Vehicle-to-Grid Techniques

Subjects: Automation & Control Systems

Contributor: Ruifeng Shi , Shuaikang Peng , Tai Chang , Kwang Y. Lee

Vehicle-to-grid (V2G) technology has received a lot of attention as a smart interconnection solution between electric vehicles and the grid.

vehicle-to-grid   electric vehicles   grid

1. Introduction

Electric vehicles (EVs) are considered to be the cleanest form of transportation [1][2]; however, the popularization of EVs brings challenges, not only to the power grid but also to our lifestyles. Vehicle-to-grid (V2G) technology, as shown in **Figure 1**, is a pivotal component of the smart grid paradigm and has garnered significant attention in recent years [3]. This technology enables EVs to obtain electricity from the grid; it stores renewable energy, including wind [4], solar [5], and water [6], as mobile energy storage devices and feeds back power to the grid when needed [7]. With the intensified global push for sustainable energy solutions and the improvement in battery capacity and storage efficiency of EVs [8], the integration of EVs with the grid has become increasingly crucial as it can offer potential solutions to challenges such as grid stability [9], peak demand management [10][11], and renewable energy integration [12].

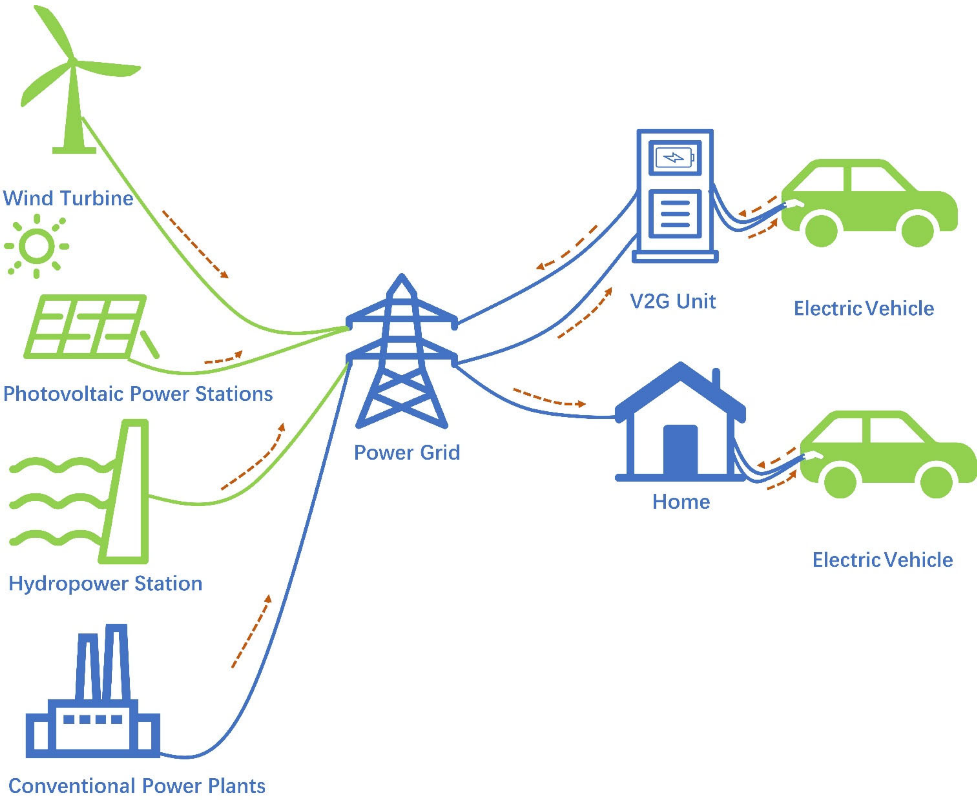

Figure 1. V2G service diagram.

The rapid evolution of V2G technology has led to a plethora of research endeavors aiming to address its multifaceted challenges and harness its potential benefits [13]. From technical intricacies related to grid integration and battery health to economic considerations [14][15] and policy implications, the V2G research landscape is both diverse and dynamic. Given the burgeoning interest and the vast scope of this field, a comprehensive survey has become a pressing need; such a survey can encapsulate the current state of V2G research, as well as highlight key findings, trends, and future directions.

2. Keyword Analysis and Application Analysis of V2G

2.1. Energy Storage, Renewable Energy Sources, and Scheduling

2.1.1. Energy Storage

Numerous scholars have conducted in-depth research on the planning and management of V2G and energy storage. Electric vehicle batteries, because of their high capacity, can be used as storage units to store excess power when the load on the grid is low and then to release it when the demand peaks, thus ensuring the stable operation of the grid [16].

The combination of V2G technology and energy storage systems provides new opportunities to realize a more efficient, flexible, and reliable power system [17]. As an energy storage medium, EV batteries can reduce investment and the construction of RE and stationary storage and minimize resource waste [18]; the introduction of smart battery technology further facilitates the realization of V2G [19]. In terms of economics, battery recession costs, electricity sales prices [20], and infrastructure costs [21] affect the ability of EVs to provide short-term operational reserves to the grid as energy storage units [22]; however, EVs still have the potential to service other facilities. For example, V2G can be embedded as energy storage in homes and IES to provide energy for domestic and commercial centers, which can reduce energy costs and improve the environmental benefits [23][24]. Sun et al. investigated how the SOC of EV batteries affects the total cost of residential energy systems that use EVs as part of the residential energy system. The results showed that the battery aging cost is still an important factor affecting the willingness of EV users to discharge their batteries [25]. By embedding V2G as energy storage in IES, Wei et al. allowed the two to be coupled to maximize the economic and environmental benefits of IES [23]. Hipolito, Vandet, and Rich estimated the energy storage potential of EVs and concluded that the willingness of EV users to discharge their batteries increases significantly only when the battery utilization is below 40% [26].

