iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 **Issue:** XII **Month of publication:** December 2025

DOI: https://doi.org/10.22214/ijraset.2025.76624

POWERDOCK: Real-Time EV Slot Booking System

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Abstract: The rapid global adoption of Electric Vehicles (EVs) is essential for sustainable transportation, yet it concurrently introduces significant challenges in efficiently managing charging infrastructure, often resulting in user frustration and underutilization of resources. This paper presents POWERDOCK, a novel, real-time slot booking system designed to optimize the experience of EV charging. Our approach leverages a scalable, cloud-native architecture to provide a seamless, user-centric reservation platform. The system allows drivers to accurately locate stations, view real-time slot availability, and pre-book a specific charging window based on essential criteria, including vehicle type, required charger connector, and precise time slot. This core functionality is supported by an efficient scheduling algorithm that mitigates station congestion and minimizes driver waiting times. Furthermore, POWERDOCK integrates secure payment gateways and a real-time notification service to ensure a dependable and fully digital transaction process. The implementation of POWERDOCK demonstrates a significant leap towards enhancing the reliability and user convenience of the EV charging ecosystem, thereby actively supporting the wider adoption of electric mobility.
Keywords: Electric Vehicles, Real-time Reservation, Charging Infrastructure, Scheduling Algorithm, Resource Optimization, Cloud-Native Architecture, E-Mobility, Congestion Mitigation.

I. INTRODUCTION

The global transition toward sustainable transportation is accelerating the adoption of Electric Vehicles (EVs) as a crucial strategy for mitigating climate change and reducing dependence on fossil fuels. This rapid proliferation of EVs, while environmentally positive, has placed unprecedented stress on the accompanying charging infrastructure, which is a major determinant of mass market acceptance and the alleviation of user "range anxiety" [1, 2].

A primary challenge in the current EV ecosystem is the inefficient management of public charging stations. The lack of real-time availability information, coupled with uncoordinated user arrivals, frequently leads to station congestion, prolonged waiting times, and suboptimal resource utilization [3, 4]. This uncertainty directly translates into user frustration and acts as a significant barrier to the widespread integration of electric mobility. Moreover, infrastructure operators struggle with managing peak demand and ensuring equitable access to limited charging resources across diverse user needs [5].

To address these critical operational and user experience challenges, this paper introduces POWERDOCK, a novel, real-time slot booking and management system for EV charging infrastructure. POWERDOCK is built upon a scalable, cloud-native architecture that provides a seamless, user-centric reservation platform. The core innovation lies in its efficient scheduling algorithm, which dynamically allocates charging slots based on criteria such as vehicle type, required connector, and specified time window [6]. By enabling users to pre-book their charging sessions and providing real-time station occupancy data, the system effectively mitigates station congestion and minimizes driver wait times. The implementation of the POWERDOCK system demonstrates a significant advancement in enhancing the reliability and user convenience of the EV charging process. By optimizing the physical infrastructure through a smart, digital layer, this research actively supports the broader adoption of electric mobility and the stability of smart grid integration.

II. LITERATURE REVIEW

The global push for Electric Vehicles (EVs) necessitates smart charging infrastructure. Research focuses heavily on overcoming challenges like congestion, long wait times, and grid instability through advanced management systems.

Seoeun Rho et al. [1]“A generic EV charging modelextracted from real charging behaviour” introduced a scheduling framework that couples solar PV generation forecasting with optimized charging reservations. Their key takeaway is the need for reservation logic to be resource-aware, considering energy supply alongside demand patterns to ensure the system is grid-friendly and cost-effective, moving beyond simple first-come, first-served queues.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XII Dec 2025- Available at www.ijraset.com

Lorenzo Sica et al. [2]"BYD EV Charging Challenges Solutions" focused on city-scale demand modeling by simulating driver preferences and station usage. Their research concluded that embedding reservation mechanisms within a comprehensive system-level design—one that considers travel behaviour and network density—is essential to effectively reduce queues and minimize idle time across the entire charging network.

Fareed et al. [3]"Charging coordination of opportunistic EV users at fast charging station with adaptive charging" emphasized the practical requirements for successful urban charging: optimal station placement, real-time operational monitoring, and highly intuitive user interfaces. The core message is that a reservation platform can only succeed and encourage user adoption if it is built on reliable data from transparent, well-managed physical stations.

