

A Scalable and Intelligent EV Charging Model Integrating Hybrid Energy and Decentralized Peer Networks

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ABSTRACT: The rapid growth of electric vehicles (EVs) has significantly increased the demand for reliable and efficient charging infrastructure. However, the existing charging ecosystem faces major challenges such as limited availability of charging stations, uneven geographical distribution, long waiting times, and lack of real-time information for users. These issues are more prominent in rural and semi-urban areas, where infrastructure development is slower. To address these problems, this project proposes a Smart and Comprehensive Hybrid EV Charging Platform that integrates both public charging stations and privately owned chargers into a unified system using a peer-to-peer (P2P) sharing model. The primary objective of the system is to improve accessibility, optimize the utilization of charging resources, and reduce waiting time for users. The platform provides features such as real-time availability tracking, advance booking, secure payment processing, and intelligent navigation support. The system is developed using a modular architecture that ensures scalability and flexibility for future enhancements. The development follows an iterative approach with continuous testing and user feedback integration. The results demonstrate that the system effectively increases charger availability, reduces congestion at public stations, and enhances user experience. The proposed solution offers a scalable and efficient framework for the next generation of EV charging infrastructure.

KEYWORDS: The Electric Vehicles (EVs), Smart and Connected Charging Systems, Internet of Things (IoT) Integration, Cloud-Based Platform, Secure Payment Solutions, System Reliability and Performance, Peer-to-peer Charger Sharing Network.

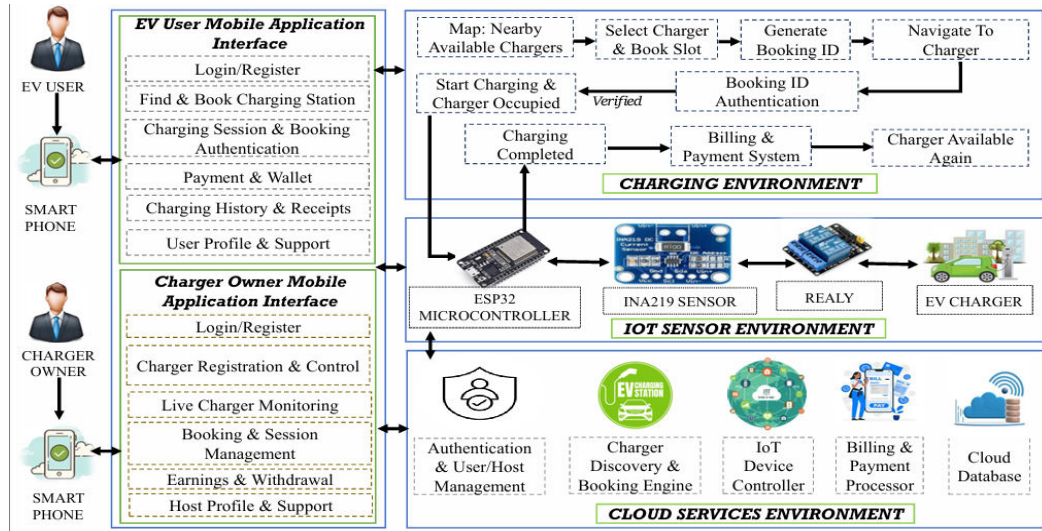
I. INTRODUCTION

The transition from conventional fuel-based vehicles to electric vehicles is accelerating due to increasing environmental concerns and the need for sustainable transportation solutions. Governments and organizations worldwide are promoting EV adoption to reduce carbon emissions and dependence on fossil fuels. However, one of the major barriers to EV adoption is the lack of adequate charging infrastructure. Existing systems are primarily dependent on public charging stations, which are often limited in number and unevenly distributed across regions. This results in long waiting times, inconvenience, and range anxiety among users. The motivation behind this project is to address these challenges by utilizing underused private charging resources and integrating them into a unified platform. The proposed system aims to provide a smart and efficient solution that enhances accessibility and user convenience. The main objectives include enabling real-time monitoring of charger availability, providing advance booking facilities, ensuring secure payment mechanisms, and supporting navigation to charging locations. The system is designed to cater to users in urban, rural, and semi-urban areas, thereby improving overall coverage. Despite its advantages, the system faces limitations such as dependency on stable internet connectivity and concerns related to trust and security in P2P sharing. This paper presents a comprehensive overview of the system design, implementation, testing, and evaluation, highlighting its effectiveness and potential for future improvements.

