Scientific Paper / Artículo Científico

UNIVERSIDAD POLITÉCNICA SALESIANA ECUADOR
INGENIUS
Revista de Ciencia y Tecnología
https://doi.org/10.17163/ings.n32.2024.03
pISSN: 1390-650X / eISSN: 1390-860X

Electric Vehicles and Their Impact on the Electric Distribution System: A Case Study of the Urban Feeder in Portoviejo

Los vehículos eléctricos y su impacto en el sistema eléctrico de distribución: Caso de estudio "Alimentador urbano de la ciudad de Portoviejo"

Arturo Zavala-Tubay[1,*], Hugo Pico-Mera[1], Gabriel Pico-Mera[2]

Received: 16-06-2023, Received after review: 05-04-2024, Accepted: 30-04-2024, Published: 01-07-2024

Abstract

In Portoviejo, the current use of electric vehicles (EVs) is limited compared to conventional vehicles. However, due to the implementation of laws, regulations, and policies promoting electric mobility in Ecuador, a significant increase in the integration of EVs into the city's electrical system is anticipated in the coming years. To anticipate the impact on the electrical infrastructure, a simulation is conducted using CYMDIST software on an electrical distribution feeder operated by the Public Company Corporación Nacional de Electricidad (CNEL EP), Manabí Business Unit (Portoviejo). The simulation considers three scenarios projected for 2030: 1. Baseline scenario without EV integration, 2. Unrestrained EV integration, and 3. Managed EV integration. This research aims to simulate the integration of up to 230 EVs into the network to provide benchmark data for understanding the potential impacts on the feeder as EV adoption increases, with vehicles being charged over extended periods. The investigation will highlight the importance of demand management with EV integration, demonstratingsignificant effects on the demand curve, voltage profile, and total harmonic distortion rate (THD%) of a 13.8 kV distribution feeder.

Keywords: EV, Electric Vehicle, Harmonics, Technical Losses, Electrical Planning, CYMDIST, Distribution, CNEL

Resumen

En la ciudad de Portoviejo, actualmente el uso de vehículos eléctricos (VE) es limitado en comparación con el uso de los convencionales. Sin embargo, debido a la implementación de leyes, reglamentos y regulaciones que impulsan la movilidad eléctrica en el Ecuador, se espera que en los próximos años se produzca un ingreso considerable de esta carga (VE) en el sistema eléctrico de la ciudad. En este sentido, para determinar probables afectaciones a producirse en el sistema eléctrico en el futuro, se realiza la simulación en el software CYMDIST de un alimentador de distribución eléctrico de la Empresa Pública Corporación Nacional de Electricidad CNEL EP Unidad de Negocio Manabí (Portoviejo), considerando tres escenarios de análisis proyectados al año 2030 como son: 1. Caso base sin ingreso de VE, 2. Ingreso no controlado de VE y 3. Ingreso controlado de VE. El presente trabajo simula el ingreso de hasta 230 vehículos en la red, puesto que, el objetivo del estudio es tomar datos referenciales para conocer la posible afectación en el alimentador cuando los VE se conecten de forma masiva y se carguen prolongadamente. Al final del estudio se comprobará la importancia de la gestión de la demanda cuando se produzca el ingreso de vehículos eléctricos, el cual refleja resultados importantes en la curva de demanda, perfil de voltaje y tasa de distorsión armónica THD % de un alimentador de distribución a 13,8 kV.

Palabras clave: VE, vehículo eléctrico, armónicos, pérdidas técnicas, planificación eléctrica, CYMDIST, distribución, CNEL

[1,*]Departamento de Planificación, Corporación Nacional de Electricidad (CNEL EP UN MAN), Ecuador.
Corresponding Author✉: arturo.zavala@cnel.gob.ec .
[2]Facultad de Ciencias Matemáticas, Físicas y Químicas, Universidad Técnica de Manabí, Ecuador.

Suggested citation: Zavala-Tubay, A.; Pico-Mera, H. and Pico-Mera, G. "Electric Vehicles and Their Impact on the Electric Distribution System: A Case Study of the Urban Feeder in Portoviejo," *Ingenius, Revista de Ciencia y Tecnología*, N.° 32, pp. 27-35, 2024, DOI: https://doi.org/10.17163/ings.n32.2024.03.

1. Introduction

The global commitment to significantly reduce carbon emissions in the short term has driven the development of environmentally sustainable technologies, such as electric vehicles (EVs) [1]. Consequently, in recent years, the adoption of this technology has spread worldwide in response to the urgent need to reduce environmental pollutant emissions [2].