In summary, it is possible to regulate electricity prices to allow EVs to actively participate in energy storage, but if EVs are allowed to supply power to the grid, a reasonable peak-to-valley electricity differential needs to be established to compensate for the cost of battery depletion to increase the willingness of users to discharge their batteries.

2.1.2. Renewable Energy Sources

The high volatility of wind and light energy brings considerable challenges to grid-connected power generation [27]. As V2G technology has a fast response time [28], a flexible in-and-out mechanism, and an energy storage device that is relatively fixed, it does not require additional investment and plays a unique and irreplaceable role in consuming excess power from clean energy sources.

Many researchers have tried to consume these renewable energy sources with EVs. Gao et al. integrated the wind power generators and EVs with V2G operation capability in the distribution grid, formulated a mathematical model of V2G power control, and deployed a dynamic power regulation for EVs [29]. Jin et al. presented a coordinated control strategy for large-scale EVs, BESSs, and traditional FR resources involved in AGC which could improve the frequency stability and facilitate the integration of renewable energy [30]. Fattori, Anglani, and Muliere analyzed the impact of PVs and EVs on the grid under different penetration scenarios, where V2G gains were not promising because the desynchronization of EV charging behavior with PV generation led to increased demand for capacity that non-PVs had to provide, and at the time, battery costs were high in relation to PV costs [11]. Fathabadi et al. analyzed the impact of power sources on the distribution network; these sources include conventional generators (CPG), DG renewable energy sources, and EVs. Experiments have demonstrated that the simultaneous use of CPG, DG renewable energy sources, and charging/discharging EVs results in the lowest cost of power production and the optimal voltage profile; thus, the lowest power loss is obtained by utilizing both CPG and DG in the grid [31]. Haddadian et al. deployed EV fleets as distributed storage and achieved their optimal coordination with wind energy. Studies indicate that the method could cut the diurnal operation cost, lower the emissions, and enable thorough consumption of forecasted wind with zero wind curtailment [32]. Uddin et al. developed a battery degradation model and seamlessly integrated it into a smart grid algorithm. This innovative approach demonstrated that linking an EV to this intelligent grid system not only effectively addressed the power network's demand with a greater infusion of clean renewable energy but also, notably, extended the lifespan of the EV battery [33]. Robledo et al. introduced the results of a demonstration project, including building-integrated photovoltaic (BIPV) solar panels, which indicated that FCEVs can integrate transport and electricity sectors in a sustainable energy system [34]. Bhatti and Salam considered daytime EV charging in an office parking lot by means of the PV grid system and proposed a rule-based energy management scheme (REMS). This work can integrate other RE sources such as wind, tidal, and biomass [35]. Sufyan et al. conducted an analysis of the influence of system costs and energy losses across varying levels of RE integration, EV capacities, and travel distances. Their simulation results clearly indicate a substantial reduction in operational expenses when renewable energy sources (RESs) are seamlessly integrated into the distribution network. Furthermore, the utilization of V2G technology has proven to be advantageous for EV users, particularly in scenarios with a high level of RES penetration [36]. Noorollahi et al. introduced a novel framework for an electric vehicle aggregator and devised models for four distinct EV charging scenarios. Their approach takes into account a wide array of renewable energy sources, including wind turbines, solar PV panels, and geothermal units. They have implemented an energy scheduling model to optimize these scenarios effectively [37]. Bartolini et al. conducted an analysis to explore how a fleet of EVs can contribute to enhancing the self-consumption capacity of a district, particularly in the context of a high and growing presence of non-controllable renewable energy sources (RES), with a specific focus on PV systems. Furthermore, their study delved into the consequences of both EVs and the extent of RES integration on the district's emissions of CO_2 [38]. Rahbari et al. proposed a method for planning the size and siting of EV smart parking lots, considering RE consumption and using EVs as energy storage devices, and they introduced an adaptive intelligent control strategy applicable to V2G and G2V to reduce the system voltage deviation and power loss [12]. Shi et al. used V2G techniques to stabilize the intermittency of renewable energy sources, where the uncertainty of wind energy and the EV charging state are modeled using a robust worst-case strategy [39]. Sangswang and Konghirun developed a scheduling strategy for a home energy management system (HEMS) that integrates solar, energy storage, and V2G functionality and optimizes the charging and discharging scheduling of electric vehicles and home batteries using real-time pricing and emergency load shedding [40].

Researchers have proposed a variety of strategies and approaches, including dynamic power tuning for EVs, coordinated control strategies, integration of energy systems, and battery life extension, to achieve more efficient integration of renewable energy sources.

2.1.3. Scheduling

V2G scheduling is influenced by several key factors, including user anxiety about mileage, the wear and condition of EV batteries [41], user revenue expectations, and the geographic location of users. It is crucial to ensure that the power transfer from electric vehicles to the grid is controlled and managed effectively.

