# The Energy Optimization and Scheduling Problem of the Vehicle-to-Grid (V2G) Technology for Electric Vehicles

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**Abstract: With the global energy structure transformation and the increasing popularity of electric vehicles (EVs), the Vehicle-to-Grid (V2G) technology has emerged as a key solution to address issues like grid load pressure and renewable energy integration. This paper reviews the research on V2G energy optimization scheduling. It analyzes the current situation of V2G energy optimization and scheduling both abroad and in China, covering aspects such as policy support, technological research and development, and market mechanisms.**

**This paper proposes a V2G parameter configuration strategy based on user response willingness and a multi-objective optimization scheduling model. The NSGA-SA algorithm is used to improve the solution efficiency, and the scheduling flexibility is increased by 15% compared with traditional methods. The research methods used in relevant studies are diverse, including data collection from actual power systems, simulation, and a combination of theoretical analysis and survey data. These methods support the construction of various V2G-related models, such as response models and optimization scheduling models, and the application of different optimization algorithms to solve these models. Through these studies, a series of models have been developed, and the effectiveness of different strategies has been verified.**

**However, existing research has limitations. It often simplifies real-world scenarios, neglects the game behavior between vehicle owners and operators, and has limited application scenarios. Future research should focus on improving models, considering complex real-world factors, studying the game behavior, and expanding application scenarios. In general, with the continuous progress of technology and the improvement of policies, V2G technology is expected to play a more significant role in energy storage and distributed energy integration, contributing to a more sustainable and efficient energy system.**

**Keywords: Vehicle-to-Grid(V2G) Technology; Sustainable Energy Integration; Energy Optimization Scheduling Model; Data-Driven Research Methods**

## 1. Introduction

With the global transformation of the energy structure, electric vehicles (EVs) have gradually become a crucial part of future transportation due to their characteristics such as zero emissions and high efficiency. However, the widespread adoption of electric vehicles has led to a large demand for electric energy, and simultaneously, has imposed greater load pressure on the power grid. Against this backdrop, the Vehicle-to-Grid (V2G) technology has emerged as an effective solution to address this issue.

Regarding the energy optimization and scheduling problem of V2G technology, the main focus is on how to rationally schedule the charging and discharging processes of electric vehicles to achieve the balance of grid load and the optimization of electric vehicle battery life. Therefore, the research on this topic has significant theoretical and practical values:

Optimizing the Allocation of Grid Resources: By rationally scheduling V2G devices and optimizing the charging and discharging cycles of electric vehicle batteries, it can assist the grid in load regulation, improving the power supply reliability and efficiency of the grid. [1] Facilitating the Integration of Renewable Energy: V2G technology can effectively address the issues of volatility and intermittency of renewable energy sources such as wind and solar energy, contributing to the large-scale application of these energy sources.[2] Enhancing the Utilization Efficiency of Electric Vehicles: Through optimized scheduling schemes, over-discharging or over-charging of batteries can be avoided, thus extending the battery life and improving the overall economic benefits of electric vehicles[3].

Environmental Protection and Energy Sustainability: It promotes the efficient utilization of renewable energy. By leveraging the energy storage capacity of electric vehicles, it helps to smooth the fluctuations of renewable energy (such as solar and wind energy) and enhance their effective integration into the grid. Effective energy scheduling not only helps to reduce the consumption of fossil fuels but also decreases greenhouse gas emissions, driving the development of a green and low-carbon economy.

In the research field of V2G energy optimization scheduling problems, numerous previous studies have achieved certain results, yet they also have corresponding limitations.

The paper "Multi-layer Coordinated Optimal Dispatch of Electric-Thermal-Hydrogen Integrated Energy System Based on V2G Load Feedback Correction" [4] has its merits in comprehensively considering multiple factors to construct a multi-objective optimization model, innovatively adopting multi-layer coordination and MPC rolling optimization, introducing an effective algorithm, and fully verifying the effectiveness of the strategy through case studies. However, its drawbacks include simplifying the actual scenario, failing to consider the game behavior between vehicle owners and operators, and limiting the application scope to a specific energy system. The paper "Optimization Scheduling with Multiple Stakeholders in V2G Mode" [5] has the advantages of constructing an optimized scheduling model by comprehensively considering the interests of multiple parties such as the power grid, EV aggregators (EVAs), and EV users, verifying it using the particle swarm optimization algorithm, and the results showing that it can mitigate load fluctuations and maximize the economic benefits of all parties. However, its disadvantages include that the model may not fully consider complex practical factors, fails to take into account more influencing factors such as market dynamics, and lacks sufficient research on the expansion of application scenarios.