Considering that the use of electric vehicles contributes to environmental conservation, it is necessary to analyze the impact that charging this new technology may have on electrical distribution networks. According to [3] and [4], since these loads are modeled and behave as nonlinear, they could have a considerable negative impact on power quality (including voltage, imbalance levels, and harmonics), altering these electrical parameters under different load conditions.

Moreover, it is anticipated that the uncontrolled increase in loads due to the integration of EVs will directly impact the electrical infrastructure of the distribution company, owing to the potential rise in demand [5].

Electric vehicles (EVs) are characterized by the use of an electric traction motor for vehicle propulsion [6]. The energy required to drive this motor is stored in batteries, which are typically charged from an external power source [7].

Typically, EVs use lithium-ion batteries due to their advantages over other technologies, including higher efficiency, low maintenance costs, and lightweight properties. These characteristics make them particularly attractive for use in electric vehicles [8].

While batteries are considered the primary energy source for EVs, this study will focus on the impact these devices will have on electrical networks rather than on the batteries themselves.

The introduction of electric vehicles into the market will result in significant variations in energy and power demand [9]. This will impact electrical networks, presenting a major challenge for distribution companies. They must ensure the continuity of service to their customers while accommodating the increasing power and energy demand.

Anastasiadis et al. [10] emphasize the necessity of anticipating suitable solutions to potential issues within the electrical system. As the popularity of electric traction vehicles continues to grow, the increased demand significantly impacts the network.

Negative effects include impacts on voltage profiles, saturation of electrical system components, voltage imbalances, harmonic distortion, and increased technical energy losses. Conversely, positive effects encompass improved energy management techniques, commonly referred to as demand management strategies [11].

To determine the impact of integrating electric vehicles (EVs) into the system, it is essential to analyze various involved variables. These include network demand, electrical system loadability, load profiles of different customer types, and thecharacteristics of electric vehicles [12].

The impact on the network is closely linked to the type of charging applied to electric vehicles. According to [13], charging can be classified into three levels: Level 1 (slow charging), Level 2 (semi-fast charging), and Level 3 (fast charging at charging stations). The type of charging corresponds to the battery charging speed. Levels 2 and 3 are typically used in public and private settings, while Level 1 is primarily designated for domestic or garage charging.

Table 1 presents the classification of battery recharge types according to EV characteristics [14].

Table 1. Battery charging levels for EVs

Charging type	Charging Level	Typical use	Maximum expected current	Charging time
Level I	Slow	Home	12 A	6 a 24 hours
Level II	Semi-fast	Private or public sector	32 A	2-6 hours
Level III	Fast	C.Satations	250 A CA 400 A CC	0,5 hours

The fast charging process can be completed in approximately 30 minutes, allowing the battery to reach 80% of its nominal capacity [15].

Although the impact of EVs on the grid is directly related to the charging performed (slow, semi-fast, or fast), the current analysis will focus solely on slow charging. This type of charging is expected to be prevalent in residential settings among consumers or clients of electric distribution companies.

Due to the challenges posed by the nonlinear loads of electric vehicles, it is essential to conduct a study to estimate their impact on the grid. This research will analyze the effects of electric vehicle charging on the demand curve of a feeder, as well as the impact on voltage profiles, harmonics, and practical technical losses.

This study will be conducted through a simulation using CYMDIST software, based on a real feeder from the electrical distribution system of Corporación Nacional de Electricidad CNEL EP, Manabí Business Unit, projected up to 2030. The program modules will encompass load distribution, load flow, harmonics, and long-term dynamics.

Data derived from readings of the electrical system under analysis will be utilized for the network simulation. An urban feeder from Portoviejo, Manabí, has been selected for this study. The electric vehicle load, designed for simulation in the CYMDIST software, will be modeled as an unbalanced multifrequency current source. The data for this modeling will be obtained from readings taken while charging electric vehicle batteries using type I (slow) charging, with measurement intervals of 10 minutes.

This study explores simulated scenarios involving the integration of 160 and 230 electric vehicles into the electrical grid. These figures are referential and can be adjustedaccording to the projected EV integration estimates published in Panorama Eléctrico magazine [16].

Considering that electric vehicles (EVs) contribute to various quality issues within the distribution network, notably voltage imbalance, alterations to voltage profiles, electrical infrastructure saturation, and deviations from nominal frequency [17], this article presents real-world data collected during the low-voltage charging process of an electric vehicle.