Wang and Wang investigated the impact of the number of networked EVs and the characteristics of EV battery packs on grid peak and trough regulation [10]. Farzin, Fotuhi-Firuzabad, and Moeini-Aghtaie considered the impact of EV battery wear on V2G scheduling and developed a battery degradation cost model to accurately assess the economic cost of V2G [42]. Huang, Yang, and Li introduced an option pricing model for price fluctuations in transactions between EV users and the grid, and derived analytical relationships between V2G reserve cooperation coefficients, trade deposits, and power contract prices in equilibrium [43]. Erdogan, Erden, and Kisacikoglu proposed a two-stage V2G discharge control scheme for peaking the grid; it determines the peak shaving and duration of V2G services based on forecasted demand and EV mobility modeling and then dynamically adjusts the EV discharge rate by considering the actual grid load and the grid-connected EV characteristics [44]. Maeng et al. analyzed the effect of EV energy (hybrid or pure EV) sources on EV users' discharge preferences and investigated the effect of the EV remaining power on the users' willingness to discharge, which is similar to the effect of EV users' mileage anxiety on the willingness to discharge [45]. Jiao et al. designed a model to study the impact of EV users' mileage anxiety on V2G scheduling, and the result shows that EV users' mileage anxiety can be mitigated by improving the average operating cost and discharge power, which in turn affects the charge/discharge scheduling plan [46]. Wei, Yi, and Yun used Q-learning to predict the power of wind turbines and proposed a reinforcement learning-based approach for optimal energy management in smart grids to dissipate RE while providing optimal power scheduling and reducing grid costs [47]. Wang, Gao, and Tang created a lightning scale transformation model to describe the demand response behavior of EV users in order to support load aggregators in making scheduling decisions. The model enhances the initial unidirectional scale transformation approach, encompassing the depth scale transformation mode and the generalized scale transformation mode, by evolving it into a hybrid bidirectional method. This innovative approach facilitates concurrent and synergistic transformations of both spatial and temporal observation scales [48]. The energy scheduling does not occur solely between EVs and the grid; many studies have delved into the inter-scheduling of various energy sources [34][49][50][51][52].

Overall, V2G scheduling will be smarter and more user-oriented in the future, focusing on battery management, pricing strategies, and renewable energy integration to meet evolving grid needs and to improve power system efficiency and reliability.

2.2. Frequency Regulation and Voltage Control

To facilitate grid functionality, the production and consumption of active and reactive power should be constantly balanced to ensure that the amplitudes of frequency and voltage are close to their rated values. Effective control of active power is attainable through the regulation of system frequency, whereas the management of reactive power hinges on the control of the system voltage. Therefore, frequency and voltage are important factors in measuring the power quality of the grid. Achieving overall voltage and frequency management through the V2G mode will go a step further towards active and reactive power quality improvement.

2.2.1. Frequency Regulation

Frequency control is essential for power systems to maintain stable operation; it involves the synergistic action of all the generators and loads in the power system and can keep the grid frequency within the normal range. V2G technology has emerged as a promising resource that can be used to assist in the frequency regulation of power systems. EVs, when utilized as distributed storage devices, hold the potential to offer frequency regulation services owing to their ability to swiftly adjust their charging and discharging power.

Liu et al. proposed a V2G control strategy for EV aggregators based on frequency regulation capacity (FRC) and expected V2G (EV2G) power; this control strategy can shift the regulation task from the EV aggregator to the EV charging station to satisfy both the frequency regulation and the charging demand of the EV charging station [53]. Lam, Leung, and Li designed a queuing network-based EV aggregation model that can be used to estimate regulation-up and regulation-down capacity to help establish a regulation contract between the aggregator and the grid operator [54]. Chen et al. proposed a hierarchical V2G system communication architecture containing a smart V2G aggregator (SVA), and they designed a multilevel online V2G (MLOV) algorithm for hierarchical V2G scheduling to achieve a balance between service quality and computation time [55]. Wang, Wang, and Liu proposed a dynamic scheduling strategy for V2G frequency regulation capacity based on deep Q-learning to evaluate the hourly regulation capacity in real time for maximizing the revenue of frequency regulation services provided by battery swapping stations [56]. Alfaverh, Denaï, and Sun scheduled EV battery charging and discharging using the deep deterministic policy gradient (DDPG) to meet driving needs and to participate in frequency regulation, as well as to meet the driving needs of car owners and the interests of aggregators [57].

Frequency regulation of the grid by V2G is related to the state of EVs, the charging demand, and the changing grid frequency, which requires understanding the state of EVs on the grid; however, accessing these states involves issues such as communication security, user privacy security and control security between the information network and the energy network [58].

2.2.2. Voltage Control

Voltage control is one of the key elements in the stable operation of power systems, and large generators and transformers are conventional means of controlling voltage. However, the operation and control of power systems have become more complex with the popularization of distributed energy resources [59][60].

V2G technology offers new possibilities for voltage control. With V2G, EVs can act as distributed energy storage devices to provide the necessary reactive power support to the grid [61], thus helping to maintain voltage stability [62]. García-Villalobos et al. solved voltage problems and load balancing issues in low-voltage distribution networks by optimizing the charging behavior of PEVs. This was conducted by executing intelligent charging algorithms through the processor unit built into the PEV and by developing an optimal charging strategy based on factors such as the price of electricity and battery life [63]. This research proposes an intelligent sag control method that is independent of line parameters, and it devises a new strategy to enable PHEVs to participate in voltage and frequency control of islanded microgrids (MGs) without a communication link, thus maintaining MG stability more efficiently [64]. Huang proposed a day-ahead optimal control model based on three-phase power flow and sensitivity methods that could solve the overrun voltage problem and mitigate the neutral potential rise, thus improving the voltage regulation of residential grids [65]. Nimalsiri et al. introduced a network-aware EV charging and discharging scheduling approach known as N-EVC(D). This method is designed to efficiently coordinate the charging and discharging of EVs within a distributed network, with the primary objectives of reducing operational costs and ensuring the stability of the supply voltage [66].

