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Review - 75 years - Special Edition

Overview and Future Challenges on the Connection of Electric Vehicles into Modern Distribution Power Systems

Jonas Villela de Souza[1,2*]
https://orcid.org/0000-0002-4130-679X

Artur Bohnen Piardi[1]
https://orcid.org/0000-0003-2720-3548

Wandry Rodrigues Faria[2]
https://orcid.org/0000-0002-8757-7595

Rodrigo Bueno Otto[3]
https://orcid.org/0000-0003-2303-066X

Almir Augusto Braggio[3]
https://orcid.org/0000-0001-8033-2205

Zeno Luiz Iensen Nadal[4]
https://orcid.org/0000-0001-6239-4488

[1]Itaipu Technological Park Foundation (FPTI), Foz do Iguaçu, Paraná, Brazil. [2]University of São Paulo (USP), São Carlos School of Engineering (EESC), Department of Electrical and Computer Engineering, São Carlos, São Paulo, Brazil.[3]Lean Automation Smart Systems S.A. (LASSE), Foz do Iguaçu, Paraná, Brazil. [4]Copel Distribuição S.A., Curitiba, Paraná, Brazil.

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*Correspondence: jonas.souza@pti.org.br; Tel.: +55-45-3576-7116 (J.V.S.)

HIGHLIGHTS

- Review of electric vehicles in the Brazilian context;
- Analysis of the possibilities of using Vehicle-to-grid technology;
- Assessment of the situation of Brazilian regulations on electric vehicles;
- Analysis of business models related to electric vehicles.

Abstract: Distribution systems worldwide have suffered profound alterations to their passive historic characteristic in the last decade due to the ever-increasing installation of distributed generators. Nowadays, it is consensual among researchers and utilities that soon most of the investments in distribution networks will be towards the materialization of smart-grids, which implies even more drastic impacts on the grid operation. In this new context, distributed generators, energy storage systems, electric vehicles and other types of resources will operate in coordination with technologies such as internet of things and big data, in an even more active distribution grid under a decentralized electricity market. Thus, it is fundamental to develop the means to control such an interactive power grid, including technologies, products, and ideas. Although several articles have been published addressing this topic, each country's distribution grids have their peculiarities, and so should the proposals for smart-grid implementation on each of them. In this sense, it is crucial investigating what has already been proposed and implemented in the Brazilian smart-grid context to forecast and formulate the next steps on this topic. Smart-grid comprises several fields, in this paper we focus on the electric vehicle branch, providing a review of the subject under the Brazilian context. Additionally, the paper addresses the development of technologies, electricity market regulation, and strategic business models under the current scenario and a near-future perspective.

Keywords: Distribution Power Systems; Electric Vehicles; V2G Technology.

INTRODUCTION

Over the last decade, the distribution systems (DSs) have been submitted to several modifications, at an ever-increasing rate, due to the installation of third-party-owned controllable devices that may either draw power from the grid or inject energy into the system. Among these technologies, distributed energy resources (DERs), energy storage systems (ESSs), and controllable loads may be mentioned. In the next few years, the DSs are expected to experience further significant alterations due to the increase of the devices mentioned above and potentialized by the expansion of the electric vehicle (EV) fleet, which could, at least, affect the DSs loading in specific scenarios wherein most of the cars are charging [1]. From a less technical and more philosophical and economic perspective, the DSs also face a complete paradigm change as the decentralized electricity market model is becoming more common worldwide. In this sense, several researchers investigate how these devices may be best employed in a decentralized energy market scenario [2-4].

In the context of a distribution grid equipped with DERs, it is plausible that these local generators could supply the DS's loads, reducing the network's dependency on the transmission grid. Since the DERs are usually third-party-owned, the competition between these owners could cause price reduction in a decentralized market. It is essential to highlight that DERs are not the only resources capable of profiting from energy trade in such environment. ESSs can provide ancillary services and trade electricity, buying when the costs are low and selling when high. Controllable loads may provide demand response services [5]. As for the EVs, they may operate as the ESSs.

Although the specific literature has been exploring the integration of DERs, ESSs, and EVs, especially over the last five years, there are still some challenges, mainly of regulatory nature, that difficult large-scale applications worldwide, or even in minor regions in some countries. Compared to the European and North-American grids, the Brazilian scenario is be late regarding the operation of such modern distribution networks. In this sense, studies addressing the Brazilian reality are necessary to map obstacles and provide suggestions towards the materialization of smart-grids.

