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Integration of Wireless Charging Into Road Networks for Electrical Vehicles

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***Abstract:** As the adoption of electric vehicles (EVs) continues to accelerate globally, there is a growing demand for efficient, sustainable, and user-friendly charging technologies. Traditional wired charging systems face several challenges, including cable wear and tear, limited mobility, and reliance on grid electricity, which often leads to higher carbon emissions. To overcome these limitations, this paper proposes a Solar-Powered Wireless Electricity EV Charging System that combines the benefits of renewable energy and contactless power transfer. The proposed system utilizes solar panels to harness solar energy, converting it into electrical power using photovoltaic effects. This energy is then managed and conditioned through power electronics and boost converters to generate the appropriate voltage required for efficient wireless transmission. The wireless charging mechanism is based on electromagnetic induction or resonant inductive coupling, using a transmitter and receiver coil pair to deliver power to the vehicle without physical connectors. A battery storage unit is incorporated to store excess solar energy for use during periods of low sunlight, enhancing the system's reliability and energy independence. A microcontroller (Arduino Nano) manages the overall operation, including power regulation, safety features, and system diagnostics. Additional components such as LCD displays, LED indicators, and charge controllers are integrated for user interaction and real-time monitoring. The entire system is programmed and monitored using the Arduino IDE, ensuring ease of development and customization. This wireless and solar-integrated charging approach not only improves user convenience by eliminating cables but also promotes environmental sustainability by reducing dependence on fossil fuels. With applications ranging from residential installations to public charging infrastructure and fleet services, this system represents a significant step toward greener and smarter transportation solutions.*
***Keywords:** Wireless Power Transfer, Inductive Charging, Dynamic Wireless Charging, Static Wireless Charging, Inductive Coupling.*

I. INTRODUCTION

The rapid transition towards electric vehicles (EVs) has become a cornerstone in the global effort to reduce greenhouse gas emissions and combat climate change. As EV adoption accelerates, the need for efficient, reliable, and environmentally sustainable charging infrastructure becomes increasingly critical. Traditional wired charging systems, while effective, pose several challenges such as the risk of cable damage, maintenance costs, limited accessibility, and safety concerns related to exposed connectors and high-current lines. These drawbacks can hinder the scalability and convenience of EV charging, especially in public or high-traffic environments.

In this context, wireless EV charging systems present a revolutionary approach, offering cable-free convenience, reduced wear and tear, and greater flexibility in deployment. When combined with solar energy harvesting, these systems provide a self-sustaining, off-grid solution that not only addresses energy efficiency but also promotes environmental sustainability. By leveraging solar panels to generate renewable electricity and wireless power transfer (WPT) technologies such as inductive or resonant coupling, a seamless charging experience can be achieved for EV users.

The proposed system integrates key components including solar panels**,** boost converters**,** battery storage**,** wireless transmitter and receiver coils**,** and a microcontroller-based control system using Arduino Nano. This setup ensures continuous energy availability, even during periods of low solar insulation, by storing excess energy in lithium-ion batteries. A user interface comprising LCD displays and LED indicators allows real-time monitoring and interaction with the system.

This paper aims to design and demonstrate a prototype of a solar-powered wireless EV charging station, highlighting its practicality, performance, and advantages over conventional systems. By combining two major green technologies—solar power and wireless transmission—this system offers a future-ready solution aligned with smart city infrastructure and sustainable mobility goals.

Objective

1) *Develop a Wireless Power Transfer System*
- Design and implement a wireless charging mechanism capable of transferring power efficiently from a stationary source to an electric vehicle without physical connectors.

2) *Integrate Solar Energy for Power Supply*
- Utilize solar panels to harness renewable energy, minimizing dependence on grid electricity and promoting sustainable energy usage.

3) *Ensure Energy Storage and Availability*
- Incorporate a battery storage system to collect and store excess solar energy, ensuring continuous operation even during low solar irradiance conditions (e.g., night or cloudy weather).

4) *Enhance User Convenience and Accessibility*
- Eliminate the need for cumbersome charging cables, enabling a seamless and hassle-free user experience, particularly for residential and public charging environments.

