Assessment of Harmonic Currents in a Low Voltage Network with the Presence of Electric Vehicles and a Peak Shaving Program

Andres D. Quevedo R, Jorge A. Alarcon V., Herbert E. Rojas C.

District University Francisco José de Caldas, Faculty of Engineering, Bogotá, Colombia. Email: adquevedor@udistrital.edu.co

This paper presents an assessment of the main parameters associated with current harmonics caused by the inclusion of electric vehicle (EVs) charging stations in a low-voltage test network. For this work, the standard IEEE 519 (similar to Colombian technical standard NTC-5001) is taken as the reference to check and compare the maximum harmonic reference levels when considering different EVs penetration levels, as well as a demand-side management (DSM) program considered to reduce peak shaving in the test network. During the study, three types of charging stations with different harmonic pollution profiles were considered. The DSM program was developed in Matlab® while the electrical behavior of the network, including EVs, was analyzed using simulations in Digsilent®. The results show that the implementation of the DSM program prevents exceeding the technical limits of the network and it helps to decrease harmonic pollution, mitigating the possible effects that could be spread in the network.

Keywords: Electric vehicle, demand side management.

INTRODUCTION

The increasing integration of EVs into electrical networks (grids) has caused several issues such as overloading of lines and transformers and power quality affectations, among others [1], [2], [3], [4]. Furthermore, the connection between EVs and the grid is made through charging stations that employ technology based on power electronic converters [5] and allow the interaction of EVs batteries and the grid.

In the case, which EVs are connected in bidirectional mode with V2G (charge and generation mode), it indicates that charging stations operate as a rectifier when the battery is in charging mode and as an inverter when the battery delivers energy to the grid [6]. The use of these types of charging stations could cause high level of harmonic pollution to the grid due to their power electronic converters and components. Consequently, current harmonics issues are generated by EVs charging stations, conducting to various studies aimed to reduce the effects of harmonic pollution on electrical distribution networks.

In the literature, diverse solutions have been proposed to mitigate the harmonics caused by EV charging stations. For example, LCL filters are used in [5] for a bidirectional charging station, while a type of inverter used in photovoltaic generator is used as an active filter to reduce grid harmonics in [6]. These experiences show that to achieve effective mitigation of harmonics due to EVs, an adequate characterization of the charging station is required, which can be developed through simulations [2], [7], [8] or measurements [5], [6], [9].

When a set of EVs is connected to the grid, it is necessary to evaluate the cumulative effect of these loads working simultaneously. In addition, it is necessary to consider that these devices have a nonlinear behavior that impacts the power quality parameters, affecting the users connected to the grid. Under this context, this paper analyses the harmonic pollution parameters of the electrical network (THDi, TDD, and THDv) caused by the integration of EVs including different penetration levels. This analysis was made within the limits established by the standard IEEE 519 (similar to Colombian Standard NTC 5001).

During the study, a demand-side management (DSM) program, focused on managing the charging and discharging of EVs, is implemented to reduce the demand peaks in the network. Likewise, the interaction of EVs and the network is carried out through the charging stations, which manage the vehicles that are charging and discharging on the network. This is done considering the energy requirements of the vehicles, and both the maximum load capacity and the demand load profile of the network (residential cluster). Thus, it is possible to compare different EVs penetration levels (scenarios), the harmonic pollution caused by these loads, and their effects on the system.

Estimation of electrical network consumption and electric vehicles in the system

The electrical test system used in this work is a low-voltage distribution network for a residential cluster of 80 users (apartments), located in Bogotá, Colombia. Each user has its own parking zone which includes and EV charging station. The main characteristics of the network are: (a) a three-phase 75 kVA transformer; (b) four buildings with a total of 80 users; (c) common areas and elevators for each building, a backup power plant and water pumps, among others; (d) each user has a parking zone with one charging station.

Load profile of users and common areas

The consumption models frequently used to represent residential demand are subject to uncertainties such as the number of household members, lifestyle, quantity and type of home appliances, among others [10]. The model proposed in this study was achieved using a stochastic model developed in [11], which incorporates the consumption patterns of residential users. The model estimates the power consumed by the users using a normal probability function, expressed in terms of the active power. Additionally, a timely load consumption curve for the common areas was defined.