One of the most urgent issues that drive investments in DERs, ESSs, and EVs is the environmental agenda. In this sense, it is essential to analyze Brazil's position and commitments for the coming years in this matter. In September 2016, after the Paris agreement, the Brazilian government committed to reducing greenhouse gas (GHGs) emissions by approximately 37%. According to data from the Climate Observatory in 2018, of the emission of GHGs reached 3.25 billion tons in 2015 [6]. In this sense, the Brazilian Federal Government and non-governmental organizations approved a series of actions and measures to identify in which categories these emissions were more intense. In [6], the author conclude that the mobility sector is a significant contributor to GHG emissions, leading the Brazilian Federal Government and Brazilian energy companies to promote a series of studies and present solutions that could contribute to GHG emission reductions. Among the most significant contributors to the increase in emissions were, precisely, automotive vehicles that yearly produce hundreds of thousands of cubic meters of carbon dioxide. Thus, a set of actions identified that increasing the EV fleet would reduce emissions to the levels required by the Paris agreement. In this context, this paper focuses on the EVs' role in a modern DS.

Seeking the success of such measures, the Brazilian Federal Government promoted the reduction of taxes on EVs' purchases. This strategy was also adopted in Law 13.755/2018 [7], known as "*Route 2030*" (which in turn is a reformulation of Law 12.715/2012, known as "*Inovar-Auto*"). Besides, the Federal Government also encourages and promotes research projects to develop national technology in related sectors. This initiative not only is essential to enable electrification in the automotive sector in Brazil, but also accelerates the development of new technologies that may, in the future, increase Brazilian independence concerning the adoption of electric vehicles by the various segments of the population.

One of the main difficulties for the popularization of EVs in Brazil is the number of charging stations available, both in cities and highways. It is estimated that tens of thousands of public electro parts will be needed to keep pace with road transport electrification in Brazil, considering a preliminary assessment analysis [8]. Once the problems for charging a large number of EVs have been identified, distribution grid operating solutions based on microgrids and smart-grids are attractive because they act in a shared way. As a result, these grids are able to operate absorbing or injecting power in compliance with the standards stipulated by Brazilian regulatory standards [9], issued by the Brazilian National Electric Energy Agency (ANEEL), and by international recommendations such as IEEE 519/2014 [10].

It is important to highlight that an ambitious project such as the energy management of several charging stations combining sustainable technologies and alternative energy sources should invest in ensuring that the power quality standards and the system's stability is maintained during the smart-grid operation. Evidently, the same concerns must be considered when sharing power. In this context, regulatory agencies have shown an interest in developing measures and technologies to meet these demands. An example of this is the research project PD 2866-0450/2016 promoted by ANEEL through the Call for Strategical R&D Projects nº 21/2016. This project seeks to develop a system for supervising vehicular charging stations to control the flow of charges and discharges in a bi-directional manner.

This paper presents a review on the development of EV research and technologies for the Brazilian scenario. Since we discuss the EV application in smart-grids, we also address the energy market regulation. Furthermore, a projection of the following decades' business models considering the expansion of the EV fleet and the alteration of the electric market regulation is provided.

Smart Grids and Electric Mobility

Smart Cities are defined as the cities' ability to incorporate advanced technologies to meet essential and indispensable services in urban centers (basic sanitation, health, transport, finance, public security, and communication) [11]. In this sense, smart grids appear as a critical element for strategies in using sustainable resources, becoming a facilitator for the use of renewable energy sources, and incorporating the appropriate infrastructure to perform all these services within cities, with a high data processing and information sharing [12].

The concept of smart cities does not address only technological issues; it also covers the intelligent integration of other infrastructures and socioeconomic functions. As a result, the use of human, financial, and technical resources are strategically used to simultaneously address environmental, demographic, social, and economic challenges. In such an environment, multiple points of view are integrated [13]. In this sense, Figure 1 presents some elements that smart cities may have.

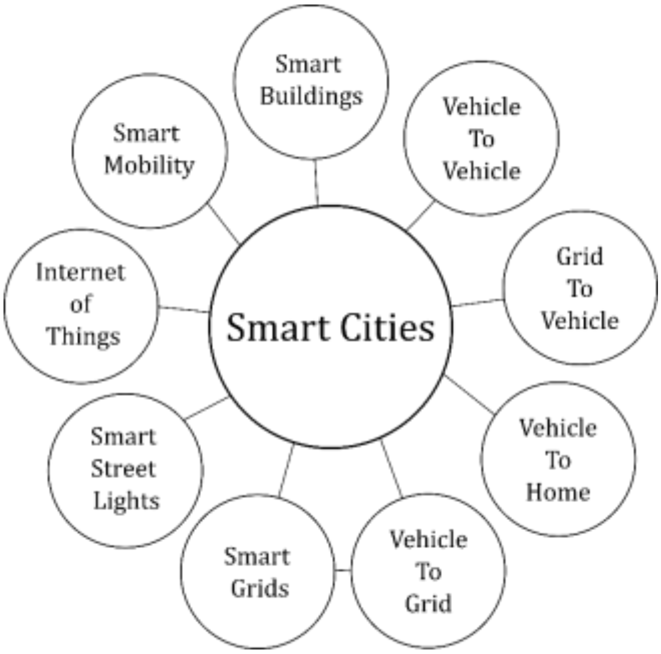

Figure 1. Some of the technologies incorporated in the concept of smart cities. Adapted from [6,9].