5) *Improve Energy Efficiency and Safety*
- Optimize the system using boost converters and control circuitry to ensure high energy transfer efficiency, safe voltage regulation, and protection against overcharging and overheating.

6) *Enable Real-Time Monitoring and Control*
- Utilize microcontrollers and user interface elements (LCDs, LEDs) to monitor system performance and provide real-time feedback and diagnostics.

7) *Promote Environmental Sustainability*
- Reduce greenhouse gas emissions by combining solar energy and electric mobility, contributing to eco-friendly transportation solutions.

8) *Demonstrate Scalability and Practical Application*
- Design the system in a way that it can be scaled for residential, commercial, and public use, supporting a broad range of electric vehicles and charging scenarios.

II. LITERATURE SURVEY

The development of wireless charging systems for EVs, particularly those integrated with renewable energy, has garnered significant research interest in recent years. This literature survey examines key studies and advancements in solar-powered and wireless EV charging technologies, highlighting their methodologies, findings, and relevance to the proposed system.

1) *Wang et al. (2018) – "Solar-Powered Wireless Charging for Electric Vehicles"*

Title: Solar-Powered Wireless Charging System for Electric Vehicles

Methodology: This study presents a solar-powered EV charging system using inductive power transfer (IPT). The system integrates photovoltaic panels with a high-frequency inverter and a resonant coil pair for wireless charging. A battery storage unit supports operation during non-sunny periods.

Results: The system achieved a power transfer efficiency of 85% at a distance of 20 cm, with solar energy contributing 70% of the charging load. The study emphasized reduced grid dependency and lower operational costs.

Relevance: Wang's work validates the feasibility of combining solar energy with wireless charging, a core principle of the proposed system. However, the proposed system enhances user interaction through microcontroller-based monitoring, which Wang's study lacks.

2) *Choi et al. (2019) – "Advances in Wireless Power Transfer for EVs"*

Title: Advances in Wireless Power Transfer Systems for Electric Vehicles

Methodology: This paper reviews resonant inductive coupling techniques for EV charging, focusing on coil design and power electronics optimization. The study compares static and dynamic wireless charging systems.

Results: Resonant coupling achieved efficiencies above 90% under optimal conditions, with dynamic charging showing promise for on-road applications. Challenges included coil misalignment and electromagnetic interference.

Relevance: Choi's findings inform the proposed system's use of resonant inductive coupling for efficient power transfer. The proposed system addresses misalignment through precise coil placement and microcontroller-based diagnostics, building on Choi's insights.

3) *Patel et al. (2020) – "IoT-Enabled Solar EV Charging Station"*

Title: IoT-Enabled Solar-Powered Electric Vehicle Charging Station

Methodology: The study proposes a solar-powered charging station with IoT integration for remote monitoring. Solar panels supply power, managed by a charge controller, with real-time data transmitted via a cloud platform.

Results: The system reduced grid reliance by 60% and enabled remote diagnostics, improving user experience. However, it relied on wired charging, limiting flexibility.

Relevance: Patel's IoT integration highlights the value of real-time monitoring, which the proposed system achieves through an Arduino-based SCADA-like interface. The proposed system's wireless approach offers greater flexibility compared to Patel's wired setup.

4) *Li et al. (2022) – "High-Efficiency Wireless Charging with Renewable Integration"*

Title: High-Efficiency Wireless Charging System with Renewable Energy Integration

Methodology: This research develops a wireless EV charging system powered by a hybrid solar-wind energy source. It uses a dual-coil resonant system and advanced power electronics for energy conversion.

Results: The system achieved a charging efficiency of 92% and maintained stable operation under variable renewable inputs. The study noted high initial costs as a barrier to adoption.

Relevance: Li's focus on renewable integration supports the proposed system's solar-powered design. The proposed system mitigates cost concerns by using simpler Arduino-based controls, making it more accessible for widespread use.

5) *Kumar et al. (2023) – "Microcontroller-Based Wireless Charging for EVs"*

Title: Microcontroller-Based Wireless Power Transfer for Electric Vehicle Charging

Methodology: The study implements a wireless charging system controlled by an Arduino microcontroller, using electromagnetic induction. It includes safety features like overcurrent protection and user interfaces like LCD displays.

