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REVISTA INGENIO

Optimal georeferenced deployment of charging stations for electric vehicles in distribution networks using a trajectory-based heuristic model

Despliegue óptimo georreferenciado de estaciones de carga para vehículos eléctricos en redes de distribución usando un modelo heurístico basado en trayectoria

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Optimal deployment, heuristic model, energy consumption, charging stations.

ABSTRACT
The progressive increase in the consumption of fossil fuels and the constant efforts to reduce CO2 emissions bring together the search for alternatives and the transport sector being one of the most dependent on fossil fuels and the cause of approximately 80% of the air pollution, the electric vehicle emerges as an alternative in mobility. That is why this article proposes a methodology for the optimal location of electric vehicle charging stations, given in a georeferenced distribution network scenario using a heuristic for the insertion of electric vehicles, taking into account energy consumption, travel and autonomy. developed based on real data, reducing the minimum location of charging stations. Evaluated in the distribution network of Santo Domingo-Ecuador, in a way that guarantees a technical and economic balance.

PALABRAS CLAVE
Despliegue óptimo, modelo heurístico, consumo de energía, estaciones de carga.

RESUMEN
El progresivo aumento del consumo de combustibles fósiles y el constante esfuerzo por reducir las emisiones de CO2 se unen para la búsqueda de alternativas, y siendo el sector del transporte uno de los más dependientes de los combustibles fósiles y causante de aproximadamente el 80% de la contaminación atmosférica, el vehículo eléctrico surge como una alternativa en movilidad. Es por ello por lo que este artículo propone una metodología para la ubicación óptima de estaciones de carga de vehículos eléctricos, en el escenario de una red de distribución georreferenciada, utilizando una heurística para la inserción de vehículos eléctricos, teniendo en cuenta el consumo de energía, los viajes y la autonomía, desarrollada con base en datos reales, reduciendo la ubicación mínima de las estaciones de carga; considerando la red de distribución de Santo Domingo-Ecuador, de manera que garantice un equilibrio técnico y económico.

I. INTRODUCTION

The need for means of transportation for the development of our occupations has been present throughout the history of the human race. According to the latest Ecuadorian Energy Balance of 2017, the transport sector represented 52.29% (45,098 kBEP; 73,427.76 GWh) of the total national energy consumption [1].

Looking for mechanisms that provide flexibility in the consumption of sources that come from fossil energy, thus facilitating the migration to other primary energy sources. These would allow the development of the same activities but with a minimum environmental impact and reduced polluting emissions to the planet [2].

The agencies in charge of energy planning must consider scenarios from the point of view of supply and demand where electric mobility systems are representative, as well as mechanisms and technical inputs not only at

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the engineering level but also in the regulatory framework that allow the technological transition without producing disadvantages in the operation of the electric power supply system's [3].

As electric vehicles increase their market share, it's going to get some attention from power companies. Its inclusion in power systems represents a large increase in load demand, causing many problems of power quality degradation, increased energy losses. However, a problem may occur between the network operators and the owners of the charging stations since it may be the case that there are differences because the owners of the charging stations look for the commercial place where they can charge the electric vehicles, but at lower cost. On the other hand, the electricity network operators estimate that the charging stations are located in such a way that they allow a predetermined number of vehicles to be fed, impacting the electricity network as little as possible [4].

Various solution methods worldwide have been proposed to locate charging stations. For example, genetic algorithms and voronoi diagrams have been incorporated. These algorithms do not consider very important factors such as: load profile, consumption, autonomy, and geographical considerations. That is why we start, for the optimization process, from candidate sites which can be conventional service stations, bus stops, shopping centers, parking lots, parks, etc. Consequently, the proposed model does not start from scenarios where candidate sites are considered, as would happen with voronoi when segmenting the area of analysis but starts from a study area. That is, he knows the study area based on its cartographic reality [5].