In Ecuador, the Energy and Non-Renewable Natural Resources Regulation and Control Agency (ARCERNNR) oversees the strategic sectors of electricity, hydrocarbons, and mines. This agency establishes directives and guidelines for the Electric Energy Distribution Company through corresponding regulations. Specifically, Resolution No. ARCERNNR 017/2020 enacts Regulation No. ARCERNNR 002/20 "Quality of Distribution and Commercialization of Electric Energy Service" [18], which comprehensively addresses product quality in its second chapter.

The referenced regulation delineates the permissible ranges for electrical variables, which are commonly influenced by integrating electric vehicles into the networks, as detailed below:

1.1. Product Quality

1.1.1. Voltage Level

Table 2 displays the voltage ranges mandated by the regulatory authority ARCERNNR for distribution companies in Ecuador, as stipulated by the regulation [18].

Table 2. Acceptable Voltage Level Ranges

Voltage Level	Acceptable Range
High Voltage (Group 1 and Group 2)	± 5,0 %
Medium Voltage	± 6,0 %
Low Voltage	± 8,0 %

For this research, the values corresponding to medium voltage will be examined, and compliance with the regulations will be assessed, as outlined in Table 2.

1.1.2. Harmonic Distortion of Voltage

The individual harmonic distortion factor of voltage (%) and the total harmonic distortion factor of voltage (THD %) adhere to the ranges specified in ARCERNNR Regulation 002-20, as detailed in Table 3. The analysis will reference values corresponding to both medium and low voltage levels.

Table 3. Maximum Voltage Harmonic Limits (% of nominal voltage)

Voltage Level	Individual Harmonic Distortion Factor (%)	THD (%)
Low Voltage	5	8
Medium Voltage	3	5
High Voltage (Group 1)	1.5	2.5
High Voltage (Group 2)	1	1.5

2. Materials and Methods

This research aims to establish a foundational baseline for subsequent demand studies to be undertaken by the Strategic Public Company Corporación Nacional de Electricidad CNEL EP, Manabí Business Unit, concerning electromobility. This initiative will equip the distribution company with an enhanced tool for long-term planning of the electrical system, considering the potential impacts of electric vehicle integration across various load scenarios.

To analyze the impact on the electrical grid, this study references a case in which a specific number of electric vehicles (EVs) were randomly integrated into the system. Their incorporation was simulated using CYMDIST software, an advanced engineering tool for electrical planning, operation, and optimization studies [19].

The materials employed for the simulation are outlined as follows:

- Georeferenced electrical network, considering loads according to user type.
- Primary measurements or readings fromthe existing 13.8 kV feeder.
- Measurements or readingsconducted on an electric vehicle by CNEL EP.

2.1. Methodology

The methodology employed aligns with the diagram depicted in Figure 1.

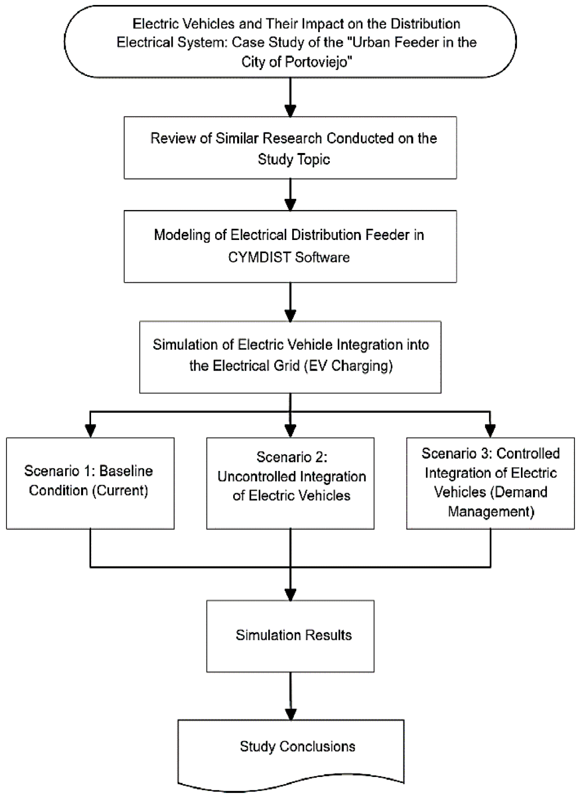

Figure 1. Flowchart of the Methodology Applied in the Study

2.1.1. Determination of Scenarios

To elucidate the impact on the electrical grid stemming from the integration of electric vehicle (EV) charging, three simulation scenarios projected up to the year 2030 have been delineated. These scenarios aim to assess the influence of EVs on various parameters, including demand, voltage drop, harmonics, and technical losses.

