

Use of Ancillary Services and Renewable Energy in Electric Vehicles: An Integrative Literature Review for Application in Brazil

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Abstract — This paper presents a comprehensive review of studies that examine the interoperation of ancillary services, renewable energy sources, and electric vehicles (EVs). The integrated literature search method was used to search the databases IEEE Xplore, ScienceDirect, and Web of Science, while to manage references and exclude studies not related to the central topic, the EndNote reference manager and the Ryvan web application were used. Four of the seven articles initially identified were closely aligned with the study's objective. Overall, the review highlights the potential synergies between ancillary services, renewables, and electric vehicles. According to the review, the integration of these elements is a promising strategy for improving grid power quality. The positive impact on voltage and frequency control during EV charging is particularly highlighted.

Keywords—Ancillary services, renewable energy resources, electric vehicles, Brazil, energy flexibility

I. INTRODUCTION

The increase in energy demand and the worldwide pressure to decarbonize clean electricity generation has led to new international relations focusing on sustainable and efficient development. The Conference of the Parties (COP27), held in 2022, focused on the global climate challenge with plans for minimizing greenhouse gas (GHG) emissions, which are still very evident in Brazil since they are mainly related to deforestation and the use of polluting sources in energy generation [1]. As a result, Brazil has been standing out on the global stage when it comes to the potential for electricity generation from Renewable Energy Sources (RES).

The Brazilian electricity matrix has become increasingly sustainable with the use of renewable energy sources such as geothermal, ocean, biomass, hydro, wind, and solar [2,3]; the principle of which contributes to minimizing the release of gases such as carbon monoxide (CO₂). According to the National Energy Balance (BEN) for 2022, this matrix is composed of 56.8% hydroelectric generation, 8.2% biomass, 10.6% wind, 2.5% solar, 12.8% natural gas, 3% oil

derivatives, 3.9% coal and derivatives, and 2.2% nuclear. When compared to the global electricity matrix, Brazil's use of renewable sources is 82.9%, compared to only 28.6% globally. Among the factors that contribute to this are the abundance of rivers with the potential to generate hydroelectric power, and favorable climatic conditions with wind and solar radiation for the generation of wind and solar power, respectively [3].

With the modernization of the electricity sector and the creation of a smart grid, distributed generation (DG) is becoming increasingly important in Brazil's energy sector, particularly in connection with the use of solar and wind energy. In DG, electricity is produced by prosumers and can be stored or distributed in the local electricity grid [4].

Advances in renewable energy are aimed at minimizing CO₂ emissions, thus opening space for other sustainable modalities. It has been observed that electromobility has gained the spotlight of modern development, especially in electric vehicles. A global and Brazilian trend and reality is the use of this mode of transportation to mitigate greenhouse gas emissions and promote the use of renewable generation sources to charge these electric vehicles (EVs) [5] [6]. Electric vehicles are charged at electric vehicle charging stations, most of which are powered by renewable energy such as photovoltaics. With the modernization of society, a promising new energy industry is emerging that allows us to use energy from the grid to charge vehicles and power homes [5] [6].

Through the use of vehicle-to-grid (V2G) technology, electric vehicles have the potential to provide energy to homes and buildings that are part of a local energy distribution system. This support becomes essential in case of unforeseen events on the grid, as this technology can be used to help temporarily. Another advantage of this technology relates to the improvement of the quality of the distribution and generation grid, due to the possibility of providing additional services to minimize harmonic oscillations in the grid, reduce peak loads, regulate energy, reduce CO₂, etc. [7]. This new instrument could transform the energy market through the

introduction of stationary wireless charging techniques for vehicles and clean energy with V2G using peer-to-peer on the basis of the blockchain, supported by the use of ancillary services [7].

Ancillary services are defined as an aggregation of services necessary for the operation of the electrical system. They aim to meet certain criteria such as network security, balance between energy generation and consumption, balance and quality, and monitoring and correction of nominal voltage and frequency levels. For this reason, a new scenario is being created in the transition of the Brazilian electricity sector to a new market, since these services help to promote the system power quality, driven by the growth in the deployment of renewable energies (wind and solar/photovoltaic) in Brazil, opening the way for the entry of new technologies in the country [8]. These services are classified as primary frequency control, secondary frequency control, operational power dispatch, reactive support, voltage control, self-regulation, and special protection [9].