II. LITERATURE SURVEY

SR. No	Title	YEAR	AUTHOR	SUMMARY
1	The Reliability and Economic Evaluation Approach for Various Configurations of EV Charging .	2024	K. VAISHALI AND D. RAMA PRABHA	Electric vehicles (EVs) become more popular as a form of transportation and companies that make useful things.
2	A Hybrid Optimization Approach for PV-BESS Integration in Grid-Tied EV Charging System.	2025	Ahmad Alferidi	A novel hybrid optimization method, GWO-SA, combining Grey Wolf Optimizer and Simulated Annealing, is introduced for optimizing the placement and sizing of PV systems and Battery Energy Storage Systems (BESS) in grid-tied EV charging stations.
3	Design and implementation of multi-protocol EV charging management cloud platform system	2025	Shuai Hao; Weiping Wang; Zhenwei Wang; Yiling Zhao; Xiao Wang; Zhaoxia Xu	The system aims to provide an efficient and reliable way to manage the charging pile, and realize the real-time communication between the charging pile and the cloud platform through MQTT protocol to ensure the timeliness and reliability of data transmission. At the same time, the HTTP protocol provides a user interface and management interface, which is convenient for users and administrators to manage and monitor the charging pile.
4	Evaluating Direct and Indirect Influence on EV Charging Stations Across the US	2024	Gabriel A. Weaver; Daniel A. Eisenberg; Emma Stewart	The adoption of new technoelectric vehicles (EV) and mobility applications can bring underappreciated vulnerabilities to the power grid. One area of potential fraud and adversarial influence is through the business ecosystem of startups that own and deploy EV technology

III. SYSTEM DESIGN AND ARCHITECTURE



The Smart and Comprehensive Hybrid EV Charging Platform that is proposed will involve collective and individual charging stations and privately owned home chargers of the users as a one, cohesive ecosystem that is capable of doing the mobile work. This system makes use of a hybrid architecture that comprises centralized public networks and decentralized sharing by peers of private chargers through the peer-to-peer (P2P) method. This platform enables the owners of vehicles to find charging stations, book charge points, charge safely, and find the direction to the charging points. The backend controllers handle the process of data processing, storage, and communications between the users and chargers as well as executive modules, making sure that the system is scalable, reliable, and functional. Its architecture is modular which means that it is easy to add new chargers, users or payment systems to the network without interfering with the rest. Centrally hosted databases are used to distribute real-time information regarding the availability and the status of the chargers and the possibility of their duplication can be mitigated with the help of AI based algorithms that allow optimizing the distribution of chargers depending on demand trends. Security is ensured by the use of standardization of messaging protocols, authentication and payment gateways that are secure. The hybrid project will ensure the urban, rural, and peri-urban users can have a reliable access to the charging services when unused private chargers can be well integrated into a community-based ecosystem.

The system is designed in a way that it has a number of modules that are interdependent and that give a seamless EV charging experience. Registration, profile management, and authentication are under the User Module, which enables the user to find the chargers, check their availability, reserve the slots, and make full payments. It also has a record of the users so as to provide a customized experience to its users. The Charger Management Module manages public and private chargers providing real-time occupancy and status information and allowing the owners of the private chargers to sign in their intentions of taking part in P2P sharing. The Administration Module equips the system monitoring and control, including maintenance schedule, dispute resolution, optimization of the operational efficiency. The Payment Module is the digital payment system that is safe and secure and that handles various types of payments in standardized channels. The proposed Navigation and Mapping Module, which will be based on the Google Maps API, will help users find their way to the chargers as effectively as possible, providing the estimated time of arrival and the available alternatives. Lastly, the Analytics and Reporting Module consolidates system operation data and determines the peak demand periods and enables the use of AI to make further advancements, including predictive maintenance and intelligent distribution of chargers. All the modules are intended to be scalable and interoperable, and can be integrated in the future with renewable energy sources and dynamic pricing systems.