Smart-grids are a crucial part of the search for a more sustainable energy future. They allow the integration of renewable energy sources and the electrification of vehicles [14]. Besides, smart grids can manage distributed energy generation and connections with many power sources (one in each residence or building, for instance). Although smart-grids may provide numerous advantages, there are some challenges associated with them also. For one, there is the possibility of bidirectional flow of energy due to the injection of power in different electrical network points. Hence, it is necessary to carefully plan and operate these distribution and transmission grids [14-15].

From Figure 1, it is possible to infer that EVs are also part of this integration due to the technologies Grid-To-Vehicle (G2V), Vehicle-To-Home (V2H), Vehicle-To-Grid (V2G), and Vehicle-To -Vehicle (V2V). The G2V technology introduced the possibility to manage the connection between the distribution network and the EVs. Through its use, it is possible, for example, to schedule low-demand or low-cost times to charge the vehicle's battery and, therefore, reduce costs for the charging operation [16]. Such solutions are well documented in the current international literature and use various analysis strategies, including single and multi-objective optimization, to demonstrate that they are feasible and advantageous from both economic and technical perspectives [17].

EVs can store energy using bidirectional converters. Due to such converters, it is also possible to inject power into the network in a controlled manner, a concept called V2G. Such technology presents some challenges related to power quality and the communication network's safety (which connects the vehicle to the charging station [18]) for its implementation. Also, the use of V2G technology enables the use of ancillary services such as peak-shaving, use as reserve energy, and smoothing of load transients through active power-sharing [14-15].

V2H technology allows the EV to supply power to specific loads in a home. Its application relates to the load curve and is associated with emergencies due to interruption of energy supply through the distribution network [16-17]. V2V technology, on the other hand, allows power exchange directly between electric vehicles, without the need for an intermediate charging station in the process. In a complementary way, this concept allows the exchange of traffic information between vehicles through sensors, consequently granting greater safety for the vehicle's driver. It is important to note that V2G technologies are linked to the concept of smart cities and smart-grids, as both require an intelligent charging point to carry out EV charging or supply energy to the local distribution network [16-17].

In this way, "connected electric mobility" is an element that relates to smart grids and expands to smart cities. For this to be possible, cities and grid operators need to plan and develop appropriate infrastructures to incorporate electric mobility into the urban context. As an example of such infrastructures, one can mention using EVs to draw power from and inject power into the electrical network [19]. The process of recharging or returning electricity to the grid can be carried out through intelligent bidirectional charging stations capable of using information such as the expected recharge time and the EV’s battery State of Charge (SoC).

Electric Mobility in The Brazilian Context

Electric mobility is under development, and, technologically, there is still a long way before operating on a large scale in Brazil. The advantages of the technologies that are part of electric mobility are quite comprehensive, given its current development and market. In this sense, reviews found in the literature focused mainly on V2G mobility technologies, such as [20-21], the authors point out the following potential benefits related to the use of this technology:

- Integration with renewable energies (usually linked to technical aspects, not environmental or economic ones);
- Provision of network operation, smart-grid, storage, and microgrid services;
- Environmental aspects (climate change and air pollution);
- Future scenarios where the bidirectional integration of energy from EVs will be better explored;
- The emergence of smarter electrical networks with great potential to reinforce the advantages of V2G.

In this sense, the main aspects that could be used to benefit Brazil's distribution networks are explored. The V2G technology allows the injection of power into the power grid during periods of higher energy cost in order to offset the demand for other loads. In other words, the owner can charge the EV battery at times when both the price and the energy demand are lower. Then, if desired, the user may sell the stored energy surplus to the power utility during times of high demand, periods in which prices are usually more attractive for sale, thus performing the so-called energy arbitrage [16]. However, it should be mentioned that V2G technology has other advantages and applications, not being limited only to charging issues.

Encouraging the use and implantation of generation from renewable energy sources, such as photovoltaic (PVs) generation in residential units, can cause problems in the distribution networks, such as overvoltage. Aiming to allow PVs to always operate at their maximum power point, which benefits the consumer and reduces the investment payback time, the authors of [22-24, 26] present an alternative management method entitled charge-discharge management scheme, to balance the voltage of the distribution network, using the connection with the EVs. In these proposals, the EVs absorb the extra power produced by renewable sources (for example, PVs) or inject power into the electrical network for voltage regulation, applying V2G technology through a charging station. In this way, V2G technology can be applied together with management to maintain the power balance in DC microgrids, which can be composed, for example, of distributed generation, ESSs, EVs, and the electric network itself.