A) Scenario 1: Baseline Scenario, Feeder Projected to 2030.

The operational dynamics of the feeder under study are meticulously analyzed. For the projection to the year 2030, a vegetative annual growth rate of 3.5% for the feeder is considered. EV charging is not included in this scenario.

B) Scenario 2: Unrestricted EV Charging (Year 2030).

In this scenario, the projected situation is analyzed by simulating that EVs will be charged when their owners return home after work. Consequently, vehicle charging is expected to start shortly after 6:00 PM.

C) Scenario 3: Controlled EV Charging (Year 2030).

This scenario anticipates the year 2030, analyzing electric vehicle (EV) charging initiation post-10:00 PM to prevent its peak from coinciding with the system's maximum demand period. It also explores strategic demand management approaches, including the staggered charging of vehicles at times that do not overlap with peak demand. This involves implementing public policies to facilitate EV charging management. One such strategy is developing charging infrastructure in public and private parking areas at workplaces, enabling vehicles to charge throughout the day and thus mitigating peak demand impacts [20]. The aim is to model a controlled charging environment for residential and commercial users. EVs are progressively connected to the distribution grid post-workday, with charging activities extending overnight into the early morning.

2.1.2. Information on the Feeder under Study

The feeder chosen for this study is part of the electrical distribution system of Portoviejo, located in the province of Manabí. According to the projection for the year 2030, the pertinent data for this feeder are detailed in Table 4.

Table 4. Characteristics of the Feeder

Substation	Customers	Voltage (kV)	Main conductor	Main Line Length (km)	Active power (MW)	Reactive power (MVAR)
Portoviejo 2	2612	13.8	ACSR 3/0	2.1	4.77	1.1

As delineated in Table 4, the network comprises 2.10 km of ACSR 3/0 conductor along the main line. The base voltage is 13.8 kV, the projected active power load is 4.77 MW, and the reactive power load is 1.10 MVAR. The network serves a total of 2612 customers, including 954 residential users.

3. Results and discussion

This section presents the results of the scenarios described in section 2.1.1, which were simulated using CYMDIST software:

- Scenario 1: Baseline scenario, feeder projected to 2030.
- Scenario 2: Unrestricted EV charging (year 2030).
- Scenario 3: Controlled EV charging (year 2030).

3.1. Demand

Figure 2 illustrates the results of the three scenarios analyzed for 2030, comparing the impact of electric vehicles on demand within the simulated electrical system.

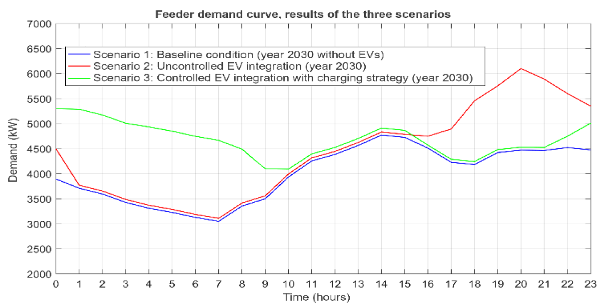

Figure 2. Demand Curve, Results Obtained in the Three Analyzed Scenarios (Consolidated)

According to Figure 2, Scenario 2, which features uncontrolled EV charging, exhibits a peak demand of approximately 6.1 MW. In contrast, Scenario 3, which implements controlled EV charging with demand management strategies, records a peak demand ofapproximately 4.5 MW during the same demand period.

This result underscores the positive impact of implementing demand management mechanisms on the feeder, significantly reducing peak loads during periods of maximum demand. Consequently, this enhances the network's efficiency and increases the feeder's available transport capacity.

This result aligns with the findings documented in [3], which assert that an uncontrolled charging strategy represents the worst scenariofor demand control and distribution network imbalances.

3.2. Voltage Drop

3.2.1. Voltage Profile

Figure 3 displays the voltage profile results for the simulated feeder for 2030, illustrating its behavior across the three proposed scenarios.

The detailed results depicted in Figure 3 elucidate the positive impact of employing demand management techniques in the EV charging process. Specifically, the voltage level along the simulated feeder in Scenario 3, which incorporates EV charging with load management strategies, is comparatively higher than that observed in Scenario 2, where EV charging is uncontrolled.

As illustrated in Figure 3, it is noteworthy that the implementation of charging strategies plays a crucial role in adhering to the ARCERNNR 002-20 regulations concerning the acceptable voltage range in the feeder, which is established at ±6%.

