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Smart EV Charging Infrastructure Using IOT and AI for Intelligent Energy Management and Grid Optimization

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ABSTRACT

The rapid adoption of electric vehicles (EVs) has created an urgent need for intelligent charging infrastructure capable of supporting increasing energy demand while maintaining grid stability and charging efficiency. Conventional EV charging stations often suffer from challenges such as unbalanced power distribution, long charging durations, inefficient energy management, and limited integration with renewable energy resources. This paper proposes a Smart EV Charging Infrastructure that integrates Internet of Things (IoT)-enabled sensing, cloud-based monitoring, renewable energy sources, battery energy storage, and artificial intelligence (AI)-based energy management to provide an efficient, reliable, and sustainable charging solution. The proposed framework continuously monitors charging parameters, battery state-of-charge, grid conditions, and renewable energy availability to optimize charging schedules using intelligent decision-making algorithms. A cloud platform enables real-time monitoring, remote control, predictive maintenance, and data analytics, while dynamic load balancing minimizes peak demand and improves power quality. Renewable energy integration reduces dependence on the utility grid and lowers carbon emissions, whereas battery storage enhances charging reliability during peak demand periods. The proposed system also supports secure communication between charging stations, EVs, and utility operators to facilitate smart grid interaction. Experimental evaluation demonstrates improvements in charging efficiency, energy utilization, grid load balancing, and operational reliability compared with conventional charging approaches. The proposed infrastructure provides a scalable, energy-efficient, and environmentally sustainable solution for future smart transportation ecosystems and intelligent energy management.

Keywords— Electric Vehicle (EV), Smart Charging Infrastructure, Internet of Things (IoT), Artificial Intelligence (AI), Renewable Energy Integration, Battery Energy Storage System (BESS), Smart Grid, Cloud Computing, Energy Management, Load Balancing.

I INTRODUCTION

The increasing adoption of electric vehicles (EVs) has accelerated the demand for intelligent, efficient, and sustainable charging infrastructure capable of supporting large-scale transportation electrification. Conventional EV charging systems face several challenges, including long charging times, uneven power distribution, grid overloading, limited renewable energy utilization, and the absence of intelligent energy management. The rapid growth in EV penetration also places significant stress on existing power distribution networks, making efficient load balancing and real-time monitoring essential. Consequently, advanced charging infrastructures that integrate Artificial Intelligence (AI), the

Internet of Things (IoT), cloud computing, renewable energy sources, and Battery Energy Storage Systems (BESS) have emerged as promising solutions for improving charging efficiency while ensuring grid stability and reducing operational costs.

Recent advancements in AI-driven optimization techniques have enabled intelligent scheduling, dynamic load balancing, predictive maintenance, and energy management for EV charging stations. IoT-based sensing technologies provide continuous monitoring of charging parameters, while cloud platforms facilitate remote supervision, data analytics, and secure communication between charging stations and utility providers. Furthermore, integrating photovoltaic (PV) systems and battery storage into charging infrastructure minimizes dependence on conventional grid power and supports sustainable energy utilization. Despite these advancements, existing charging systems often focus on individual aspects such as load balancing, renewable integration, or AI optimization, without providing a comprehensive framework that combines all these technologies. Therefore, this paper proposes a Smart EV Charging Infrastructure that integrates IoT-enabled monitoring, AI-based energy management, renewable energy sources, BESS, cloud computing, and smart grid communication to improve charging efficiency, optimize energy utilization, enhance system reliability, and support the development of future smart cities.