There are several state-of-the-art papers regarding V2G addressing control and management strategies associated with this technology. They mostly deal with the charging station's management and studies of their implementation and impacts. In [25-26], the authors present strategies to manage EVs' fast charging in charging stations at peak times, reducing the battery charge speed and, consequently, reducing the cost of energy during the process. Through the use of such strategies it is observed a relief in the electrical grid during peak times. Besides, EVs can provide services such as voltage and frequency regulation to the network due to the use of V2G.

The works [27-28] address the penetration of EVs in the distribution network with the primary objective of dealing with voltage regulation. In [29-31], the reactive power compensation is carried out using EVs. All works use the V2G concept for the application of their methodologies. In this context, works like [32,33] address control techniques for synchronizing charging stations with the electric network. In [32-35], the authors approach control techniques using V2G to maintain stability in charging stations - composed of renewable energy sources.

Probing further into the concept of vehicles connected to the network, one can find other applications of the same technology to share reactive power [36], referred to by these authors as Vehicle-for-Grid (V4G). In this context, a set of EVs could still be seen as an energy storage group and mobile active filtering when inserted into a smart grid infrastructure. However, many of these concepts still depend on the development of equipment and management systems suitable for the intelligent execution of the prerogative technologies themselves, which are essential on the path to further technological developments.

Thus, in the literature, it is possible to observe that power electronics devices are used extensively, applied to V2G concepts, represented by bidirectional charging stations, incorporating efficient control and protection technologies. They also consider important factors such as EV battery life, power quality, and safety when charging and discharging.

Regulation Status

Despite the advantages already presented, and the fact that a V2G initiative for the use of charging stations has already been regularized, the Technical Note Nº. 0063/2018-SRD/ANEEL presented by ANEEL on May 25, 2018, reports that the current stage of electric mobility, model, and sectoral regulation is still unsatisfactory for the permission of V2G technology to follow its path in the Brazilian scenario. The electric energy compensation system established in Normative Resolution (REN) 482/2012 [37] encompasses only energy generation sources, not including energy storage elements, such as batteries. On the other hand, ANEEL justifies the lack of their inclusion due to the reduced number of EVs, the market's insufficiency, and losses involved in the charge-discharge cycle of the batteries [38].

Subsequently, REN 819/2018 already has procedures and conditions for EV charging activities by concessionaires and allows holders of public electricity distribution services. However, it is recommended to wait for the response of the technological advances of EVs in the Brazilian market and the revision of REN 482/2012, with a forecast to occur in a not-so-distant time into the future, to be able to apply the V2G integration [39].

Economic, Business, and Market Aspects

Currently, the Brazilian energy market model is strictly regulated. Therefore, as described in the previous sections, the Brazilian regulation for electric mobility technologies is still not favorable for constructing a market around such technologies. In this sense, the perspectives expected for when we have the proper regulations regarding the construction of the economic, business, and market aspects will be presented, observing what has been applied worldwide.

Electric mobility can use the benefits found in adopting V2G technology to increase the use of EVs. One motive is the owner's future possibility to use it in residential energy storage applications. A second would be the possibility of being remunerated for making the EV asset available in providing network services, creating new revenue sources. For electric networks and their operators, vehicles' bidirectional energy function can increase the cost-benefit ratio of ancillary services. The use of such services reduces operating costs, provides storage in a variety of scales and contexts, postpones investments and network readjustments, among other economic benefits. Thus, the development of V2G markets in countries with this potential takes into account four main aspects [40]:

- The total size of the automotive market, V2G hardware, and service providers segmented areas with large automotive markets and high vehicle turnover due to the opportunity to sell EVs;
- The continuation of the EV fleet and V2G potential expansion depends on two conditions: the market moves from fossil fuel vehicles to electric versions, and EVs do not give way for vehicles with fuel cells;
- Existing levels of charging stations infrastructure;
- National energy market that already allows the aggregation of distributed generation assets and with regulatory instruments for EVs.

Recently, the European market has shown itself to be the most receptive to V2G technologies, supported by innovation projects through R&D projects carried out in the region [40]. France and the United Kingdom are the main markets. Germany, on the other hand, as the headquarters of many important automotive companies, also has a significant secondary market. Also, they have incentives to use batteries that support solar energy. However, it has barriers to the Demand Side Response (DSR) and the lack of support from EV's German manufacturers to V2G.

In the North American market, Canada is the leader. Despite representing only 2% of the global automotive market, it has seen consistent and robust growth in EVs sales in recent years. It is an active country in supporting DSR's participation in its energy markets. The USA also tends to be a strong market in this segment. It represents 30% of the world's automotive transport and comprises different regional markets, both for EVs and for energy [41].