This result aligns with the findings of Lascano et al. [21], who report that integrating each electric vehicle (EV) leads to a progressive voltage drop, resulting in values that eventually exceed the limits prescribed by the referenced regulations.

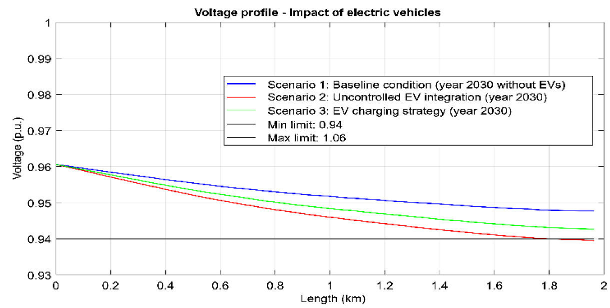

Figure 3. Voltage Profile, Results Obtained in the Three Analyzed Scenarios (Consolidated)

3.2.2. Voltage at the Farthest Node of the Feeder

Figure 4 illustrates the voltage behavior at the most distant node of the feeder across the three scenarios proposed in this study. As detailed in Section 3.2.1, the figure demonstrates that voltage levels at the farthest point of the feeder are higher when a demand management system for EV charging is implemented.

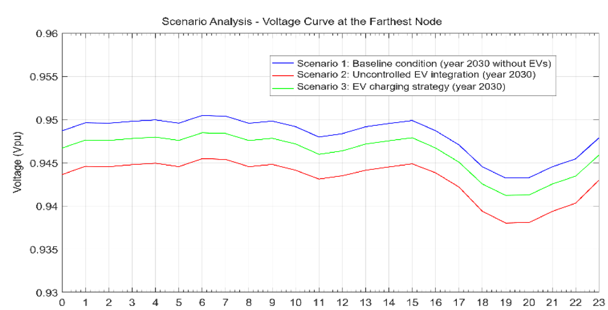

Figure 4. Voltage Profiles at the Farthest Node, Results in Three Scenarios

From Figure 4, it is evident that the voltage at the farthest point will be affected by the integration of EVs if strategies to mitigate this impact are not implemented. This result aligns with the findings of [21].

3.3. Total Harmonic Distortion Rate (THD %)

Table 5 presents the projected total harmonic distortion factor of voltage (THD %) for the year 2030, reflecting the impact of integrating 230 electric vehicles into the simulated feeder.

Table 5. Total Harmonic Distortion of Voltage in Medium Voltage (THD %)

NODE	kV L-N	180,00 Hz IHD (%)	300,00 Hz IHD (%)	420,00 Hz IHD (%)	THD (%)
Main Feeder Output (Phase A)	7.58	0.019	0.008	0.007	0.023
Main Feeder Output (Phase B)	7.67	0.023	0.011	0.009	0.027
Main Feeder Output (Phase C)	7.71	0.013	0.007	0.005	0.016

As depicted in Table 5, the integration of electric vehicle (EV) loads, as simulated in the study, ensures that the total harmonic distortion of voltage (THD%) remains within the 5% threshold established by the ARCERNNR 002-20 regulation for medium voltage.

For simulation purposes, EV loads were gradually introduced using CYMDIST software. Even when the number of connected EVs reached 230, no significant levels of harmonic distortion were observed at medium voltage. Consequently, it is anticipated that the total harmonic distortion percentage (THD%) at this voltage level will not be substantially impacted when slow-charging EVs (Type I) are charged with the simulated number of EVs.

On the other hand, readings obtained using a power quality analyzer during the electric vehicle (EV) charging process at low voltage levels indicate that the total harmonic distortion of voltage (THD%) remains within limits prescribed by the ARCERNNR 002-20 regulation. However, there is a notable presence of the third and fifth current harmonics, suggesting that the total harmonic distortion of current includes significant values that must beconsidered when multiple EVs are connected to the same circuit.

Figures 5, 6, and 7 depict the curves for the total harmonic distortion of voltage (THD%) at low voltage and those for the third and fifth harmonics, respectively, at the same voltage level (real data measured at low voltage).