Regarding the profile of charge and consumption of Electric Vehicles (EV), the historical information of the records of electric taxis that operate in the city of Loja was considered, as well as a model developed by the authors that takes into account the process of charging of EV batteries modified in a novel model that represents the electric vehicle battery charging system based on its state of charge and its current variability and charging time.

The general problem lies in optimally locating and sizing the charging stations along a georeferenced distribution network of 34 nodes, so that the proposed heuristic starts from candidate sites in the network, of which they can be public places, that is, it is an iterative method that knows the study area since this information is extracted from Open Street Maps (OSM), as well as the use of MATLAB software to implement graph theory that will allow finding the nodes and topology that is part of the solution set. To later evaluate the voltage profiles and load losses simulated in Cymdyst [6].

2. METHOD

2.1. ENERGY CONSUMPTION OF ELECTRIC VEHICLES

The prerequisite for the planning of charging stations is to create the conditions for an adequate consumption of electrical energy. On the other hand, electric vehicles have zero emission characteristics; Low engine noise and higher propulsion efficiency [7], [8], [9], [10], [11].

From the point of view of transport systems, whether public or conventional, a huge proportion of energy consumption is due to the inefficient movement of traffic. The flexible energy consumption estimation model is based on the evaluation of consumption based on data from other vehicles on the road network, which have the possibility of being accurate thanks to the different vehicle models and energy efficiency [12], [13].

The cost for energy consumption per 100 km of an electric transport is up to three times less than the cost of a conventional vehicle that uses fossil fuel, this taking into account that in Ecuador there are lower rates, both for gasoline and electricity [14].

When analyzing the real cost of electricity in the country and the international price of gasoline, the EV is still lower than that of a thermal combustion vehicle, therefore, the electric vehicle is more profitable and efficient even with the fuel subsidy that exists in the country. This advantage is also visible in Europe [14].

2.2. ELECTRIC DISTRIBUTION NETWORK IN ELECTRIC VEHICLES

Within the exponential growth of EVs in moderate portions, it should not cause too many inconveniences, however, its wide adoption will probably create an impact on the operation and management of electrical distribution networks, such as congestion, voltage problems and load imbalances between phases [15].

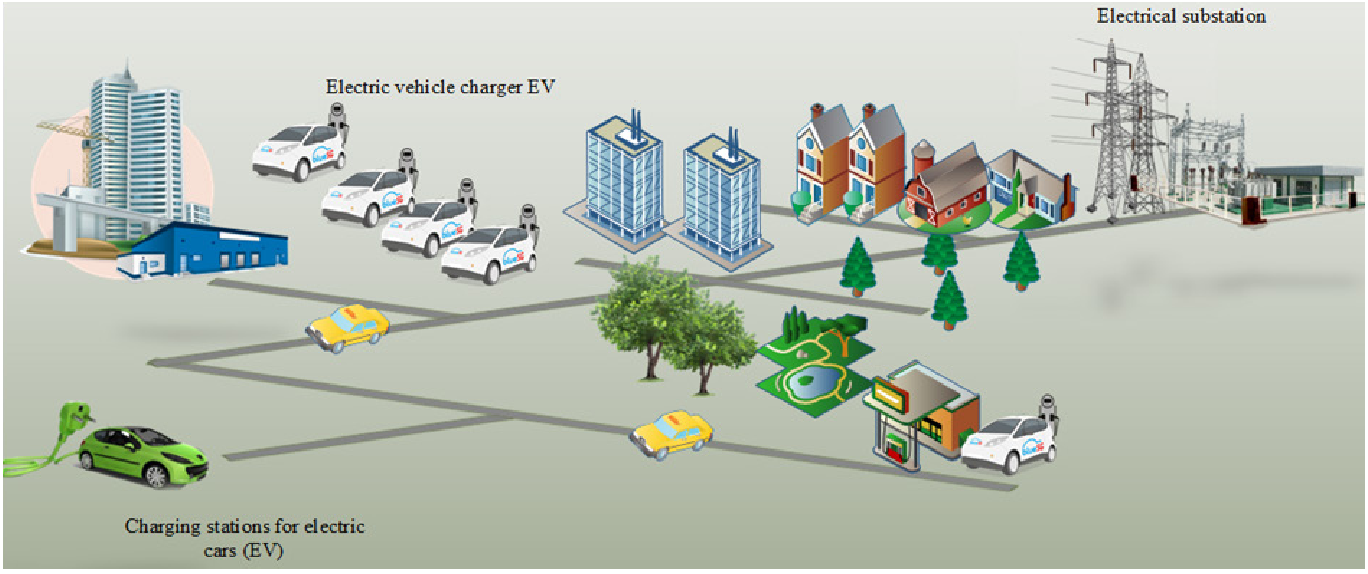
Depending on the autonomy of the Electric Vehicle, the excessive charge of the batteries of said cars will have an impact on the distribution system, which would increase the load demand, introducing disturbances in the Interconnected Electric System, which imposes an increase in the generation and make probable reinforcements with the penetration of renewable energy in order to maintain the balance between what is generated and consumed [16] (see Table 1).