Fig. 1 shows the results obtained for each load (users and common areas) based on the simulation of two days of consumption. The total load demand seen from the low voltage side of the power transformer (residential cluster substation) is presented in blue. The peak demand of the system is between 60% and 65% of the installed capacity of the transformer (highlighted in red).

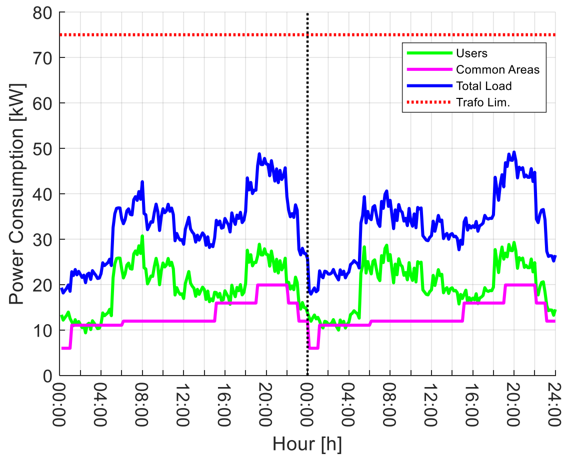

Fig. 1 Load curve of the users and common areas network

Charging profile of the electric vehicles

The vehicles considered in this study are full electric vehicles that can be connected to the grid as plug-in electric vehicles. To estimate the load demanded by the batteries, the methodology developed in [12] was used. In this, a Log-Normal probability function is applied to calculate the amount of power that must be delivered by the grid to the EVs. Furthermore, the connection pattern presented in [13] was taken as reference, where the EVs are connect to the grid according to arrival order. In the case of the residential cluster, it is expected that most of the EVs will be connected in the afternoon and evening hours.

Aggregated load profile of electrical network

When considering the inclusion of EVs in the network, an increase in power consumption is expected. This situation depends on the penetration level of EVs and their impact on the total power demand, compared to the initial conditions (without EV connections). For example, with a 70% penetration level, which corresponds to 56 EVs connected simultaneously to the grid, the aggregated load profile is shown in Fig. 2.

As a result of the integration of EVs into the network there is a noticeable increase in power demand from 18 to 22 hours, reaching up to 120% of the installed power of the transformer. This situation creates a peak of demanded load that affects the operation of the grid. The increase in consumption may cause issues such as drop voltages, overcurrent and overheating on power conductors, and leading potential failures in the power transformer and conductors, if these conditions persist.

Given the penetration level above mentioned, it is necessary to implement a DSM program to reduce load peaks and return the electrical network to normal operating conditions (below its maximum operational limits).

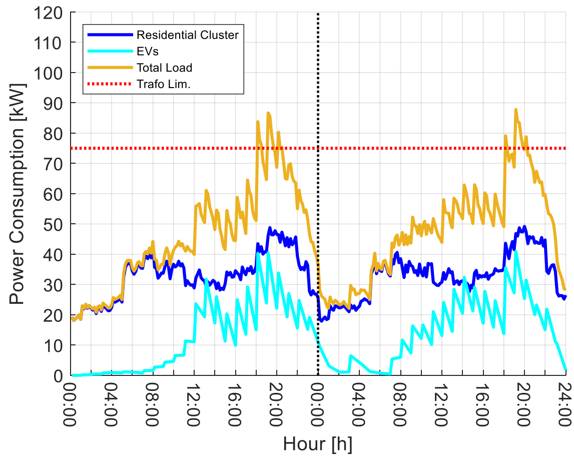

Fig. 2 Aggregated load curves with 70% PL of EVs

Demand side management Program

As evidenced in the previous section, the integration of EVs into the grid generates technical problems such as exceeding the installed capacity, that leads to energy losses. Therefore, it is important to implement a DSM program that allows controlling and managing the connections of EVs to the grid. The strategy to be implemented is focused to ensure operational constraints of the grid such as the maximum power capacity, as well as the upper and lower voltage limits at each node. The main objective is to ensure the required supply for all loads while maintaining the operational limits in the electrical network under test.