Felix et al. [4]"Forecast-based optimal operation of EV charging station with PV considering charging demand and distributed system" proposed a generic EV charging model that captures diverse driver behavior using a minimum number of parameters. This lightweight and generalizable behavior model is crucial for improving slot prediction and no-show management without the need for massive, specialized datasets, making the system adaptable across different cities or fleets.

Konara M. et al. [5]"Optimal location of electric vehicle charging station and its impact on distribution network: A review" concentrated on adaptive scheduling for fast-charging by treating the process as a dynamic queueing challenge. The findings established that achieving low wait times and fairness requires a reservation engine capable of continuous capacity reallocation to instantly adjust the schedule based on real-time events, such as early departures or sudden increases in demand.

Tianjin et al. [6]"An in-depth analysis of electric vehicle charging station infrastructure, policy implications, and future trends," investigated location optimization and power resource allocation to balance service quality with grid stability. The study provided a fundamental insight: the physical placement of chargers and the strategy for power distribution are the primary factors determining network smoothness, reminding modern systems that the application must be backed by data-driven infrastructure planning.

III. SYSTEM DESIGN AND METHODOLOGY

The system begins by modeling real EV charging behavior to capture heterogeneous charging curves, SOC switching points, and nonlinear charging patterns, which ensures accurate estimation of energy demand and flexibility during operation [1]. To improve operational accuracy, the system incorporates a forecasting layer capable of predicting short-term PV generation, regional electrical load, and EV charging demand using advanced time-series learning models, enabling the system to anticipate variations in energy availability and load requirements [4]. User charging preferences are then analyzed using behavior-based modeling techniques that consider socio-economic factors, mobility patterns, and charging accessibility, helping the system identify high-demand zones and time periods with increased charging activity across the city [11].

For infrastructure development, an optimization framework determines the optimal placement, number, and capacity of EV charging stations by evaluating power loss, voltage stability, cost factors, and user grid constraints and demand scenarios [5]. During real-time operation, an adaptive coordination mechanism reallocates unused slow-charging resources to fast-charging users when necessary, improving station utilization and ensuring that grid limitations are not violated while maintaining user comfort [3]. In addition, the system implements a V2G-enabled accessibility under different scheduling strategy that allocates charge and discharge cycles based on forecasted PV output and demand profiles to minimize operational cost and reduce dependency on the main grid [4]. The overall workflow integrates data acquisition, forecasting, behavioral modeling, station placement optimization, real-time charging coordination, and V2G scheduling to produce an intelligent and efficient EV charging ecosystem. This combined methodology enhances prediction accuracy, supports effective infrastructure planning, improves energy utilization, and ensures stable, cost-efficient charging operations across the EV ecosystem.

A. System Architecture

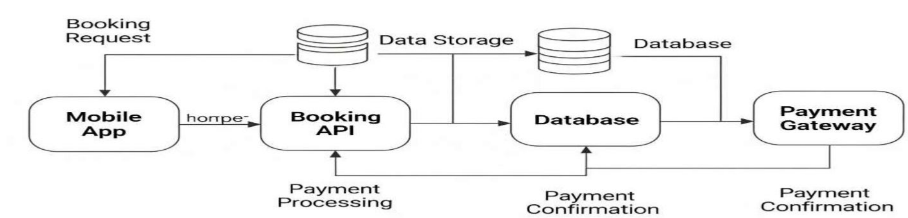

Figure 1: Architecture Diagram of POWERDOCK Real-Time EV Slot Booking System.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XII Dec 2025- Available at www.ijraset.com

The figure 1 illustrates how the POWERDOCK system manages EV slot bookings. Users submit booking requests via the Mobile App, which communicates with the Booking API to process these requests. The Booking API interacts with the Database to store and retrieve booking information, and also connects with the Payment Gateway for secure payment processing. Upon successful payment, confirmations are updated in the Database and relayed back to the user, ensuring a seamless and efficient experience from booking to confirmation.