In conclusion, V2G technology is driving advancements in voltage control for power systems and harnessing EVs as dynamic energy resources. These developments are expected to enhance voltage stability and regulation, particularly as distributed energy resources become more prevalent. Researchers are focusing on intelligent algorithms and strategies to optimize voltage control through V2G for a more resilient and reliable power grid in the future.

2.3. Smart Grid and Communication Networks

2.3.1. Smart Grid

As with the application of V2G and smart grid technology [67], EV grid technology is an important part of “smart grid technology” in the solving of the problems related to the large-scale development of EVs brought about by the grid load pressure [68]. Moreover, EVs, as mobile distributed energy storage units, are connected to the power grid for peak shaving, valley filling, and rotating standby in order to improve the flexibility of the power supply and the reliability and efficiency of energy utilization and to slow down investment in power grid construction.

Waraich et al. proposed an agent-based transport simulation framework tailored for PHEVs. Furthermore, they expanded the framework to encompass V2G capabilities and decentralized smart grid functionalities [69]. In a separate study, Jian et al. explored the concept of a household smart microgrid. They investigated how to potentially reduce load variance within the household microgrid by adjusting the charging patterns of family PHEVs. Their findings revealed a significant reduction in the variance of load power when such regulations were implemented [70]. Kennel, Goerges, and Liu proposed an energy management system designed for smart grids. This system incorporates load frequency control (LFC), economic efficiency optimization, and the integration of electric vehicles through a HiMPC approach. The simulation findings underscore the fact that electric vehicles can play a significant role in mitigating fluctuations in renewable energy generation, thereby contributing to grid stability [58]. Vachirasricirikul and Ngamroo presented the new coordinated V2G control and frequency controller for robust LFC in the smart grid system with wind power penetration. The simulation results clearly showcase the resilience and effectiveness of the suggested V2G control strategy and proportional–integral (PI) controllers in LFC, even when subjected to altered system parameters and diverse operating conditions [51]. Morais et al. considered the evaluation of the EV impact on the power demand curve under a smart grid environment and further addressed the impact of EVs on system operation costs and on the power demand curve for a distribution network with the deep penetration of distributed generation (DG) units [71]. In another study by Jian et al., they discussed a V2G implementation scenario within regional smart grids. They introduced a double-layer optimal charging (DLOC) strategy to address the computational challenges posed by large-scale PEVs and charging stations [72]. Liang and Zhuang believe that the forthcoming smart grid is anticipated to take the form of an interconnected network comprising small-scale, self-sustained microgrids. They also provided an overview of the latest advancements in stochastic modeling and optimization tools which was aimed at facilitating the planning, operation, and control of these microgrids [73].

The integration of EVs and smart grid technology continues to evolve, and numerous studies have been conducted to explore the potential benefits and challenges of this integration. These studies encompass various aspects, from enhancing the self-consumption of PV power to the development of comprehensive battery degradation models. Van der Kam and van Sark presented a model designed to investigate the augmentation of the self-consumption of PV power through the utilization of smart charging EVs with smart grid technology. The outcomes of their study conspicuously illustrate the advantages of employing smart charging and V2G technologies within a microgrid context [5]. López et al. proposed an optimization-driven model for executing load shifting within the framework of smart grids. They presented findings based on a test system derived from the IEEE 37-bus distribution grid. These results not only demonstrate the efficacy of their approach but also highlight the impact of hourly energy prices on the smoothing out of the load curve [74]. Xing et al. concentrated on acquiring load shifting services through the optimal scheduling of PEVs for charging and discharging within smart grids, adopting a decentralized approach. Their research culminated in the development of a decentralized algorithm rooted in iterative water-filling techniques [75]. Soares et al. presented a decision-making framework designed to aid virtual power plants (VPPs) in the management of smart grids characterized by a substantial presence of sensitive electricity loads. They further devised a two-stage optimization algorithm, leveraging the weighted sum methodology, to facilitate this management process [76]. Uddin et al. developed a comprehensive battery degradation model based on long-term ageing data and integrated a comprehensive battery ageing model into a smart grid algorithm. The result demonstrated that linking an EV to this smart grid system can effectively meet the power network's demand, particularly as the proportion of clean renewable energy in the system increases [77]. Dileep gave an overview of the evolution of the smart grid and explained various smart grid technologies, like smart meters, smart sensors, V2G, and PHEV, and their application in the smart grid [33]. The integration of EVs and smart grid technology holds significant promise for the future of sustainable energy. Through various models, algorithms, and frameworks, researchers are paving the way for a more efficient, reliable, and environmentally friendly power grid system.

Ambiguous definitions of smart grids, or technologically oriented definitions, often lead to the ignoring of the differences between the smart grid concepts and to the overlooking of the important aspects for the customers that implement them. For the time being, most of the research on smart grids has focused on distributed smart grids and less on centralized grids or centralized–decentralized connections.

2.3.2. Communication Networks

The integration of communication networks with battery-operated vehicles and the electrical grid is a transformative step in the evolution of energy systems. This integration streamlines the coordination of the electric load, but it introduces challenges, especially with regard to security and privacy.