Approximately, the battery charging speed depends on the output of the charging station and the technical specifications of the electric car. The peak daily load curve during a day in the worst case would have a higher consumption

Table 1
Charge mode data

	Charging mode			
	Mode1	Mode2	Mode3	Mode4
Corrent (A)	16A	32A	64A	Hasta 400A
Type of load	slow	slow	Accelerated charging	Fast charging
Power (kw)	3,8-11	7,7-22	14,8-43	40-120
Specific Connector	No	No	Yes	Yes

Figure 1
Model of charging stations. Electric vehicles in distribution networks



in the midday and afternoon hours, and a lower consumption in the early morning [17] (see Figure 1).
To guarantee the continuity of the electricity supply and stabilize the demand curve, which in fact changes according to the time and type of daily charge of an electric vehicle, strategies and procedures are considered where it does not affect the electrical system and carry out a massive integration of electric vehicles in a planned way [18].

2.3. MOST REPRESENTATIVE CHARACTERISTICS OF THE FLEET SYSTEM TO DETERMINE CONSUMPTION

To determine the characteristics of the vehicle fleet, a comparison was made of both the conventional and electric vehicles, taking into account the route, autonomy and consumption. For this, the costs of various models of electric vehicles that are used in the United States without taxes and without subsidies are shown, but these low-end vehicles have already been inserted in Ecuador (see Table 2).

To carry out the cost comparison, the most used combustion vehicle in Ecuador was taken into account, the model is the Chevy Aveo, and the Nissan Leaf model as an electric vehicle, for which the initial cost of the electric vehicle vs. the combustion vehicle, the electric vehicle has an increase in cost with 85% compared to the cost of the conventional vehicle.

The costs for energy consumption were determined based on the technical specifications provided by the manufacturer of the electric vehicle. Several brands and models of electric vehicles are expected to soon circulate on the roads of Ecuador.

It is established that vehicle users generally log less than 50 km per day, with a performance index for electric vehicles of 8 km/kWh (0.122 kWh/km) under ideal conditions of traffic and geography, it is concluded that the energy demanded by the EV of the network would be 0.144 kWh for each kilometer traveled.

2.4. ALGORITHM

The algorithm will be responsible for determining the optimal location of charging stations by extracting the characteristics of electric vehicles, through the network of 34 georeferenced nodes. This route may be useful for the study of any real scenario of an electrical system depending on the demand scenarios determined by Cymdyst (see Table 3).

