The Smart Grid perspective Related to Electric Vehicle

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Smart grids (SG) is a concept that has been modernizing the energy sector since it allows to establish a bidirectional communication infrastructure, allowing to improve the control, efficiency, and quality of service of power systems.

electric vehicles | Vehicle-to-Grid | Vehicle-to-Home | smart grid

1. Vehicle-to-Grid

Regarding V2G technology, this consists of the bidirectional transfer of energy, where the EVs can discharge the energy stored in the batteries to the grid, thus serving to regulate the energy system, as can be seen at [1][2]. This technology is complex, where for it to work correctly, it requires the coexistence of several components, which can only be achieved through charging and communication protocols. Thus, the aggregator is crucial for this technology since it creates business models according to the interests of EVs' owners [3]. In this way, the aggregator allows the link between EV owners and energy market participants to be maintained. Another notable aspect of this technology is the ancillary services that allow the electricity grid's quality and efficiency to be preserved [4][5].

Figure 1 also illustrates another way to present the structure of the V2G system, which focuses more on the respective connection between the EV and the electric grid through the charging station from the parking lot. In general, depending on whether the EV is charging/discharging, a voltage conversion must occur to level the voltage entering or leaving the EV battery. In case the EV is charging, the voltage coming from the grid first goes through the AC/DC conversion process, and then the voltage is reduced by means of a downward converter. In case the EV is discharging, the voltage coming out of the EV battery is first increased through an upward converter, and then the DC/AC conversion is carried out to level with the mains voltage. In both cases mentioned above, the respective converter is aided by a reference signal that enables it to perform the respective conversions accurately, regardless of the direction of the conversion [6].

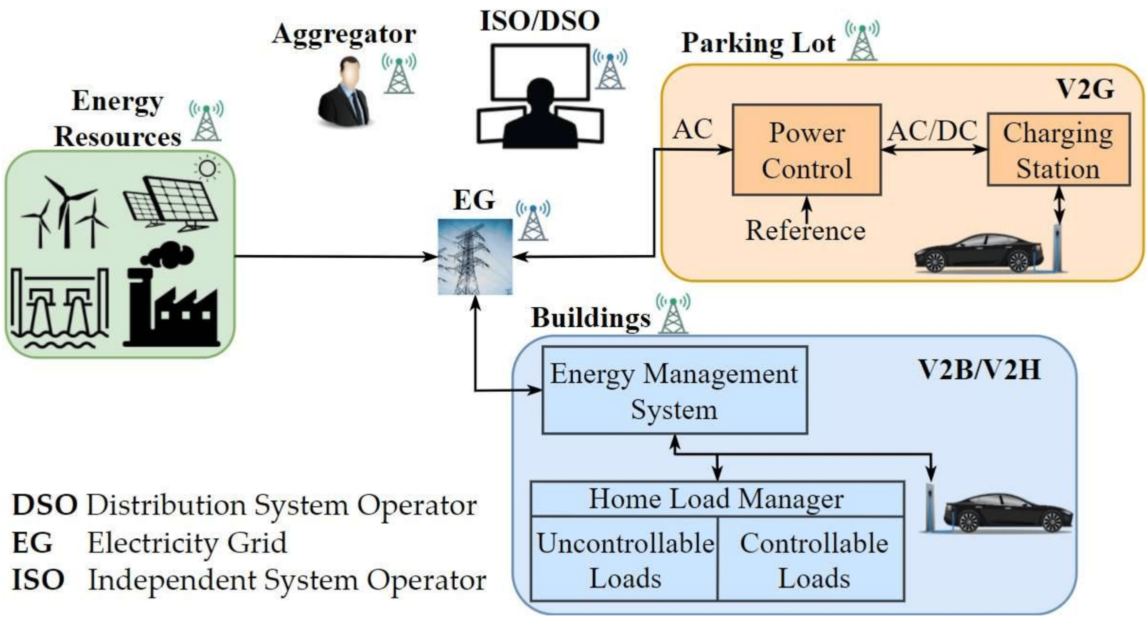

Figure 1. Proposed Vehicle-to-Everything framework.

