Proceedings of CONF-MCEE 2026 Symposium: Advances in Sustainable Aviation and Aerospace Vehicle Automation
DOI: 10.54254/2755-2721/2026.KA26137

Impact of the Synergistic Optimization of V2G Technology and Renewable Energy on the Power Grid

Rui Li

Department of Electrical and Computer Engineering, University of Ulsan, Ulsan, South Korea
lirui565659@outlook.com

Abstract: As the proportion of Renewable Energy (RE) in the power system continues to increase and the number of Electric Vehicles (EVs) also grows year by year, the coordinated optimization of the two has become the key to enhancing the flexibility and stability of the power grid.Vehicle-to-Grid (V2G) technology, by enabling bidirectional energy exchange between electric vehicles and the power grid, provides an effective regulatory means to address the intermittency and volatility of renewable energy generation and is reshaping the operation mode of the power system.This article introduces the basic principles of V2G technology, the definition and types of RE, analyzes the existing collaborative mechanisms from three aspects: technology, market, policy and standard support, elaborates on the benefits that can be generated through the collaboration of the two, and discusses the challenges currently faced by the collaboration of V2G and RE in terms of user acceptance and battery life. Finally, the prospects for technological reform were made and the future research directions were pointed out.

Keywords: V2G technology, Renewable energy, Microgrid scenarios, Virtual power plant aggregation, Demand response mechani

1. Introduction

In recent years, due to the rapid development of economy and the rapid growth of population, the human demand for energy is increasing.The extensive use of fossil fuels such as coal, oil and natural gas has led to a large amount of carbon dioxide emissions, causing climate change and ecological environment deterioration on a global scale. Therefore, there is an urgent global need for an energy transition to achieve carbon neutrality [1]. Under the background of carbon neutrality, the proportion of renewable energy sources such as wind and solar power has been increasing year by year, but its intermittent problems are prominent, and flexible energy sources are needed to coordinateV2G technology is an effective means to solve intermittent problems. EVs applying V2G technology can be regarded as an uninterrupted mobile energy storage unit, which can form spatio-temporal complementarity with RE, thereby enhancing system resilience [2]. In order to better promote technological development, this paper discusses the existing collaborative mechanism, benefits and challenges faced by V2G and RE, and proposes directions for technological improvement, expecting to achieve better collaborative effects.

© 2025 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2755-2721/2026.KA26137

2. Basic principle of V2G technology

V2G technology was proposed by Amory Lovins in 1995, as shown in Figure 1.This technology is developed based on the relationship between EVs and power grids. EVs act as mobile energy storage units and are connected to the power grid through bidirectional charging and discharging devices to achieve bidirectional energy flow. The interaction between is realized by the ISO15118 communication protocol.Compared with traditional EV charging technology, V2G technology can not only charge EVs from the power grid to meet the daily travel needs of car owners, but also feed electrical energy back to the power grid from the EVs battery to relieve the load pressure on the power grid.V2G technology will become a key link between electric vehicles and smart grids, and it is one of the core technologies for building a clean and efficient future energy system.