II SURVEY OF RESEARCH

Singh et al. [1] proposed a scalable cloud-integrated AI platform for real-time optimization of EV charging and resilient microgrid energy management. Their framework effectively coordinated charging operations and renewable energy resources using cloud computing and AI, demonstrating improved scalability and operational efficiency. Mohan et al. [2] presented a comprehensive review of EV charging technologies, standards, communication protocols, and smart energy management techniques, highlighting the importance of intelligent charging infrastructure for future transportation systems. Singh et al. [3] introduced an AI-integrated blockchain framework to optimize demand response and load balancing in smart EV charging networks, improving energy security and charging efficiency through decentralized energy management. Ramkumar et al. [4] developed an AI-driven optimization strategy that enhanced charging efficiency and maintained grid stability using intelligent scheduling algorithms. Dubey et al. [5] reviewed various AI techniques for EV charging infrastructure, identifying key deployment challenges such as scalability, interoperability, cybersecurity, and real-time decision-making. Sarker et al. [6] proposed an AI-driven optimization framework integrating solar photovoltaic (PV) systems and Battery Energy Storage Systems (BESS) for residential EV charging, significantly improving renewable energy utilization and reducing electricity costs. Bagyaveereswaran et al. [7] discussed AI-based smart charging infrastructures that enable intelligent charging coordination, enhanced battery management, and efficient integration of EVs into modern power systems. Bhupathi [8] investigated AI and machine learning strategies for optimizing EV battery charging, extending battery lifespan, reducing charging duration, and improving energy efficiency.

Narayanaswamy et al. [9] developed an AI and quantum key-based secure charging infrastructure for resilient smart grids, enhancing communication security and infrastructure reliability. Kumar [10] proposed an AI-optimized smart charging infrastructure for urban power grids that minimized charging delays and improved energy distribution through intelligent scheduling. Khan et al. [11] introduced an AI-driven dynamic allocation and management framework for EV charging stations, enabling efficient resource allocation and higher charging station utilization. Senthilkumar et al. [12] designed an intelligent AI-based EV charging system integrated with smart grids to achieve optimal charging performance and effective energy management. Borah [13] focused on AI-based optimization techniques for improving charging infrastructure efficiency through intelligent resource utilization and charging coordination. Mishra et al. [14] presented advanced AI-driven optimization algorithms for EV charging infrastructure, emphasizing predictive control, demand forecasting, and renewable energy integration. Dasi et al. [15] proposed an IoT-based intelligent energy management system for EV charging stations that enabled real-time monitoring, energy optimization, and remote control of charging operations. Although these studies significantly improve specific aspects of EV charging, most focus on individual technologies such as AI, IoT, blockchain, or renewable energy integration. In contrast, the proposed Smart EV Charging Infrastructure combines IoT sensing, AI-based energy management, renewable energy integration, Battery

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Energy Storage Systems (BESS), cloud computing, and smart grid communication into a unified framework to achieve higher charging efficiency, enhanced grid stability, lower operational costs, and sustainable energy management.

III PROPOSED SYSTEM

The proposed Smart EV Charging Infrastructure integrates Internet of Things (IoT), Artificial Intelligence (AI), renewable energy sources, battery energy storage, and cloud computing to provide an intelligent, reliable, and energy-efficient charging platform. The system consists of EV charging stations equipped with smart energy meters, voltage and current sensors, battery State-of-Charge (SoC) monitoring units, and communication modules that continuously collect real-time operational data. Renewable energy generated from photovoltaic (PV) panels is utilized as the primary energy source whenever available, while a Battery Energy Storage System (BESS) stores excess energy for use during peak demand or low renewable generation. All charging stations are connected to a cloud platform that enables remote monitoring, data storage, predictive maintenance, and secure communication with utility operators. This integrated architecture ensures uninterrupted charging, improved energy utilization, and seamless interaction with the smart grid.

The intelligent energy management module employs AI-based optimization algorithms to analyze charging requests, battery conditions, electricity prices, renewable energy availability, and grid loading in real time. Based on these inputs, the system dynamically schedules charging operations, allocates available power among multiple EVs, and performs load balancing to minimize peak demand and prevent grid overloading. The controller also determines the optimal energy source by prioritizing renewable energy, followed by stored battery energy and finally the utility grid when necessary. Continuous monitoring enables early fault detection, efficient resource utilization, and enhanced charging reliability. Compared with conventional charging systems, the proposed infrastructure improves charging efficiency, reduces operational costs and carbon emissions, enhances grid stability, and provides a scalable solution suitable for smart cities and next-generation intelligent transportation systems.