In the context of V2G systems, there are several works of literature where they report that these systems can contribute in various ways. For example, ref. [7] uses a Mixed Integer Linear Programming (MILP) model that supports the bidirectional capabilities of V2G to reduce the degradation of EVs' batteries and increase the participation payoff. In [8], the study on the optimization of EVs at small charging stations was elaborated. Through the V2G technology, the respective optimization model allows the improvement of the EV charging/discharging processes, consequently reducing the energy costs of the respective EVs and minimizing the charge–discharge cycles of the EV batteries.

There are also studies that focus on energy resource management, as can be seen in [9][10]. In [9], a linear optimization model is studied, where it combines V2G with other technologies, such as smart charging, to control the penetration of EVs and PV production into electric systems. The respective simulations have shown that the respective linear optimization model can provide flexibility to deal with the uncertainty resulting from the penetration of EVs and PV production. In [10], a model was proposed to minimize the operating cost of the distributed energy resources available in a grid that benefits from V2G through a hybrid metaheuristic algorithm. This research considers different energy resources, such as biomass, PV, wind, mini-hydro, and others, as well as a fleet of 2000 EVs, where the requirements of the EV owners were taken into account. The results show that, with EVs' help, the operating cost of the distributed energy resources decreased by 1.94%.

Other works focused more on ancillary services, giving the participants of these systems the possibility to be remunerated. One example is the reference [5], where the simulation of frequency regulation services carried out in Italy was analyzed. Three types of frequency regulation simulation were highlighted, each of which has its remuneration model. These regulations were influenced by the types of users used and the capacity of the batteries, and EV specifications.

EV owners can also be compensated if they participate in V2G programs that have the scope of coordinating their charging/discharging processes. In the case of [11], a model was developed that allows the development of an optimized charging/discharging schedule that maximizes the respective participant's remuneration.

V2G technology can also cooperate with other systems, as shown in [12]. A control system was developed to be applied to a bidirectional inductive power transfer charger. This charger can operate either in G2V mode or V2G mode, where the respective simulations performed on this charger have shown that it works well in both modes.

Energy providers can also benefit from V2G. In [13], a hybrid computing architecture is highlighted to be applied in 5G-based V2G networks, which improves the quality of service of energy providers through the bidirectional flow of energy and information between the SG and the schedulable EVs.

2. Vehicle-to-Home

V2H technology makes it possible to offer greater energy efficiency to a given residence by combining local renewable energy sources (RES), such as wind or solar, with storage systems, i.e., EV batteries [14]. In this way, the EV batteries can facilitate the local integration of the RES, storing their excesses and later discharging in situations where the price of energy is high or where the domestic demand is higher or even in emergencies. Likewise, these excesses can be sold to the energy market if the price is justified. Thus, this technology allows optimizing the energy consumption of the house [6].

Figure 1 also shows the V2H system, where the energy management system, which supervises energy transfers, and the home load manager are connected in parallel to the charging station installed in the residence. If there is a greater demand on the home's electric grid, the EMS allows the respective EV to transfer energy to the domestic loads, thus supporting the home.

Several kinds of literature have conducted studies on the application of this technology. For example, in [15][16], they studied the combined coordination of V2H technology with renewable and non-renewable distributed generation, together with DR programs. In [15][16], they considered wind and PV production, together with a diesel generator, where in these studies its verified that the combination of V2H technology with the others permits significantly reduce the energy cost. Another example of applying this technology was illustrated in [17], where the study focused on coordinating the EV batteries with the PV production installed in the homes. In this one, it was verified that in Japan, in 2030, the combination of "PV + EV" was quite promising. In [18], a model was presented based on the V2H system, which aims to minimize the energy cost of a smart home that takes advantage of wind and PV generation. Considering the charging/discharging processes of the batteries of EVs and smart equipment, this model seeks to optimize the planning of energy resources through MILP. The simulations demonstrate that EVs' participation allows reducing the energy cost significantly.

This technology also allows using the batteries of EVs as additional storage, as shown in [19]. This research presents a model for a V2H system that uses an EV battery and a stationary battery as additional energy storage for a residence. This research aims to develop a system capable of managing the energy resources of the residence through the charging and discharging processes of both available batteries. For this purpose, models for different subsystems of the V2G system were highlighted, such as the energy demand of the residence, the additional energy storage, and the energy converters used to perform the respective long-term simulations and obtain data.