Consequently, in [33] the heuristic model is explained in a standard way to solve the programming problem

Table 2
EV sales prices in Ecuador

Vehicle type	Model	Sales price in the usa without tax [usd]
	Chevy Bolt	37.495
	Ford Focus Electric	29.120
	Nissan Leaf	30.680
EV	Fiat 500e	31.800
	BYD e5	34.990
	Volkswagen e- Golf	28.995

Table 3
Pseudocode of the solution algorithm

Algorithm placement of charging stations

Step 1:	Georeferencing and scenario generation
Step 2:	Get the coordinates of the area.
Step 3:	Declaration of variables Xij, Zij, λ
Step 4:	Read OSM file Openstreetmap.
Step 5:	Minimum enabling distance. For k longitud (Xij) [v]=BVE (λ, Xij) end for
Step 6:	Writing Purpose Function.
Step 7:	Candidate sites for the study area
Step 8	End

for which the kmeans algorithm will be used to generate cluster, through the distribution network model of 34 nodes generated in Cymdyst will be distributed in scenario where you will get the power, voltage and consumption at which the charging stations act taking into consideration, public places [19].

3. Results and discussion

Once the model to be used is proposed, a result will be obtained, which is developed in two scenarios that are based on a base case study where it will be the starting point to analyze the different behaviors of the network when the charging stations come into operation. and the impact on the elements to future case studies of load to the distribution network.

3.1. ANALYSIS OF OPTIMAL LOCATION OF CHARGING STATIONS IN THE DISTRIBUTION NETWORK

One of the objectives of this article is to find the optimal location for charging stations, to evaluate in a georeferenced distribution network taking into account the characteristics of electric vehicles, inserted in Ecuador both in their consumption and autonomy compared to conventional vehicles. based on satisfying user demand. In the first instance, it is necessary to extract the coordinates of the area to be studied, through the Open Street Maps that helps the georeferencing of the scenario, therefore the longitude and latitude given below were obtained as data (see Table 4).

Next, the results obtained from the optimization are presented to find the strategic points of charging stations for the correct functioning of the network, since strategic points of access to the public in the georeferenced network were taken into account, such as parks, centres

Table 4
Limits of the real scenario to study

Length	Latitude
-79,19	-0,254
-79,14	-0,242

Figure 2
Optimal location and load points located using the Heuristic model

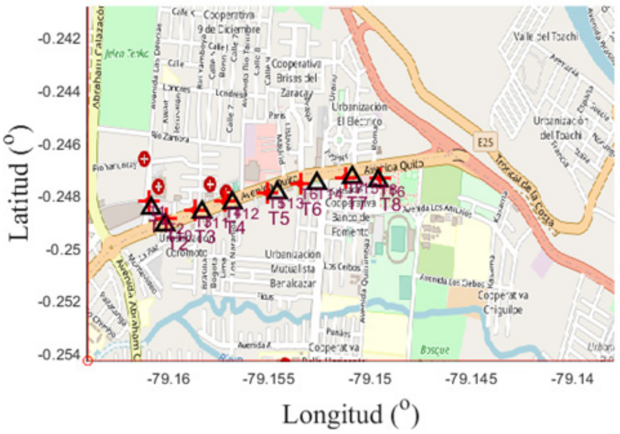


Figure 3
Georeferenced network to study in Cymdyst

commercial, gas stations, the partition of the scenario arises from the distribution network, therefore the minimum distance from the location of the electric vehicle is taken depending on the characteristics towards the charging station (see Figure 2).

Figure 2 shows the strategic points to place the charging stations for electric vehicles, the algorithm suggests a number of 8 candidate sites for the charging stations, which represents a minimum connectivity route where it will be analyzed in the network of distribution, the analysis was carried out with fast charging feeders, taking into consideration the characteristics of electric vehicles, as well as the technical factors analyzed in chapter 3. In the comparative study of [20], the number of 5 stations is suggested for 11 buses, taking into account that the load is 1 hour. For a strong network like the one studied, each station has 3 fast charging points of 25 minutes, which means that 58 vehicles could be charged in approximately one hour.