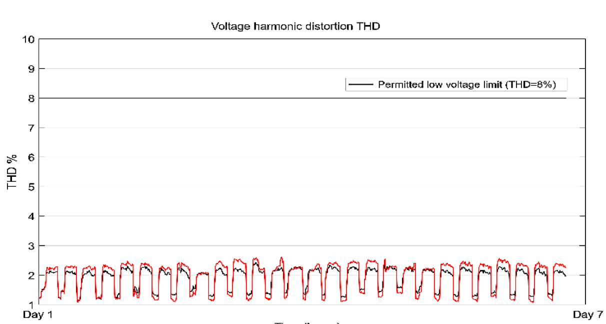

Figure 5. Total Harmonic Distortion of Voltage THD % Curve (Real Data from EV Charging Readings at Low Voltage)

The data depicted in Figure 5 indicate that the harmonic distortion rate during the low-voltage charging process of an electric vehicle remains within the parameters set forth by current quality regulations.

Figure 6 presents the third harmonic current for phases 1 (IhL1) and 2 (IhL2). When correlated with the data in Figure 5, these currents fall within the permissible values specified by current regulations. Notably, the harmonics illustrated in Figure 6 were observed exclusivelyduring the EV charging process.

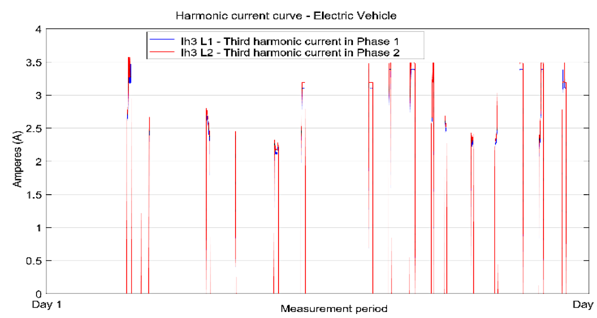

Figure 6. Third Harmonic Current Curve (Measured in EV, Low Voltage)

Figure 7 illustrates the fifth harmonic currents for phases 1 (IhL1) and 2 (IhL2). When compared with the data in Figure 5, these currents remain within the values allowed by current regulations for this parameter.

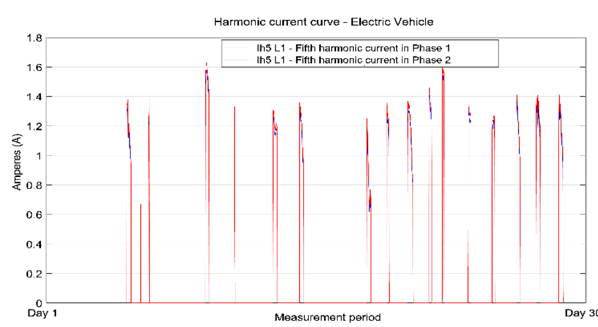

Figure 7. Fifth Harmonic Current Curve (Measured in EV, Low Voltage)

It is important to note that, despite the significant contributions of harmonics at low voltage (specifically, the third and fifth harmonic currents) during electric vehicle (EV) charging, these levels do not exceed the limits established by the ARCERNNR 002-20 regulation. However, these values will probably increase with the number of connected chargers. Consequently, the electric distribution utility should consider implementing preventive measures as necessary.

The case presented in this section aligns with the findings of [3], where the authors indicate that an increase in EV load can lead to harmonic distortion issues due to the heightened injection of the third harmonic.

3.4. Technical Losses

Table 6 presents the projected contribution of technical losses in power and energy for 2030, with detailed identification according to the analyzed scenario. The final projection for 2030 includes the integration of 230 electric vehicles.

Table 6. Projected Technical Losses for the Year 2030

Technical Losses	Year 2030 (baseline without EV load)	Year 2030 (uncontrolled EV load)	Year 2030 (controlled EV load)
Power (kW)	151.51	265.21	200.87
Energy (MWh/year)	790.68	1333.95	1026.49

As indicated in Table 6, integrating electric vehicles into the grid will substantially increase the system's technical power and energy losses. Specifically, when comparing the baseline scenario (Scenario 1, projected for 2030 without EVs) to the scenario where EVs are charged uncontrollably (Scenario 2), technical losses increase by 113 kW. In contrast, if EVs are charged using demand management strategies (Scenario 3), the increase in technical losses is limited to 49.36 kW compared to the baseline scenario.

These results demonstrate the positive impact of implementing demand management methods to reduce operational losses within the system.

4. Conclusions

This study has successfully established a baseline that will inform future demand studies conducted by the Strategic Public Company Corporación Nacional de Electricidad CNEL EP, Manabí Business Unit, focusing on electromobility.