3. Vehicle-to-Building

V2B technology is very similar to V2H, where it also combines storage systems with power generation technology, such as RES. The main difference between these technologies is the magnitude of energy consumption involved in the problem in which these technologies are inserted. In V2B technology, the energy transferred between the non-residential building and the set of EVs is higher than in V2H. Likewise, the amount of EVs involved in these technologies is different [6].

In the example in [20], a method based on linear programming is developed, where the objective of this one is to minimize the operational cost of the building in question, where it benefits from PV production and the EV charging station that collaborated. With this method, it is concluded that the collaborative strategy between the building and the EV charging station is more economical than the non-collaborative strategy. A similar example was [21], wherein this research still considered the degradation of the building's storage system. It was verified that the total costs can reduce up to 7.2%.

In [22], the study on the peak-shaving and valley-filling problem of consumption in the Spanish university building was considered. In the context of V2B technology, EVs parked in the university parking lot were used to regulate the building's energy consumption in question through the optimized scheduling of EV's charging/discharging process. Furthermore, this research used linear programming, where the results obtained from it proved its viability.

Microgrids can benefit from V2B technology, as shown in [23][24][25]. In [24], it aimed to develop an optimization framework to reduce/shave the peak load of a building incorporated in a microgrid, considering the EV owners' preferences. In this context, by taking advantage of V2B technology, the microgrid can increase its efficiency and performance while ensuring the high quality of services provided to the EV owners through bidirectional energy flow. The studies of [23][25] investigated EVs' impact on an office building embedded in a microgrid. The studies demonstrated that scheduling the charging of EVs made it possible to attenuate the energy flow of the grid at times of most significant stress.

4. Charging Levels, Modes, and Methods

Currently, in the transportation sector, it is possible to verify two charging methods, the unidirectional, where this consists of the grid transferring energy to the batteries of the EVs, and the bidirectional. The latter allows the EVs to transfer the energy stored in the batteries to the electric grid. On the one hand, it should be noted that the EVs' batteries are charged by charging systems that can be in AC or DC. According to the American model SAE J1772

Standard, developed by the Society of Automotive Engineers, these systems have three charging power levels [26][27], as shown in **Table 1**. On the other hand, these charging's can be elaborated in four ways [26][28], taking into account the respective individual characteristics of each EV. These charging modes are formalized by the International Electrotechnical Commission through the IEC 61851-1 model, where they are illustrated in **Table 2**.

Table 1. AC and DC Charging Power Levels.

Power Levels		Nominal Voltage (V)	Max Current (A)	Power (kW)	Type of Charge
AC	Level 1	120, 1-phase	≤16	1.9	Slow
	Level 2	240, 1-phase	≤30	≤7.2	Slow
		240, 3-phase	≤80	≤19.2	Slow
	Level 3	400, 3-phase	>80	≤130	Slow
DC	Level 1	200–450	≤80	≤36	Slow
	Level 2	200–450	≤200	≤90	Medium
	Level 3	200–600	≤400	≤240	Fast

Table 2. Different Charging Modes.

Connection Mode	Grid Connection	Voltage (V)	Max Current (A)	Type of Charge
Mode 1 (AC)	1-phase	250	10	Slow
	3-phase	480	16	Slow
Mode 2 (AC)	1-phase	250	32	Slow
	3-phase	480	32	Slow
Mode 3 (AC)	1-phase	250	32	Slow
	3-phase	480	250	Medium
Mode 4 (DC)	-	600	400	Fast

In general, Mode 1 is usually installed in homes, and in this mode, the charging cable does not allow communication between the EV and the mains socket, nor does it protect the EV itself against overloads. On the contrary, Mode 2 already has a cable that allows communication and protects the EV against overload.

As for Mode 3, it is similar to the previous one; however, it allows charging the EVs more quickly. Finally, Mode 4, as a rule, is associated with fast charging, where the EV is charged in less than one hour by a DC power supply. Considering the unidirectional and bidirectional charging methods presented in [29], these are described in **Table 3**.

Table 3. Different Charging Methods.

