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CARRERA DE ELECTRICIDAD

COMPORTAMIENTO DEL SISTEMA DE DISTRIBUCIÓN EN BAJO VOLTAJE FRENTE A LA CARGA DE VEHÍCULOS ELÉCTRICOS EN ZONAS RESIDENCIALES

Trabajo de titulación previo a la obtención del título de Ingeniero Eléctrico

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Cuenca - Ecuador
2024

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RESUMEN

Los vehículos eléctricos [VE] ganan terreno rápidamente gracias a su eficiencia energética y su menor impacto ambiental. Aunque esta transición hacia una movilidad más sostenible es alentadora desde el punto de vista ecológico, también plantea retos para la infraestructura eléctrica, especialmente en las zonas residenciales. Este estudio evalúa cómo afecta el VE a las redes eléctricas y propone soluciones. Una de estas soluciones es la carga inteligente, que utiliza tecnologías como Vehicle-to-Grid (V2G) y algoritmos de agrupación para gestionar mejor la carga de los vehículos eléctricos. V2G permite a los vehículos eléctricos no sólo tomar energía de la red, sino también devolverla cuando sea necesario, ayudando así a equilibrar la demanda de energía al aliviar la carga del transformador en un 40%. Los algoritmos de clustering agrupan los vehículos con patrones de carga similares, evitando los picos que podrían sobrecargar la red. Esta estrategia pretende facilitar la integración de los vehículos eléctricos en el sistema eléctrico, asegurando una mejora mínima del 0,20% en los perfiles de voltaje, garantizando así una transición suave hacia una movilidad más sostenible.

ABSTRACT

Electric vehicles [EV] quickly gain ground due to their energy efficiency and lower environmental impact. Although this transition to more sustainable mobility is encouraging from an ecological point of view, it also presents challenges for electrical infrastructure, especially in residential areas. This study evaluated how EV affects power grids and proposed solutions. One of these solutions is smart charging, which uses technologies such as Vehicle-to-Grid (V2G) and clustering algorithms to manage electric vehicle charging better. V2G allows electric vehicles to not only take power from the grid but also return it when needed, thus helping to balance power demand by easing the load on the generator by 40%. Clustering algorithms group vehicles with similar charging patterns, avoiding peaks that could overload the network. This strategy aims to make it easier for electric vehicles to be integrated into the electrical system, ensuring a minimum improvement of 0.20% in voltage profiles, thus guaranteeing a smooth transition towards more sustainable mobility.

PALABRAS CLAVES TEMÁTICAS

Distributed resources.

K-means.

Smart recharge.

Vehicle to grid.

Voltage profile.

Comportamiento del sistema de distribución en bajo voltaje frente a la carga de vehículos eléctricos en zonas residenciales

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ABSTRACT

Electric vehicles [EV] quickly gain ground due to their energy efficiency and lower environmental impact. Although this transition to more sustainable mobility is encouraging from an ecological point of view, it also presents challenges for electrical infrastructure, especially in residential areas. This study evaluated how EV affect power grids and proposed solutions. One of these solutions is smart charging, which uses technologies such as Vehicle-to-Grid (V2G) and clustering algorithms to manage electric vehicle charging better. V2G allows electric vehicles to not only take power from the grid but also return it when needed, thus helping to balance power demand by easing the load on the generator by 40%.Clustering algorithms group vehicles with similar charging patterns, avoiding peaks that could overload the network. This strategy aims to make it easier for electric vehicles to be integrated into the electrical system, ensuring a minimum improvement of 0.20% in voltage profiles, thus guaranteeing a smooth transition towards more sustainable mobility.

1. Introduction

Electric vehicles [EV] are developing rapidly due to their energy efficiency and reduced environmental impact. Technological advances have improved the efficiency and range of these vehicles and there is a growing interest in their use around the world. Many countries are imposing standards that will soon lead to the mass introduction of electric cars into the grid, particularly in the residential sector [2]. This shift towards more sustainable mobility, while encouraging from an environmental perspective, poses new challenges concerning the capacity and resilience of the electric infrastructure, especially in residential environments.

The rise of electric vehicles in residential areas goes beyond the mere adoption of new means of transport. However, these vehicles can potentially transform how we live and travel, and it is essential to understand the implications for the design of sustainable cities and the quality of life of residents [5]. This adoption not only offers a solution to the environmental challenges associated with fossil fuels but also raises new questions about the ability of the residential electric infrastructure to support this mobility revolution efficiently.

Urban and suburban areas are experiencing a significant change in the mobility of their inhabitants, and electric vehicles play a vital role in this transformation; therefore, as more homeowners opt for electric vehicles, positive and negative impacts are generated in residential areas [8].

As homes become sites for EV charging, we must thoroughly evaluate the resulting impact of the charging process on residential electric systems. EV charging adds a new dimension to residential energy demand as homeowners seek to recharge their vehicles in the comfort of their homes.

One potential problem that arises is the penetration of massive electric vehicle charging, which will generate problems such as voltage variations, harmonics in the grid, and transformer overloads, having negative consequences for grid stability and power quality in these environments [10].

Therefore, it is essential to analyze and understand the behavior of EV chargers currently available on the market, either by vehicle type or recharging speed that can support it. Once all these parameters have been studied, possible challenges and solutions can be identified to ensure the safety and reliability of the electrical supply, especially during peak hours, when people typically arrive home and connect their vehicles.

The following article will explore the implications of this additional load and analyze solutions and recommendations such as:

- Smart chargers
- Distributed energy

This study will not only yield data on the technical challenges associated with low voltage during electric vehicle charging. However, it will also provide critical information for planning and developing more innovative and adaptive electric infrastructures. Ultimately, by addressing these challenges, we advance our scientific understanding and contribute to the promotion of sustainable electric mobility that benefits both people and the planet we share [18]. By understanding the relationship between EV charging and residential voltage, we can optimize electric infrastructure to ensure a smooth transition to electric mobility, maximizing environmental benefits and improving the quality of life in urban communities.