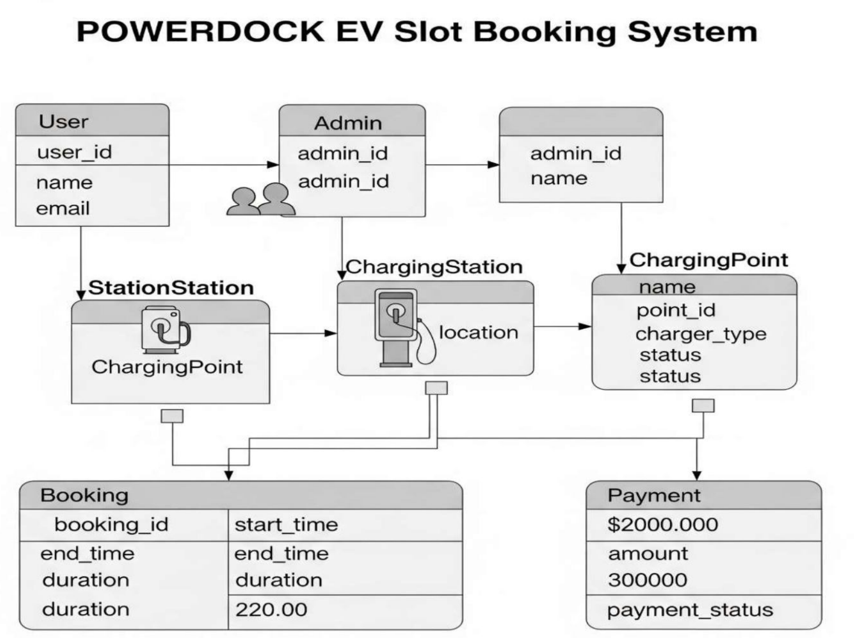

Figure 2: Database Design diagram for POWERDOCK Real-Time EV Slot Booking System.

The figure 2 represents the relationships between key entities in the system. Users interact with charging stations through bookings, while admins oversee operations. Each charging station contains multiple charging points, and every booking record links the user, station, charging point, and payment status. This design enforces data integrity and facilitates seamless management of user reservations, resource allocation, and secure payment processing within the application.

IV. IMPLEMENTATION

A. Frontend Development

The user-facing interface of POWERDOCK was developed using React js to ensure a modern, responsive, and intuitive experience across devices, Users can effortlessly search for nearby charging stations, view real-time slot availability on interactive maps, and initiate bookings or cancellations through a clear navigation flow. Integration with mapping APIs allows for dynamic display of station locations, while form elements and asynchronous HTTP requests support smooth input handling and communication with backend services, the frontend design prioritizes user accessibility and simplifies the management of EV charging, leading to efficient and convenient operations for drivers.

B. Backend Development

The backend of the POWERDOCK system was developed using Node js and Express js, providing a scalable and efficient management layer for EV slot bookings. It handles key functionalities such as request routing, booking logic, user authentication, and real-time updates. RESTful APIs facilitate secure communication between the frontend, database, and third-party services, including payment gateways and notification systems. The backend ensures data consistency, implements business rules like auto-cancellation of expired bookings, and supports role based access control for users, administrators, and operators.

C. Database Schema

The POWERDOCK application utilizes MongoDB as its database management system to provide flexible, scalable, and real-time data handling capabilities. The database is designed to store critical entities such as user profiles, charging stations, charging points, slot bookings, and payment transactions. Backend APIs interact with the database to perform CRUD operations, ensuring immediate updates of slot availability and booking statuses. Efficient schema design and appropriate indexing facilitate fast query responses, while data relationships between collections maintain integrity and synchronization across the system. This integration supports seamless user experience and reliable management of EV charging resources, enabling the system to handle concurrent operations and prepare for future scalability enhancements.

D. Security and User Authentication

Security is a critical aspect of the POWERDOCK system to protect user data, prevent unauthorized access, and ensure safe usage of EV charging resources. The system implements JWT (JSON Web Token) based authentication to manage secure user logins and session verification. Passwords are encrypted using hashing algorithms such as bcrypt, safeguarding credentials against breaches. Role-based access control restricts functionalities based on user roles—including EV users, station operators, and administrators—ensuring appropriate permissions and protecting sensitive system operations. Additionally, secure communication protocols like HTTPS are utilized to encrypt data exchanged between clients and servers, thus maintaining data integrity and confidentiality throughout all transactions.