Charging Methods			Main Characteristics
Unidirectional	Uncontrolled		• Usually used by ordinary EV users; • Does not guarantee full charging of the EV; • Does not consider the price of electricity (uncertain cost); • Does not require any investment (cheap to implement);
	Controlled	Centralized	• Higher level of organization and control; • The EV charging control is done by an aggregator, a distribution system operator, or a multi-agent system; • Being centralized requires more communication between the owner and the entity controlling the EV charging; • Susceptible to data privacy violations;
		Decentralized	• Enables EV owners to lower the cost of charging, according to their preferences; • Easy and reliable to implement; • The owner can control the EV charging control; • Since it is decentralized, it demands fewer communications and has greater data privacy;
	Bidirectional		• It allows the transfer of power from the grid to the EV and from the EV to any entity, i.e., Vehicle-to-Everything (V2X); • It needs EVs with batteries with bi-directional energy flow.

It is essential to highlight that in order to charge or discharge EV batteries, the battery state of charge (SOC) level must first be estimated. At present, there is a variety of battery SOC estimation methods, where the most commonly known are machine learning-based methods, electromechanical model-based methods, Ah Integration, Equivalent Circuit Model, Extended Kalman Filter, and Open Circuit Voltage [30]. Each of these has its advantages and disadvantages. However, Ah Integration is the most widely used method mentioned above due to its simplicity compared to the others.

References

1. Sami, I.; Ullah, Z.; Salman, K.; Hussain, I.; Ali, S.M.; Khan, B.; Mehmood, C.A.; Farid, U. A Bidirectional Interactive Electric Vehicles Operation Modes: Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) Variations within Smart Grid. In Proceedings of the 2019 International Conference on Engineering and Emerging Technologies (ICEET), Lahore, Pakistan, 21–22 February 2019; pp. 1–6.
2. Kumar, M.; Vyas, S.; Datta, A. A Review on Integration of Electric Vehicles into a Smart Power Grid and Vehicle-to-Grid Impacts. In Proceedings of the 2019 8th International Conference on Power Systems (ICPS), Jaipur, India, 20–22 November 2019; pp. 1–5.
3. Høj, J.C.M.L.; Juhl, L.T.; Lindegaard, S.B. V2G—An Economic Gamechanger in E-Mobility? World Electr. Veh. J. 2018, 9, 35.
4. Choi, W.; Lee, W.; Han, D.; Sarlioglu, B. Shunt-Series-Switched Multi-Functional Grid-Connected Inverter for Voltage Regulation in Vehicle-to-Grid Application. In Proceedings of the 2018 IEEE Transportation Electrification Conference and Expo (ITEC), Long Beach, CA, USA, 13–15 June 2018; pp. 961–965.
5. Latini, L.; Armani, F.B.; Leva, S.; Ninno, F.D.; Ravina, G. Economics of Vehicle-to-Grid Application for Providing Ancillary Services in Italy. In Proceedings of the 2019 IEEE Milan PowerTech, Milan, Italy, 23–27 June 2019; pp. 1–6.
6. Vadi, S.; Bayindir, R.; Colak, A.M.; Hossain, E. A Review on Communication Standards and Charging Topologies of V2G and V2H Operation Strategies. Energies 2019, 12, 3748.
7. Kaur, K.; Kumar, N.; Singh, M. Coordinated Power Control of Electric Vehicles for Grid Frequency Support: MILP-Based Hierarchical Control Design. IEEE Trans. Smart Grid 2019, 10, 3364–3373.
8. Mehrjerdi, H.; Rakhshani, E. Vehicle-to-grid technology for cost reduction and uncertainty management integrated with solar power. J. Clean. Prod. 2019, 229, 463–469.
9. Fattori, F.; Anglani, N.; Muliere, G. Combining photovoltaic energy with electric vehicles, smart charging and vehicle-to-grid. Sol. Energy 2014, 110, 438–451.
10. Sousa, T.; Vale, Z.; Carvalho, J.P.; Pinto, T.; Morais, H. A hybrid simulated annealing approach to handle energy resource management considering an intensive use of electric vehicles. Energy 2014, 67, 81–96.