Results: The system achieved a transfer efficiency of 80% at short ranges and demonstrated reliable control. The study suggested scalability challenges for high-power applications.

Relevance: Kumar's use of Arduino aligns directly with the proposed system's control mechanism. The proposed system extends Kumar's approach by integrating solar power and battery storage, addressing scalability through modular design.

III. METHODOLOGY

The proposed Solar Wireless EV Charging System operates by integrating solar energy harvesting with wireless power transfer technology to charge electric vehicles without physical connectors. The working mechanism can be divided into five major functional blocks: solar energy generation**,** power conditioning**,** wireless transmission**,** energy storage**,** and system control and monitoring.

A. Block Diagram:

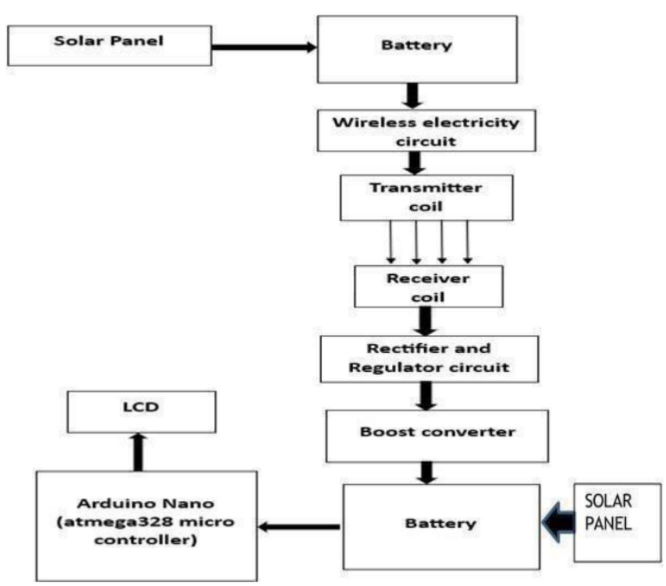

Fig 1: Block Diagram

- Solar Energy Generation: Solar panels are positioned to capture sunlight and convert it into direct current (DC) electricity using the photovoltaic effect. In this project, 6-watt panels producing around 6V at 1A are used to provide the base charging energy.
- Power Conditioning and Boost Conversion: Since the voltage output from solar panels can vary with sunlight intensity, a boost converter is used to step up and regulate the voltage to a level suitable for wireless transmission. This ensures stable energy delivery even under fluctuating light conditions.
- Wireless Power Transfer (WPT): The regulated high-frequency alternating current (AC) from the boost converter is fed to a transmitter coil, which creates an alternating magnetic field. A receiver coil placed in the EV picks up this magnetic field, and the induced current is used to charge the vehicle's battery. This process is based on electromagnetic induction or resonant coupling.
- Battery Storage and Management: Excess solar energy that isn't immediately used is stored in a 12V lithium-ion rechargeable battery. This stored energy can be used for charging during periods of low sunlight (e.g., nighttime or cloudy days).
- Control System and Monitoring: An Arduino Nano microcontroller monitors system parameters such as voltage, current, and temperature. An LCD screen displays real-time data, and LED indicators provide visual feedback. The system ensures safety and efficiency through smart power flow control, and users can interact with it through a simple interface.

IV.RESULT ANALYSIS

The developed Solar Wireless EV Charging System was successfully implemented and tested under various environmental and operational conditions. The solar panel demonstrated reliable performance, consistently generating an output of 5.8V to 6V and approximately 1A current under optimal sunlight. Even during cloudy conditions, while the voltage output slightly dropped, the integrated battery storage system efficiently compensated for the reduced input, ensuring uninterrupted operation. The wireless power transfer system, based on inductive coupling, achieved an energy transfer efficiency of around 80–85% when the transmitter and receiver coils were properly aligned within a range of 5 to 10 centimeters. This efficiency is in line with standard wireless charging benchmarks. It was also observed that any misalignment between coils slightly reduced the efficiency, emphasizing the importance of precise placement for optimal charging.