Thus, a new panorama for the Brazilian electricity sector is created by the implementation of ancillary services. The products generated in excess can cause disturbances in the electric network due to the injection of harmonics into the electric network, which interferes with the nominal frequency levels, and consequently affects the network voltage levels, which in some cases can cause undervoltage and overvoltage [8]. However, when used in electric vehicles, the stored energy can mitigate the adverse effects, especially during peak load periods, EV digital governors may provide frequency regulation through energy injection into the grid [10].

Therefore, the research questions in this study aim to identify the main studies and applications of ancillary services with renewable energy sources used in EVs, based on an integrative review of the literature on the international and national scene in publications that have explored the application of modalities in the electricity sector.

II. METHODOLOGY

This paper has adopted the methodology of an integrative literature review with the aim of collecting, synthesizing, and generating new approaches to the subject, based on the large number of studies previously proposed. This review perspective is widely used in research related to agricultural sciences [11] and health [12], but it is not yet widespread in the field of electrical engineering. One of the motivations for developing this line of research is that it will make it possible to analyze issues related to ancillary services using renewable energy sources to charge electric vehicles, highlighting the subject's understanding, possible gaps, and problems, allowing lines of research to be mapped out in the field of electrical engineering.

The integrative methodology is divided into 6 stages: 1) elaboration of the research problem question; 2) defining the research databases and the inclusion and exclusion criteria; 3) presentation of the selected studies in tables, with data collection, data extraction and selection of texts with similar characteristics; 4) critical analysis phase of the included studies, highlighting the characteristics of each publication and the differences and conflicts between them; 5) results discussion; and 6) synthesis of the integrative review in a clear and complete way with a critical view and presentation of the results [13, 14, 15, 16, 17].

For this study, the following databases were used: IEEEExplore, ScienceDirect, and Web of Science. The search procedure used the English language descriptors: ancillary services, renewable energy resources, and electric vehicles, together with the Boolean operator AND, adapted according to the search specificity of each database, as detailed in Table 1.

The search was carried out between March and April 2023, and the inclusion criteria were as follows: articles in Portuguese and English language, published between January 2018 and April 2023. In this way, the search in the databases allowed access to 21 articles (IEEE Xplore n=6; ScienceDirect n=3; Web of Science n=12;) of which, for a better analysis, exclusion criteria were adopted in order to adapt the knowledge found to the objective of this review. Duplicate articles were excluded with the help of the online reference manager EndNote Basic, then the web application Rryan was used to read the titles and abstracts of the articles to check the eligibility criteria for this review, and for the studies classified as eligible, the full text was analyzed.

TABLE 1. DATA BASE SEARCH STRATEGY

Database	Search Method	Identified Studies
IEEEExplore	"Ancillary Services*" AND "renewable energy resources*" AND "electric vehicles*" [All Metadata] Filters: from 2018-2023; articles	Six (6) studies
ScienceDirect	"Ancillary Services" AND "renewable energy resources" AND "electric vehicles" [Title, abstract, keywords] Filters: from 2018-2023; articles	Three (3) studies
Web of Science	"Ancillary Services*" AND "renewable energy resources*" AND "electric vehicles*" [All topics] Filters: from 2018-2023; articles	Twelve (12) studies

III. RESULTS

The search in the reference manager identified 3 duplicate articles, leaving 18 articles for the next stage of analysis, which was the classification of eligible studies. From this number of articles, titles, and abstracts were selected for reading using Web Rryan. Of these, 11 studies did not meet the main goal of the research, leaving 7 studies, which were read in full, leaving only 4 articles selected eligible for treatment in a relevant way and without tangents on the topic proposed for this integrative review. Fig. 1 presents the flowchart of the methodology proposed based on the PRISMA method [18].

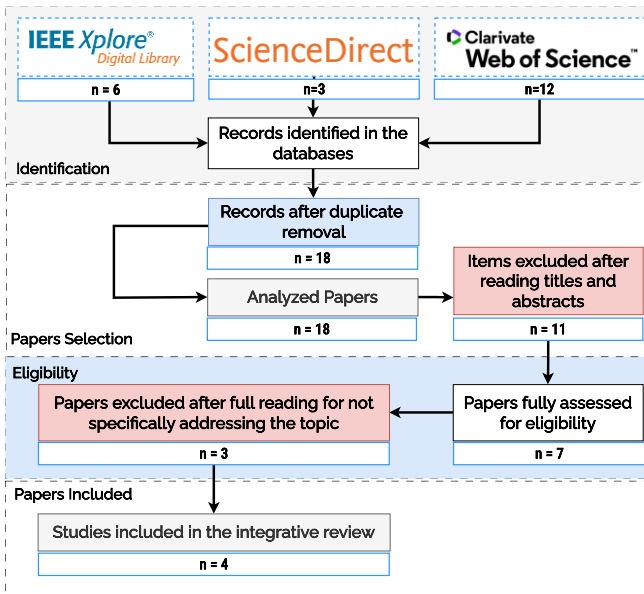


Fig. 1. Flowchart for selecting studies for this integrative review, adapted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model [18].