Economic analysis [6] is another crucial aspect in the application of V2G technology. Researchers are concerned with how to generate economic benefits by providing ancillary services (such as frequency regulation and load balancing) through V2G systems. For instance, studies on the charging and discharging scheduling strategies of electric vehicle batteries based on market mechanisms analyze the profits obtained by electric vehicle users through participating in power market transactions.

## 2. Current Situation

Current Situation of V2G Energy Optimization and Scheduling Abroad

Countries globally are actively promoting V2G. The US, via acts like the Energy Policy Act and Clean Energy Act, offers tax incentives and funds V2G R&D. California uses time-of-use pricing to integrate EVs into the grid. Denmark and the Netherlands in Europe promote V2G R&D with subsidies. The EU's "Fit for 55" plan deems smart and bi-directional charging as key for emission reduction, spurring V2G in Europe. The UK's Grid and Nissan's "Powerloop" project uses Nissan Leaf's bi-directional charging to release power during peak grid hours, enhancing grid stability and benefiting users through time-of-use pricing.

Many countries are leading. The US DoD verified V2G's role in military base energy autonomy at Los Angeles Air Force Base. After Fukushima, Japan included V2G in its emergency power supply, increasing public acceptance. International standardization orgs like ISO and IEC are speeding up development of EV-grid interaction comms protocols and tech standards (e.g., ISO15118), improving V2G system compatibility and interoperability, cutting costs, and attracting more enterprises. Auto manufacturers and research institutions, especially in Europe and America, are exploring V2G. Some projects are in commercial trials.

"Peak-valley arbitrage" is a core V2G business model. Denmark's Parkerproject shows users can profit from charging low and selling high, offsetting charging costs. The Netherlands, with policy incentives, has integrated V2G into the power market, and many cities have V2G charging station network pilots. Also, the "Vehicle-to-Home" (V2H) model is emerging. Nissan's "Nissan Energy" project lets vehicle owners power their homes, enhancing energy independence and providing grid backup.

Current Situation of V2G Energy Optimization and Scheduling in China

In 2025, China has also achieved certain results in the field of V2G energy optimization and scheduling, and the development momentum is rapid. At the policy level, strong support has been provided. [7] In 2024, the General Office of the Development and Reform Commission and three other ministries jointly issued the "Notice on Promoting the Large-scale Application Pilot of Vehicle-Grid Interaction", clearly stating the need to comprehensively promote the orderly charging of new energy vehicles and expand the scale of bi-directional charging and discharging (V2G) projects. The notice sets specific quantitative indicators for pilot regions and projects. For example, pilot regions should fully implement time-of-use electricity pricing for charging, striving to ensure that more than 60% of the annual charging electricity is concentrated during off-peak hours, and more than 80% of the electricity charged through private chargers is concentrated during off-peak hours. The total discharge power of V2G projects participating in the pilot should be no less than 500 kilowatts in principle, and the annual discharge volume should be no less than 100,000 kilowatt-hours. It also encourages V2G projects to aggregate and participate in power spot markets, green power trading, and energy storage capacity leasing markets. In terms of project pilots, localities have actively responded. According to incomplete statistics, V2G demonstration projects have been successively established in Jiangsu, Zhejiang, Shandong, Hebei, Hunan, Hubei, Anhui, Beijing, Shanghai, Tianjin, and other places. The State Grid has deployed 42 projects in 15 provinces and cities, and the North China Power Grid has included them in the peak-shaving auxiliary service market settlement. For example, Chongqing has been striving to promote the integration and interaction between new energy vehicles and the grid. On August 24, 2024, Chongqing launched its first large-scale vehicle-grid interaction application. A total of 75,600 new energy vehicles participated in off-peak charging, V2G reverse discharging, and connection to virtual power plants. Among them, 120 new energy vehicles participated in the V2G large-scale reverse discharging pilot application, with a cumulative discharge of more than 1,700 kilowatt-hours. Chongqing also plans to build more than 100 bi-directional charging and discharging (V2G) projects by 2025 to further enrich the vehicle-grid interaction application scenarios.