Hardware and software are carefully considered in order to make them robust, scalable and user-friendly. On the hardware side, the smartphones or tablet users use Android or iOS based phones, whereas the car chargers be it in AC or DC connect to the network using standard protocols. Centrally hosted servers receive data, provide APIs, and real time messaging and this is supported by a reliable internet connectivity and networking infrastructure. Non-obligatory

IoT sensors and smart adapters will be able to track charger status and provide real-time information. The mobile application is built on cross-platform frameworks like Flutter or React Native on the software side and makes it compatible. The server is based on the API development of Node.js or Python and the use of Firebase or MySQL to work with real-time databases and store the information in a relational form. The Google Maps API is used to manage navigation and positioning, and the process of paying is supported by the Stripe or Razorpay platforms. The usage of hosting services such as AWS, Google Cloud, or Azure can guarantee the high availability and scalability of the systems, and encryption measures and safe management of tokens can protect the integrity of the systems and keep sensitive data safe.

IV. METHODOLOGY

The methodology of the proposed Smart and Comprehensive Hybrid EV Charging Platform follows a structured and iterative approach to ensure efficient system development, integration, and performance. The process begins with a detailed requirement analysis, where the needs of electric vehicle users, charging station operators, and potential peer-to-peer (P2P) participants are identified. Both functional requirements, such as user registration, charger discovery, booking, and payment, and non-functional requirements, including scalability, security, and usability, are carefully defined to guide the system design.

Following requirement analysis, a hybrid system architecture is designed that integrates centralized public charging infrastructure with decentralized private charger sharing through a P2P model. The system is divided into multiple modules, including user management, charger management, booking, payment, navigation, administration, and analytics. This modular design ensures flexibility, scalability, and ease of integration of future features without affecting the overall system performance.

The development process follows an agile methodology, where the system is built in incremental phases. Each module is developed, tested, and integrated step-by-step to ensure stability and reliability. Continuous feedback from users and stakeholders is incorporated during each iteration to refine system functionality and improve user experience. This approach allows quick identification and resolution of issues during development.

V. IMPLEMENTATION

The implementation of the system follows an iterative development approach to ensure flexibility and continuous improvement. The development process begins with the creation of core functionalities such as user registration, authentication, and charger listing. This is followed by the implementation of real-time availability tracking, which ensures that users receive accurate and updated information about charging stations. The booking system is then integrated, allowing users to reserve charging slots in advance and reduce waiting time. Secure payment functionality is implemented to enable seamless and reliable transactions. The navigation feature is incorporated to help users locate charging stations efficiently. Various algorithms are used to optimize system performance, including availability tracking, slot allocation, and authentication mechanisms. Each module is developed independently and later integrated to ensure smooth communication between components. The implementation focuses on creating a reliable, scalable, and user-friendly system that meets the needs of both users and charger owners.

VI. TESTING AND EVALUATION

The testing and evaluation phase plays a crucial role in ensuring that the proposed Smart and Comprehensive Hybrid EV Charging Platform operates efficiently, reliably, and securely under real-world conditions. A systematic and multi-level testing approach is adopted to validate both functional and non-functional aspects of the system. The primary objective of this phase is to identify defects, verify system behavior, and evaluate overall performance and user experience.

The testing process begins with **unit testing**, where individual modules such as user registration, authentication, charger management, booking, and payment processing are tested independently. Each function is evaluated using valid, invalid, and boundary inputs to ensure correctness and robustness. This stage helps in detecting logical errors at an early stage of development.