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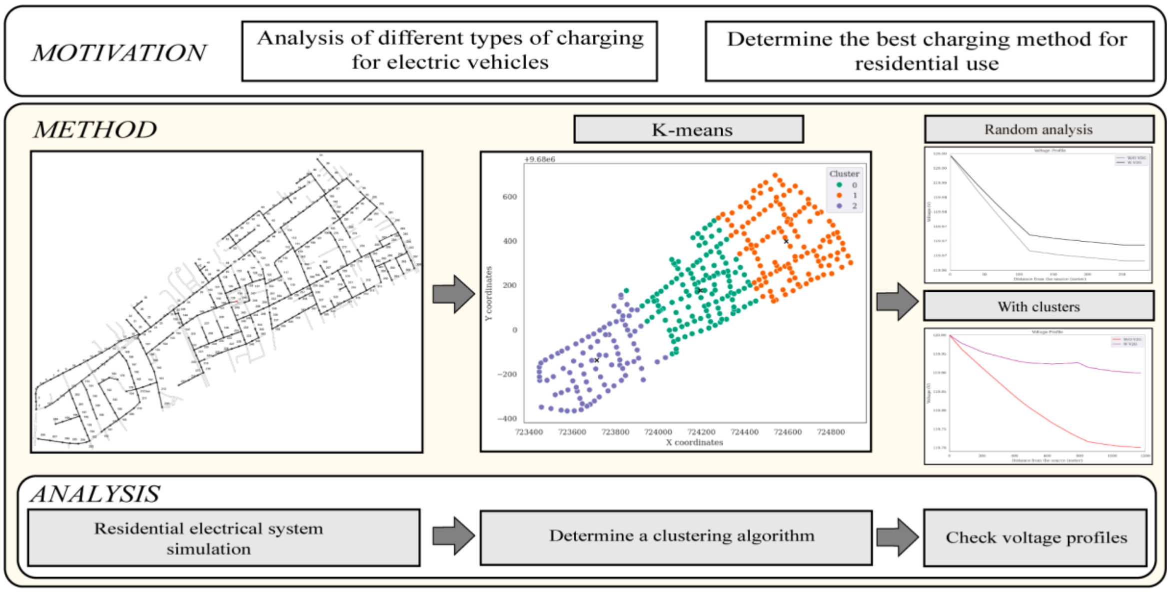

Figure 1: Concept figure.

Table 1
Nomenclature & Description

Nomenclature	Description
EV	Electric vehicle
EVPR	Electric Vehicle Routing Problem
GHGs	Greenhouse gases
HEMSs	Home Energy Management System
kVA	Kilo Volts Amperes
kV	Kilo Volts
MST	Minimum spanning tree
f(M)	Manhattan algorithm
PEV	Plug-in electric vehicle
S	Rated power
V2G	Vehicle-to-grid
VP	Voltage Profile
ΔV	Voltage drop

2. Related Works

Different methodologies are proposed to achieve charging control and management for electric vehicles.

The author [2] simulates a residential distribution system with unplanned loads and creates an intelligent management algorithm based on a selection scheme in which the EV owner's preferred charging schedules are taken into account, as long as, in [11] they apply the same principle but focus on a parking center in work areas, thus studying the daily cost and the average peak-to-average ratio to develop strategies to reduce these values.

The concept of co-funded charging based on optimal charging time [OSCT] is created, for which [16] uses time-of-use charging schemes in which vehicle departure time is taken into account and night charging is projected using evolutionary binary programming.

[20] presents the Electric Vehicle Routing Problem [EVRP] as an alternative to minimize energy consumption. It proposes effective solutions using algorithms based on ant colonies. It suggests using energy consumption minimization instead of distance traveled minimization as an objective function, which can greatly benefit vehicle efficiency.

Taking into account the above mentioned, load profiles are created that represent a daily graph on energy consumption and, in this way, [7] makes a comparison in a 10-year horizon in which it analyzes the behavior of the recharge in 3 different scenarios, which are direct, valley hours, and controlled. The result is that controlled recharge is the best option.

On the other hand, [9] creates an algorithm that achieves filling in valley areas, thus flattening the load during the night; the problem it formulates has an objective function that is limited to restrictions, is a decentralized control scheme, in this way, it is achieved that all chargers update their data to perform new calculations to schedule a recharge through in-

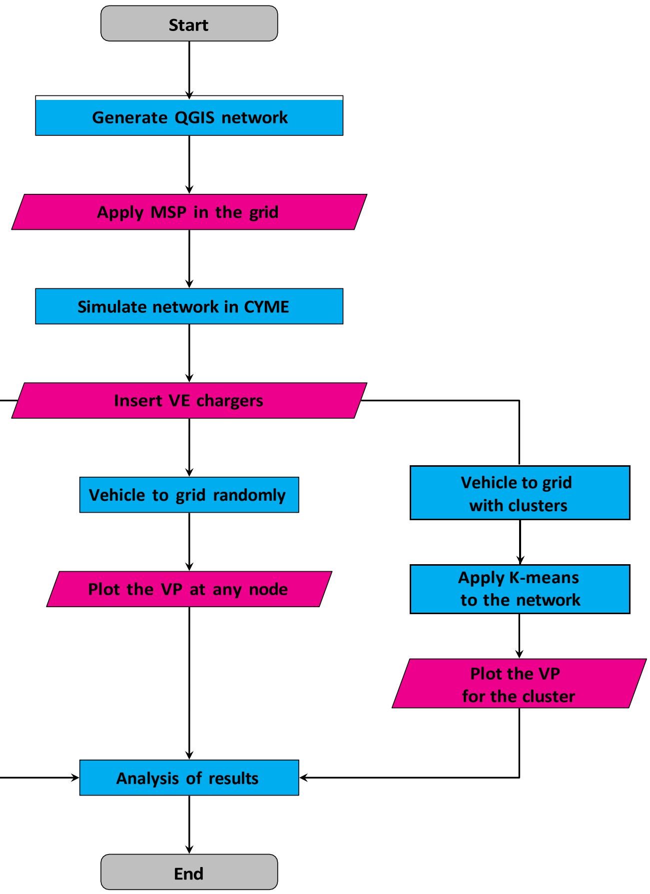

Figure 2: Flow Diagram & Authors.

ternal communication between them. The algorithm can be applied to vehicle charging and energy-cost minimization for other network levels.

