RADemics

IoT-Integrated EV Charging Systems with AI Energy Optimization

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Abstract

The rapid expansion of electric vehicle (EV) adoption has created significant demand for intelligent, efficient, and sustainable charging infrastructure capable of supporting urban mobility while maintaining grid stability. Integrating the Internet of Things (IoT) with EV charging networks enables real-time monitoring, seamless communication between vehicles and stations, and dynamic control of energy distribution. Artificial Intelligence (AI) enhances these capabilities by optimizing charging schedules, predicting energy demand, and aligning operations with renewable energy availability. AI-driven frameworks facilitate adaptive load management, predictive maintenance, and multi-objective optimization, balancing energy efficiency, cost reduction, and battery health preservation.

Renewable energy integration and Vehicle-to-Grid (V2G) interactions further improve system sustainability, allowing bidirectional energy flow and efficient utilization of distributed energy resources. Scalable and interoperable IoT architectures support large-scale urban deployment, while secure communication protocols and privacy-preserving mechanisms ensure network resilience and trustworthiness. Predictive analytics, real-time control, and modular system designs collectively establish a robust, adaptive, and intelligent EV charging ecosystem. This chapter explores architectural frameworks, optimization algorithms, and practical implementations, offering insights into the development of sustainable, energy-efficient, and user-centric EV infrastructure suitable for future smart cities.

Keywords: Electric Vehicles, IoT, Artificial Intelligence, Renewable Energy, Smart Grid, Energy Optimization

Introduction

The accelerated adoption of electric vehicles (EVs) worldwide has transformed the landscape of urban transportation, necessitating the development of advanced charging infrastructure capable of meeting increasing energy demands while maintaining grid stability [1]. Conventional charging systems, which operate on fixed schedules and limited monitoring capabilities, are inadequate for addressing the dynamic and complex nature of EV charging in densely populated areas. Urban centers face challenges such as high peak loads, fluctuating energy demands, and integration with intermittent renewable energy sources [2]. Intelligent charging systems enabled by the Internet of Things (IoT) offer real-time monitoring of charging stations, vehicles, and grid conditions,

allowing for adaptive control and optimization of energy distribution [3]. IoT networks facilitate communication between heterogeneous devices, enabling predictive maintenance, fault detection, and efficient resource allocation. Such connectivity provides a foundation for scalable and responsive EV infrastructure that can adapt to evolving urban energy requirements without compromising reliability or efficiency [4]. The integration of IoT also ensures data-driven decision-making by continuously collecting and analyzing operational parameters, allowing operators to anticipate demand surges and manage energy flow effectively [5].

Artificial Intelligence (AI) enhances IoT-enabled EV charging systems by introducing predictive and adaptive capabilities that optimize energy consumption and load management [6]. Machine learning algorithms can analyze historical and real-time data to forecast peak demand, detect anomalies in usage patterns, and recommend optimal charging schedules [7]. Reinforcement learning strategies allow dynamic adjustment of charging rates based on grid conditions, user preferences, battery health, and cost factors. By incorporating AI, EV networks can perform multi-objective optimization, simultaneously minimizing operational costs, maximizing energy efficiency, and preserving battery longevity [8]. These intelligent frameworks reduce energy wastage and prevent grid overload, ensuring a more resilient infrastructure [9]. In addition, AI-driven insights enable operators to integrate renewable energy sources effectively, scheduling charging sessions when solar or wind energy was abundant, thereby reducing reliance on fossil-fuel-based electricity and contributing to sustainable urban mobility [10].

Integration of renewable energy with EV charging networks presents both opportunities and challenges due to the intermittent and variable nature of solar and wind generation [11]. Predictive models leveraging AI algorithms can forecast energy availability, allowing charging stations to align operations with renewable production [12]. Coupled with IoT-enabled sensors and edge computing, these models support real-time adjustment of charging schedules, ensuring efficient utilization of distributed energy resources. Energy storage systems, including batteries and supercapacitors, complement this integration by storing excess energy during periods of high renewable output and releasing it during peak demand, mitigating fluctuations in energy supply [13]. Vehicle-to-Grid (V2G) technology further enhances system flexibility by allowing bidirectional energy flow, enabling EVs to return stored energy to the grid when needed [14]. Coordinated management of these resources through AI and IoT ensures stable grid operations, optimized energy distribution, and reduced environmental impact. This approach supports sustainable urban electrification while accommodating the growing number of EVs and the variability of renewable energy sources [15].