11. Chai, Y.-T.; Tan, W.-N.; Gan, M.-T.; Yip, S.-C. An Optimal Charging and Discharging Schedule to Maximize Revenue for Electric Vehicle. In Proceedings of the 2019 IEEE Conference on Sustainable Utilization and Development in Engineering and Technologies (CSUDET), Penang, Malaysia, 7–9 November 2019; pp. 240–245.
12. Molina-Martínez, E.J.; Roncero-Sánchez, P.; López-Alcolea, F.J.; Vázquez, J.; Torres, A.P. Control Scheme of a Bidirectional Inductive Power Transfer System for Electric Vehicles Integrated into the Grid. Electronics 2020, 9, 1724.
13. Shen, Y.; Fang, W.; Ye, F.; Kadoch, M. EV Charging Behavior Analysis Using Hybrid Intelligence for 5G Smart Grid. Electronics 2020, 9, 80.
14. Lazzeroni, P.; Olivero, S.; Repetto, M.; Stirano, F.; Vallet, M. Optimal battery management for vehicle-to-home and vehicle-to-grid operations in a residential case study. Energy 2019, 175, 704–721.
15. Mehrjerdi, H.; Hemmati, R. Coordination of vehicle-to-home and renewable capacity resources for energy management in resilience and self-healing building. Renew. Energy 2020, 146, 568–579.
16. Mehrjerdi, H.; Saad, M.; Lefebvre, S. Efficiency-Resilience Nexus in Building Energy Management under Disruptions and Events. IEEE Syst. J. 2020, 16, 299–308.
17. Kobashi, T.; Say, K.; Wang, J.; Yarime, M.; Wang, D.; Yoshida, T.; Yamagata, Y. Techno-economic assessment of photovoltaics plus electric vehicles towards household-sector decarbonization in Kyoto and Shenzhen by the year 2030. J. Clean. Prod. 2020, 253, 119933.
18. Aslam, S.; Khalid, A.; Javaid, N. Towards efficient energy management in smart grids considering microgrids with day-ahead energy forecasting. Electr. Power Syst. Res. 2020, 182, 106232.
19. Hinov, N.; Dimitrov, V.; Vacheva, G. Model for Vehicle to Home System with Additional Energy Storage for Households. Electronics 2021, 10, 1085.
20. Kuang, Y.; Hu, M.; Dai, R.; Yang, D. A Collaborative Decision Model for Electric Vehicle to Building Integration. Energy Procedia 2017, 105, 2077–2082.
21. Wu, D.; Zeng, H.; Lu, C.; Boulet, B. Two-Stage Energy Management for Office Buildings with Workplace EV Charging and Renewable Energy. IEEE Trans. Transp. Electrif. 2017, 3, 225–237.
22. 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.
23. Aziz, M.; Budiman, B.A. Extended utilization of electric vehicles in electric grid services. In Proceedings of the 2017 4th International Conference on Electric Vehicular Technology (ICEVT), Bali, Indonesia, 2–5 October 2017; pp. 1–6.

24. Ouammi, A. Peak load reduction with a solar PV-based smart microgrid and vehicle-to-building (V2B) concept. Sustain. Energy Technol. Assess. 2021, 44, 101027.
25. Umetani, S.; Fukushima, Y.; Morita, H. A linear programming based heuristic algorithm for charge and discharge scheduling of electric vehicles in a building energy management system. Omega 2017, 67, 115–122.
26. Skouras, T.A.; Gkonis, P.K.; Ilias, C.N.; Trakadas, P.T.; Tsampasis, E.G.; Zahariadis, T.V. Electric Vehicles: Current State of the Art, Future Challenges, and Perspectives. Clean Technol. 2020, 2, 1.
27. Williamson, S.S.; Rathore, A.K.; Musavi, F. Industrial Electronics for Electric Transportation: Current State-of-the-Art and Future Challenges. IEEE Trans. Ind. Electron. 2015, 62, 3021–3032.
28. Kongjeen, Y.; Bhumkittipich, K. Impact of Plug-in Electric Vehicles Integrated into Power Distribution System Based on Voltage-Dependent Power Flow Analysis. Energies 2018, 11, 1571.
29. Saldaña, G.; Martin, J.I.S.; Zamora, I.; Asensio, F.J.; Oñederra, O. Electric Vehicle into the Grid: Charging Methodologies Aimed at Providing Ancillary Services Considering Battery Degradation. Energies 2019, 12, 2443.
30. Zhang, H.; Zhou, M.; Lan, X. State of Charge Estimation Algorithm for Unmanned Aerial Vehicle Power-Type Lithium Battery Packs Based on the Extended Kalman Filter. Energies 2019, 12, 3960.

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