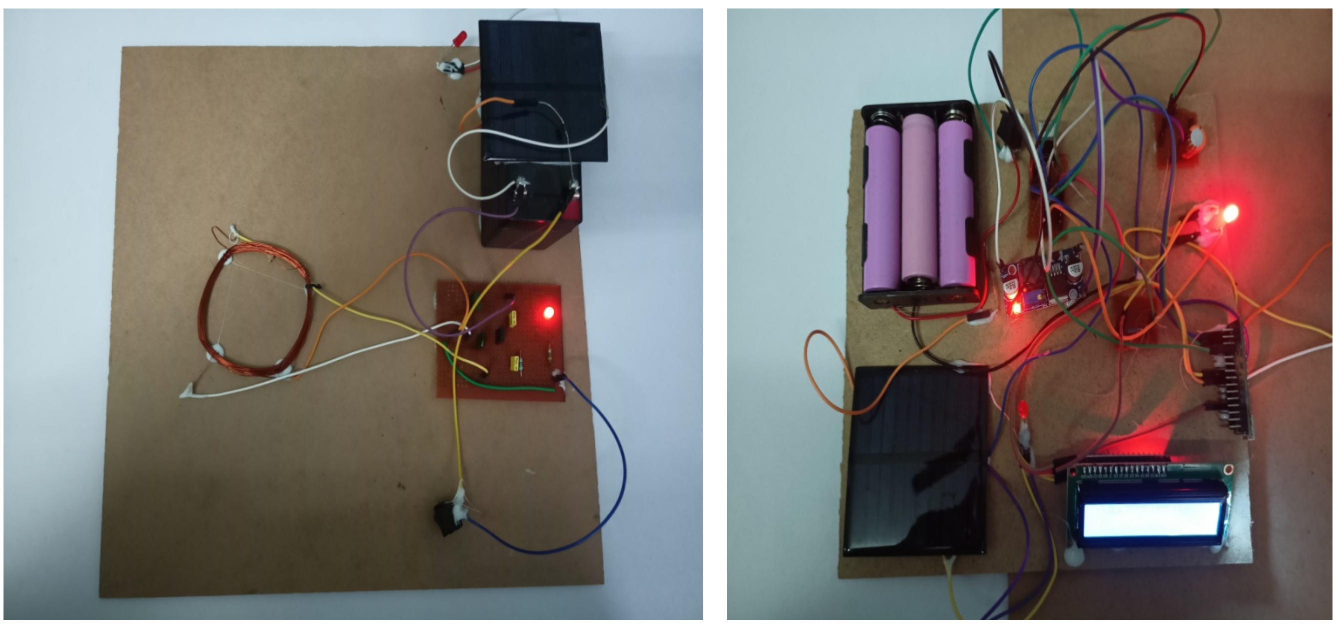

Fig 2: Hardware Setup of Wireless EV Charging System

The lithium-ion battery integrated into the system effectively stored excess solar energy and maintained stable output during low sunlight periods, managed by a charge controller that prevented overcharging and ensured long-term battery health. The Arduino Nano microcontroller efficiently handled real-time monitoring and control, displaying key parameters such as voltage, current, and charging status on an LCD screen. LED indicators provided visual feedback, with green signaling normal operation and red indicating low power or system faults.