The papers by the authors M. Latifi, A. Khalili, A. Rastegarnia, and S. Sanei, 2019; S. Sehgal, A. Ganesh and V. K. Kamboj, 2020 and S. M. B. Sadati, J. Moshtagh, M. Shafiekhah, J. P.S. Catalão, 2018 [19] [20] [21], were excluded from the analysis. Therefore, Table 02 summarizes the final sample for the integrative analysis of the studies.

TABLE 2 . FINAL SAMPLE FROM THE INTEGRATIVE REVIEW

Author	Title	Indexed Database
S. Iqbal et al., 2018	"Aggregated Electric Vehicle-to-Grid for Primary Frequency Control in a Microgrid- A Review"	IEEE Explore
H. Nakano et al., 2021	"Aggregation of V2H Systems to Participate in Regulation Mark"	IEEE Explore
K. Sevdari, L. Calearo, P. B. Andersen, M. Marinelli, 2022	"Ancillary services and electric vehicles: An overview from charging clusters and chargers technology perspectives"	ScienceDirect
L. Luo et al., 2020	"Coordinated allocation of distributed generation resources and electric vehicle charging stations in distribution systems with vehicle-to-grid interaction"	ScienceDirect

IV. DISCUSSION

In this section, the results based on the problem statement proposed for this study, and the contribution of the articles in supporting this problem will be examined and discussed.

The article by S. Iqbal et al. 2018 [22] conceptualizes electric vehicles connected to the power grid and analyzes how ancillary services provide benefits to the power system, addressing the efficient and balanced performance of the power system. This work also highlights how V2G has a significant impact on peak power control and load balancing and can be used in frequency regulation. Also, according to the author, V2Gs primarily use renewable energy sources (solar and wind) to maintain ancillary services in frequency

control to improve network performance. Electric vehicles therefore become an attractive option because they offer facilities such as Primary Frequency Control (PFC) due to their ability to reduce active power using digital converters [22].

The paper also highlights that electric vehicles can have a significant impact on the operation of the electricity grid due to their storage capacity and can both act as a source of energy for the grid, known as Grid-to-Vehicle (G2V), in which case the energy stored in the vehicle's batteries is injected into the grid. The use of energy stored in batteries and/or energy from renewable sources by the vehicle to the grid has a drastic impact on the reduction of greenhouse gas emissions. Therefore, these types of arrangements have essential functionality in ancillary services such as grid voltage control, and congestion management, among others [22]. In order to balance the load, EVs help to supply energy at peak times by discharging their batteries to meet local energy demand and may also generate energy through intelligent load control. Another perspective is related to supporting the use of renewable energy sources, as these can be used for different functions, such as storage in electric vehicles, and this surplus production is a factor that does not overload the grid [22]. Therefore, the regulation of voltage and primary frequency, as relevant ancillary services, is a predominant impact factor in the energy market. For example, when voltage levels are low, electric vehicles may stop working, but when voltage levels are high, electric vehicles function normally, but there is still interference in the injection of harmonics into the power distribution system, which in turn interferes with the frequency of the power system [22]. Consequently, frequency regulation aims to keep its levels closer to its nominal value, which would be 50 Hz or 60 Hz, and this happens when the demand for load in the system is greater than the generation, so the frequency levels will rise above the nominal value.

In the opposite case, when generation is greater than load demand, frequency levels will fall below the nominal value, and so the introduction of electric vehicles can help with this storage control between energy consumption and supply [22].

H. Nakano et al. 2021 [23] discuss the architecture of a Home Energy Management System (HEMS) using electric vehicles and hybrid electric vehicles to participate in energy trading through ancillary services such as frequency control, using renewable energy sources [23]. Nakano (2021) mainly focuses on the design of an aggregated system using HEMS with V2H in the energy market. Thus, this aspect aims to provide ancillary services in an aggregated manner with residential generation to minimize charges on energy bills and maximize profits. This is done by implementing a computational mathematical system for multiple homes equipped with HEMS [23].