For the rest of the world, the main opportunities are grouped in Japan, China, and South Korea. Despite hosting many of the leading EV manufacturers and 12% of the world's automobiles, Japan is still struggling to take a prominent position in EVs and the existence of barriers to DSR in the energy markets. China also has a relatively closed energy market for DSR. However, it is responsible for the second-largest automotive market in the world and a large concentration of EVs in some of its cities (which will contribute, proportionally, to a high number of V2G units when their market starts its operation). Unlike Japan and China, South Korea presents an exciting opportunity for V2G, due in part to the dynamic nature of the DSR market, although the share of EVs is still low [41].

In Brazil, according to the Brazilian Electric Vehicle Association (ABVE) and the historical data provided by the National Association of Motor Vehicle Manufacturers (ANFAVEA), in 2020, the country registered its record in registration of new electric vehicles. However, in 2020, electric vehicles are still 1% of the total number of registered vehicles in the period, even with significant growth. By the end of 2021, according to ANFAVEA, this percentage is expected to reach 1.5%.

In this sense, considering the economies mentioned above and the high costs of V2G technology, it is projected that only around 2030 will there be adequate assimilation of technologies and potential strategic markets to apply V2G technologies. Figure 2 presents the forecast for developing the V2G market in the countries mentioned earlier.

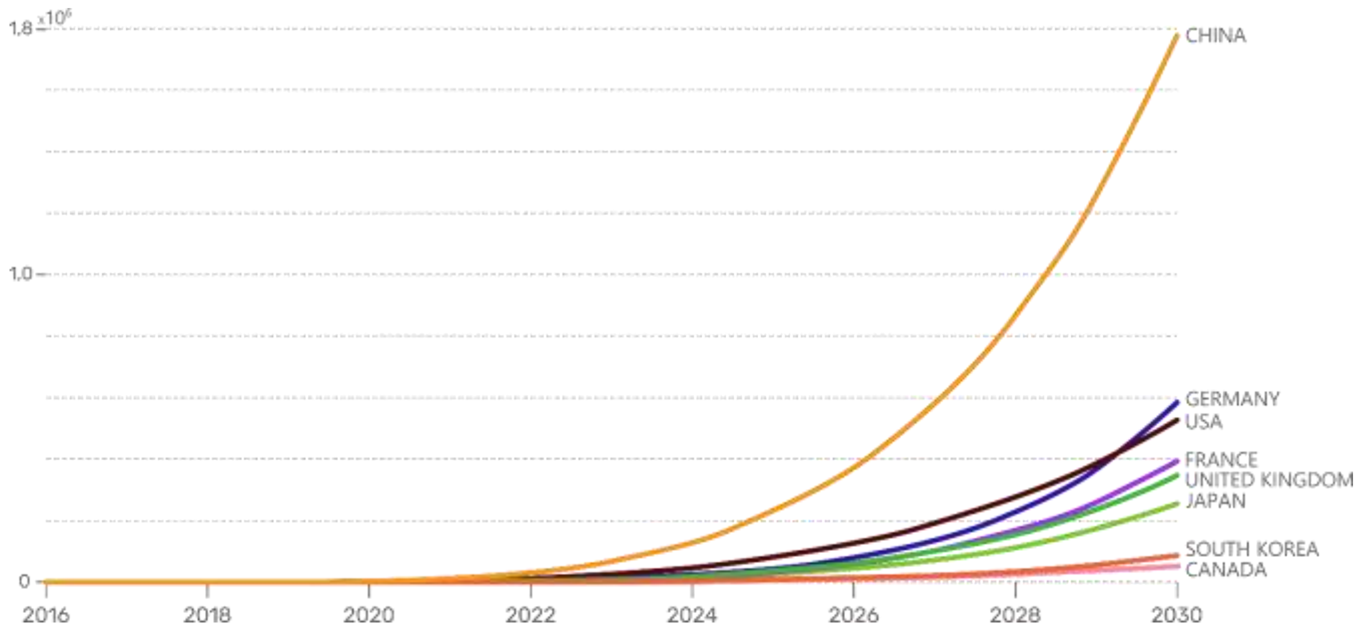

Figure 2. Forecast of the development of the V2G market in the countries of the world with the greatest potential for the use of electric mobility. Adapted from [42].

Environmental, Social and Corporate Governance (ESG)

The scenarios, both worldwide and in Brazil, presented in the previous sections demonstrate that EV technology still demands much investment, financial and research-wise. In this sense, it is instrumental highlighting that companies, governments, and technologies do not receive capital based only on their capacity to pay the investor's interests; instead, three central factors are usually used to estimate the company/government/technology's future financial performance. The factors are: environmental, social, and corporate governance (ESG). In this sense, when investing in a technology, the investor is concerned with climate risks/impacts and the product's sustainability. From a social perspective, human rights and animal welfare are the most pressing matters. However, the corporate governance aspect is not related to the technology, but with the company that owns such technology [42].

