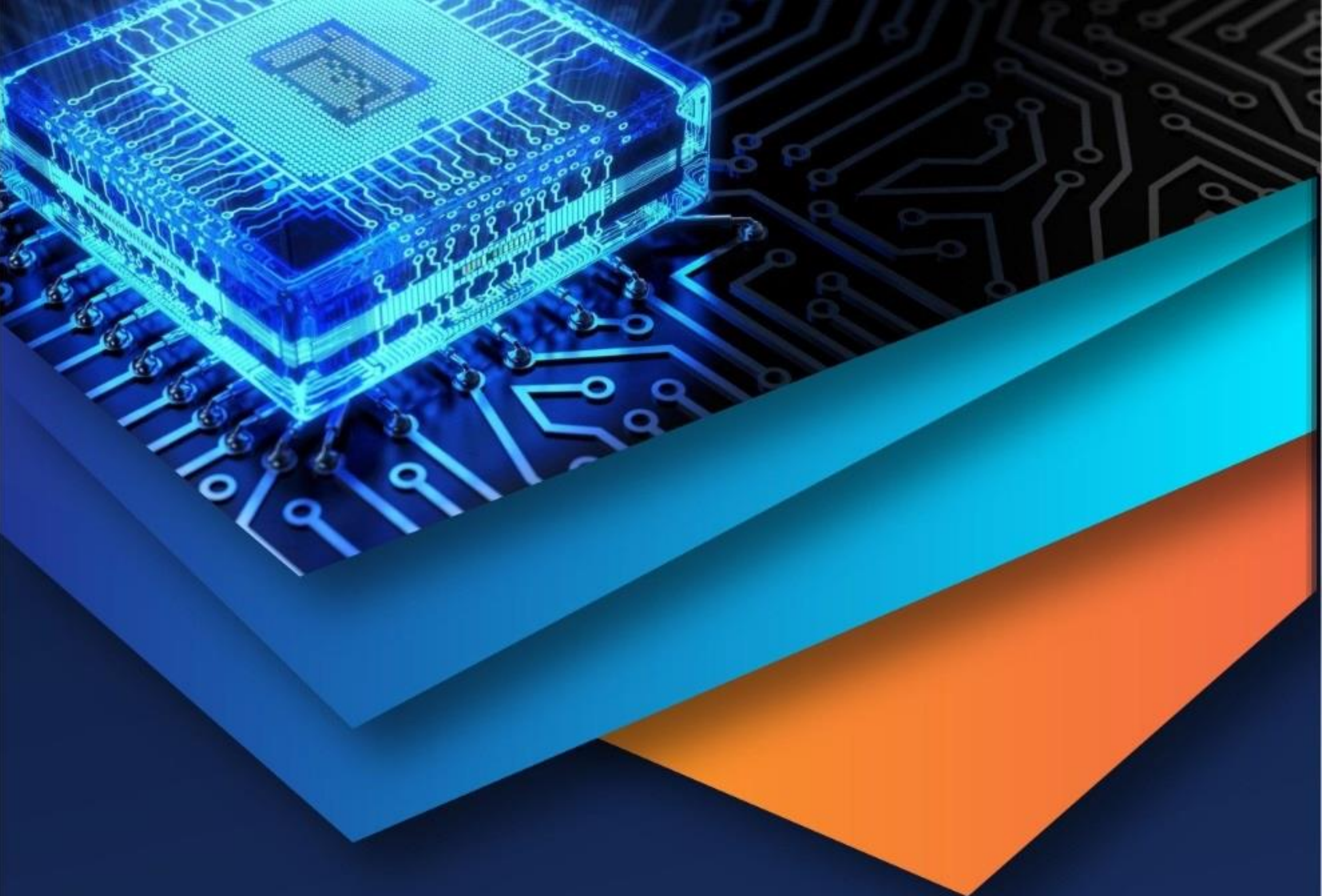

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