To avoid overloads in the network produced by uncoordinated loads, the author [1] focuses on minimizing the cost of recharging based on the price of electricity by reducing rates in valley hours; for this to happen, it is necessary to use intelligent chargers that collect information on the state of recharge of the vehicle, On the other hand, the study of [17] states that the solution to extend the life of the batteries and get a lower load of the network is intelligent driving, explains that this is possible thanks to the planning of routes in which daily trips are scheduled to avoid problems of autonomy and thus prevent the complete recharge of the vehicle.

Another study supports the use of this type of charger.[3] simulates a large-scale implementation projected for the year 2030 and concludes that, with a penetration of more than 75%, it is possible to flatten the charging curve by taking advantage of charging during off-peak hours. Furthermore, he points out that the only way to achieve this objective is through rigorous requirements in installing these devices to ensure their correct operation.

In [14], charge control methods were used in which EV batteries are used as distributed energy storage systems to maintain voltages, as this is possible through the use of fuzzy logic controllers [12] and an algorithm was proposed to optimally schedule the EV loads.

It also promotes the adoption of plug-in electric vehicles [V2G] by implementing intelligent meters; the author [5] analyzes the behavior of the grid, resulting in a more significant smoothing at the peak load of the grid. However, according to Moon, the availability analysis for domestic charging options has not been sufficiently studied.

To address voltage imbalance problems caused by the use of distributed resources and vehicle chargers, [18] proposes the implementation of Vehicle-to-Grid [V2G] technology. His proposal is based on an algorithm that analyzes the lower and upper ranges of voltage levels to stabilize the power grid within the allowed limits. The efficiency of this strategy is directly related to the type of plug-in vehicle used and its battery capacity.

Battery care for this type of technology is vitally important, which is why [13] proposes a home energy management system (HEMS) that focuses on the long-term use of the plug-in vehicle in the face of uncertainty of other technologies such as photovoltaics.

Distributed energy systems are currently gaining popularity in residential areas, which will also affect the quality of the voltage being generated. It is also necessary to analyze the response to demand, which aims to allocate existing resources so as not to need more generation; this is possible due to the Hungarian algorithm proposed by [4] in his study,

Table 2
Summary of articles related to electric vehicle recharging

		Parameters considered				Thematic			
Author, year	objectives	Schedule	Coordinated recharge	Minimal cost	Peak loads	Methodology	V2G	Optimization	Smart Charging
Badugu J, 2019 [2]	Recharging methods for electric vehicles	✠	✠	✠	-	✠	-	✠	-
Ayyadi S, 2019 [1]	Minimization of recharge cost	✠	-	✠	✠	-	-	✠	✠
Mehta R, 2018 [11]	Smart Charging Strategies	-	✠	✠	-	-	✠	✠	-
Usman M, 2021 [16]	Coordinated Charging Scheduling	✠	✠	✠	-	✠	-	-	-
Gerboni R, 2021 [5]	Different recharge scenarios	-	✠	✠	✠	✠	-	✠	-
Vatanparvar K, 2017 [17]	Optimized Charge and Drive Management	✠	-	-	✠	-	✠	-	✠
Mhaisen N, 2020 [12]	Real-Time Scheduling for Ev's	✠	-	-	✠	-	✠	✠	✠
Present work	Low voltage analysis for residential EVs	-	✠	✠	✠	✠	✠	✠	✠

the author suggests different scenarios such as summer or winter, resulting in the maximum use of non-conventional energy at peak hours and getting the most out of the use of distributed resources.

In the study of [19], an algorithm is created that regulates the high penetration of photovoltaic resources [PV] with a control scheme formed by plug-in electric vehicles [PEV], which, thanks to its intelligent chargers, allows the maximum utilization of the storage capacity available in the cars.

This type of vehicle, according to [6], can contribute as a distributed energy resource; the author proposes a methodology for the coordinated allocation of wind farms [WF] to minimize the total costs of purchased energy resulting in the flexibility of commercial, residential and industrial loads.

Finally, [15] thoroughly considered the gas emissions generated by increasing energy production to meet the demand for electric vehicles. In this context, he proposed a heuristic algorithm whose main function is to minimize greenhouse gas emissions [GHG] while complying with constraints from the power grid. This approach implies that people should plan their trips to optimize the use of chargers, thus avoiding grid saturation.

This work presents a summarized analysis in Figure 1, starting from a selected scenario in an urban environment with residential use. An algorithm was applied to group the data and obtain results that compare the presence of electric vehicles in the system, both without control and with smart chargers. The study evaluates the impact of these vehicles on the electrical grid and possible solutions. A flow diagram 2 can help you comprehend the steps taken to get the desired outcomes. This diagram shows the case studies that were analyzed and the research carried out in each of them.

3. Problem Formulation and Methodology

The process of charging an electric car is a multifaceted and complex area of research. We will be concentrating on the difficulties that come with incorporating this technology into our houses in this study; thus, it is essential that we run simulations to investigate workable solutions that would optimize the system as a whole.

We begin the analysis using the QGIS program, which allows us to create a study area with georeferenced data. This strengthens the project by guaranteeing its fidelity to the real environment. The scenario is shown in figure 3 and has been designed with 345 nodes that simulate light poles. These nodes will later be used to place transformers according to the required demand. The distances between nodes are determined using the Manhattan algorithm, as expressed in Equation 1.

$$f(M) = |(x_1 - x_2)| + |(y_1 - y_2)| \tag{1}$$

A Minimum Spanning Tree [MST] is constructed on the basis of these distances to establish optimal routes and avoid a system with multiple connections. Once the MST is applied, the substation is centralized by calculating the average of its coordinates, and the transformers will be located based on the number of projected users, in this case, 79 load points.