Communication networks bridge the gap between user battery-operated vehicles and the electrical grid, enhance the coordination of electric loads, and improve energy efficiency and reliability. Zhang et al. discussed the V2G network architecture and described the different security challenges during V2G power and communication interactions. A new context-aware authentication solution was also proposed for this problem [78]. Saxena et al. described the challenges of the security and privacy in smart V2G networks and proposed a cybersecurity architecture that attempted to address the problem; this architecture encompassed anonymous authentication, blind signatures, fine-grained access control, and payment system security [79]. Tao et al. proposed a hybrid computing model based on fog and cloud computing for V2G networks in 5G networks. This hybrid computing model can respond more flexibly and in a more timely manner to EV mobility; it can provide auxiliary power services for renewable energy sources in V2G systems, as well as manage and monitor power usage [80]. A privacy-friendly and efficient secure communication (PESC) framework was proposed by He, Chan, and Guizani [81]. It used group signatures and public key cryptography for access control from each EV to the aggregator and established shared keys (with the Diffie–Hellman key exchange algorithm), which could reduce the communication and computation overhead while ensuring privacy and security. Ahmed et al. designed a signature-encrypted, privacy-preserving authentication key agreement scheme that enables all participants to verify each other; it uses a one-way hash function to improve verification efficiency [82]. Umoren, Shakir, and Tabassum proposed a strategy to balance the efficiency of both spectral considerations and cost by expressing resource efficiency as a weighting factor, which improved the efficiency of V2G wireless communication networks [83]. Pokhrel and Hossain developed a novel, adaptive demand-side energy management framework for the wireless charging of V2G systems that employed privacy-preserving techniques based on federated learning [84]. Hossain, Pokhrel, and Vu proposed a demand-side energy management approach based on reinforcement learning using rechargeable batteries for V2G cost-friendly privacy, efficient scheduling, and accurate billing [85].

References

1. Taiebat, M.; Xu, M. Synergies of four emerging technologies for accelerated adoption of electric vehicles: Shared mobility, wireless charging, vehicle-to-grid, and vehicle automation. J. Clean. Prod. 2019, 230, 794–797.
2. Yao, X.; Fan, Y.; Zhao, F.; Ma, S. Economic and climate benefits of vehicle-to-grid for low-carbon transitions of power systems: A case study of China’s 2030 renewable energy target. J. Clean. Prod. 2022, 330, 129833.
3. Ravi, S.S.; Aziz, M. Utilization of Electric Vehicles for Vehicle-to-Grid Services: Progress and Perspectives. Energies 2022, 15, 589.
4. Ahmadian, A.; Asadpour, M.; Mazouz, A.; Alhameli, F.; Mohammadi-Ivatloo, B.; Elkamel, A. Techno-economic evaluation of PEVs energy storage capability in wind distributed generations planning. Sust. Cities Soc. 2020, 56, 102117.
5. van der Kam, M.; van Sark, W. Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a microgrid; a case study. Appl. Energy 2015, 152, 20–30.

6. Román, A.; García De Jalón, D.; Alonso, C. Could future electric vehicle energy storage be used for hydropeaking mitigation? An eight-country viability analysis. Resour. Conserv. Recycl. 2019, 149, 760–777.
7. Liu, C.; Chau, K.T.; Wu, D.; Gao, S. Opportunities and Challenges of Vehicle-to-Home, Vehicle-to-Vehicle, and Vehicle-to-Grid Technologies. Proc. IEEE 2013, 101, 2409–2427.
8. Martyushev, N.V.; Malozyomov, B.V.; Khalikov, I.H.; Kukartsev, V.A.; Kukartsev, V.V.; Tynchenko, V.S.; Tynchenko, Y.A.; Qi, M. Review of Methods for Improving the Energy Efficiency of Electrified Ground Transport by Optimizing Battery Consumption. Energies 2023, 16, 729.
9. Gajduk, A.; Todorovski, M.; Kurths, J.; Kocarev, L. Improving power grid transient stability by plug-in electric vehicles. New J. Phys. 2014, 16, 115011–115014.
10. Wang, Z.; Wang, S. Grid Power Peak Shaving and Valley Filling Using Vehicle-to-Grid Systems. IEEE Trans. Power Deliv. 2013, 28, 1822–1829.
11. Fattori, F.; Anglani, N.; Muliere, G. Combining photovoltaic energy with electric vehicles, smart charging and vehicle-to-grid. Sol. Energy 2014, 110, 438–451.
12. Rahbari, O.; Vafaeipour, M.; Omar, N.; Rosen, M.A.; Hegazy, O.; Timmermans, J.; Heibati, S.; Bossche, P.V.D. An optimal versatile control approach for plug-in electric vehicles to integrate renewable energy sources and smart grids. Energy 2017, 134, 1053–1067.
13. Liu, X.; Zhao, F.; Hao, H.; Liu, Z. Opportunities, Challenges and Strategies for Developing Electric Vehicle Energy Storage Systems under the Carbon Neutrality Goal. World Electr. Veh. J. 2023, 14, 170.
14. Hidrue, M.K.; Parsons, G.R. Is there a near-term market for vehicle-to-grid electric vehicles? Appl. Energy 2015, 151, 67–76.
15. Liu, J.; Zhong, C. An economic evaluation of the coordination between electric vehicle storage and distributed renewable energy. Energy 2019, 186, 115821.
16. Ioakimidis, C.S.; Thomas, D.; Rycerski, P.; Genikomsakis, K.N. Peak shaving and valley filling of power consumption profile in non-residential buildings using an electric vehicle parking lot. Energy 2018, 148, 148–158.
17. Hosseini, S.S.; Badri, A.; Parvania, M. A survey on mobile energy storage systems (MESS): Applications, challenges and solutions. Renew. Sustain. Energy Rev. 2014, 40, 161–170.
18. Forrest, K.E.; Tarroja, B.; Zhang, L.; Shaffer, B.; Samuelsen, S. Charging a renewable future: The impact of electric vehicle charging intelligence on energy storage requirements to meet renewable portfolio standards. J. Power Sources 2016, 336, 63–74.
19. Teodorescu, R.; Sui, X.; Vilsen, S.B.; Bharadwaj, P.; Kulkarni, A.; Stroe, D. Smart Battery Technology for Lifetime Improvement. Batteries 2022, 8, 169.