3.2. FLOW SCENARIO WITHOUT LOADING STATIONS

Once the simulation has been carried out in the radial distribution network, which has 147 bars, one of which is oscillation, with an operating voltage of 13.60 kV, the analysis was carried out in 34 main nodes where the other bars are load bars and are located related to different types whether residential, industrial and commercial are shown in figure 3 (see Figure 3).

Figure 4 shows the load flow with maximum demand, without the insertion of charging stations, where the behavior of the bars given in (pu) can be seen, where it goes from a voltage limit to 1 (pu) in the 34 main nodes, so it is observed that none exceeds the operating limit, as well as no node has a low voltage profile, for which the flow runs the network is optimal (see Figure 4).

Next, in table 5, the result of the load flow is observed, as well as the losses in lines and cable (see Table 5).

For the case study, it can be seen that the flow is optimal and there is no overload or overvoltage in any bus and distribution lines, therefore, the losses are evaluated and these are minimal. This is essential and it can be mentioned that the vehicle management problem is stochastic demand and peak hours [21], a situation that would be resolved at this point.

3.3. FLOW SCENARIO WITH INSERTION OF CHARGING STATIONS IN THE DISTRIBUTION NETWORK

Through the load flow at maximum demand with fully discharged electric vehicles, the voltage behavior in the network is analyzed since each selected node of the distribution network will have 3 charging stations each with a power of 150Kw since it has with a fast charge that benefits the use of electric vehicles.

Figure 5 shows the voltage in (pu) of each bar analyzed once the charging stations have been inserted, where the network behaves efficiently, although the

Table 5
Load flow results without EV insertion

	Simulation Results		
	kW	kVAr	kVA
Total production	449,34	97,76	459,85
Total Charges	448,64	96,13	458,82
Losses Lines	0,43	1,26	1,34
Cable Losses	0	0	0
Total Losses	0,7	3,96	4,03

Figure 4
Voltage at each Node in (pu)

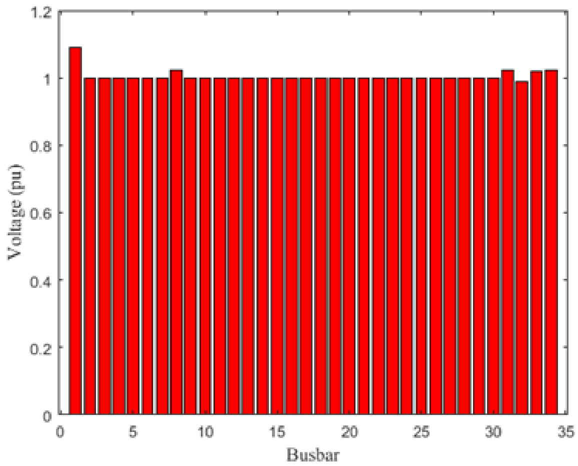
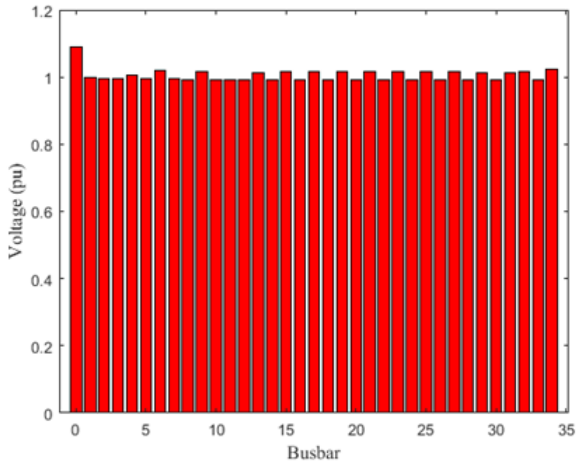


Figure 5
Voltage in (pu) with insertion of VE in the network



voltage profile is still within the prescribed limits, and it already operates with an overvoltage of 9.06% in the Network feeder (see Figure 5 and Table 6).