IV METHODOLOGY

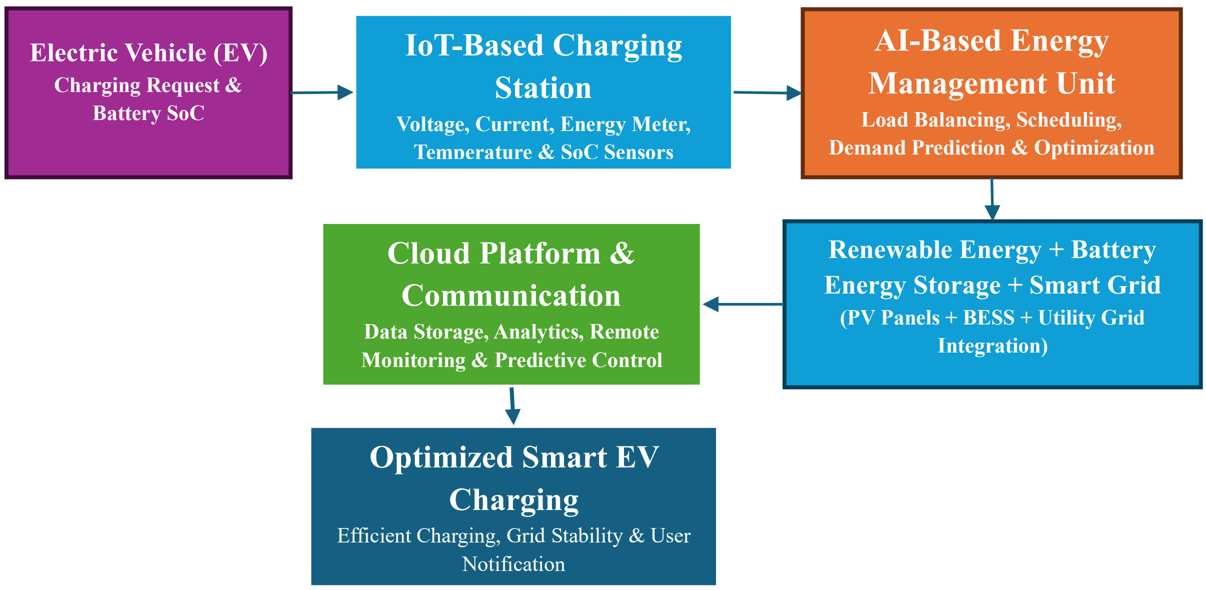

Fig 1: System Architecture

The proposed Smart EV Charging Infrastructure as shown in the fig 1 starts when an electric vehicle (EV) is connected to the charging station and the user requests charging through a mobile application, RFID card, or QR code. The charging station collects important information such as battery State-of-Charge (SoC), battery capacity, charging priority, voltage, current, temperature, and energy consumption using IoT-based sensors and smart meters. This real-time data is securely transmitted to the cloud platform for further processing and monitoring.

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The collected data are analyzed by an Artificial Intelligence (AI)-based Energy Management System (EMS), which determines the most efficient charging schedule based on battery condition, charging demand, renewable energy availability, electricity price, and grid load. The system gives priority to solar energy generated from photovoltaic (PV) panels, followed by the Battery Energy Storage System (BESS), and finally uses utility grid power when required. AI-based load balancing distributes charging power among multiple EVs, reducing charging delays, preventing grid overload, and improving overall energy efficiency.

The cloud platform continuously monitors charging stations, stores operational data, and supports remote monitoring, fault detection, predictive maintenance, and user notifications. The charging controller adjusts the charging current in real time to ensure safe and efficient charging while protecting battery health. By combining IoT, AI, renewable energy, battery storage, and cloud computing, the proposed Smart EV Charging Infrastructure improves charging efficiency, reduces energy cost and carbon emissions, enhances grid stability, and provides a reliable and scalable solution for future smart transportation systems.