V. RESULTS

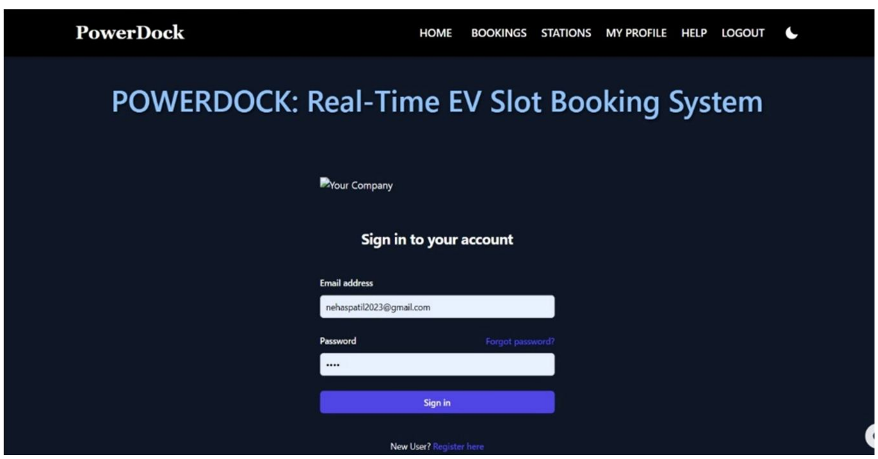

Figure 3: User Login Interface

The above figure 3 is login screen allows registered users to securely access the EV slot booking system. It provides a clean and user-friendly interface with email and password authentication. This ensures secure entry into the system before accessing booking features.

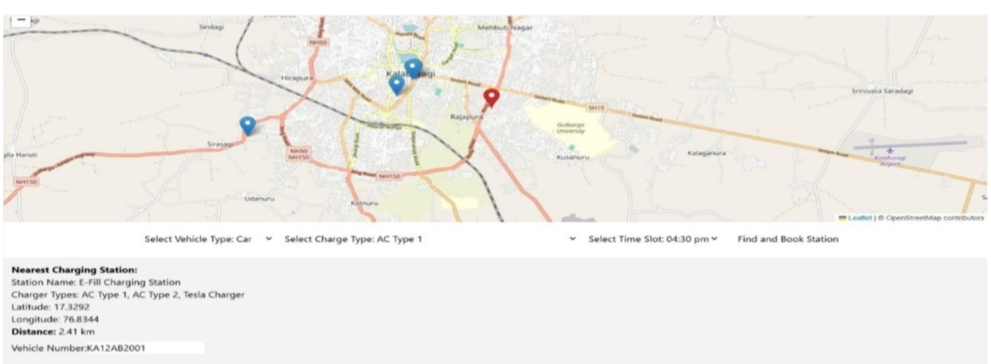

Figure 4: Displaying Nearest Station Details

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue XII Dec 2025- Available at www.ijraset.com

The figure 4 displays the nearest compatible charging station after applying vehicle and charger-type filters. It provides complete station details including charger types, latitude–longitude, and distance from the user's current location. This enables users to make informed booking decisions with accurate real-time data.