The above target can be achieved by managing the time in which the EVs are plugged into the grid, considering the power consumed by users, the power required by the common areas at the same time, and the maximum capacity of transformer and conductors. Based on this information, the time in which EVs should be connected to the network is analyzed for a given time. This strategy helps to reduce the load peaks and to avoid the possibility of exceeding the capacity of the grid. To accomplish this objective two factors must be analyzed:

- System requirements: these are the operational conditions required for each element connected to the grid. In this case, the system must be operated within the limits of the power transformer (75kVA), and it must be guaranteed that EVs are fully charged before their departure.
- Information on loads connected to the grid: among the most relevant information are the consumption characteristics of residential users, common areas and EVs.

DSM program peak shaving

This program aims to control power consumption during peak periods and ensure it does not exceed the transformer capacity. It has been observed that the peak periods occur between 18 to 22 hours. This approach helps to delay the investment required to increase the power transformer capacity and the main feeders of the grid. Additionally, it ensures supplying the changing power needs of the users and EVs. The procedure to apply this program is composed of three steps described below:

Step 1: Identify the power to be shaved: the management strategy evaluates during the day the power needs hour by hour to determines which vehicles should start recharging at plug-in time and which ones should postpone their connection for recharging (load to be shaved). This strategy is done according to the Equation (1).

$$Pot_{SH} = \sum_{i=1}^{80} \left(P_{Ap}(i) + P_{EV}(i) + P_{CS}(i) \right) - P_{TR} \qquad (1)$$

Where Pot_{SH} is the power that must be shaved for the time frame i, $P_{Ap}(i)$ is the power of the i-th apartment (residential user), $P_{CS}(i)$ is the power of the common areas at the same time i, $P_{EV}(i)$ is the power of the i-th vehicle plugged at time i, and P_{TR} is the nominal capacity of the power transformer.

Step 2. EVs charging hierarchy according to power: once the power to be shaved is determined, EVs are organized from the highest to the lowest power requirement (charging needs) to choose which ones should be connected. The goal of the program is to ensure that demand is supplied while controlling overload conditions by disconnecting the minimum number of EVs. Finally, the delayed EVs would be prioritized to start recharging at the next frame of time. Table 1 shows an example where 8 EVs are plugged during a frame of time. In this case, if the power to be shaved is 20 kW, the DSM program postpones the vehicles with IDs 74, 75, 45 and 68. These EVs represent greater power consumption for the grid.

Table 1 Organization of EVs for DSM program

ID EV	DEMAND POWER [kW]	AGGREGATED POWER [kW]
74	6,5	6,5
75	5,9	12,3
45	5,0	17,3
68	4,0	21,3
21	2,4	23,7

Step 3. Deferring of EVs connection: when the EVs to be disconnected are identified, the DSM program postpones their recharging stage for the next frame of time.

By following these steps, a load curve that fits within the operational limits of the network is obtained, ensuring that the capacity is always below the maximum limits of the conductors and the transformer. An example of the implementation of the DSM program is shown in Fig. 3, which simulates a residential cluster with a 100% of EVs penetration level.

As can be seen in Fig. 3, the maximum peak of load is 103 kW, and occurs at 20 hours, meaning a 37.3% overload of the transformer capacity. These situations could lead to a reduction in the lifetime of the facilities or failures in the medium and long term. When the DSM program is implemented, the aggregated power load of the system (orange dashed line) remains below the limits because of the shifting of power consumption towards off-peak hours (early morning of the next day).