20. Rahman, M.M.; Gemechu, E.; Oni, A.O.; Kumar, A. The development of a techno-economic model for assessment of cost of energy storage for vehicle-to-grid applications in a cold climate. Energy 2023, 262, 125398.
21. Gough, R.; Dickerson, C.; Rowley, P.; Walsh, C. Vehicle-to-grid feasibility: A techno-economic analysis of EV-based energy storage. Appl. Energy 2017, 192, 12–23.
22. Atia, R.; Yamada, N. More accurate sizing of renewable energy sources under high levels of electric vehicle integration. Renew. Energy 2015, 81, 918–925.
23. Wei, H.; Zhang, Y.; Wang, Y.; Hua, W.; Jing, R.; Zhou, Y. Planning integrated energy systems coupling V2G as a flexible storage. Energy 2022, 239, 122215.
24. Dik, A.; Kutlu, C.; Omer, S.; Boukhanouf, R.; Su, Y.; Riffat, S. An approach for energy management of renewable energy sources using electric vehicles and heat pumps in an integrated electricity grid system. Energy Build. 2023, 294, 113261.
25. Sun, Y.; Yue, H.; Zhang, J.; Booth, C. Minimization of Residential Energy Cost Considering Energy Storage System and EV With Driving Usage Probabilities. IEEE Trans. Sustain. Energy 2019, 10, 1752–1763.
26. Hipolito, F.; Vandet, C.A.; Rich, J. Charging, steady-state SoC and energy storage distributions for EV fleets. Appl. Energy 2022, 317, 119065.
27. Shang, B.; Dai, N.; Cai, L.; Yang, C.; Li, J.; Xu, Q. V2G Scheduling of Electric Vehicles Considering Wind Power Consumption. World Electr. Veh. J. 2023, 14, 236.
28. Singh, M.; Kumar, P.; Kar, I. A Multi Charging Station for Electric Vehicles and Its Utilization for Load Management and the Grid Support. IEEE Trans. Smart Grid 2013, 4, 1026–1037.
29. Gao, S.; Chau, K.T.; Liu, C.; Wu, D.; Chan, C.C. Integrated Energy Management of Plug-in Electric Vehicles in Power Grid With Renewables. IEEE Trans. Veh. Technol. 2014, 63, 3019–3027.
30. Zhong, J.; He, L.; Li, C.; Cao, Y.; Wang, J.; Fang, B.; Zeng, L.; Xiao, G. Coordinated control for large-scale EV charging facilities and energy storage devices participating in frequency regulation. Appl. Energy 2014, 123, 253–262.
31. Fathabadi, H. Utilization of electric vehicles and renewable energy sources used as distributed generators for improving characteristics of electric power distribution systems. Energy 2015, 90, 1100–1110.
32. Haddadian, G.; Khalili, N.; Khodayar, M.; Shahiedehpour, M. Security-constrained power generation scheduling with thermal generating units, variable energy resources, and electric vehicle storage for V2G deployment. Int. J. Electr. Power Energy Syst. 2015, 73, 498–507.

33. Uddin, K.; Jackson, T.; Widanage, W.D.; Chouchelamane, G.; Jennings, P.A.; Marco, J. On the possibility of extending the lifetime of lithium-ion batteries through optimal V2G facilitated by an integrated vehicle and smart-grid system. Energy 2017, 133, 710–722.

34. Robledo, C.B.; Oldenbroek, V.; Abbruzzese, F.; van Wijk, A.J.M. Integrating a hydrogen fuel cell electric vehicle with vehicle-to-grid technology, photovoltaic power and a residential building. Appl. Energy 2018, 215, 615–629.

35. Bhatti, A.R.; Salam, Z. A rule-based energy management scheme for uninterrupted electric vehicles charging at constant price using photovoltaic-grid system. Renew. Energy 2018, 125, 384–400.

36. Sufyan, M.; Rahim, N.A.; Muhammad, M.A.; Tan, C.K.; Raihan, S.R.S.; Bakar, A.H.A. Charge coordination and battery lifecycle analysis of electric vehicles with V2G implementation. Electr. Power Syst. Res. 2020, 184, 106307.

37. Noorollahi, Y.; Golshanfard, A.; Aligholian, A.; Mohammadi-Ivatloo, B.; Nielsen, S.; Hajinezhad, A. Sustainable Energy System Planning for an Industrial Zone by Integrating Electric Vehicles as Energy Storage. J. Energy Storage 2020, 30, 101553.

38. Bartolini, A.; Comodi, G.; Salvi, D.; Ostergaard, P.A. Renewables self-consumption potential in districts with high penetration of electric vehicles. Energy 2020, 213, 118653.

39. Shi, R.; Li, S.; Zhang, P.; Lee, K.Y. Integration of renewable energy sources and electric vehicles in V2G network with adjustable robust optimization. Renew. Energy 2020, 153, 1067–1080.

40. Sangswang, A.; Konghirun, M. Optimal Strategies in Home Energy Management System Integrating Solar Power, Energy Storage, and Vehicle-to-Grid for Grid Support and Energy Efficiency. IEEE Trans. Ind. Appl. 2020, 56, 5716–5728.