The analysis has confirmed the effects on a feeder's demand curve due to controlled and uncontrolled electric vehicle (EV) charging. In scenarios where residential EV charging is concentrated at a specific hour of the day (uncontrolled charging), demand can increase by up to 1 MW for every 160 vehicles. Conversely, when EVs are charged in a controlled manner, the demand increase is estimated to be around 0.1 MW for the same number of electric vehicles connected to the grid.

Based on the cases studied, it is clear that the controlled scenario is the most suitable for implementing EV charging within a distribution feeder. Although voltage drops are inherent to the load characteristics in this scenario, they are considerably less severe compared to the uncontrolled charging scenario. In the latter, there is a significant deterioration in the voltage profile, potentially degrading to levels below those permitted by the quality regulations cited in this document.

Incorporating EV charging introduces an additional load on the electrical system. To mitigate the risk of high demand peaks that could lead to grid instability, component overloading, and reduced lifespan of infrastructure, it is advisable to manage this load through effective electric demand management mechanisms.

The implementation of electric demand management mechanisms to regulate EV charging (controlled demand) has effectively flattened the feeder's demand curve by reducing peak demands. This strategic control enhances the network's efficiency and, consequently, increases the available transport capacity within the feeder. In the cases examined, this approach resulted in a favorable reduction of 1.6 MW in peak demand when comparing Scenario 2 with Scenario 3 during the same demand period.

An additional positive impact on the system is the enhancement of voltage levels along the feeder, as evidenced by the improved voltage profile. This observation confirms that the voltage level at the most distant point of the feeder remains elevated when EV charging is controlled.

With the integration of an average of 230 electric vehicles utilizing Type I charging, the harmonic distortion rate does not compromise compliance with the Total Harmonic Distortion (THD%) standards for medium voltage in the analyzed feeder. Specifically, the feeder exhibits an approximate average harmonic distortion rate of 0.02% at its output. However, it is essential to note that the harmonic distortion rate (THD) may escalate with the increase in connected chargers, necessitating careful monitoring and management to maintain regulatory compliance and system integrity.

Data collected from an electric vehicle have shown that at low voltage, the third and fifth current harmonics make significant contributions. This finding indicates that the total harmonic distortion of current encompasses considerable values, which should be carefully considered by the distribution company.

The gradual integration of electric vehicles (EVs) into the electrical distribution system will considerably increase technical power losses. Specifically, for the feeder under study, technical losses may increase by approximately 113 kW when EV charging is uncontrolled. In contrast, adopting demand management methods and controlled EV charging can significantly mitigate these losses, limiting the increase to just 49.36 kW.

References

[1] H. Pico, I. Pazmiño, and B. Ponce, "Análisis de los factores que intervienen en el envejecimiento prematuro de las baterías de ion-litio mediante modelo teórico validado en laboratorio,"

Revista Técnica Energía, vol. 17, no. 2, pp. 83–91, 2021. [Online]. Available: https://doi.org/10.37116/revistaenergia.v17.n2.2021.432.

[2] CEPAL, *Propuesta de marco regulatorio para acelerar la inversión en electromovilidad mediante la reconversión de vehículos que usan combustibles fósiles*. Comisión Económica para América Latina y el Caribe, 2021. [Online]. Available: https://bit.ly/3QBManI

[3] P. Rodríguez-Pajarón, A. Hernández, and J. V. Milanović, "Probabilistic assessment of the impact of electric vehicles and nonlinear loads on power quality in residential networks," *International Journal of Electrical Power & Energy Systems*, vol. 129, p. 106807, 2021. [Online]. Available: https://doi.org/10.1016/j.ijepes.2021.106807

[4] A. A. Ismail, N. T. Mbungu, A. Elnady, R. C. Bansal, A. Kadir Hamid, and M. AlShabi, "Impact of electric vehicles on smart grid and future predictions: a survey," *International Journal of Modelling and Simulation*, vol. 43, no. 6, pp. 1041–1057, 2023. [Online]. Available: https://doi.org/10.1080/02286203.2022.2148180

[5] A. Jenn and J. Highleyman, "Distribution grid impacts of electric vehicles: A California case study," *iScience*, vol. 25, no. 1, p. 103686, 2022. [Online]. Available: https://doi.org/10.1016/j.isci.2021.103686

[6] A. Ibrahim and F. Jiang, "The electric vehicle energy management: An overview of the energy system and related modeling and simulation," *Renewable and Sustainable Energy Reviews*, vol. 144, p. 111049, 2021. [Online]. Available: https://doi.org/10.1016/j.rser.2021.111049