From this point on, the CYME program simulates the low-voltage network. The program is fed with data from transformers typically located on the streets, and a point load is introduced to simulate the regular consumption of an urban area. A quick representation of the system is shown in Figure 4.

The charging points have been configured so that they do not exceed 50 % of the transformer capacity with the inten-

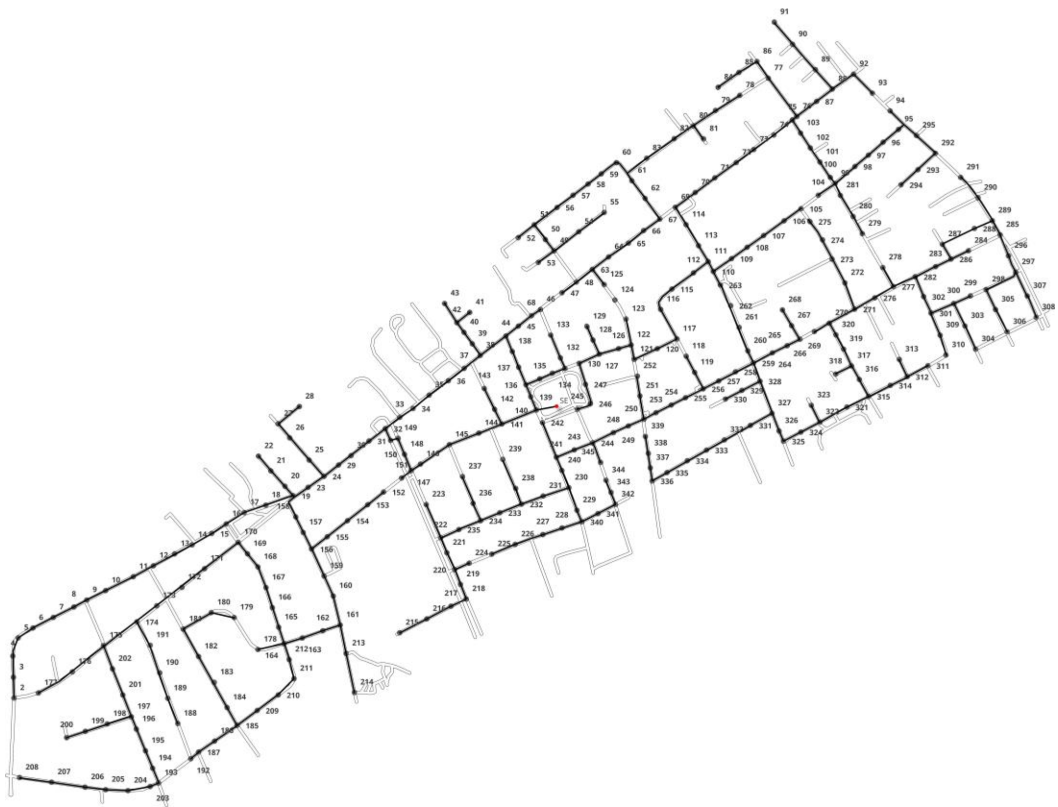

Figure 3: Scenario.

Table 3
System characteristics in normal staten

S/E Capacity	8 MVA
Total Load	
Real Power	6.136 MW
Reactive Power	0.143 MVAR
Apparent Power	6.137 MVA
Load Used	
Real Power	6.124 MW
Reactive Power	0.153 MVAR
Apparent Power	6.125 MVA
Total losses	0.169 MVA
Max ΔV	1.20%
Length	9650.5 m

tion that electric vehicle chargers can later be implemented. In addition, an alert system has been established that is activated when the load exceeds 80%, indicating the proximity of an overload. This is because operating a transformer at maximum capacity increases the risk of failure, shortens its useful life, and generates instabilities in the electrical grid.

The proposed case studies are carried out once the system is configured according to the parameters mentioned above. The uncoordinated reloading scenario reveals highly aggressive behavior. An environment is simulated in which all users connect their vehicles to the network without control, particularly during the night hours. At this time, users tend to return home to recharge their cars. 11 kW power is assigned to load points at random, causing an overload in specific transformers that were not previously planned to cope with this sudden connection.

To mitigate overloads generated by uncoordinated charging of electric vehicles, the implementation of distributed resources that contribute to the electrical system is proposed without modifying the existing infrastructure.

Table 4
Study cases

Case	Analysis type	Node
Uncoordinated recharge	Transformer load	60
Vehicle to grid randomly	Voltage profile	99
Vehicle to grid with K-Means	Voltage profile	147 - 215 -376

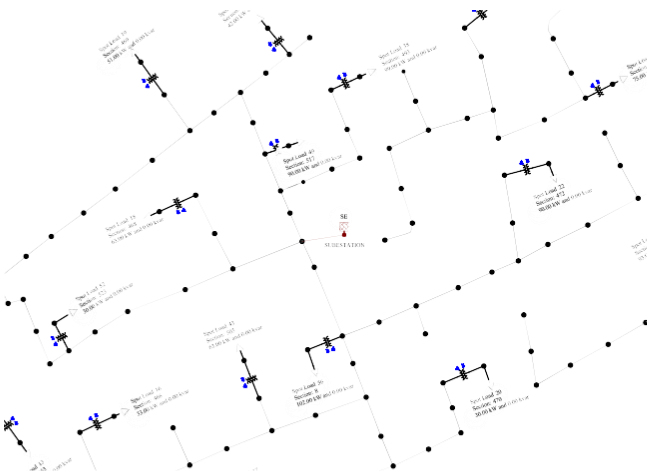

Figure 4: Short representation in the electrical distribution network & CYME.

EV are excellent energy accumulators due to the vast capacities of their batteries. They can play a critical role as resources for strengthening the electrical grid. When the user gets home and connects his vehicle to the grid, it takes advantage of the excess energy from its battery to relieve the load on the transformer. Smart chargers allow you to automatically detect when the vehicle can no longer contribute more and wait until hours of lower demand to start charging. In this way, the user benefits by integrating their truck into the network. The electricity company will compensate for this contribution by offering discounts on the electricity bill.