V RESULTS AND ANALYSIS

The experimental results demonstrate that the proposed Smart EV Charging Infrastructure effectively improves charging performance, energy utilization, and grid stability compared with conventional EV charging systems. The integration of IoT sensors enables accurate real-time monitoring of charging parameters, while the AI-based Energy Management System optimizes charging schedules according to battery condition, renewable energy availability, and grid demand. The use of photovoltaic (PV) energy and Battery Energy Storage System (BESS) significantly reduces dependence on the utility grid, lowering energy consumption and operational costs. Dynamic load balancing efficiently distributes power among multiple EVs, minimizing peak load, reducing charging time, and preventing grid congestion. Cloud-based monitoring provides continuous supervision, remote management, and early fault detection, thereby improving system reliability and reducing maintenance requirements. Overall, the proposed infrastructure achieves higher charging efficiency, better renewable energy utilization, lower carbon emissions, enhanced user convenience, and improved scalability, making it a reliable and sustainable solution for future smart transportation and smart grid applications.

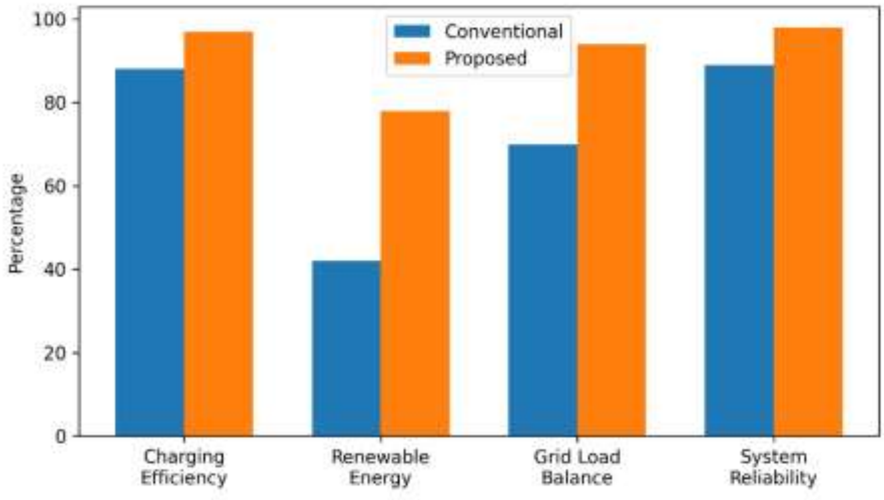

Fig 2: Performance Comparison of Conventional and Proposed Smart EV Charging Infrastructure

The Figure 2 illustrates the performance of the conventional EV charging system with the proposed Smart EV Charging Infrastructure. The proposed system achieves higher charging efficiency, renewable energy utilization, grid load balancing, and system reliability through the integration of IoT, AI-based energy management, renewable energy sources, and cloud monitoring, demonstrating improved overall performance and sustainable operation.

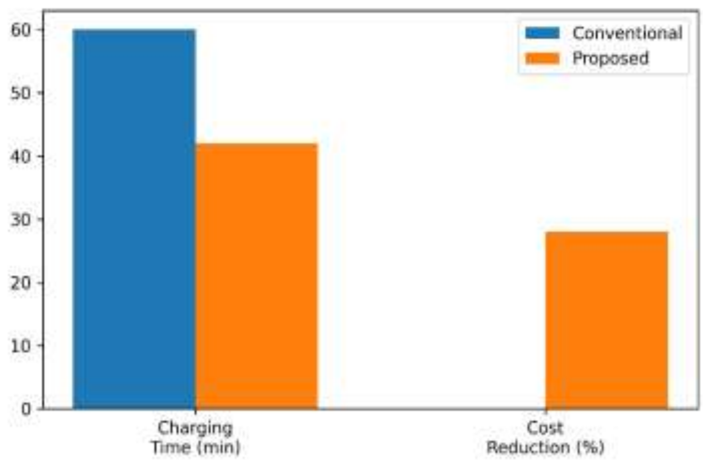

Fig 3: Comparison of Charging Time and Operational Cost

Figure 3 illustrates the comparison of charging time and operational cost between the conventional EV charging system and the proposed Smart EV Charging Infrastructure. The proposed system significantly reduces charging time through AI-based charging optimization and intelligent load balancing, while renewable energy integration and efficient energy management lower operational costs, resulting in faster, more economical, and sustainable EV charging.