V2G technology offers socioenvironmental advantages by reducing damage to the environment and health. From the point of view of the electric sector, these gains promoted by V2G have been widely represented in the literature by reducing the carbon footprint. These gases, harmful to health, have their primary origin in generators and automobiles moved by fossil fuels. The reduction in the emission of these gases is linked to the large-scale integration of alternative sources to the network, including EVs, V2G technology is expected to play an essential role in this reduction in the short and long term.

In November 2018, a study published by Transport Policy Magazine addressed the benefits of using EVs. The study was carried out through 227 interviews with experts and researchers. Over 200 institutions conducted it in 5 countries (Denmark, Finland, Iceland, Norway, and Sweden). Among the main advantages reported by the study were the zero-emission of pollutants, reduction in the level of noise, the ability to operate jointly with renewable sources, in addition to the possibility of selling surplus energy supply to the electricity grid [43].

Considering that the electric demand is ever-growing, EVs are a significant asset, as it can simultaneously address the grid security concerns and the integration of sustainable technologies. However, it is important to mention that the advantage of decreasing the emission of polluting gases may be diluted depending on how the energy matrix develops, i.e., if the energy produced to meet the load comes from non-renewable sources [12].

Brazilian R&D Projects Applied To The Implementation Of Electric Mobility

Keeping in mind the benefits and concerns linked to the process of implantation and use of EVs connected to the network, ANEEL has fostered research in the field over the past ten years. To this end, it regulated and supported R&D projects in Brazil, developing activities in research, development and assembly of light and heavy EVs. In this sense, the following are some successful Brazilian study cases both finished and under development promoted by ANEEL.

Development and Urban Bus Tests with Electric Traction

The initiative started in 2010 with the first prototype's development, moving on to the second in 2012. The project was carried out through partnerships between **(1)** Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering (COPPE), at the Federal University of Rio de Janeiro (UFRJ); **(2)** *Furnas Centrais Elétricas;* and **(3)** Tracel, the latter comprising a technology-based company located in the State of Rio de Janeiro. The project applies the use of hydrogen in the generation of electrical energy for mass transit vehicles. The hybrid-electric bus, developed at COPPE's Hydrogen Laboratory, also has batteries onboard charged during the vehicle's journey, maximizing its autonomy and efficiency [44].

Búzios: An Intelligent City

This project started in 2011 and was chosen to be developed in the city of Búzios, in Rio de Janeiro. Promoted by Enel SpA, the project focuses on achieving an innovative energy management model, making Búzios the first smart city in Latin America. The project's initiative also sought to integrate an intelligent network composed of modern technologies to complement traditional technologies, promoting digital and innovative solutions. In this way, the project made it possible to improve the power system's flexibility, promoting more significant benefits in power quality through real-time data management, control, and the integration of alternative energy sources [45].

Electric mobility is also included in this project. As a result, four vehicles, thirty bicycles, and an electric aqua-taxi (a type of ship used in the region) were manufactured. Finally, the project also covered the intelligent use of public lighting, smart meters, telecommunications, control, and broadband internet. The project was completed in November of 2016 [45].

Technical and Commercial Insertion of Electric Vehicles in Business Fleet in The Metropolitan Region of Campinas

The project was proposed to establish a Real Electric Mobility Laboratory in the Metropolitan Region of Campinas, which allowed obtaining real-time data on EVs' impact in the electricity sector. In this context, the Companhia Paulista de Força e Luz (CPFL-Campinas), through the Emotive project, implemented recharge points that enabled the use of charging stations via a card. The user previously registered this card with his personal information and EV characteristics. CPFL also carried out studies on the prospects for implementing EVs connected to the network and how they would behave due to this new demand.

According to the company, its data showed that this technology would increase between 0.6% and 1.6% the total energy consumption in 2030, considering the penetration of EVs between 4 and 10.1 million units [46]. An interesting result that is analyzed in the Emotive project is its autonomy. The scenario observed in 2016 consisted of a lower-cost operation, in which the kilometer traveled with a fossil fuel vehicle was R$ 0,31, while the EV cost was equivalent to R$ 0,11.

Eletroposto CELESC

The *Eletroposto CELESC* project is entitled "Rapid Recharge System with Hybrid-Stationary Energy Storage for Electric Vehicle Supply in the Concept of Smart Grids." Forming partnerships with Weg*, Fundação Certi* (Reference Centers in Innovative Technologies - Non-profit research institution located in Florianópolis, in the State of Santa Catarina), and *Centrais Elétricas de Santa Catarina* (CELESC), the project proposed the implementation of a fast recharge infrastructure for EVs, in addition to studying the impacts generated by them in the electricity sector. The project was proposed in 2014 by ANEEL (PD-5697-0414/2014) with a term of execution of 24 months [47].