Vehicle-to-grid technology [V2G] allows electric vehicles [EV] to receive power from the electrical grid to charge their batteries and return power to the grid when necessary.

To simulate the following two study cases, generating units that simulate the V2G system, such as a synchronous motor, will be used. The focus will be on analyzing the behavior of the load profiles from the charging point to the farthest node in the study area.

The second case study occurs in a random environment where a lesser presence of technology is perceived. In this context, the generating unit is introduced randomly along with its power to evaluate the system's capacity to support the entire network. Here, it is not considered whether it will be necessary to use more units or to group the charging points in different areas. The following case takes into account the parameters mentioned above.

Finally, the third case study concerns the size of the power and the necessary number of generating units. To achieve this, machine learning-based classification algorithms are used to group nodes and obtain an optimal network. K-means is an unsupervised classification algorithm that organizes objects into different groups based on their internal components.

The algorithm is developed in three steps:

1. Initialization: The number of groups is chosen and centroids are established in the data space, selected randomly.

2. Assignment: Each object is assigned to the nearest centroid.

3. Update: The centroid position of each group is updated using the average of the objects' positions as the new centroid position.

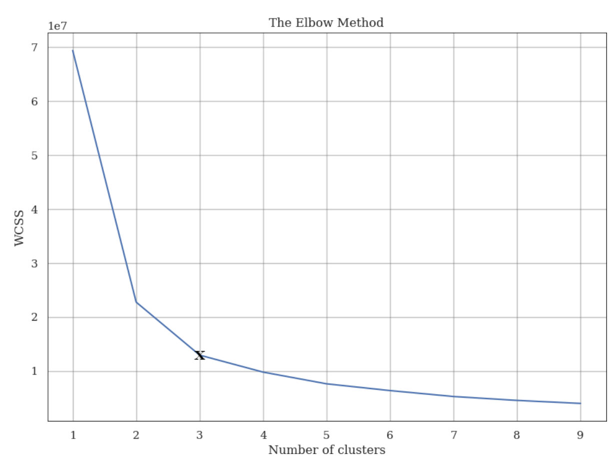

Figure 5: Elbow graph.

Complementing K-Means, the elbow method is necessary. This method involves using the inertia values derived from applying the K-means algorithm with different clusters ranging from 1 to N clusters. Inertia 2 is defined as the sum of the squared distances of each cluster point from its respective centroid.

$$Inertia = \sum_{i=0}^{N} |x_i - \mu|^2 \tag{2}$$

Once the inertia values for different cluster numbers have been calculated, a linear graph is generated that shows the

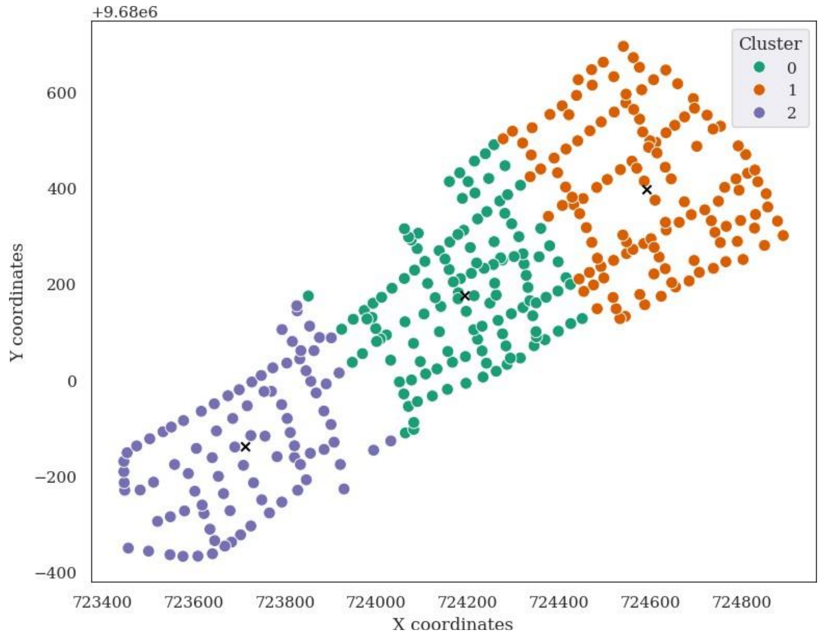

Figure 6: K-means method.

inertia as a function of the number of clusters. This graph is expected to exhibit an abrupt change in the inertia trend, visualized as a line break that resembles an arm bend. This point where the abrupt change in inertia occurs indicates the optimal number of clusters.

For this case study, the elbow was generated; see figure 5, in which it can be seen that 3 clusters are suitable to continue the analysis. The clusters are inserted into the study area and different colors are assigned, as can be seen in figure 6, which helps us identify the groups in which the V2G technology will be injected.

To analyze the voltage profile, it is necessary to calculate the power required for the curve to level out in your results. Therefore, the following equation 3 will be applied, representing the apparent kVA power for a single-phase system.

$$S = (U_{NR} + U_R) \cdot I \cdot 10^{-3} kV\,A \tag{3}$$

With these data, we proceed to enter the results into the software and analyze how the voltage drop is reduced. In figure 7, the profile without V2G technology is illustrated in red, and the results once the vehicles are connected to the network are described in purple.

V2G technology faces significant challenges that limit its widespread adoption. These include the lack of adequate infrastructure for two-way charging and the high costs and technical complexity of retrofitting electric vehicles. Together, these factors make it difficult for V2G to expand commercially. Currently, V2G technology chargers are not commercially available. However, for the purposes of study and comparison of data, its availability is assumed, allowing comparison between three prominent brands. The leading brands in the market have been selected as references, such as Tesla, Chargepoint [Hyundai], and Wallbox (Kia).