After analyzing the chargeability represented in figure 6, the lines with the highest index in the distribution network with approximately 35% are those that are close to the source, as they move away the percentage remains stable except for the nodes where they are connected. the charging stations, at node 17 where it increases by 24% and goes constantly until reaching the furthest node where there is also a 13% chargeability in the lines and conductors where there is not a considerable percentage, therefore it is not necessary to increase lines in this section of the network. One of the most widely used indices in the operation and planning of distribution systems was proposed by Gallego. In which it is used to find a set of candidate nodes to locate capacitors on a distribution network which allows defining certain indices based on the impact on the technical losses that they generate on the system. The philosophy of this indicator is to find the nodes that will have the least impact on technical losses by installing EV charging stations there. This is achieved by making use of the exchange ratio between the active power losses of the system and the reactive power injections in the nodes. Depending on the lesser impact generated to the technical losses of the network, the set of possible spaces for the EV Charging Stations is previously available depending on the needs of each of the agents involved; that is, the electrical network and the mass transport network (see Figure 6).

When analysing the losses in the lines, it is observed that the greatest number is at the source due to the extensive distance to the charging stations, therefore, it is where there is the greatest number of losses in the nodes of the distribution network, where they are connected. the charging stations, as well as in the conductors, the losses are minimal, therefore the voltage drop at maximum load demand is 0.254%, thus being acceptable and optimal for the operation of charging stations in the electrical distribution network (see Figure 7).

The transformer loads of the two simulated cases in Figure 7 are shown in a first base case in the absence of EV charging stations. In the simulation it can be seen that the maximum load of the feeder transformer is approximately 60% in the base case. However, it increased to 70% when charging stations were integrated into the distribution network. The same happened with the transformer at node 17, where its load percentage increased from 57% in the base case to 69% in the case of inserting charging stations. It is also clear that there is no overload on any transformer. Furthermore, when comparing the results of the base case with the insertion of charging stations, it

Table 6
Load flow results with EV insertion

	Simulation results		
	kW	**kVAr**	**kVA**
Total production	3634	287,65	3645,37
Total Charges	3598,55	96,14	3599,83
Losses Lines	22,29	62,49	66,35
Cable Losses	0,03	0	0,03
Total Losses	35,45	3.96	4.03

Figure 6
Chargeability in the lines of the distribution network

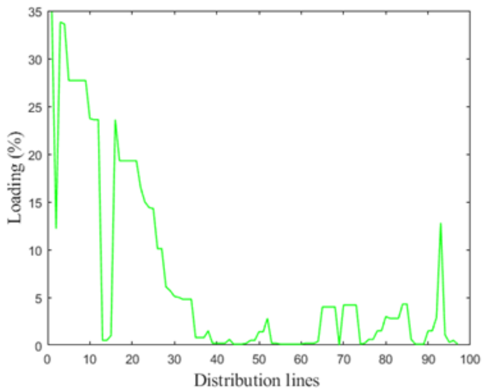
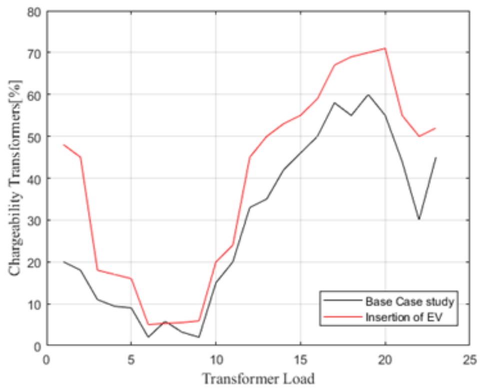


Figure 7
Transformer Chargeability



can be seen that the maximum load of the transformers is almost identical in both cases. This is because the additional loads resulting from EV charging shifted from peak hours.