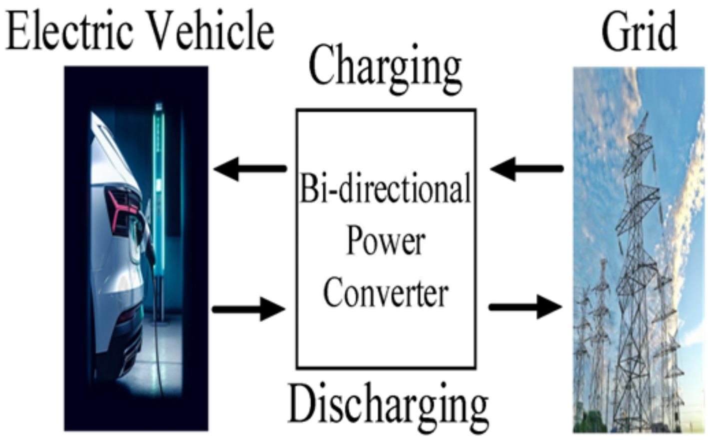

Figure 1. Relationship diagram between EVs and power grid

3. Definition and types of renewable energy

Renewable energy refers to the clean energy from nature that can be continuously replenishable and recycled, among which wind and solar energy are the most important representatives, and are also the fastest growing forms of renewable energy.Wind energy is converted into electrical energy through wind turbines, while solar energy is transformed into electricity through photovoltaic panels or solar thermal systems.These two types of energy sources have significant advantages such as abundant reserves, wide distribution, and almost zero emissions. However, they also face the core challenge of intermittency - the strength of wind is unpredictable, and sunlight is affected by day and night as well as weather, which leads to unstable power generation.Despite these challenges, with breakthroughs in energy storage technology and the development of smart grids, the status of wind and solar energy in the global energy transition is constantly rising, and they will become the core pillars of the low-carbon energy system in the future.

4. Current status of the collaborative operation of V2G and RE

V2G is a means to solve the RE problem. This article provides an overview of the current situation from three aspects: technology, market and policy.In terms of technology, by localizing and coordinating the charging and discharging behaviors of V2G and RE, virtual power plants aggregate scattered EV energy storage resources to participate in grid dispatching, energy management systems optimize charging and discharging strategies to balance economy and stability, and the

DOI: 10.54254/2755-2721/2026.KA26137

ancillary service market provides V2G with revenue channels such as frequency regulation and voltage regulation, achieving technological synergy.In terms of the market, the demand response mechanism encourages users to respond to electricity price signals, while the distributed power market allows V2G to directly trade the remaining electricity, promoting the optimal allocation of resources through market-based means.In terms of policy, the open access and two-way billing mechanism ensure the fair grid connection of V2G. Incentive and subsidy policies lower the threshold for user participation, while interoperability standards address the compatibility issues of equipment interfaces and communication protocols. The "technology - market - system" trinity can significantly enhance the flexibility and stability of the power grid.

4.1. Collaborative mechanism at the technical level

4.1.1. Microgrid scenario

A microgrid is a small-scale power system composed of distributed power sources, energy storage systems, loads and control systems [3]. Today's microgrid is mainly powered by renewable energy sources such as photovoltaic and wind energy, but these two forms of power generation have significant randomness and volatility, so energy storage systems are needed to stabilize power.EVs applying V2G technology can be regarded as mobile energy storage systems by achieving bidirectional energy flow, which precisely meets the demands of microgrids.There are two modes for microgrids, namely grid-connected mode and islanding mode.In grid-connected mode, the integrated photovoltaic storage and charging community microgrid is a typical application scenario. Its operation logic is that during the day when there is abundant sunlight, photovoltaic power is generated for household use, and the excess electricity is stored in electric vehicles.At night or on cloudy days, electric vehicle EVs discharge electricity to meet daily power demands. When the main grid fails, the microgrid switches from grid-connected mode to islanding mode. At this time, V2G becomes the main source of electricity, continuously supplying power to critical loads. It is particularly suitable for disaster-prone areas and scenarios with high requirements for power supply reliability.

4.1.2. Virtual Power Plant (VPP) aggregation

VPP is an energy management platform based on digital technology. By aggregating V2G technology and renewable energy, it supports large-scale access of EVs and renewable energy, and can achieve deep collaboration between mobile energy storage and clean power generation [4]. Different from microgrids that focus on local power supply security, the core function of VPP lies in economic optimization. According to grid load, real-time electricity price and weather conditions, VPP uniformly optimizes and schedules the access of wind and solar resources and the charging and discharging behavior of EVs. Thus, more benefits from ancillary services and electricity price arbitrage can be obtained.The key technology "aggregation" refers to the consolidation of scattered small-scale resources into large-scale dispatchable units, such as aggregating the battery capacity of thousands of EVs into an equivalent large-scale energy storage system.

4.1.3. Integration of Energy Management Systems (EMS)

EMS utilizes automated measures to conduct intelligent monitoring, analysis and optimized dispatching of power grid flow through mechanisms such as real-time monitoring, dynamic dispatching and multi-data fusion [5]. Its core is to realize the balance of power supply and demand

DOI: 10.54254/2755-2721/2026.KA26137

through intelligent dispatching, and improve resource utilization efficiency. EMS predicts EVs charging and discharging behavior and wind power generation, and combines electricity price to realize economic, efficient, stable and reliable power dispatching optimization.EMS adopts a cloud-edge-terminal hierarchical control architecture. The cloud formulates hourly dispatching plans, the edge layer realizes minute-level power allocation, and the terminal performs second-level charge and discharge regulation. Under the premise of protecting user privacy, it achieves real-time optimized dispatching of electric vehicles and renewable energy.