4. Analysis of results

Uncoordinated charging exerts the most significant impact on the low-voltage network, with an average overload of 110% in transformers where electric vehicle chargers have been inserted, pushing them to the limit of their capacity and causing failures within the network, the graph comparison between normal use of the transformer and uncoordinated recharging can be seen in 7. Problems such as voltage drop, transformer overload, and electrical service interruption can occur in the system. This leads us to consider solutions, such as the use of distributed resources. This technological approach manages to cover the consumer demand for electric vehicles through the use of V2G technology, providing energy to the network. However, to the date of this article, V2G chargers are not commercially available.

A first analysis was carried out using this technology in a random location, and the results showed a minimal improvement compared to the investment required. In graph 8, you can see the load profile at node 99, which reflects an improvement of almost 0.001%. This makes it unfeasible to operate the system without any control. It is crucial to consider that more power is required to obtain better results, which led us to consider the application of the K-Means algorithm.

From this point on, the system landscape has improved significantly, thanks to the implementation of the algorithm that divides the system into three parts and uses centroids to represent the implementation of V2G technology. Furthermore, the power has been calculated according to the voltage

Table 5
Uncoordinated recharge

Equip No.	Cap Nom (kVA)	Total Power (kW)	Total Power (kvar)	Total Power (kVA)	Loading (%)
9	75.00	68	3	68	112.0
36	150.00	126	5	126	103.5
37	150.00	123	5	123	101.0
60	100.00	83	3	83	118.5
62	100.00	83	3	83	118.5

Table 6
Vehicle to grid randomly

Technology	Source Node	Source Voltage (V)	Study Node	Study Voltage (V)	ΔV
W/O V2G	0	120	99	119.698	0.25%
W V2G	0	120	99	119.812	0.16%

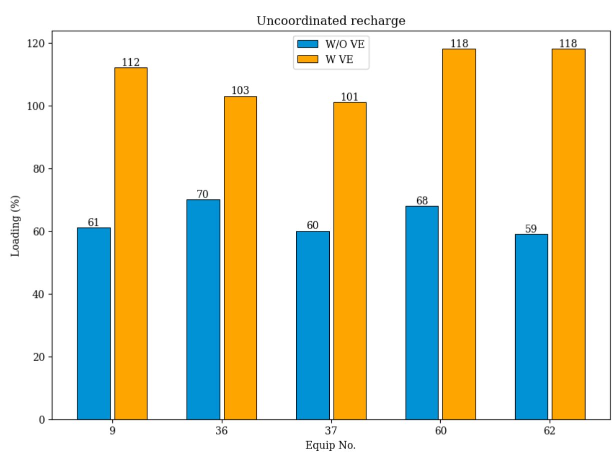

Figure 7: Transformer load data.

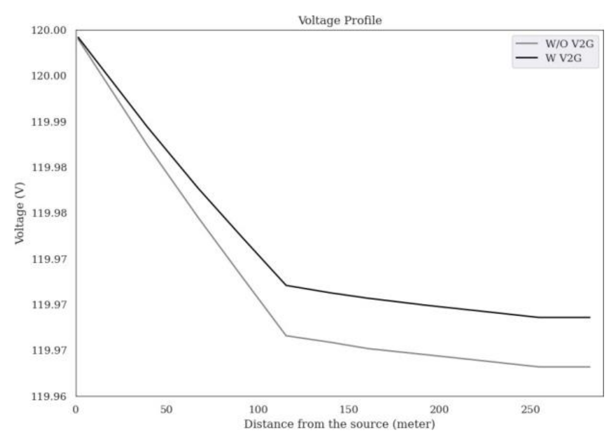

Figure 8: Load profile in node 99.

drop and the current necessary to supply the network. The result of the second cluster can be seen in graph 9, with an improvement of 0.20%. Although it may not seem like much, it is essential to remember that the simulated network is relatively small compared to the networks of large metropolises. This means that the model is scalable and can expand and improve the results.

Taking the above into account, we can see that several problems that could initially have led to the collapse of the network are solved. One of the main ones was the transformer overload due to uncoordinated recharging. However, by having vehicles contribute to the grid, the transformer load is reduced, the voltage profile is improved, and the charger is only used off-peak hours.

This reduces the voltage drop, which is mostly determined by the battery's capacity to provide the grid with varying amounts of energy.

A comparative study has been conducted between different brands that are available in the home market to support the analysis. Given their comparable costs and power outputs, the three brands considered appear to be good choices for usage in a house with a single-phase network. Figure 10 presents the results graphically, showing ChargePoint as the winner of the comparison. The results start at node 192, where the various chargers were initially installed. ChargePoint's maximum charging capacity is notable not just for its independence from vehicle manufacturers but also for its adaptability to new vehicle models, eliminating the need to update the charger.

In second place is Tesla, a commercial leader in the electric vehicle market, although it is suggested that the company could benefit from greater openness to competition. Finally, Wallbox offers lower-power chargers within the type 2 category, but its catalog is broader than those of the above-mentioned brands.

The evidence in these results suggests that EV manufacturers will be eager to bring smart chargers with V2G technology to market without delay. These chargers are set to

Table 7
Vehicle to grid with K-Means

Technology	Source Node	Source Voltage (V)	Study Node	Study Voltage (V)	ΔV
W/O V2G	0	120	215	119.503	0.42%
W V2G	0	120	215	119.899	0.08%

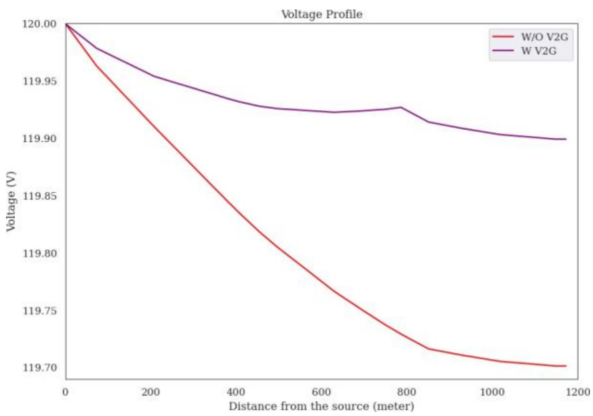

Figure 9: Load profile in node 215.