The First Eletrovia (Road with charging stations) in Brazil

Based on the electric mobility initiative, *Companhia Paranaense de Energia* (COPEL), in partnership with *Itaipu Binacional* (IB), is looking for alternatives through research to incorporate electric mobility in the national scenario. In this sense, through this partnership, in December 2018, COPEL inaugurated the first *eletrovia* in Brazil, comprising a 730 km extension on the Brazil Road (BR) 277, connecting the cities of Paranaguá (east region) to the falls of Foz do Iguaçu (west region) in the state of Parana. As a result, COPEL is considered a pioneer in constructing a network capable of serving an entire highway in the country, comprising charging stations [48].

Electric Mobility Associated with Renewable Energy Sources

A partnership aggregating Grupo Energisa, Alsol, and the Federal University of Paraíba is currently developing an R&D project fomented by ANEEL (PD-06585-1912/2019), which combines electric mobility and renewable power sources. They propose to develop a fast-charging system for EVs and install charging stations on the Campinas – Brasilia route; the charging stations are to be installed in Uberlândia–MG. Solar farms were and still are being installed to supply the vehicles recharges. The investments in this project were approximately R$ 100 million in 2020, and they expect to invest R$ 300 million more until 2023 [49].

V2G Charging Station

Fomented by ANEEL, financed by *COPEL Distribuição S.A.* and *COPEL Geração e Transmissão S.A.*, and executed by the Itaipu Technological Park Foundation (FPTI), the project entitled: “National energy storage and management system for bidirectional charging station” has carried out the development of a vehicle charging station supervision system for the control of the flow of charging and discharging in a bi-directional way using V2G technology, acting in the management of the demand side, through the development of simulation environments consisting of storage devices and their peripherals, such as vehicle batteries, bi-directional inverters, among others, in a way to be able to analyze its impacts on the distribution system. The following contributions delivered by the respective project are:

- Implementation of a DC microgrid composed of high-power electronic converters capable of interconnecting a renewable energy source, in this case, photovoltaic panels (PV), energy storage elements (battery bank), and a vehicle charging station in the local concessionaire's network (in this case, COPEL's distribution network);
- Include the electric vehicle as an ESS applying the V2G concept, which will add efforts to the power balance in a DC microgrid composed of alternative energy sources;
- Develop an efficient and safe algorithm to manage the dispatch of the sources of the DC microgrid (PV, battery bank, and EV), considering or not the connection with the distribution system;
- Implementation of a computational interface (HMI, human-machine interface, and a supervision system), which will be able to act locally in the energy management of the charging station, in addition to providing a computational tool for supervising vehicle chargers connected to the concessionaire's network;
- Analysis of the impacts of this technology on the distribution system, through Hardware-in-the-Loop (HIL) simulations, using a real-time simulation platform, so that this information can assist in the developments;
- Development of the functional prototype of a bidirectional charging station with Brazilian technology.

Strategic Current And Future Business Models Regarding V2G

The proposal for a model to profit from the connection between EVs and energy distribution systems depends fundamentally on the laws regulating the energy trade and the number of EVs available. Consequently, this section is divided into two subsections. One of them describes the current scenario in terms of regulation and provides possible business models considering this scenario. The second subsection provides a reading of the future.

Current Scenario

Regulation

Nowadays, the power injection directly into the distribution network is regulated by ANEEL’s REN 687/2015 [51] and addresses only distributed generators. In this sense, until this moment, it is not possible to profit from energy arbitrage using V2G. Even if REN 687/2015 accounted for V2G, it is worth mentioning that the residential consumer does not receive the energy surplus with money under the current regulation but with energy credits. Since the credits can be used anytime and the energy fee throughout the day is constant, the EV owner would not benefit from buying and selling energy.

The only way to profit from energy trades is by participating in energy auctions, which in Brazil are held by the *Câmara de Comercialização de Energia Elétrica* (CCEE) [50]. However, there is a power injection/demand threshold to participate, eliminating the possibility of a residential consumer engagement.

Business Models

Profiting from energy arbitrage is not presently available; however, there are still come strategic subjects to attend to, as, at this stage, it is critical to foment investments in EVs. Although EV is a promising technology, it is also in its initial stages, especially in Brazil. In this sense, in order to be adopted, it must provide the involved parties with benefits not achievable otherwise. In the context of V2G, there are three major stakeholders: vehicle manufacturers, customers, and electric grid operators. Nonetheless, the government's involvement in the matter is fundamental to incentivizing the players to migrate from combustion vehicles to EVs. Given the country's commitment to the Paris agreement, it is in the government's best interest to provide tax reductions, for instance, to EVs; thus, addressing the first stakeholder.