Enterprises are also actively involved. Nezha Auto has reached a strategic cooperation with CATL, 360, and Beijing Chainyu Technology on the V2G vehicle-grid smart energy demonstration project, jointly building a new vehicle-grid interaction industry ecosystem of "vehicle-charging pile-power grid-user-society". GAC Aion announced that it will build 2,000 Aion super charging and swapping stations with V2G technology by the end of 2025 and extend the V2G technology to private charging piles. Charging pile enterprises are also accelerating their R & D efforts. The V2G product of Golden Crown Co., Ltd. has reached its second generation, with a rated power of 120kW. It adopts an integrated dual-gun structure design, enabling it to charge two vehicles simultaneously. Tonghe Technology has launched a 20kW V2G charging module and a 15kW bi-directional DC-DC charging module, and plans to launch a 30kW bi-directional DC-DC charging module.

In addition, the rapid growth of the domestic electric vehicle stock provides broad space for the development of V2G technology. As of February 2025, the number of new energy vehicles in China has exceeded 40 million. If all of them are connected to V2G, they can provide 3.5 billion kilowatts of peak-shaving capacity, which is equivalent to 50% of the national non-fossil energy installed capacity.

## 3. Methods

### 3.1 Data Collection Methods

In "V2G-Enabled Active Support for Coordinated Day-Ahead and Real-Time Optimization Scheduling of Transmission and Distribution Systems",[8] actual power system data is adopted, such as load data, wind and photovoltaic power generation data, and electric vehicle operation data from modified IEEE standard test systems (T30-D33 and T118-D69 + 85 test systems). These data reflect the actual operation status of the power system and provide a real-world basis for model construction and verification.

In "Optimal Scheduling Strategy Considering V2G Compensated Battery Capacity under Photovoltaic Microgrids",[9] data is generated through simulation. The number of electric vehicles, starting times, initial battery capacities, etc., are set to follow a normal distribution to simulate load conditions under different operation modes. This method enables extensive simulation and analysis in the absence of actual data.

In "User Response-Driven V2G Parameter Configuration Strategy and Its Application on

Optimization Scheduling",[10] a combination of theoretical analysis and actual survey data is used. The membership function is constructed based on the analysis of the relationship between user characteristics and V2G parameters, Weber-Fechner law, battery aging model, and user acceptance. Meanwhile, actual data such as vehicle networking and off-grid information of two-way charging stations are obtained from relevant literature.

In "Multi-objective Capacity Allocation Optimization Method of Photovoltaic EV Charging Station Considering V2G"[11], statistical data and simulation data are employed. By comparing with the driving data of Chinese cities, this study verifies the representativeness of the data from the US Department of Transportation. The adjusted driving range distribution is suitable for the urban context in China. .The probability distribution of the daily driving range of electric vehicles is determined according to the survey data of private electric vehicles by the US Department of Transportation, and the Monte Carlo method is used to simulate the charging and discharging load curves of electric vehicles. Additionally, actual statistical data such as radiation formulas and photovoltaic module power data in a specific area are referenced.

### 3.2 Research Design

In "V2G-Enabled Active Support for Coordinated Day-Ahead and Real-Time Optimization Scheduling of Transmission and Distribution Systems", a vehicle-to-grid (V2G) response model for electric vehicles considering energy market, flexibility market, and reactive power ancillary service market mechanisms is constructed, along with a distributed optimization scheduling model for coordinated day-ahead and real-time operation of transmission and distribution systems. The active and reactive power support potential of electric vehicles is analyzed through market mechanisms, and various resources are coordinated to meet the power supply-demand balance of the system.

In "Optimal Scheduling Strategy Considering V2G Compensated Battery Capacity under Photovoltaic Microgrids", a collaborative scheduling model for batteries and V2G in a photovoltaic microgrid is established with the dual objectives of economy and grid-connected load volatility. Different electric vehicle load modes, including no-EV mode, unordered EV mode, shifted EV mode, and scheduled EV load mode, are considered.