4.1.4. Participation in the Ancillary Services Market (ASM)

ASM is an important component of the electricity market, aiming to ensure the safe and stable operation of the power grid through services such as frequency regulation and peak shaving.The synergy between V2G technology and RE is reflected in the following: EVs can quickly compensate the power difference when the wind and solar power generation fluctuates, and optimize the market bidding strategy combined with power generation prediction to improve the response speed and reliability of auxiliary services.

4.2. Market-level collaborative mechanisms

4.2.1. Demand Response (DR) mechanism

DR is an energy management mechanism that guides users to flexibly adjust their electricity consumption behavior through prices or incentive measures to balance the supply from the power grid [6,7]. The synergy between V2G and RE is manifested as follows: EVs charges and stores energy when RE generates sufficient electricity based on real-time electricity prices or grid demand signals, and discharges and supplies power when supply is tight.This model not only alleviates the pressure on the power grid but also increases users' income through arbitrage of electricity price differences.Combined with smart meter, automatic control system and big data analysis technology, this mechanism can effectively reduce the peak load of power grid, improve the stability of power grid operation, and reduce the electricity expenditure of users [8].

4.2.2. Distributed Electricity Market (DEM)

DEM adopts a decentralized trading model [9], breaking the monopoly of traditional centralized power trading and allowing distributed energy to directly participate in market transactions.V2G technology enables EVs to form a micro "power generation - energy storage - power consumption" closed loop with distributed photovoltaic and wind power. In the community power market, EVs can not only consume excess green electricity but also discharge it to the power grid during peak electricity price periods.Combined with block chain intelligent automatic point-to-point transaction contract, can not only improve the local green electricity given rate, and through the market mechanism to optimize profits, finally construct the flexible and efficient energy Internet community.

DOI: 10.54254/2755-2721/2026.KA26137

4.3. Existing policy and standard support mechanism

4.3.1. Open access and two-way billing mechanism

The open access and two-way billing mechanism allows energy resources such as photovoltaic and electric vehicles on the user side to be fairly and legally connected to the power grid through standardized interfaces and two-way metering rules, without being restricted by asset ownership, thus breaking the monopoly of traditional power companies.The two-way billing mechanism uses smart meters to record users' electricity consumption and sales data in real time, and settles accounts separately based on dynamic electricity prices: when EVs are charging, electricity charges are paid according to the retail electricity price; Profits are obtained at market prices during discharge.Under these two systems, V2G technology can not only effectively balance the fluctuations in the generation of renewable energy, but also enhance the grid's capacity to accommodate clean energy, while ensuring market fairness.

4.3.2. Incentive and subsidy policies

In the collaborative system of V2G technology and RE, incentive and subsidy policies play a key role [10]. For EVs users, policies such as subsidies for the construction of two-way charging facilities, dynamic discharge compensation mechanisms, and preferential electricity prices are implemented to enhance users' participation in V2G.For new energy enterprises, policies such as capacity subsidies and market access preferences should be provided to reduce operating costs.The innovation of this policy lies in the flexible binding of new energy subsidies with V2G. For instance, wind and solar power stations are required to be equipped with V2G energy storage to enjoy full subsidies, thus forming a virtuous cycle of "clean power generation - flexible consumption - mutual benefit between vehicles and the grid", which can significantly enhance the stability of the renewable energy system.

4.3.3. Interoperability standard

Interoperability standards (ISO15118) ensure seamless collaboration between electric vehicles and renewable energy by unifying communication protocols, data formats, and interface specifications [11]. These standards enable V2G systems to dynamically respond to grid demands while also smoothing out the power generation fluctuations of RE, achieving power balance and optimized dispatching.The lack of a unified standard will lead to data interaction barriers between different devices and hinder multi-party collaboration. The establishment of a standardized system can significantly reduce integration costs, speed up the promotion and application, and promote the stable operation of a high proportion of renewable energy grids.