Table 8
Charger comparison

Brand	Study Node	Contribution to the network (%)	
Chargepoint	192	99.91%	Best
Tesla	192	98.80%	Well
Wallbox	192	96.7%	Good

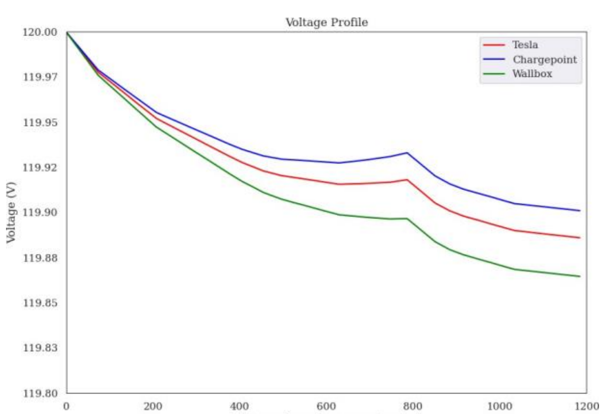

Figure 10: Charger comparison in node 192.

revolutionize how we interact with electric vehicles, providing unparalleled efficiency and safety. By intelligently managing the charging process and adapting to various conditions, these devices offer a comprehensive solution to maximize battery performance and longevity. It is not just about convenience; it is about ushering in a new era of sustainable transportation that is both efficient and reliable.

5. Discussion

The results are specifically applied to a low-voltage network because residential use is the least controlled and in which there is more misinformation; in this way, we try to offer an easily understandable perspective for the end consumer. This contrasts with research that often delves into more technical aspects, as proposed by the author [2]. The purpose of this paper has been to analyze the positive and negative aspects of different charging methods. The tariff scheme, which penalizes the user for charging outside their designated hours, has been left out of this analysis due to the difficulty of adequately simulating it over time to verify its effectiveness.

Instead, the emphasis has been placed on improving the charging system, especially by implementing smart chargers focusing on V2G. Following the plug-in vehicle line [11] gives a more technical-economic perspective and carries out the study with buses. This is outside the use that could be applied to a person who acquires a plug-in vehicle, which is why this study has been complemented with a residential analysis.

This approach demonstrates that purchasing an electric vehicle goes beyond reducing greenhouse gas emissions; it is also about generating and managing energy more efficiently. The hypothesis is that residential users primarily use their vehicles for basic daily tasks, such as commuting to work, shopping, and visiting family. Thus, by integrating the ability to generate energy at home through the electric vehicle, you can save money and contribute to a more sustainable and efficient long-term electricity network.

This perspective suggests a broader evolution in how we perceive the role of electric vehicles in our daily lives, transforming them from mere energy consumers to active participants in intelligent energy generation and management. In addition, it promotes a more proactive mentality on the part of users, encouraging practices that benefit people.

6. Conclusions

Electric vehicle technology is much closer to what is generally believed. For this reason, possible strategies have been examined to mitigate their impact on the network without making radical changes to the existing infrastructure. The risk posed by uncoordinated recharge is evident, which could bring the network to the brink of collapse. Due to this great problem, it is necessary to focus on investigating the use of smart chargers, which have shown positive results by reducing the load at all the points analyzed.

However, the use of these smart chargers has the disadvantage of having a high installation cost due to the power required and the need for a bidirectional meter so that the company can monitor the contribution made to the network. This contribution can occur through the use of distributed generation. When considering that the vehicle is a large energy storage, it can be used when it is not fully discharged.

In this context, an excess battery is simulated as a generator that provides power to the grid when needed. This has positive effects by reducing the load on the transformer and saving energy when not in use. When using K-means to compare the use of smart chargers, an improvement of 0.20% occurs compared to 0. 001% which represents the use of the technology randomly.

The brands that invest in these chargers are deeply committed to advancing technological efficiency. Through rigorous research and development, they continually strive to push the limits of what is possible in electric vehicle charging. This commitment is evident in the comparisons between the main market players, which reveal consistent and promising results.

In conclusion, the analysis provides appropriate guidelines for the use of our electric vehicles. This includes responsible practices when connecting vehicles to the grid, especially in the absence of a smart charger, and the possibility of such a device, budget permitting, optimally handling this task.

To improve the prospects for early deployment of electric vehicles (EVs), a more in-depth study is needed. It is recommended that more straightforward solutions be explored and strategies devised to disseminate information to the public. This approach aims to facilitate a better understanding and smoother adaptation to the new era of electric vehicles, thus mitigating the complexities associated with their integration.

Future projects

As a future project, it is suggested to perform a dynamic analysis using load profiles to obtain more accurate results. This will allow us to study a person's behavior throughout the day with their vehicle, simulating variables such as the time of arrival home, the time of recharging the vehicle, and the time of departure, and observing the results during hours of high demand and in hours of low energy demand.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this document.

CRediT authorship contribution statement

Sebastian Astudillo: Methodology, Software, Formal analysis, Investigation, Writing. **Pablo Robles:** Conceptualization, Methodology, Software, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization.

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References

[1] Ayyadi, S., Bilil, H., Maaroufi, M., 2019. Optimal charging of electric vehicles in residential area. Sustainable Energy, Grids and Networks 19, 100240. doi:10.1016/j.segan.2019.100240.

[2] Badugu, J., Obulesu, Y., Babu, C., 2019. Recharging methods of electric vehicles in residential distribution systems. Journal Europeen des Systemes Automatises 52, 617–623. URL: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85080996578&doi=10.18280%2fjesa.520609&partnerID=40&md5=0286deba36e18b45c590677f7f3085cc, doi:10.18280/jesa.520609. cited By 2.

[3] Bastida-Molina, P., Hurtado-Pérez, E., Pérez-Navarro, , Alfonso-Solar, D., 2020. Light electric vehicle charging strategy for low impact on the grid. Environmental Science and Pollution Research 28, 18790–18806. URL: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85084147074&doi=10.1007%2fs11356-020-08901-2&partnerID=40&md5=02c46dde04349a86cbc684a2f7fbd573, doi:10.1007/s11356-020-08901-2. cited By 15.