41. Tabatabaee, S.; Mortazavi, S.S.; Niknam, T. Stochastic scheduling of local distribution systems considering high penetration of plug-in electric vehicles and renewable energy sources. Energy 2017, 121, 480–490.

42. Farzin, H.; Fotuhi-Firuzabad, M.; Moeini-Aghtaie, M. A Practical Scheme to Involve Degradation Cost of Lithium-Ion Batteries in Vehicle-to-Grid Applications. IEEE Trans. Sustain. Energy 2016, 7, 1730–1738.

43. Huang, S.; Yang, J.; Li, S. Black-Scholes option pricing strategy and risk-averse coordination for designing vehicle-to-grid reserve contracts. Energy 2017, 137, 325–335.

44. Erdogan, N.; Erden, F.; Kisacikoglu, M. A fast and efficient coordinated vehicle-to-grid discharging control scheme for peak shaving in power distribution system. J. Mod. Power Syst. Clean. Energy 2018, 6, 555–566.

45. Maeng, K.; Ko, S.; Shin, J.; Cho, Y. How Much Electricity Sharing Will Electric Vehicle Owners Allow from Their Battery? Incorporating Vehicle-to-Grid Technology and Electricity Generation Mix. Energies 2020, 13, 4248.

46. Jiao, Z.; Ran, L.; Zhang, Y.; Ren, Y. Robust vehicle-to-grid power dispatching operations amid sociotechnical complexities. Appl. Energy 2021, 281, 115912.

47. Wei, L.; Yi, C.; Yun, J. Energy drive and management of smart grids with high penetration of renewable sources of wind unit and solar panel. Int. J. Electr. Power Energy Syst. 2021, 129, 106846.

48. Wang, A.; Gao, X.; Tang, M. A space variable-scale scheduling method for digital vehicle-to-grid platform under distributed electric energy storage. Appl. Soft Comput. 2023, 133, 109911.

49. Wu, T.; Yang, Q.; Bao, Z.; Yan, W. Coordinated Energy Dispatching in Microgrid With Wind Power Generation and Plug-in Electric Vehicles. IEEE Trans. Smart Grid 2013, 4, 1453–1463.

50. Honarmand, M.; Zakariazadeh, A.; Jadid, S. Integrated scheduling of renewable generation and electric vehicles parking lot in a smart microgrid. Energy Conv. Manag. 2014, 86, 745–755.

51. Vachirasricirikul, S.; Ngamroo, I. Robust LFC in a Smart Grid With Wind Power Penetration by Coordinated V2G Control and Frequency Controller. IEEE Trans. Smart Grid 2014, 5, 371–380.

52. Paterakis, N.G.; Erdinc, O.; Pappi, I.N.; Bakirtzis, A.G.; Catalao, J.P.S. Coordinated Operation of a Neighborhood of Smart Households Comprising Electric Vehicles, Energy Storage and Distributed Generation. IEEE Trans. Smart Grid 2016, 7, 2736–2747.

53. Liu, H.; Hu, Z.; Song, Y.; Wang, J.; Xie, X. Vehicle-to-Grid Control for Supplementary Frequency Regulation Considering Charging Demands. IEEE Trans. Power Syst. 2015, 30, 3110–3119.

54. Lam, A.Y.S.; Leung, K.; Li, V.O.K. Capacity Estimation for Vehicle-to-Grid Frequency Regulation Services With Smart Charging Mechanism. IEEE Trans. Smart Grid 2016, 7, 156–166.

55. Chen, X.; Leung, K.; Lam, A.Y.S.; Hill, D.J. Online Scheduling for Hierarchical Vehicle-to-Grid System: Design, Formulation, and Algorithm. IEEE Trans. Veh. Technol. 2019, 68, 1302–1317.

56. Wang, X.; Wang, J.; Liu, J. Vehicle to Grid Frequency Regulation Capacity Optimal Scheduling for Battery Swapping Station Using Deep Q-Network. IEEE Trans. Ind. Inform. 2021, 17, 1342–1351.

57. Alfaverh, F.; Denaï, M.; Sun, Y. Optimal vehicle-to-grid control for supplementary frequency regulation using deep reinforcement learning. Electr. Power Syst. Res. 2023, 214, 108949.

58. Kennel, F.; Gorges, D.; Liu, S. Energy Management for Smart Grids With Electric Vehicles Based on Hierarchical MPC. IEEE Trans. Ind. Inform. 2013, 9, 1528–1537.

59. Azzouz, M.A.; Shaaban, M.F.; El-Saadany, E.F. Real-Time Optimal Voltage Regulation for Distribution Networks Incorporating High Penetration of PEVs. IEEE Trans. Power Syst. 2015, 30,

3234–3245.