5. Synergy benefits of V2G and RE

5.1. Enhance the capacity to consume RE

The large-scale application of RE is constrained by intermittent problems, mainly manifested as random, fluctuating, uncontrollable and unpredictable output [12]. For instance, photovoltaic power generation is affected by weather conditions. Cloudy and rainy days lead to a significant reduction in power. Wind power generation has the characteristic of fluctuating between day and night. Its power is high at night and low during the day, which is mismatched with the peak electricity consumption

DOI: 10.54254/2755-2721/2026.KA26137

period, making the power generation unstable and affecting the quality of electricity.V2G technology can charge EVs in the period of high RE output and low load, absorb excess electric energy, realize local consumption to a certain extent, and alleviate the problem of abandoned wind and light.

5.2. Enhance the flexibility and stability of the power grid

When large-scale integration of volatile RE such as wind and solar power into the grid, which has an impact on grid voltage and frequency, the V2G system can fully play its energy storage role and quickly respond to regulate grid voltage and frequency.Especially when the grid capacity is insufficient, V2G technology can quickly drive EVs to discharge electricity to support the grid, effectively enhancing the grid's adaptability to the volatility of renewable energy and the overall robustness of its operation.

5.3. Increase user revenue

This collaborative mechanism creates multiple benefits for users through V2G technology: users can obtain economic benefits from the difference in electricity prices. Charging EVs through self-produced photovoltaic power not only increases the self-consumption rate of photovoltaic power but also reduces electricity costs [13]. Finally, EVs travel can also enjoy government subsidies. This multi-party win-win model effectively promotes the sustainable development of the transportation energy system

5.4. Reduce the overall cost

V2G technology can effectively reduce the construction investment and operation and maintenance costs of traditional energy storage systems by using EVs battery resources instead of fixed energy storage devices.This model only requires users to pay for participation incentives to achieve equivalent energy storage functions, which has significant economic advantages. Meanwhile, the distributed feature of RE can achieve local voltage regulation, reduce the demand for traditional reactive power compensation equipment, and realize the dual benefits of optimizing grid investment and efficiently utilizing user resources [14,15].

5.5. Promote carbon emission reduction

V2G technology has significant environmental benefits. During peak electricity consumption periods, it replaces the operation of traditional fossil energy peak shaving units by dispatching EVs discharge. At the same time, combined with clean energy such as photovoltaic power generation, it can significantly reduce the carbon emission intensity of the power system, achieving dual benefits of environmental benefits and grid stability [16].

6. Challenge

Although V2G technology and RE have broad application prospects, its commercialization process still faces multiple challenges.Deep discharge of EVs and frequent charging and discharging will accelerate battery aging and cause its performance to decline.At the same time, the volatility and uncertainty of RE make it difficult for V2G technology to adjust the grid balance, and high-precision prediction algorithms must be used for efficient cooperation between the two, which is still in the exploratory stage.In terms of economy, the cost of bidirectional charging piles is 2 to 3 times that of ordinary charging piles. Currently, most charging piles are unidirectional, and the cost of transforming them into bidirectional charging piles is very high.In addition, the cost of power grid renovation is huge. The large-scale infrastructure investment and the long investment payback period have restricted its commercial promotion.In terms of user acceptance, car owners will believe that the long-term implementation of V2G technology will shorten battery life and increase battery maintenance costs.At the same time, there are problems in aspects such as the conflict between charging and discharging scheduling and travel demands: When the power grid needs to call on the battery discharge of electric vehicles to support peak electricity consumption, it may exactly overlap with the commuting demands of vehicle owners, resulting in insufficient vehicle power and inability to travel. Or frequent charging and discharging schedules may disrupt the car owner's original charging plan, putting them at risk of running out of power during temporary trips.

7. Summary and prospect

This article systematically introduces the basic principles of V2G technology, the definition and types of RE. The collaborative mechanism between V2G and RE was reviewed at three levels: technology, market, policy and standard support. And it expounded the benefits that can be generated through the synergy of the two.Finally, the challenges existing in the current collaboration between V2G and RE in terms of user acceptance and battery life were deeply discussed.Based on a systematic analysis of the collaborative mechanism, benefits and challenges, this paper puts forward suggestions for future development: In terms of technology, efforts should be made to develop a new generation of batteries with high energy density and long cycle life.In terms of system integration, efforts should be made to deeply integrate EVs into the smart transportation network and truly transform EVs into a mobile energy storage network. In terms of policy, the incentive mechanism should be improved and the promotion of V2G technology should be strengthened.Through multi-dimensional collaborative innovation, the ultimate goal is to achieve RE providing clean power for V2G technology, and V2G technology offering RE flexible regulation and market channels.