In "User Response-Driven V2G Parameter Configuration Strategy and Its Application on Optimization Scheduling", a V2G parameter configuration strategy based on user response willingness is proposed, and a quantitative evaluation model for user response willingness considering multiple parameter factors is constructed. Vehicle classification criteria are defined, and a power aggregation model based on these criteria is built and applied to real-time optimization scheduling of the distribution network.

In "Multi-objective Capacity Allocation Optimization Method of Photovoltaic EV Charging Station Considering V2G", two charging and discharging load models for electric vehicles are constructed: an unordered charging and discharging model based on travel habits and an ordered charging and discharging model based on time-of-use (TOU) price. A mathematical model with the objective functions of maximizing energy efficiency and minimizing system investment and operation costs is established, and NSGA-II and NSGA-SA intelligent optimization algorithms are used to solve the model.

### 3.3 Data Processing and Diagnosis

In "V2G-Enabled Active Support for Coordinated Day-Ahead and Real-Time Optimization Scheduling of Transmission and Distribution Systems", the collected data is sorted and pre-processed and then used for setting and initializing model parameters. The alternating direction method of multipliers (ADMM) is used to solve the model in a distributed manner. During the solution process, parameters are iteratively updated to meet the convergence conditions, ensuring the accuracy of the model results.

In "Optimal Scheduling Strategy Considering V2G Compensated Battery Capacity under Photovoltaic Microgrids", the particle swarm optimization algorithm is used to solve the model. The objective function is calculated and optimized during the solution process, and the optimal solution set is found through continuous iteration. The performance and effectiveness of the model are analyzed by comparing the load power curves under different modes.

In "User Response-Driven V2G Parameter

Configuration Strategy and Its Application on Optimization Scheduling", the collected data and model parameters are processed. The user response willingness is quantified through a fuzzy logic system, the vehicle status is classified using the classification criteria model, and then a power aggregation model is constructed to calculate the V2G response capacity. In the real-time optimization scheduling model, network power flow, new energy output, and electric vehicle-related constraints are processed and solved.

In "Multi-objective Capacity Allocation Optimization Method of Photovoltaic EV Charging Station Considering V2G", the Monte Carlo method is used to simulate and calculate the charging and discharging load model of electric vehicles, obtaining the charging and discharging power curves under different modes. The NSGA-II and NSGA-SA algorithms are used to process and solve the objective function and constraint conditions, obtaining the Pareto optimal solution frontier.

### 3.4 Data Analysis Strategy

In "V2G-Enabled Active Support for Coordinated Day-Ahead and Real-Time Optimization Scheduling of Transmission and Distribution Systems", different scenarios are set for comparative analysis. For example, in the day-ahead stage, the scenarios of unordered charging of EVS and EVS participating in V2G response are compared, and in the real-time stage, scenarios with different providers of active and reactive power regulation resources are compared. The performance and effectiveness of the proposed optimization scheduling method are evaluated by comparing indicators such as scheduling results and system operation costs under various scenarios.

In "Optimal Scheduling Strategy Considering V2G Compensated Battery Capacity under Photovoltaic Microgrids", a comparative analysis method is adopted. The total load power under different operation modes is compared pairwise according to the difficulty and progressive relationship of optimization, and the impacts of different modes on the load peak-valley difference, cost, and revenue are analyzed, thereby obtaining the optimization effect of V2G in the photovoltaic microgrid.

In "User Response-Driven V2G Parameter Configuration Strategy and Its Application on Optimization Scheduling", multiple cases (S1-S5) are set for comparative simulation. The user response willingness values, battery loss situations, economic benefits, and V2G response capacities under different cases are analyzed. The feasibility and effectiveness of the proposed V2G parameter configuration strategy and aggregation model are evaluated by comparing the results of each case.

In "Multi-objective Capacity Allocation Optimization Method of Photovoltaic EV Charging Station Considering V2G", the charging and discharging load curves under different charging modes are compared to analyze their impacts on the grid load. By comparing the optimization results of NSGA-II and NSGA-SA algorithms under different charging modes, the impacts of different algorithms and charging modes on system energy efficiency, investment cost, etc., are evaluated, so as to determine the optimal capacity configuration scheme.