[7] Y. Sáez, E. Collado, and M. Serrano, "Modelado de estaciones de recarga lenta para vehículos eléctricos mediante software: revisión del estado del arte," *Revista de Iniciación Científica*, vol. 7, no. 2, pp. 9–19, 2021. [Online]. Available: https://doi.org/10.33412/rev-ric.v7.2.3334

[8] S. Goel, R. Sharma, and A. K. Rathore, "A review on barrier and challenges of electric vehicle in India and vehicle to grid optimisation," *Transportation Engineering*, vol. 4, p. 100057, 2021. [Online]. Available: https://doi.org/10.1016/j.treng.2021.100057

[9] D. T. Sandoval and E. G. Torres, "Respuesta de demanda de energía por introducción de vehículos eléctricos: estado del arte," *Revista de I+D Tecnológico*, vol. 16, no. 1, pp. 5–11, 2020. [Online]. Available: https://doi.org/10.33412/idt.v16.1.2433

[10] A. G. Anastasiadis, G. P. Kondylis, A. Polyzakis, and G. Vokas, "Effects of increased electric vehicles into a distribution network," *Energy Procedia*, vol. 157, pp. 586–593, 2019. [Online]. Available: https://doi.org/10.1016/j.egypro.2018.11.223

[11] H. Das, M. Rahman, S. Li, and C. Tan, "Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review," *Renewable and Sustainable Energy Reviews*, vol. 120, p. 109618, 2020. [Online]. Available: https://doi.org/10.1016/j.rser.2019.109618

[12] A. K. Karmaker, S. Roy, and M. R. Ahmed, "Analysis of the impact of electric vehicle charging station on power quality issues," in *2019 International Conference on Electrical, Computer and Communication Engineering (ECCE)*, 2019, pp. 1–6. [Online]. Available: https://doi.org/10.1109/ECACE.2019.8679164

[13] S. Habib, M. M. Khan, F. Abbas, L. Sang, M. U. Shahid, and H. Tang, "A comprehensive study of implemented international standards, technical challenges, impacts and prospects for electric vehicles," *IEEE Access*, vol. 6, pp. 13 866–13 890, 2018. [Online]. Available: https://doi.org/10.1109/ACCESS.2018.2812303

[14] S. Sharma, A. K. Panwar, and M. Tripathi, "Storage technologies for electric vehicles," *Journal of Traffic and Transportation Engineering (English Edition)*, vol. 7, no. 3, pp. 340–361, 2020. [Online]. Available: https://doi.org/10.1016/j.jtte.2020.04.004

[15] L. González, E. Siavichay, and J. Espinoza, "Impact of EV fast charging stations on the power distribution network of a Latin American intermediate city," *Renewable and Sustainable Energy Reviews*, vol. 107, pp. 309–318, 2019. [Online]. Available: https://doi.org/10.1016/j.rser.2019.03.017

[16] ARCERNNR, *Panorama Eléctrico*. Agencia de Regulación y Control de Energía y Recursos Naturales No Renovables, 2022. [Online]. Available: https://acortar.link/jikL6I

[17] A. Mohammad, R. Zamora, and T. T. Lie, "Integration of electric vehicles in the distribution network: A review of PV based electric vehicle modelling," *Energies*, vol. 13, no. 17, 2020. [Online]. Available: https://doi.org/10.3390/en13174541

[18] AECERNNR, *Regulación Nro. ARCERNNR - 002/20, Calidad del servicio de distribución y comercialización de energía eléctrica*. Agencia de Regulación y Control de Energía y Recursos Naturales No Renovables, 2020. [Online]. Available: https://bit.ly/44vx74C

[19] EATON. (2024) Análisis de sistemas de distribución CYMDIST. EATOn Power Business World Wide. [Online]. Available: https://bit.ly/3Uu3L1T

[20] A. A. Navarro Espinosa, M. A. Díaz Verriera, and J. M. Yáñez Castro, "Vehículos eléctricos y el impacto en el sistema de potencia. Análisis de la operación y emisiones," *Revista de energía de Latinoamérica y el Caribe ENERLAC*, vol. 5, no. 2, pp. 14–39, 2021. [Online]. Available: https://bit.ly/44zJXiw

[21] J. Lascano, L. Chiza, R. Saraguro, C. Quinatoa, and J. Tapia, "Estimación de la demanda de una estación de carga para vehículos eléctricos mediante la aplicación de métodos probabilísticos," *Revista Técnica Energía*, vol. 20, no. 1, pp. 52–64, 2023. [Online]. Available: https://doi.org/10.37116/revistaenergia.v20.n1.2023.569