References

[1] Fang C，Zhang H，Cheng H，et al. Framework planning of distribution network containing distributed generation considering active management [J]. Power System Technology，2014，38(4): 823-829.
[2] IIic P D.Vehicle to Grid Technology: supporting renewable energy source [J].Proceeding of ISES World Congress 2007(Vol.I-VoI.V), 2012, 33(17): 2291-2292.
[3] Yang Xiaodong, Zhang Youbing, Jiang Yangchang, et al. Interactive Response Control Strategy for Electric Vehicles Considering Distributed Power Consumption under Microgrid [J] Transactions of the China Electrotechnical Society, 2018, 33(02): 390-400
[4] Wei Zhinong, Yu Shuang, Sun Guoqiang, et al. The Concept and Development of Virtual Power Plant [J]. Automation of Electric Power Systems, 2013, 37 (13) : 1-9.
[5] Sauer D U, Kleimaier M, Glaunsinger W.Relevance of energy storage in future distribution network with high penetration of renewable energy sources [C].2009 20th International Conference and Exhibition on Electricity Distribution -Part1, Prague, Czech Republic, 2009: 1-4.
[6] Su Su, Li Jiahao, Li Zening, et al. Electric Vehicle Virtual Synchronous Machine Auxiliary Frequency Regulation Control Strategy Considering User Requirements [J]. Electric Power Automation Equipment, 2021, 41(11): 40-47.
[7] M-Naina P., K. S-Swarup. Double-Consensus-Based Distributed Energy Management in a Virtual Power Plant [J]. IEEE Transactions on Industry Applications, 2022, 58(6): 7047-7056.
[8] Kempton W, Tomic J. Vehicle-to-grid power fundamentals: calculating capacity and net revenue [J]. Journal of Power Sources, 2005, 144(1): 268-279.

DOI: 10.54254/2755-2721/2026.KA26137

[9] Chen Wenzhi, Song Huiqi, Niu Zhiyan, et al. Application of Blockchain in Safety Certification of Electric Vehicle Charging Piles [J]. Mass Standardization, 2024, (22): 193-195.
[10] Zhang Jianhong, Zhao Xingyong, Wang Xiuli. Electric Vehicle Charging Optimization Guidance Strategy Considering Reward Mechanism [J]. Power Grid and Clean Energy, 2024, 40(01): 102-108.
[11] WANG Qunfei, LU Xiaoli, YANG Dongjunming. Fault diagnosis of DC-DC module of V2G charging pile based on fuzzy neural network [J]. IOP Conference Series: Earth and Environmental Science, 2021, 772(1).
[12] Shi R, Li S, Zhang P, et al.Integration of renewable energy sources and electric vehicle in V2G network with adjustable robust optimization [J].Renewable Energy, 2020, 153: 1067-1080.
[13] Gao Jinrui, Zhang Zhijun, Dou Chunxia. Double-layer Economic Dispatching Strategy for Electric Vehicles Connected to Virtual Power Plants Based on Information Gap Decision Theory and Dynamic Time-of-use Electricity Price [J] Electric Power Automation Equipment, 2022, 42 (10) : 77-85.
[14] ZERAATI M, GOLSHAN M E H, GUERRERO J M. Voltage Quality Improvement in Low Voltage Distribution Networks Using Reactive Power Capability of Single-Phase PV Inverters [J]. IEEE Transactions on Smart Grid, 2019, 10(5): 5057–5065. DOI: 10.1109/TSG.2018.2874381.
[15] MA L, XU G. Distributed Resilient Voltage and Reactive Power Control for Islanded Microgrids under False Data Injection Attacks [J]. Energies, 2020, 13(15): 3828. DOI: 10.3390/en13153828.
[16] Chunming Zhu, Gang Bao, Yikai Liu. Low-carbon economic analysis of a virtual power plant with wind and solar power considering the integrated flexible operation mode of a carbon capture thermoelectric unit [J]. International Journal of Greenhouse Gas Control, 2023, 130(130): 104011