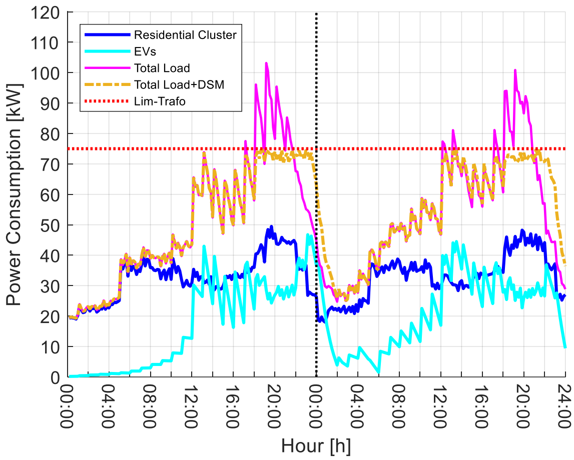

Fig. 3 Load curve with 100% PL of EVs with DSM program

Harmonic modeling of charging stations

The chargers used by EVs causes harmonic currents associated with their normal operation. The massive use of charging stations produces, in some periods, a considerable increase in harmonic pollution injected to the network. Typically, the chargers use a 4-pulse (single-phase inverter) or 6-pulse (three-phase inverter) rectifier, connected to a DC/DC converter that controls the output voltage and allows batteries of VEs to be recharged. Considering a symmetric rectifier with an ideal source, the order of the harmonics can be established by the following expression:

$$h = k * p \pm 1 \qquad (2)$$

Where p is the number of rectifier pulses and k is the harmonic amplitude in percentage, referenced to the magnitude of the fundamental current component [2]. A slow three-phase charging station is used in the simulations, whose time of recharging may oscillate between 4 to 8 hours. These chargers inject current harmonics of odd order, excluding the third harmonic and their multiples. After reviewing the literature, and under the aspects explained above, for this study, three chargers with different harmonic current profiles (low, medium, and high) were selected.

In this way, the harmonic current profiles of the charging stations considered during tests are the following: the charger described in [14] has a low contamination profile, which was modeled in a laboratory using a perfect sinusoidal voltage source. The charger with a medium contamination profile presented in [6] was characterized by using a real EV that runs small daily distances. Finally, the charger with a high contamination profile shown in [4] represents the measurements carried out on three chargers of different brands that were monitored for three years.

Table 2 shows the harmonic profile of the chargers mentioned. Due to the difference in the measurements taken for each charger, only harmonics up to order 13 were considered. Additionally, it was observed that the higher order harmonics are lower compared with the fundamental current. It is important to mention that this study does not consider the angular phase shift of the harmonics, because this parameter was not available in the reports.

Table 2 Harmonic Contribution Components of Charging Stations

Harmonic order	Low contribution	Medium contribution	High contribution
1	100,00%	100,00%	100,00%
5	0,20%	20,00%	55,00%
7	0,44%	14,30%	40,00%
11	0,46%	9,10%	16,25%
13	0,47%	7,70%	12,50%

Methodology for harmonic evaluation

This section describes how the results obtained during the implemented simulations are evaluated, having the IEEE 519 Standard as the reference framework. The equivalent standard in the Colombian context is NTC 5001.

Evaluation periods or intervals

According to the standard IEEE-519, for recording the harmonic components of voltage and current a continuous measurement of one week with 10-minute intervals is recommended. However, since consumption patterns of residential users do not exhibit significant variations in a week, the grid under study was simulated for two days, resulting in 288 packages of information. During that period, the effects of all loads are included to analyze the voltage profile, the performance of the electrical network, as well as the DSM program described in Section III.

Aspects to be considered for harmonics evaluation

To evaluate harmonics in the test system, according to the standard, the location of the measurement devices (monitoring points in the simulations) must be selected, and the electrical parameters to be recorded must be defined, as indicated ahead:

- Point of common coupling (PCC): corresponds to the node where the main feeder is connected (low voltage output of the power transformer) and the switchboard of the electrical installation that groups all the loads.
- Total harmonic distortion of current (THDi) and voltage (THDv): distortion rate referenced to the fundamental frequency (60 Hz) that is recorded at the PCC. In line with the reference standard, the total harmonic distortion limits for voltage and current are presented in Table 3 and Table 4, respectively.