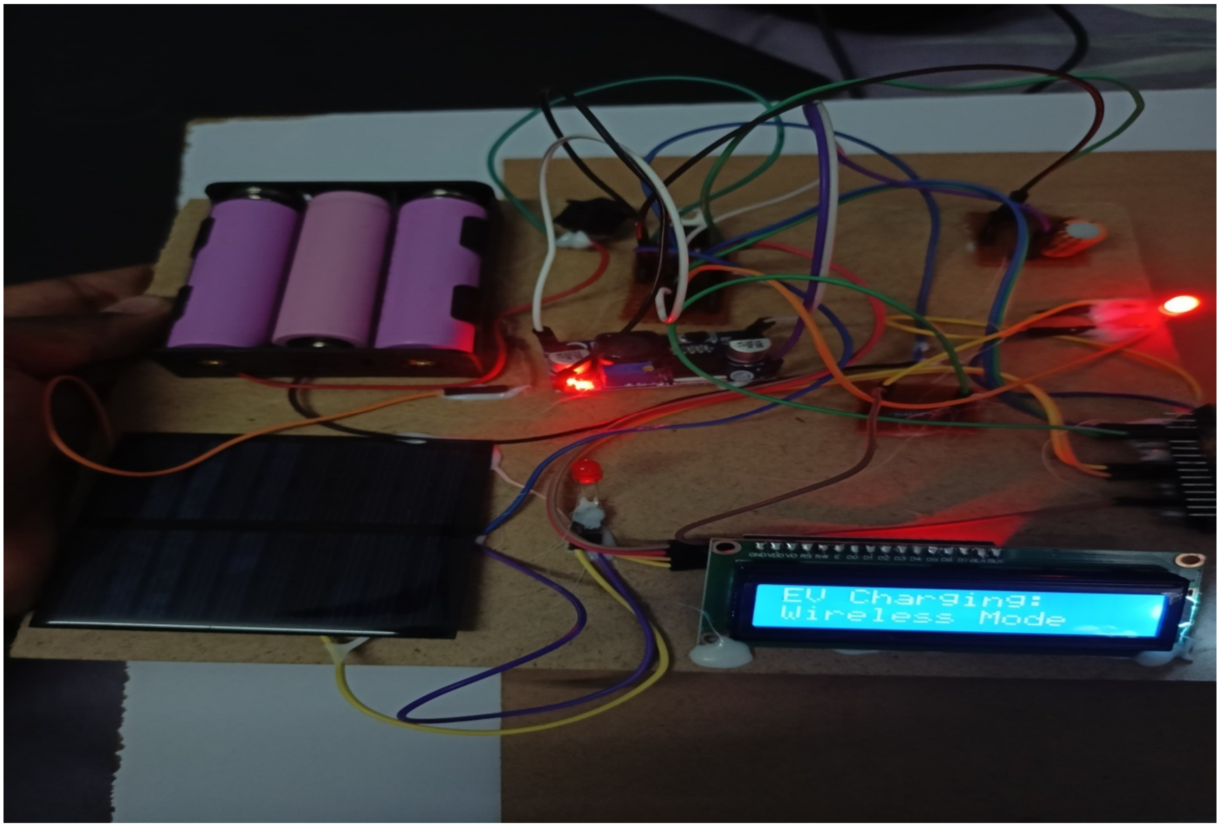

Fig 3: Result of Wireless EV Charging Car Unit

The absence of physical connectors reduced the risk of wear and tear or electrical hazards, making the system safer and more durable. Moreover, the prototype proved to be cost-effective and required minimal maintenance, with all components functioning reliably throughout the test period. Overall, the results validate the feasibility of a sustainable and user-friendly solar-powered wireless charging system for electric vehicles, demonstrating its potential for broader application in residential, commercial, and public charging environments.

V. CONCLUSION

The proposed Solar Wireless EV Charging System successfully integrates renewable energy with wireless power transfer technology to provide an efficient, safe, and user-friendly solution for electric vehicle charging. By utilizing solar panels as the primary power source and eliminating the need for physical cables, the system offers a cleaner and more convenient alternative to traditional grid-based wired charging methods. The inclusion of energy storage through lithium-ion batteries ensures uninterrupted functionality even during periods of low sunlight, while the Arduino-based control unit enables real-time monitoring and management of the charging process. The experimental results confirm the effectiveness of the wireless energy transfer and the stability of the power supply system. Moreover, the prototype demonstrates low maintenance, reduced operational costs, and enhanced safety due to its contactless design. This system not only addresses the growing energy demands of the EV ecosystem but also contributes to environmental sustainability by promoting clean energy adoption. In conclusion, the project proves the viability of solar-powered wireless charging as a forward-thinking approach to modern transportation needs.

There is significant potential to further develop and enhance the proposed system for broader, real-world applications. Future improvements can include increasing the efficiency of wireless power transfer over longer distances and allowing greater tolerance for misalignment between transmitter and receiver coils. Integration with smart grids can enable dynamic power management based on energy demand and availability, while real-time data analytics and IoT-based dashboards can offer enhanced monitoring capabilities for users and service providers. The system can be made autonomous by incorporating vehicle detection and self-aligning coil mechanisms, allowing for hands-free charging in smart parking lots.