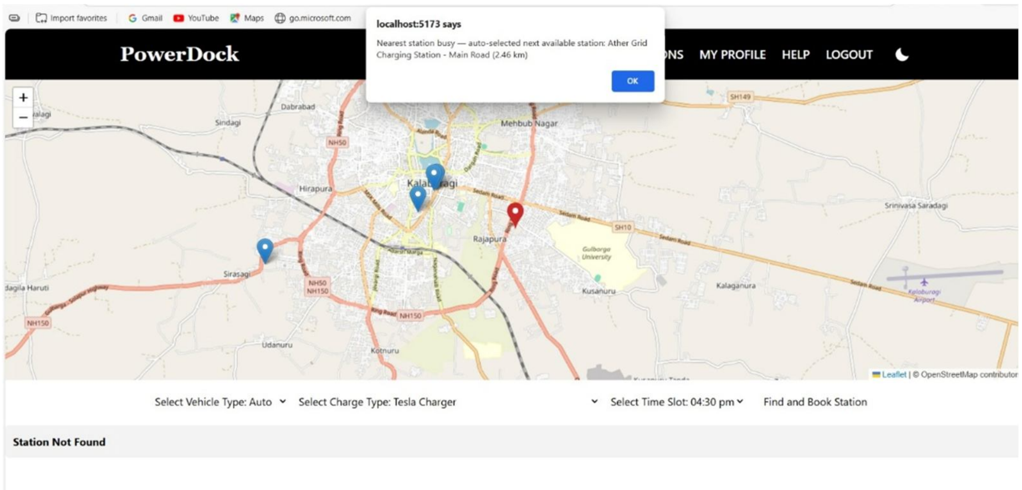

Figure 5: Auto-Selecting Nearest Available Station.

The figure 5 detects when the nearest charging station is busy and automatically selects the next available station based on proximity. A pop-up alert informs the user of the alternate station along with the calculated distance. This ensures seamless and uninterrupted booking even during peak usage.

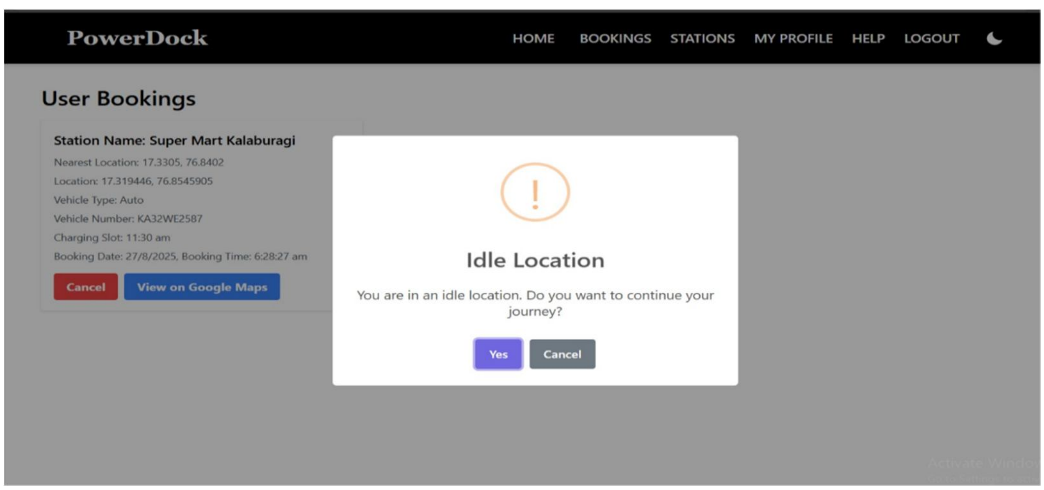

Figure 6: Idle Location Alert

The figure 6 continuously monitors the user's movement after booking a slot. When the user remains stationary for a long duration, an "Idle Location" alert is triggered, prompting them to confirm whether they wish to continue the journey. This feature prevents unnecessary slot blocking and ensures efficient utilization of charging resources.

VI. SYSTEM FEATURES AND INNOVATIONS

A. Real-Time Slot Availability

Dynamically updates charging slot availability to users, preventing double bookings and reducing wait times through instant synchronization with the backend.

B. User-Friendly Interface

Intuitive web-based interface with integrated interactive maps for easy discovery of nearby charging stations and real-time reservation management.

C. Automated Booking Management

Includes features like automatic cancellation of expired or unconfirmed bookings to optimize resource utilization without manual intervention.

D. Notification System

Automated alerts and confirmations via email or SMS keep users informed of their booking status and any changes in real time.

E. Efficient Database Design

Uses a document-oriented database (MongoDB) optimized for handling complex relationships, real-time queries, and rapid data updates.

VII. CONCLUSIONS

The POWERDOCK Real-Time EV Slot Booking System offers a practical and efficient solution to address the increasing demand for accessible and reliable electric vehicle charging infrastructure. By enabling users to easily locate, book, and manage charging slots through a user-friendly interface integrated with real-time data and secure payment options, the system significantly reduces wait times and optimizes charging station utilization. Its scalable and modular architecture supports smooth operations even during peak demand, while security mechanisms maintain data privacy and user trust. Overall, POWERDOCK contributes to the advancement of sustainable mobility by improving the convenience and efficiency of EV charging, facilitating broader adoption of electric vehicles in urban and semi-urban environments.