[4] Chávez, M.C.R., Martínez-Gómez, J., Meza, J., Jose, D., Anthoniraj, S., 2023. Energy efficiency in charging stations for electric vehicles with minimum affection to the electrical distribution network through resource allocation, in: Namrata, K., Priyadarshi, N., Bansal, R.C., Kumar, J. (Eds.), Smart Energy and Advancement in Power Technologies, Springer Nature Singapore, Singapore. pp. 241–256.

[5] Gerboni, R., Caballini, C., Minetti, A., Grosso, D., Dalla Chiara, B., 2021. Recharging scenarios for differently electrified road vehicles: A methodology and its application to the italian grid. Transportation Research Interdisciplinary Perspectives 11. URL: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85115772032&doi=10.1016%2fj.trip.2021.100454&partnerID=40&md5=fc3422f7e1a43063cdc06285d0846ec7, doi:10.1016/j.trip.2021.100454. cited By 0.

[6] Kianmehr, E., Nikkhah, S., Vahidinasab, V., Giaouris, D., Taylor, P.C., 2019. A resilience-based architecture for joint distributed energy resources allocation and hourly network reconfiguration. IEEE Transactions on Industrial Informatics 15, 5444 – 5455. URL: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85073353719&doi=10.1109%2fTII.2019.2901538&partnerID=40&md5=d31adf7c2ebbcfbbb1d3392569dfff53, doi:10.1109/TII.2019.2901538. cited by: 68; All Open Access, Green Open Access.

[7] Knak Neto, N., Piotrowski, L., 2019. Methodology for analysis of the impact of residential charging of electric vehicles. doi:10.1109/TLA.2019.8896818.

[8] Li, Y., Lim, M., Tan, Y., Lee, S., Tseng, M.L., 2020. Sharing economy to improve routing for urban logistics distribution using electric vehicles. Resources, Conservation and Recycling 153. URL: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85074952638&doi=10.1016%2fj.resconrec.2019.104585&partnerID=40&md5=b6b56b8fcc9544cb43aaddda777ad389, doi:10.1016/j.resconrec.2019.104585. cited By 51.

[9] Liu, M., Phanivong, P., Shi, Y., Callaway, D., 2019. Decentralized charging control of electric vehicles in residential distribution networks. IEEE Transactions on Control Systems Technology 27, 266–281. doi:10.1109/tcst.2017.2771307.

[10] Medina Aguirre, S.X., 2021. Calidad y gestion de eneria en centros de carga para vehiculos electricos considerando tipos de cargabilidad. Master's thesis. Universidad Politecnica Salesiana. URL: https://dspace.ups.edu.ec/handle/123456789/21558.

[11] Mehta, R., Srinivasan, D., Khambadkone, A., Yang, J., Trivedi, A., 2018. Smart charging strategies for optimal integration of plug-in electric vehicles within existing distribution system infrastructure. IEEE Transactions on Smart Grid 9, 299–312. doi:10.1109/tsg.2016.2550559.

[12] Mhaisen, N., Fetais, N., Massoud, A., 2020. Real-time scheduling for electric vehicles charging/discharging using reinforcement learning, in: 2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT), pp. 1–6. doi:10.1109/ICIoT48696.2020.9089471.

[13] Paul, S., Padhy, N.P., 2019. Resilient scheduling portfolio of residential devices and plug-in electric vehicle by minimizing conditional value at risk. IEEE Transactions on Industrial Informatics 15, 1566–1578. doi:10.1109/TII.2018.2847742.

[14] Singh, M., Kumar, P., Kar, I., 2013. A multi charging station for electric vehicles and its utilization for load management and the grid support. IEEE Transactions on Smart Grid 4, 1026–1037. doi:10.1109/TSG.2013.2238562.

[15] Tu, R., Gai, Y., Farooq, B., Posen, D., Hatzopoulou, M., 2020. Electric vehicle charging optimization to minimize marginal greenhouse gas emissions from power generation. Applied Energy 277, 115517. doi:10.1016/j.apenergy.2020.115517.

[16] Usman, M., Tareen, W., Amin, A., Ali, H., Bari, I., Sajid, M., Seyedmahmoudian, M., Stojcevski, A., Mahmood, A., Mekhilef, S., 2021. A coordinated charging scheduling of electric vehicles considering optimal charging time for network power loss minimization. Energies 14, 5336. doi:10.3390/en14175336.

[17] Vatanparvar, K., Al Faruque, M., 2017. Electric vehicle optimized charge and drive management. ACM Transactions on Design Automation of Electronic Systems 23. URL: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85027017023&doi=10.1145%2f3084686&partnerID=40&md5=1465149171fc2631d6688cc8704355c1, doi:10.1145/3084686. cited By 9.

[18] Wang, Y., John, T., Xiong, B., 2019. A two-level coordinated voltage control scheme of electric vehicle chargers in low-voltage distribution networks. Electric Power Systems Research 168, 218–227. doi:10.1016/j.epsr.2018.12.005.

[19] Zeraati, M., Hamedani Golshan, M.E., Guerrero, J.M., 2019. A consensus-based cooperative control of pev battery and pv active power curtailment for voltage regulation in distribution networks. IEEE Transactions on Smart Grid 10, 670 – 680. URL: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85029177839&doi=10.1109%2fTSG.2017.2749623&partnerID=40&md5=ce85433bf678a88c0bf85ba5372eb4dc, doi:10.1109/TSG.2017.2749623. cited by: 147; All Open Access, Green Open Access.

[20] Zhang, S., Gajpal, Y., Appadoo, S., Abdulkader, M., 2018. Electric vehicle routing problem with recharging stations for minimizing energy consumption. International Journal of Production Economics 203, 404–413. URL: https://www.sciencedirect.com/science/article/pii/S0925527318302810, doi:https://doi.org/10.1016/j.ijpe.2018.07.016.