Following unit testing, **integration testing** is performed to verify the interaction between different modules. Since the platform relies on seamless communication between components such as booking, payment, and real-time availability updates, this phase ensures that data flows correctly across the system. Issues such as synchronization delays and incorrect data updates are identified and resolved during this stage.

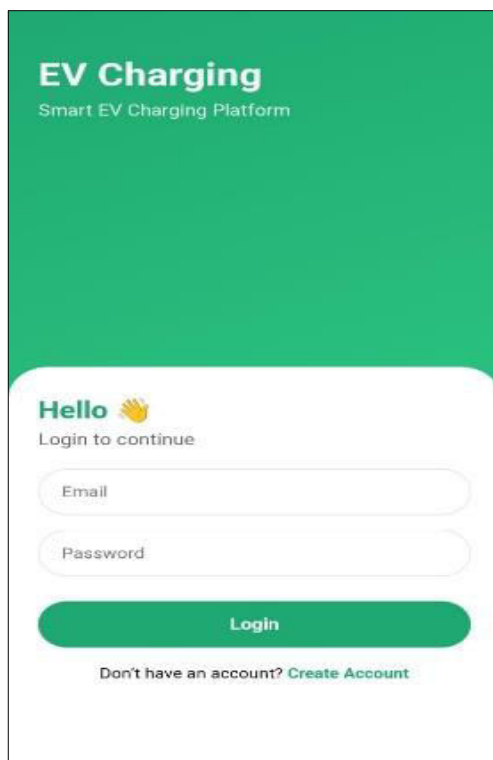
The system is further evaluated through **system testing**, where the complete platform is tested as a whole. Real-world scenarios are simulated, including searching for charging stations, checking availability, booking slots, navigating to the location, and completing payment transactions. This ensures that all modules function together smoothly and deliver a seamless user experience.

To assess system performance, **performance testing** is conducted under varying load conditions. Load testing simulates multiple users accessing the system simultaneously to evaluate response time and stability, while stress testing examines system behavior under extreme conditions. The results indicate that the system performs efficiently under normal conditions, with minor latency observed during peak usage.

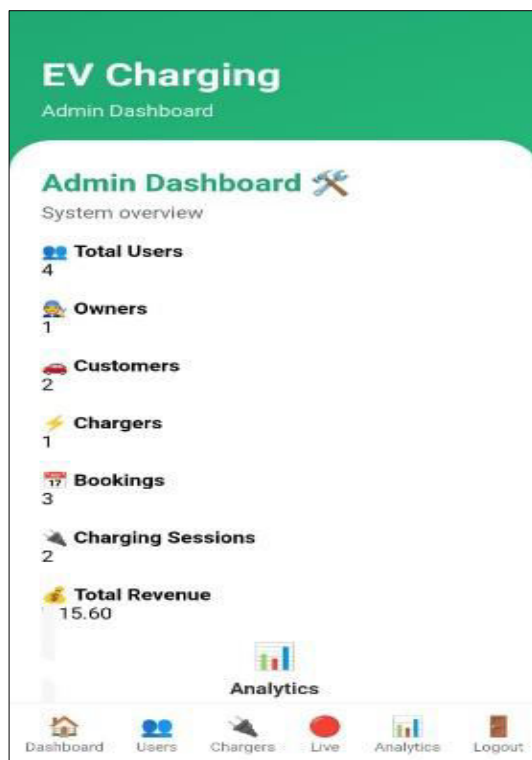
Additionally, **usability testing** is carried out to evaluate the user interface and overall experience. Feedback from users helps in identifying areas for improvement in navigation, booking flow, and error handling. This ensures that the system remains user-friendly and intuitive.