Currently, the price of EVs is still much higher than the combustion ones; however, the tax incentive associated with the possibility in the near future of attaining profit through energy arbitrage using a V2G-based approach may be decisive in gaining the second class of stakeholders. Finally, considering a scenario wherein V2G is a reality, the distribution utilities may benefit from the additional reliability provided by additional power sources and the reduction of peak hours demand as the EVs could operate, mitigating it, thus postponing investments in grid expansion. Since V2G-based trades are founded in energy arbitrage, the energy consumed by the DS would not be altered; therefore, the economic gains for the distribution companies are unclear when considering the V2G scenario. In this sense, a different form of compensation must be proposed for utilities with V2G.

Based on the current scenario's overview, one can observe that the main impediments towards modern DS's materialization in Brazil, at least E2G-wise, are: energy trade regulation and technology price. The first topic will certainly be resolved in the next few years; as for the technology price, there is a natural tendency to decrease costs, besides the development of R&D projects and investment in local research which may provide cheaper products. Another point to be considered is the standardization of equipment and communication protocols used in each element involved in the energy trade so the energy and data flows can be adequately interpreted. In this sense, a strategic business model may address the integration of every device-related to V2G and intelligent systems (such as machine learning and IoT). In this sense, it would be possible to forecast the grid's loading (based on historical data or real-time communication) and then adjust the EVs charging/discharging dynamics for each user's consumption profile.

Future of V2G in Brazil

Regulation

Due to the necessity of reducing GHG emissions, numerous incentives to EVs are expected in the next few years, including the revision of REN 687/2015 to include V2G and modify the energy credit policy. It is important to stress that, in a scenario wherein the energy price is constant throughout the day, it would be impossible to profit from energy arbitrage, *i.e.*, V2G-based trades would not provide financial gains to its owner.

Nonetheless, CCEE has announced that by 2026 there will be no power demand/injection threshold for participating in energy auctions. In this sense, EV owners will profit from selling energy in the short-term electricity market.

Business Models

It is important to highlight that profiting from a V2G interaction is far more complex than installing a DER. A residential level generator (*e.g.*, photovoltaic solar panels) is not able to control how much power neither when to inject power into the system. In this sense, the user does not need to determine an action plan for buying and selling energy. However, when connected to the grid, the EV operates as an ESS; hence, an operation plan must be created to profit from the energy price's oscillations throughout the day. In this sense, even though the EV owner may participate in auctions or sell energy to the distribution utility, it may be too complex or time-demanding, discouraging the users from doing so. In this context, the proposal of EV aggregators is a pertinent business model. The aggregator would be responsible for grouping several V2G-enabled EVs and determining their operation through the day (or a period defined by the EV owner). The aggregator trades in the electricity market to maximize the gains obtained from energy arbitrage and share the profit between the EV owners based on their hourly participation [51-52].

Noteworthy, an aggregator not necessarily has a long-term contract with the EV owners. Instead, it may be a free parking lot for V2G-enabled EVs, and the owners must inform how long the car will be parked and allow the parking lot owner (aggregator) to use the EV's battery meanwhile. The aggregator must guarantee that the EV's state of charge will be the same as before and may profit from energy arbitrage while the EV owner goes to work, for instance.

Finally, the existence of a scenario wherein EV aggregators are financially feasible business models depends on the available EV fleet, as energy arbitrage using a third-party-owned asset may provide a small profit margin, and the aggregator would have to invest in volume. In this sense, it is fundamental to consider the EV fleet growth projections for the future. The study presented in [52] provides a projection for the Brazilian electric mobility evolution for the next nine years. The authors even address how COVID-19 may affect investments in the sector. According to the study, the growth factor of the EV fleet (including light and heavy vehicles) until 2023 may be small, characterizing a moderate-conservator scenario (e.g., the participation of plug-in light vehicles in new salles should be within the range of 0,02% and 0,4%). Nonetheless, from 2023 onwards, the number of new EVs should increase faster, and, by 2030, the participation of EVs in new sales may reach 20%.

CONCLUSION

In this paper, we presented an overview of the smart grids and electric mobility and electric mobility in the Brazilian context, including a review of the Brazilian R&D projects in the subject. As we have shown, most initiatives are recent and need further investigation.

In the last part, we explored the current and future scenarios regarding regulation and business models to adopt the V2G technology. Projects that leverage this technology may be promising in the short to medium term and capable of corroborating with pollution reduction goals and other benefits.

Future work would involve updating this paper with the constant changes in this scenario, ongoing and new projects related to electric vehicles, microgrids, and the V2G applications.

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