

A Review of the Analysis on the Interaction Between New Energy Vehicle Charging and the Power Grid

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ABSTRACT

Against the backdrop of widespread adoption of new energy vehicles in China, dual core contradictions drive this research. The proliferation of new energy vehicles significantly increases the burden on the power grid, necessitating the exploration of charging solutions that alleviate grid load. From a research value perspective, this study systematically collects and organizes literature to identify charging methods that minimize grid load, reduce grid losses, and enhance energy utilization efficiency. It also delves into the interactive effects between new energy vehicle charging and the power grid, providing a theoretical foundation for subsequent technological development and engineering applications. Aligned with the national strategic context of achieving the "dual carbon" goals and high penetration rates of new energy vehicles, this research holds significant practical and strategic value.

KEYWORDS

Grid load; New energy vehicle charging station; Smart grid; Energy management strategy

1 Introduction

1.1 Domestic Research Status

Domestic research on the interaction between new energy vehicle charging and the power grid has closely centered on the "dual carbon" goals and the backdrop of high new energy vehicle penetration. Core research focuses on three major directions: power grid load regulation, charging technology iteration, and regional scenario adaptation. Research outcomes demonstrate both theoretical depth and engineering applicability.

Regarding grid load impacts and regulation, early studies centered on macro-level impact analysis. Gao Ciwei and Zhang Liang were the first to systematically examine the effects of electric vehicle charging on distribution grid peak-to-valley load differences and voltage stability. They highlighted that uncoordinated charging could increase distribution grid peak loads by 20%-30% and proposed the preliminary concept of "off-peak charging," laying the foundation for subsequent research^[1]. As research deepened, load regulation shifted from "passive peak shifting" to "active optimization": Lin Shunjiang's team proposed a dispatch framework based on "generation-grid load-storage" coordination, integrating EV charging loads as grid-adjustable resources and employing robust optimization algorithms to mitigate the impact of load uncertainty on the grid. Fu Baochuan's team demonstrated that charging load smoothing strategies combined with energy storage can reduce charging load fluctuations within microgrids by 15%-20%, providing solutions for distributed energy replenishment scenarios^[2-3].

In the realm of charging technology and efficiency enhancement, domestic research exhibits a dual-track approach of "hardware iteration + strategy optimization." On the hardware front, Bao Jie proposes that charging stations utilizing gallium nitride (GaN) devices can elevate power conversion efficiency to 96% at , providing hardware support for high-power charging (180kW and above)^[4]. Strategically, Li Meng compared wired fast charging, battery swapping, and wireless charging, noting that while battery swapping reduces user wait times, it does not fundamentally resolve charging duration issues^[5]. Wireless charging, constrained by transmission distance and efficiency, still requires breakthroughs in magnetic coupling structure optimization. Additionally, Zou Bowen explored applying reinforcement learning to charge-drive energy allocation^[6]. While not directly targeting grid load optimization, this approach offers novel insights into "coordinating charging strategies with vehicle energy consumption."

However, existing domestic research exhibits two shortcomings: First, specialized optimization for high-load scenarios (e.g., concentrated high-power charging at highway service areas) remains inadequate. Most studies focus on dispersed residential charging, lacking precise simulations of extreme load impacts such as "simultaneous high-power charging by over 50 EVs in a single area." Second, there is limited research on phased dynamic adaptation of charging parameters (voltage, current, power). Most studies employ "fixed-power charging" or "single-parameter optimization," failing to fully explore the potential of "multi-parameter coordinated adjustment" for smoothing grid loads.

1.2 International Research Landscape

International research emphasizes technological innovation and cross-disciplinary integration, with foundational studies leading globally. Commencing earlier than domestic efforts, core research centers on breakthroughs in wireless charging technology, smart grid coordination, and multi objective optimization algorithms. This focus on fundamental

principle innovation and interdisciplinary integration provides valuable technical references for domestic research.

Wireless charging technology stands as a core international research direction. Early studies centered on single-coil wireless charging^[7]. As demands evolved, multi-coil structures emerged as a breakthrough focus: Kim proposed a dual-receiver-coil wireless charging system, optimizing coil magnetic coupling to achieve 92% charging efficiency while expanding spatial freedom for dynamic wireless charging. Additionally, "Wireless Power Transfer: An Overview" systematically reviews technical pathways including magnetic coupling, electromagnetic induction, and magnetic resonance^[8]. It highlights that magnetic resonance wireless charging holds advantages in 1-3m transmission scenarios but faces challenges in electromagnetic radiation safety regulation. Internationally, the IEC 61980 standard has been established to specify its electromagnetic compatibility requirements.