Finally, it is estimated that in the 5-year projection distribution network, it would necessarily be necessary to increase transformers and distribution lines to meet the demand in existing loads, as well as in that of electric vehicles (see Figure 8).

The worst case is examined in which, in 2030, 80% of the entire car fleet is electric in the distribution network are shown in Figure 8. In this case, the chargeability of the transformer exceeds the maximum capacity threshold of 150% and, since it will work above 100% of its capacity, even applying smart techniques applied, or placing power with solar panels, it should be considered to replace it with one. of larger size, likewise with the conductors, their caliber would have to be increased as new distribution lines, likewise in the worst case there is an overload in the nodes where the charging stations are located with 200% abnormal conditions. The voltage profile is critical as it almost reaches the lowest level.

4. Conclusions

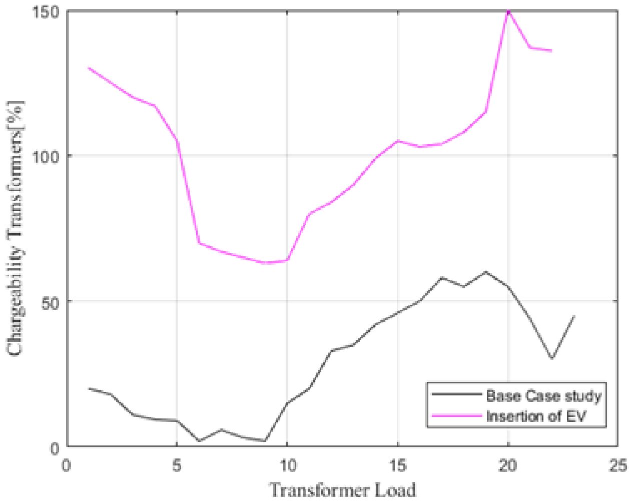
In relation to the modelling and charging behavior of electric vehicles, it should be taken into account that this developed model can be applied to any locality in real scenarios with the consideration of the characteristics and distance traveled, only of the national automotive mobility system.

Through an adequate study of the characteristics of electric vehicles, it is concluded that the optimal positions of each charging station can be displayed, depending on the user's requirement, where they could recharge in 25 minutes, reducing the range of anxiety. of drivers allowing it to obtain considerable autonomy around the city through the distribution network.

Through the study at the capacity level of the distribution network system, and knowing both the load of the transformers, where the increase in energy is noted from 108.4% in the base case to 121.8% in the charging station scenario, as well Like the total losses of the simulation in the load station insertion scenario, the impact of VE is still evident, but even during the peak period, in the base case it is highly tolerable in fact, the increase with respect to the base case is around 15%, compared to the scenario with charging stations. The voltage profile is very similar in the first two cases, so currently this level of electric vehicle diffusion is acceptable without any intervention, therefore, although no changes were made to the components of the electrical system, the income is acceptable for electric vehicle charging stations.

As a result of each operation scenario in the georeferenced distribution network and the application of the optimization model as well as the analysis of the power flow, they are favorable especially for the operation of electric

Figure 8
Transformer chargeability worst case



vehicles, especially in public transport in the study sector, specifically in a cooperative of taxis that benefit from said charging stations.

In the simulated worst-case scenario to the year 2030, the installation of charging stations on this network in the future is likely to create problems, particularly with respect to transformer overloading and expected voltage limits, as transformers start to operate at 150% of its capacity, for which it will necessarily have to be replaced since the useful life operating above 100% decreases drastically, for which investments are required to change said components, and guarantee the full availability of the high power charging stations.

REFERENCIAS

[1] Ministerio de Energía y Recursos Naturales no Renovables, «Balance Energético Nacional 2017», 2019.

[2] A. Corral, F. Izurieta, V. Guayanlema, J. P. Díaz, H. Acurio, and P. Quintana, «Assessment opportunities for energy efficiency in ecuadorian road transport. Oportunidades de evaluación de eficiencia energética en el transporte terrestre en Ecuador», vol. 84, N.º 200, pp. 309-315, 2017.