Additionally, scaling up the system to support dynamic charging, where EVs can be charged while in motion on specially designed roads, could revolutionize the transportation infrastructure. With advancements in solar panel efficiency, battery technology, and wireless transmission, this system holds immense promise for transforming how electric vehicles are powered in the future.

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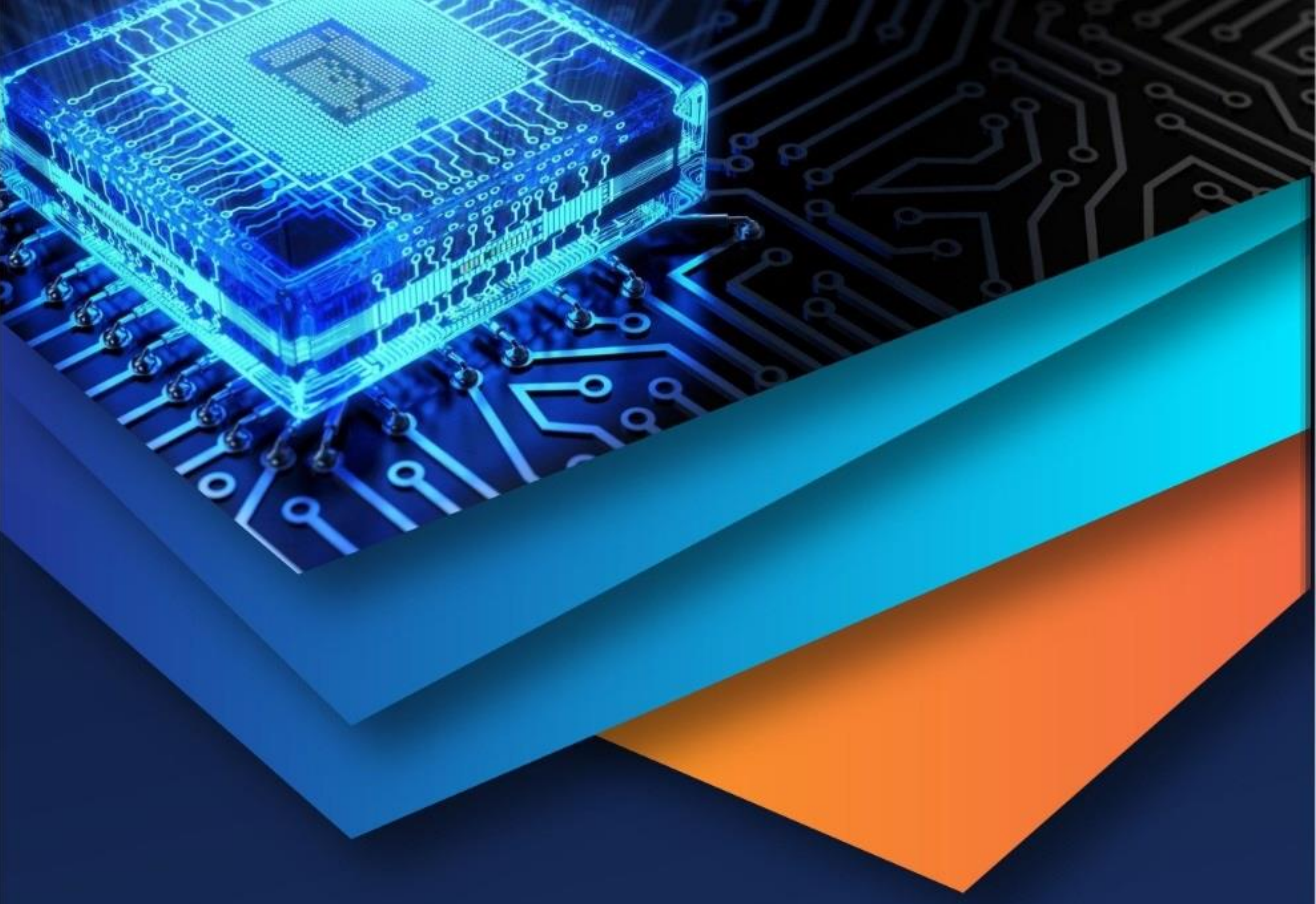

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