The review article by K. Sevdari, L. Calearo, P. B. Andersen, M. Marinelli, 2022 [24], also addresses ancillary services with the use of electric vehicles charged from renewable sources, and also analyzes the gaps identified from studies in terms of frequency and service flexibility. It also provides guidance on energy systems with ancillary services and focuses on what ancillary services EVs can provide.

Similarly, S. Iqbal et al, 2018 [22] and Sevdarari 2022 [24] studies discuss the importance of V2G technology in the

attractive energy sector market, considering that this technology can feed and consume from the electricity grid as it has bidirectional chargers, which makes it more cost-effective.

The article by L. Luo et al. 2020 [25] deals with the implementation of electric vehicles connected to a power distribution system for the control of ancillary services in voltage regulation. The author mentions that there are currently major obstacles to the implementation of distributed generation and proposes a solution with an optimization model for the installation of electric vehicle charging stations and the use of this generation. In this model, L. Luo et al, 2020 used a convex mathematical model linearized by Distflow equations, through tests carried out on 31 electric bus distribution systems in China. This is one of the reasons why the author mentions that much of the research carried out is related to operational problems such as the ancillary services market, the economic system, and tariffs.

According to the study, the use of renewable PV-based EV2G systems will improve system integration capabilities, reduce SOD, and increase the economic viability of EV2G distributed generation resources. In light of the contributions to the discussion, there is a need for a general reflection on these approaches. Ancillary services are extremely important when it comes to their use in new market models, such as their use in connection with renewable energy sources and electric vehicles. Renewable energy systems combined with electric vehicles can have many advantages in terms of controlling the energy quality of the system, especially in meeting the future energy needs of the energy sector. However, no scientific papers were found in the indexed databases that were limited to this approach. With this new configuration of Brazil's electricity matrix and the global trend toward decarbonization, Brazil is poised to enter a new energy trading market in which residential consumers can participate significantly in the generation, transmission, and control of energy.

The topics proposed for this review: ancillary services, renewable energy, and electric vehicles were noted in the discussion of articles by S. Iqbal et al. 2018, H. Nakano et al. 2021, K. Sevdari, L. Calearo, P.B. Andersen, M. Marinelli, 2022, L. Luo et al. 2020. However, the lack of more studies that address these topics together has been the main shortcoming of the review.

Therefore, there is a need to develop studies on the relationship between ancillary services and renewable energy correlated with the use of electric vehicles. In addition, the development of economic systems to model the feasibility of implementing such a system, the creation of an intelligent communication model, the marketing of energy, and also the implementation of blockchain technology to ensure the security of purchase and sale transactions; basically, the development of pilot projects to serve as a model for future changes in Brazil's electricity sector.

Finally, this integrative literature review achieved its objective of analyzing the main studies related to ancillary services, renewable energy, and electric vehicles, which were fully analyzed according to the exclusion and inclusion criteria. One of the weaknesses of the articles was that there was a lack of complete and incisive coverage of the topics proposed, including a lack of content.

The implementation of an integrated methodology for the economic analysis of the impact of electric vehicles with

renewable electricity generation, the study of blockchain technology as a trend for the commercialization of electricity from renewable sources, and the analysis of the implementation of ancillary services for electricity systems with renewable energy sources in order to achieve an economically balanced energy market are some of the possible topics that could be developed as a research agenda to give more ground to this topic. In order to fill this gap in the coming years, research should be carried out focusing on the Brazilian energy system, especially in the development of studies aimed at an intelligent electricity system for the market and for Brazilians, due to its great potential.

V. CONCLUSION

This paper presents an integrative literature review of publications relating ancillary services and renewable energy sources to the use of electric vehicles. In this review, the articles were screened and analyzed using the proposed methodological research procedures. In this way, only studies with relevance to the topic were the subject of discussion in this work. The limitations of the study are related to the delimitation of the topics and the eligibility criteria. Only a few studies were found that dealt in depth with the intended topic, and none of them were related to case studies or to the implementation in Brazil.

Nevertheless, in the studies reviewed, certain links have been identified between the use of electric vehicles and the impact on ancillary services based on the use of renewable energy. This perspective opens a new scenario for the analysis of the energy market with distributed generation. It also allows to increase the efficiency of the electricity grid with frequency and voltage control, which are essential factors for the quality of the electricity. Therefore, the link between the use of renewable energy sources, ancillary services, and electric vehicles not only contributes to the improvement of ancillary services but also promotes the use of renewable energy sources for sustainable development. Finally, this review model has been able to identify gaps in previous related research that can be mitigated based on the development of new studies and projects to provide scientific society with an accurate analysis.

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