[3] J. Clairand, «Smart charging for electric vehicle aggregators considering users'», vol. 3536, N.º C, pp. 1-12, 2018, DOI: 10.1109/ACCESS.2018.2872725

[4] M. M. Vazifeh, H. Zhang, P. Santi, and C. Ratti, «Optimizing the deployment of electric vehicle charging stations using pervasive mobility data», *Transp. Res. Part A*, vol. 121, N.º january 2017, pp. 75-91, 2019, DOI: 10.1016/j.tra.2019.01.002.

[5] Y. Fan, D. Mengnuo, G. Pei, Z. Zhang, L. Yingying, and W. Xiao, «The influence on distribution network planning and investment strategy of power grid corp under electric power system reform», in *2018 China International Conference on Electricity Distribution (CICED)*, 2018, pp. 2426-2430, DOI: 10.1109/CICED.2018.8592014.

[6] J. A. Sanguesa, V. Torres-Sanz, P. Garrido, F. J. Martínez and J. M. Márquez-Barja, «Smart cities a review on electric vehicles: technologies and challenges», pp. 372-404, 2021.

[7] E. García, «Demand response systems for integrating energy storage batteries for residential users», 2016.

[8] W. Kempton, «Electric vehicles as a new power electric utilities source for» vol. 2, N.º 3, pp. 157-175, 1997.

[9] K. Schneider, C. Gerkensmeyer, R. Fletcher, and S. Member, «Impact assessment of plug-in hybrid vehicles on Pacific northwest distribution systems» pp. 1-6, 2008.

[10] D. C. Published *et al.*, «The beginners guide to electric vehicles (EV)», N.º august, 2014.

[11] K. Hu, J. Wu, and T. Schwanen, «Differences in energy consumption in electric vehicles: an exploratory real-world study in Beijing», 2017.

[12] F. Badin, F. Le Berr, H. Briki, M. Petit, S. Magand, and E. Condemine, «Evaluation of EVs energy consumption influencing factors», vol. 6, pp. 112-123, 2013.

[13] X. Qi, G. Wu, K. Boriboonsomsin, and M. J. Barth, «Data-driven decomposition analysis and estimation of link-level electric vehicle energy consumption under real-world traffic conditions», *Transp. Res. Part D*, N.º april, pp. 0-1, 2017, DOI: 10.1016/j.trd.2017.08.008.

[14] B. W. B. Auquilla, «Estudio de estrategias para la inserción de vehículos eléctricos tipo taxi en la ciudad de Quito», 2019.

[15] G. Celli, F. Pilo, G. Monni, and G. G. Soma, «Optimal multi-objective allocation of fast charging stations», 2018.

[16] P. Frías and C. Mateo, «Evaluación del impacto de la integración del coche eléctrico en las redes de distribución de energía eléctrica», pp. 56-61.

[17] M. R. Rodríguez, «Impacto de un parque vehicular eléctrico en los requerimientos de reconfiguración de la red de distribución de la ciudad de Santiago», 2013.

[18] M. Campaña and E. Inga, «Despliegue óptimo georreferenciado de estaciones de carga vehicular pública considerando capacidad de flujo y distancias máximas habilitantes (Georeferenced optimal deployment for public vehicle charge station considering restrictions of capacity flow and maximal enablers distance)», vol. 15, n.º 2, pp. 68-78, 2019.

[19] M. Campaña, «Optimal Allocation of public charging stations based on traffic density in smart cities», 2019.

[20] L. A. M. Maldonado, «Análisis técnico para la implementación de estaciones de carga rápida para vehículos eléctricos en la provincia de Galápagos», 2020.

[21] T. Carlos and H. Rojas, «Estaciones de carga de vehículos eléctricos y su influencia en el funcionamiento de la red de distribución», 2016.