## 4. results

### 4.1 Model Construction

4.1.1 V2G Response Model

All four papers constructed V2G-related models. "V2G-Enabled Active Support for Coordinated Day-Ahead and Real-Time Optimization Scheduling of Transmission and Distribution Systems" considered the traffic behavior characteristics of electric vehicles (EVs) and constructed V2G response models for single EVs and EV aggregations (EVS) from the perspectives of power and energy accumulation.

4.1.2 Optimization Scheduling Model

"V2G-Enabled Active Support for Coordinated Day-Ahead and Real-Time Optimization Scheduling of Transmission and Distribution Systems" constructed a distributed optimization scheduling model for coordinated day-ahead and real-time operation of transmission and distribution systems. The problem was decomposed into sub-problems of the transmission network and the distribution network for separate modeling and solution, taking into account various operation constraints.

"Multi-objective Capacity Allocation Optimization Method of Photovoltaic EV Charging Station Considering V2G" established a mathematical model with the objective functions of maximizing energy efficiency and minimizing system investment and operation costs, considering decision-variable constraints and power-balance constraints (see Figure 1 and Figure 2).

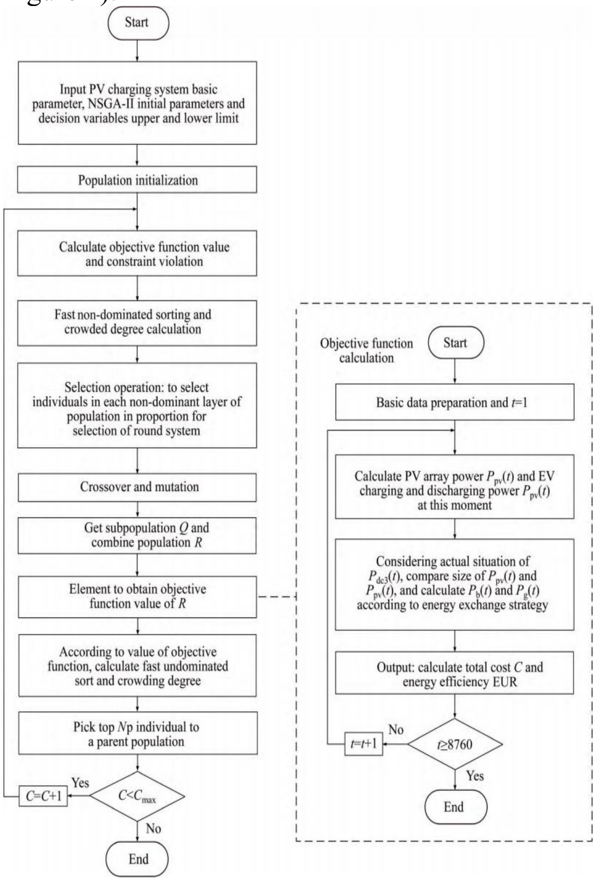


**Figure 1. Flow Chart of Solving m Odel based on N SG A -II Optim Ization Algorithm**

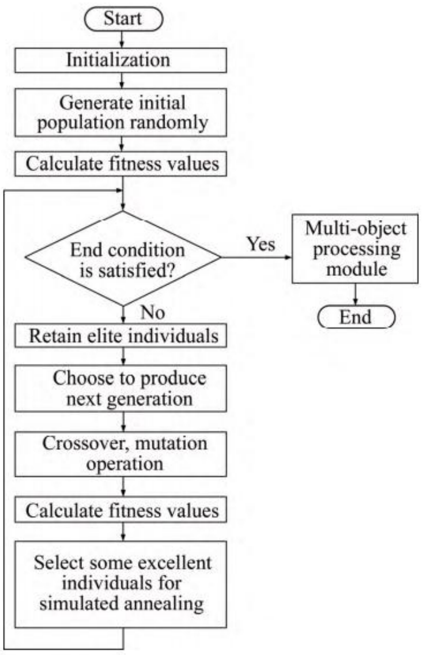


**Figure 2. Flow chart of solving model based on N SG A -SA Optimization Algorithm**

## 4.2 Algorithm Application

4.2.1 Optimization Algorithms

"V2G-Enabled Active Support for Coordinated Day-Ahead and Real-Time Optimization Scheduling of Transmission and Distribution Systems" used the Alternating Direction Method of Multipliers (ADMM) to solve the coordinated transmission-distribution model in a distributed manner. The parameters were iteratively updated to obtain the optimization results when the convergence conditions were met.