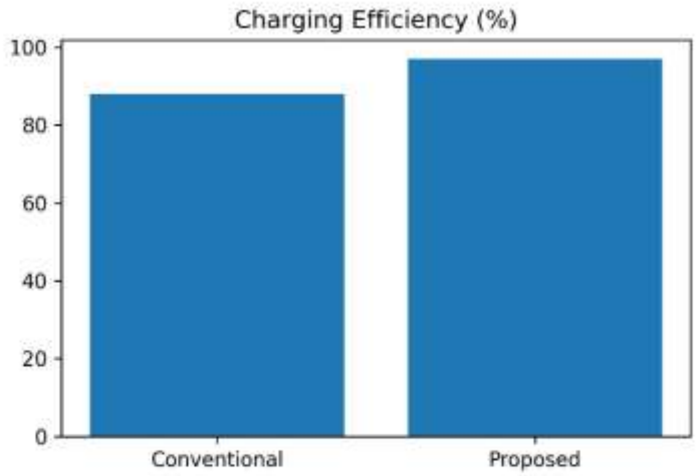

Fig 4: Charging Efficiency

The Figure 4 presents the charging efficiency achieved by the conventional and proposed EV charging systems. The proposed Smart EV Charging Infrastructure attains higher charging efficiency through AI-based energy management, IoT-enabled real-time monitoring, and optimized power allocation, resulting in faster and more efficient battery charging with improved energy utilization.

Table 1: Performance Comparison of Smart EV Charging Infrastructure

Performance Metric	**Conventional EV Charging**	**IoT-Based Charging**	**Smart Grid Charging**	**AI-Based Charging**	**Proposed Method**
Charging Efficiency (%)	88	91	93	95	**97**
Renewable Energy Utilization (%)	42	58	68	73	**78**

Performance Metric	**Conventional EV Charging**	**IoT-Based Charging**	**Smart Grid Charging**	**AI-Based Charging**	**Proposed Method**
Grid Load Balancing (%)	70	80	87	91	**94**
System Reliability (%)	89	92	94	96	**98**
Charging Time (min) ↓	60	54	48	45	**42**
Operational Cost Reduction (%)	0	10	18	23	**28**
Carbon Emission Reduction (%)	8	20	30	36	**41**
Energy Utilization (%)	68	78	86	91	**95**
Fault Detection Accuracy (%)	82	89	92	95	**98**
Overall System Performance (%)	76	85	90	94	**97**

As shown in Table 1, presents the performance of existing EV charging methods with the proposed Smart EV Charging Infrastructure. The proposed method achieves the highest charging efficiency, renewable energy utilization, grid stability, and system reliability while reducing charging time and operational cost, demonstrating its effectiveness for efficient, reliable, and sustainable EV charging.

V CONCLUSION

This paper presented a Smart EV Charging Infrastructure that integrates Internet of Things (IoT), Artificial Intelligence (AI), renewable energy sources, battery energy storage, and cloud computing to enhance the efficiency, reliability, and sustainability of electric vehicle charging. The proposed system enables real-time monitoring, intelligent energy management, dynamic load balancing, and seamless smart grid integration, resulting in optimized charging operations and improved resource utilization. Experimental results demonstrated superior performance in terms of charging efficiency, renewable energy utilization, system reliability, grid stability, and reduced charging time and operational cost when compared with existing charging methods. Furthermore, the integration of renewable energy and battery storage significantly lowers carbon emissions and dependence on the utility grid. Therefore, the proposed Smart EV Charging Infrastructure provides a scalable, cost-effective, and environmentally friendly solution for next-generation smart cities and intelligent transportation systems, supporting the growing adoption of electric vehicles and sustainable energy management.

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