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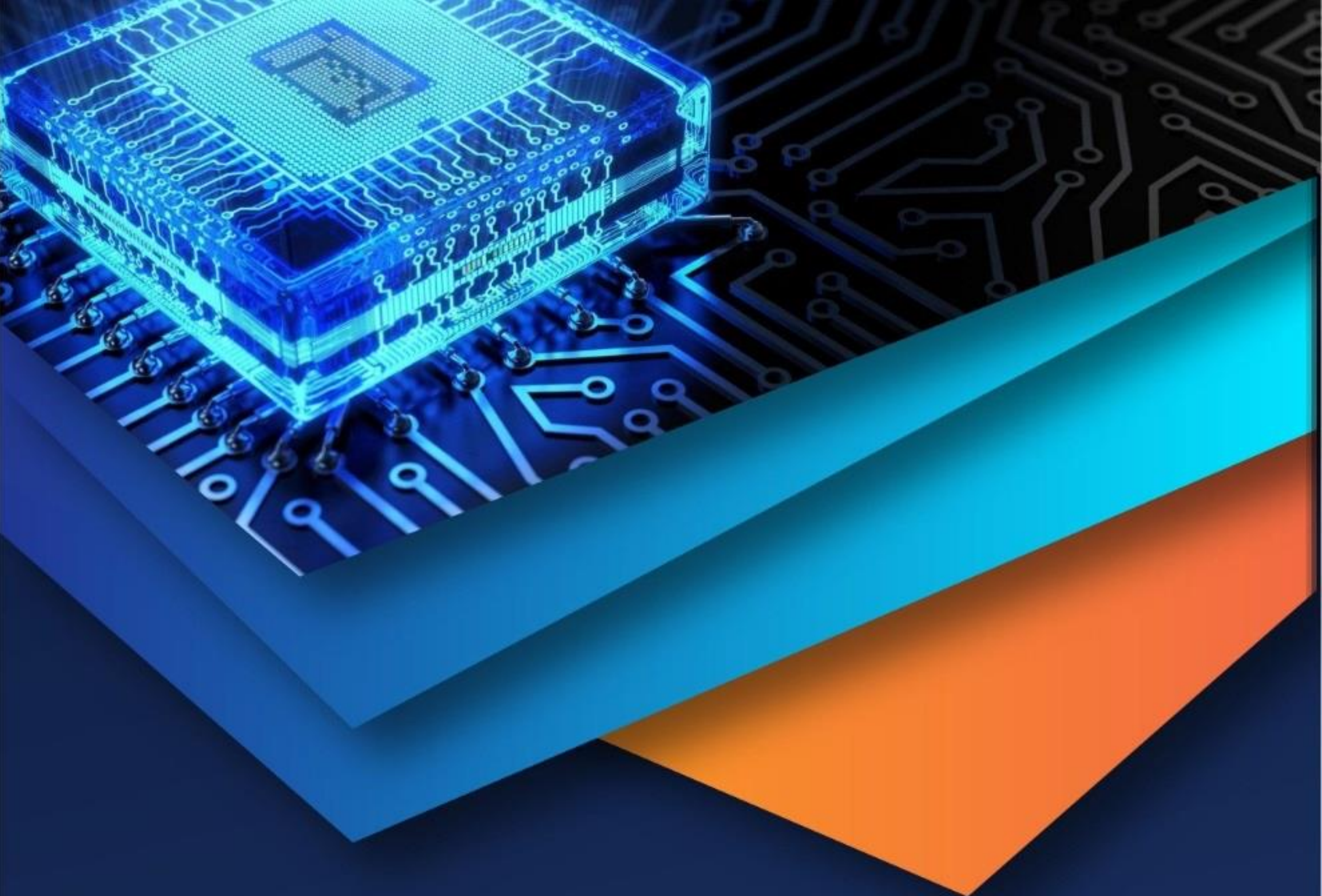

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