"Optimal Scheduling Strategy Considering V2G Compensated Battery Capacity under Photovoltaic Microgrids" employed the particle swarm optimization algorithm to solve the collaborative scheduling model. The optimal solution set was found through steps such as initializing the particle swarm, calculating the objective function, and updating the particles.

"User Response-Driven V2G Parameter Configuration Strategy and Its Application on Optimization Scheduling" utilized a quantitative evaluation model based on the Mamdani fuzzy logic system to set V2G parameters, and evaluated the V2G response capacity through the classification criterion model and the power aggregation model, which was applied to real-time optimization scheduling.

"Multi-objective Capacity Allocation Optimization Method of Photovoltaic EV Charging Station Considering V2G" used the NSGA-II and NSGA-SA intelligent optimization algorithms to solve the capacity configuration model of the photovoltaic charging station. The Pareto optimal solution frontier was obtained through operations such as population initialization, objective function calculation, selection, crossover, and mutation.

## 4.3 Experimental Analysis

4.3.1 Experimental Setup

"V2G-Enabled Active Support for Coordinated Day-Ahead and Real-Time Optimization Scheduling of Transmission and Distribution Systems" used the modified T30-D33 test system (coupled with a 30-node transmission network (TN) and a 33-node active distribution network (ADN)) and the T118-D69 + 85 test system (coupled with a 118-node TN and a 69-node ADN and an 85-node test system

## 5. Disscusion.

In the research of the V2G energy optimization and scheduling field, a variety of research methods have been widely applied. Data collection encompasses actual power system data, simulation data, and the combination of both, providing a solid foundation for model construction and verification. Research designs focus on constructing various V2G-related models, such as V2G response models considering market mechanisms and collaborative scheduling models, deeply analyzing the application of V2G technology in energy systems from different perspectives. In terms of data processing and diagnosis, multiple algorithms like the particle swarm optimization algorithm and the alternating direction method of multipliers are used to solve models, ensuring the accuracy and reliability of the results. The data analysis strategy conducts comparative analysis by setting different scenarios and cases to evaluate the performance and effectiveness of various optimization scheduling methods and parameter configuration strategies.

We suggest incorporating an interaction model between building owners and operators based on the Stackelberg game to quantify the trade-off between the economic incentives for building owners to participate in V2G and the scheduling costs of operators.

However, there are still some limitations in current research. Some studies simplify the actual scenarios and fail to fully consider complex real-world factors, such as differences in power grid structures in different regions and the diversity of user behaviors. In model construction, the game behavior between vehicle owners and operators is rarely considered, which may affect the practical effectiveness of optimization scheduling strategies. Moreover, the application scenarios of most studies are relatively limited, and insufficient attention is paid to V2G energy scheduling problems in special scenarios.

Future research should focus on improving models, fully considering complex factors in actual scenarios, and enhancing the practicality and accuracy of models. It is necessary to deeply study the game behavior between vehicle owners and operators and establish a more complete game model to achieve more reasonable resource allocation and scheduling strategies. Additionally, it is essential to expand the application scenarios of research and explore the application of V2G technology under extreme working conditions and special power grid environments to enhance the universality of research results.

## 6. Prospect

Based on the current research status and development trends of V2G energy optimization and scheduling, significant breakthroughs are expected in this field in the future. With continuous technological innovation, V2G technology will play a more crucial role in energy storage and distributed energy integration, further improving energy utilization efficiency.

From the perspectives of the market and policies, with the continuous improvement of relevant policies and the gradual maturity of market mechanisms, the commercial application of V2G technology will have more broad space. Governments and relevant departments should continue to increase support for the research, development, and application of V2G technology, and formulate unified technical standards and specifications to promote the healthy development of the market. Enterprises and research institutions should strengthen cooperation to jointly promote the industrialization process of V2G technology, reduce technical costs, and improve the reliability and stability of the system.

Looking ahead, V2G energy optimization and scheduling technology will play an important role in achieving sustainable energy development and enhancing the intelligence level of power grids, providing strong support for building a clean and low-carbon energy system.

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