VII. EXPERIMENTAL RESULTS

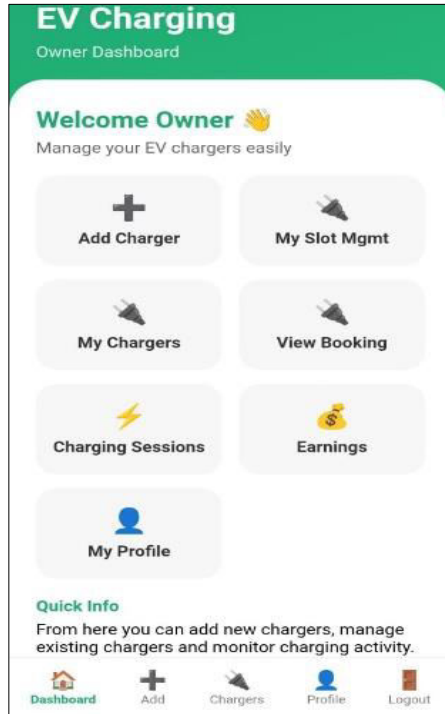
Figures show the results of a scalable and intelligent EV charging model integrating hybrid energy and decentralized peer networks. Fig(a) shows the login interface where users can securely sign in using their email and password. Fig(b) displays the admin dashboard of the EV charging platform, providing an overview of system activities. It shows key statistics like total users, owners, customers, chargers, bookings, and charging sessions. Admins can also monitor overall revenue and access different management sections from the dashboard.



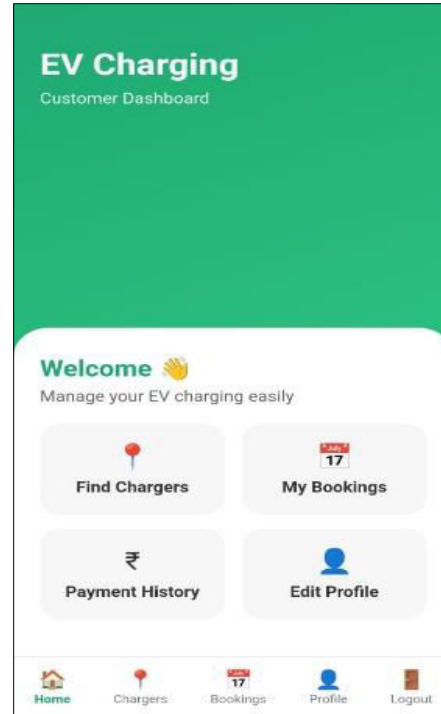
(a)



(b)



(c)



(d)

Fig (c) shows the owner dashboard of the EV charging platform, where charger owners can manage their services efficiently. It allows users to add chargers, manage slots, view bookings, track charging sessions, and monitor earnings. The dashboard also provides quick access to profile settings and overall activity management. Fig (d) shows the customer dashboard of the EV charging platform, designed for easy access to charging services. Users can find nearby chargers, manage bookings, view payment history, and update their profile. It provides a simple interface to handle all EV charging activities in one place.

VIII. CONCLUSION

The development of the EV charging model provided in this design can be taken as the major step towards helping to provide the extended ecosystem of the electric mobility. The design was able to deal with the significant expostulations on EV charging structure, like its scarcity, absence of real-time data, was crippled resource use, and a request concerning charging vacuity. The system has demonstrated the possibility to alleviate both stoner luxury and dynamism effectiveness through the perpetration of a smart EV charging platform where tackle factors, IoT technology, and software- grounded monitoring and operation are integrated to achieve the eventuality.

The coinage of a stoner- friendly platform that allows the electric agent possessors to find out the availability of charging stations, see the empty side, and book one in advance is one of the most significant achievements of this design. Real- time monitoring enables the position drivers to monitor dynamism operation, charging duration and system health. This is not only helping to improve stoner satisfaction but also helps the indulgence providers to be structured well. The design also showed that it was feasible to incorporate sources of renewable dynamics with charging units, which would promote sustainable dynamism use and limit the reliance on reactionary sources of energy, which is the generation of electricity through reactionary methods.

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