In the field of smart grid and charging synergy optimization, international research has placed greater emphasis on the deep integration of algorithms and grid dispatch. A team from the University of California, Berkeley proposed a charging load optimization strategy based on "Distributed Model Predictive Control (DMPC)"^[9]. This approach divides the grid into multiple subsystems, with each subsystem using a local controller to adjust charging parameters in real time, achieving global load leveling. In a pilot project on the California grid, this strategy reduced the peak-to-valley difference in charging loads by 25%. European research institutions (e.g., Germany's Fraunhofer Institute) focus on "V2G (Vehicle-to-Grid)" technology, utilizing bidirectional charging strategies to transform electric vehicles into "mobile energy storage units" for the grid^[10]. These vehicles charge during low demand periods and discharge during peak hours, effectively smoothing load patterns. However, constrained by battery cycle life limitations, this approach remains in small-scale pilot stages.

Key gaps in international research include: First, high implementation costs hinder large-scale adoption; second, insufficient consideration of adaptability to diverse grid architectures means direct application of foreign strategies may yield suboptimal results for domestic grid optimization.

2 Mainstream Charging Methods

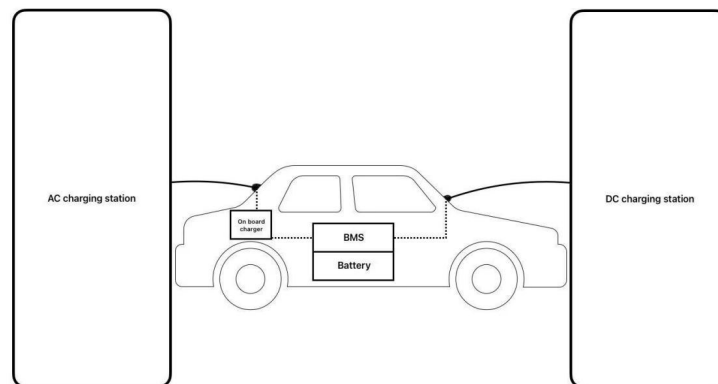


Figure 1 New Energy Vehicle Charging Methods

2.1 Slow Charging

Slow charging utilizes an onboard charger to convert AC power from a wall outlet into the DC power required by the battery. Due to the limited power capacity of onboard chargers (typically below 10 kW), charging speeds are relatively slow. This method is commonly employed via home-based fixed charging stations or portable chargers. It causes minimal battery damage, offers high safety, and is cost effective.

2.2 Fast Charging

The core difference between fast charging and slow charging lies in the location of current conversion. AC power is converted to DC directly within the charging station's high-power DC converter module before charging the battery. This method offers high charging efficiency and rapid charging speed. However, it causes greater battery damage and incurs higher costs.

3 Research Content

3.1 Research Background

China currently leads globally in new energy vehicle (NEV) development. By the end of 2024, 11.25 million NEVs were newly registered, accounting for 41.83% of all new vehicle registrations. This growth has driven continuous expansion of charging infrastructure, including charging stations. By the end of 2023, China's cumulative charging infrastructure

reached 8.596 million units. According to Yang Min's research team on the impact of new energy vehicle charging on provincial grid load characteristics, Anhui Province alone will see a charging load of 3.63 million kW by 2025, equivalent to 6% of the region's peak load [11]. However, the total charging volume in 2025 will only reach 3.3 billion kWh, accounting for 1% of the region's total electricity consumption. This demonstrates that new energy vehicle charging exhibits characteristics of low electricity consumption per unit, high load intensity, short utilization duration, and concentrated load patterns.

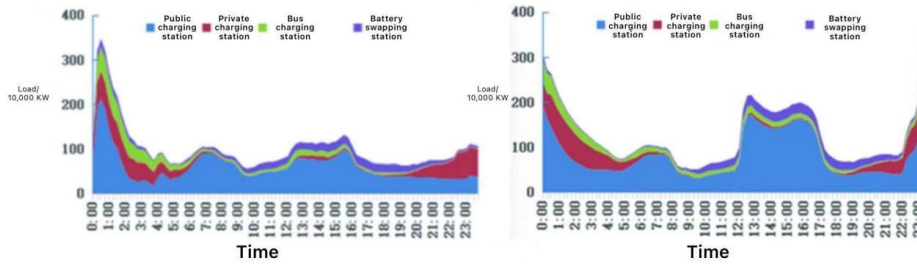


Figure 2 Anhui Province Grid Load in 2025 (Left: Summer 2025, Right: Winter 2025)[12]

3.2 Research Methodology

Employing literature review and scenario validation methods, this study systematically analyzed core domestic and international literature around keywords such as "charging control strategies" and "grid load optimization." It distilled the core approaches and limitations in existing research on charging parameter optimization. The investigation explored the current proportion and impact of new energy vehicle charging on local grid loads.