60. Cheng, L.; Chang, Y.; Huang, R. Mitigating Voltage Problem in Distribution System With Distributed Solar Generation Using Electric Vehicles. IEEE Trans. Sustain. Energy 2015, 6, 1475–1484.
61. Sun, X.; Qiu, J. A Customized Voltage Control Strategy for Electric Vehicles in Distribution Networks With Reinforcement Learning Method. IEEE Trans. Ind. Inform. 2021, 17, 6852–6863.
62. Hu, J.; Ye, C.; Ding, Y.; Tang, J.; Liu, S. A Distributed MPC to Exploit Reactive Power V2G for Real-Time Voltage Regulation in Distribution Networks. IEEE Trans. Smart Grid 2022, 13, 576–588.
63. García-Villalobos, J.; Zamora, I.; Knezović, K.; Marinelli, M. Multi-objective optimization control of plug-in electric vehicles in low voltage distribution networks. Appl. Energy 2016, 180, 155–168.
64. Pournazarian, B.; Karimyan, P.; Gharehpetian, G.B.; Abedi, M.; Pouresmaeil, E. Smart participation of PHEVs in controlling voltage and frequency of island microgrids. Int. J. Electr. Power Energy Syst. 2019, 110, 510–522.
65. Huang, Y. Day-Ahead Optimal Control of PEV Battery Storage Devices Taking Into Account the Voltage Regulation of the Residential Power Grid. IEEE Trans. Power Syst. 2019, 34, 4154–4167.
66. Nimalsiri, N.I.; Ratnam, E.L.; Mediwaththe, C.P.; Smith, D.B.; Halgamuge, S.K. Coordinated charging and discharging control of electric vehicles to manage supply voltages in distribution networks: Assessing the customer benefit. Appl. Energy 2021, 291, 116857.
67. Shaukat, N.; Khan, B.; Ali, S.M.; Mehmood, C.A.; Khan, J.; Farid, U.; Majid, M.; Anwar, S.M.; Jawad, M.; Ullah, Z. A survey on electric vehicle transportation within smart grid system. Renew. Sustain. Energy Rev. 2018, 81, 1329–1349.
68. Shen, J.; Jiang, C.; Li, B. Controllable Load Management Approaches in Smart Grids. Energies 2015, 8, 11187–11202.
69. Waraich, R.A.; Galus, M.D.; Dobler, C.; Balmer, M.; Andersson, G.; Axhausen, K.W. Plug-in hybrid electric vehicles and smart grids: Investigations based on a microsimulation. Transp. Res. Part C Emerg. Technol. 2013, 28, 74–86.
70. Jian, L.; Xue, H.; Xu, G.; Zhu, X.; Zhao, D.; Shao, Z.Y. Regulated Charging of Plug-in Hybrid Electric Vehicles for Minimizing Load Variance in Household Smart Microgrid. IEEE Trans. Ind. Electron. 2013, 60, 3218–3226.
71. Morais, H.; Sousa, T.; Vale, Z.; Faria, P. Evaluation of the electric vehicle impact in the power demand curve in a smart grid environment. Energy Conv. Manag. 2014, 82, 268–282.
72. Jian, L.; Zhu, X.; Shao, Z.; Niu, S.; Chan, C.C. A scenario of vehicle-to-grid implementation and its double-layer optimal charging strategy for minimizing load variance within regional smart grids.

Energy Conv. Manag. 2014, 78, 508–517.

73. Liang, H.; Zhuang, W. Stochastic Modeling and Optimization in a Microgrid: A Survey. Energies 2014, 7, 2027–2050.
74. Lopez, M.A.; de la Torre, S.; Martin, S.; Aguado, J.A. Demand-side management in smart grid operation considering electric vehicles load shifting and vehicle-to-grid support. Int. J. Electr. Power Energy Syst. 2015, 64, 689–698.
75. Xing, H.; Fu, M.; Lin, Z.; Mou, Y. Decentralized Optimal Scheduling for Charging and Discharging of Plug-In Electric Vehicles in Smart Grids. IEEE Trans. Power Syst. 2016, 31, 4118–4127.
76. Soares, J.; Ghazvini, M.A.F.; Vale, Z.; de Moura Oliveira, P.B. A multi-objective model for the day-ahead energy resource scheduling of a smart grid with high penetration of sensitive loads. Appl. Energy 2016, 162, 1074–1088.
77. Dileep, G. A survey on smart grid technologies and applications. Renew. Energy 2020, 146, 2589–2625.
78. Zhang, Y.; Gjessing, S.; Liu, H.; Ning, H.; Yang, L.; Guizani, M. Securing vehicle-to-grid communications in the smart grid. IEEE Wirel. Commun. 2013, 20, 66–73.
79. Saxena, N.; Grijalva, S.; Chukwuka, V.; Vasilakos, A.V. Network Security and Privacy Challenges in Smart Vehicle-to-Grid. IEEE Wirel. Commun. 2017, 24, 88–98.
80. Tao, M.; Ota, K.; Dong, M. Foud: Integrating Fog and Cloud for 5G-Enabled V2G Networks. IEEE Netw. 2017, 31, 8–13.
81. He, D.; Chan, S.; Guizani, M. Privacy-friendly and efficient secure communication framework for V2G networks. IET Commun. 2018, 12, 304–309.
82. Ahmed, S.; Shamshad, S.; Ghaffar, Z.; Mahmood, K.; Kumar, N.; Parizi, R.M.; Choo, K.R. Signcryption Based Authenticated and Key Exchange Protocol for EI-Based V2G Environment. IEEE Trans. Smart Grid 2021, 12, 5290–5298.
83. Umoren, I.A.; Shakir, M.Z.; Tabassum, H. Resource Efficient Vehicle-to-Grid (V2G) Communication Systems for Electric Vehicle Enabled Microgrids. IEEE Trans. Intell. Transp. Syst. 2021, 22, 4171–4180.
84. Pokhrel, S.R.; Hossain, M.B. Data Privacy of Wireless Charging Vehicle to Grid (V2G) Networks With Federated Learning. IEEE Trans. Veh. Technol. 2022, 71, 9032–9037.
85. Hossain, M.B.; Pokhrel, S.R.; Vu, H.L. Efficient and Private Scheduling of Wireless Electric Vehicles Charging Using Reinforcement Learning. IEEE Trans. Intell. Transp. Syst. 2023, 24, 4089–4102.