3.3 Factors Influencing Grid Impacts from New Energy Vehicle Charging

In Gao Ciwei's research, under the premise of disorderly charging of new energy vehicles, multiple vehicles charging simultaneously exacerbates load peak-to-valley differences and causes overloading of regional transformers and transmission lines, leading to fault tripping [1]. Furthermore, the grid connection of large clusters of charging piles generates significant inrush currents, disrupting grid voltage and frequency stability.

Charging stations introduce harmonic pollution into the grid. As demonstrated in Li Eshou's research, the extensive use of power electronic devices during charging injects substantial harmonic currents into the grid [12]. Particularly in "uncontrolled rectifier + chopper" charging equipment, the fifth harmonic current content ranges from 60% to 69%, with total current distortion reaching 86.2%. This adversely affects power quality in the supply system, leading to inaccurate measurement instruments, damage to large-capacity capacitors, and overheating of power conductors.

3.4 Charging Solutions Capable of Reducing Grid Load

Current solutions primarily focus on time-of-use charging allocation, upgrading charging equipment, and re-planning charging station infrastructure.

Regarding time allocation, this involves preventing new energy vehicles from charging simultaneously during peak periods. This approach effectively reduces peak loads while improving equipment utilization by distributing charging times evenly across a 24-hour period. However, it offers limited convenience to users, who cannot specify charging times according to their needs.

Second, upgrading charging equipment: The nonlinearity of new energy vehicle battery chargers generates significant harmonic currents, necessitating the addition of PWM rectifiers and high frequency DC/DC converters [12]. PWM is employed on the rectifier side to improve power factor, thereby reducing grid-side harmonics. It also offers good dynamic performance and high conversion efficiency. However, its complex structure and high cost make full replacement impractical.

Alternatively, filters can be deployed within the power system. Passive AC filters—comprising combinations of power capacitors, reactors (typically air-core), and resistors—operate in parallel with the charging station load. Beyond filtering,

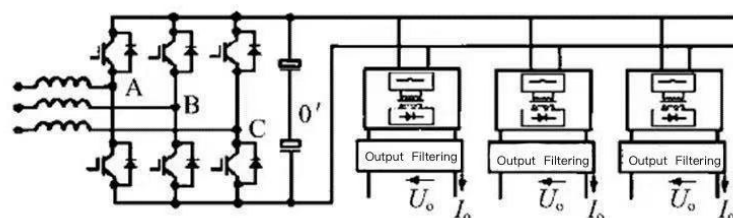


Figure 3 Block Diagram of a Charger Powered by a PWM Rectifier

they also provide reactive power compensation and voltage regulation. Their simplicity, operational reliability, and ease of maintenance have led to widespread adoption. Of course, when designing LC filters, they should be targeted to address 5th, 7th, 11th, and 13th harmonic currents. Capacity design must ensure effective harmonic current absorption while avoiding overcompensation of reactive power. When employing active filters, charging stations are time-varying loads with rapidly changing characteristics. The demands for filtering, reactive power compensation, and voltage regulation are sometimes difficult to balance simultaneously, making passive filtering methods insufficient to meet all requirements. When employing active filtering technology, installing capacitor compensation devices near the charging station's grid connection point may induce 5th and 7th harmonic resonance. Design testing and analysis are required, with potential modifications to nearby capacitor branches if necessary.

Redesigning charging station construction represents the newest approach among these solutions. To avoid interaction between charging equipment and the grid, charging stations could incorporate their own power generation facilities or be planned near power plants. BYD has proposed photovoltaic energy storage charging stations that utilize solar panels to generate electricity during daylight hours, storing it in capacitors for release during evening charging peaks. This approach could effectively reduce grid load under large-scale deployment while promoting renewable energy generation. However, its high cost and unproven adaptability suggest it may lack mature theoretical foundations and methodologies.

4 Conclusions

Research on new energy vehicle charging and grid load has been extensive, with decades of effort by numerous power professionals yielding many effective solutions for high grid load scenarios. Building upon this body of work, completed this review and summarized the relationship between new energy vehicle charging and grid load:

- (1) Currently, new energy vehicle charging exhibits characteristics of low electricity consumption but significant grid load impact.
- (2) The charging process introduces harmonic pollution into the grid, affecting its operation.
- (3) As the new energy vehicle market continues to expand, the impact of their charging on the grid will gradually increase.

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