Table 3 Voltage harmonic distortion limits [15]

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0$ kV	5.0	8.0
1 kV $\leq V \leq$ 69 kV	3.0	5.0

Table 4 Current harmonic distortion limits [15]

Maximum harmonic current distortion in percent (%) of I_L			
Individual harmonic order (odd harmonic)			
I_{SC}/I_L	$3 \leq h \leq 11$	$11 \leq h \leq 17$	TDD
<20	4.0	2.0	5.0
20<50	7.0	3.5	8.0

- Total demand distortion (TDD): total harmonic distortion rate referenced to the maximum current measured at the PCC. The TDD obtained from simulations corresponds to the 95th percentile of the recorded data, which is calculated according to Equation 3.

$$TDD = THD_i \frac{I1}{IL} \qquad (3)$$

- Demand power: is the power demanded by the grid at the PCC, which in this case corresponds to the measurement on the power transformer.
- Electrical parameters of the network to be analyzed
- To evaluate the harmonics, it is necessary to obtain several parameters of the electrical network that are taken from the simulations:
- Load Current (IL): corresponds to the maximum load current required by the grid during the whole simulation period with a 95th percentile.
- Short circuit current (Ish): is the short circuit current on the low voltage side of the transformer. It is calculated using Equations (4) and (5).

$$I_N(BT) = \frac{Sn}{\sqrt{3} * Vs} \qquad (4)$$

$$I_{sh}(BT) = \frac{I_N(BT)}{Ucc} \qquad (5)$$

Where I_N and V_S are the rated current and voltage on the low voltage winding of the transformer, while U_{cc} is the short-circuit impedance, and $I_{sh}$is the short-circuit current of the transformer. Considering that the rated power of the transformer is 75kVA, the low voltage is 208V and the short circuit impedance is 3.5%, the short circuit current of the system using equation (4) y (5) is 5948 Amperes.

Additional currents: these are the total system current ($\boldsymbol{I_{RMS}}$) and the fundamental current ($\boldsymbol{I_1}$) that are extracted from the simulation at the PCC.

Test scenarios and results

This section presents the test scenarios proposed and the results obtained after implementing the DSM program. During these tests, the components of current (THDi), voltage (THDv) and total (TDD) harmonics have been recorded as indicated in the IEEE 519 standard.

Scenario definitions

Three study cases with different EV penetration levels are established in order to demonstrate the impact associated with the integration of EVs on the grid.

Scenario #1: with 30% penetration level

Scenario #2: with 70% penetration level. This represents a moderate EVs penetration that could be feasible in reality.

Scenario #3: with a 100% penetration level. This is the most power-demanding case for the grid, with 80 EVs connected.

For each scenario, three simulations were carried out using the battery chargers indicated in Section IV (low, medium, and high pollution profiles), but including a different number of them in each simulation, as follows:

Simulation Group 1: all types of chargers are used equally. For example, in scenario # 1, each type of charger is used by 8 users (24 in total).

Simulation Group 2: The charger with low harmonic contribution is used by 10% of users, while the charger with medium harmonic contribution is used by 60% and the chargers with high harmonic contribution are used by 30% of users.

Simulation Group 3: The charger with low harmonic contribution was not used, while the chargers with medium and high harmonic contribution are used by 70% and 30% of users, respectively.

The above scheme implies that the simulation of Group 3 could have the greatest impact on harmonics injected into the grid, while the simulation of Group 1 will cause the least impact.

Results from the simulations

Scenario #1: 30% of EVs penetration level

In this scenario, the load curve does not exceed the installed capacity of the grid. The EVs demand a peak of 17.3 kW, while the maximum power reaches 61.8 kW. In this case, the use of the DSM program is not required since the capacity of the power transformer is not exceeded.

In general, the harmonic measurements for this scenario are as follows: (a) the limit for TDD is 8% because the $Isc/Ilthe$ ratio is between 20 and 50; (b) the THDv limit is 8% since the PCC is less than 1 kV; (c) the THDi limit is 7% since it has the same ratio as the TDD. In this context, and according to the results presented in Table 5, the TDD exceeds the limits in cases where medium and high harmonic pollution are presented (simulations from Group 2 and Group 3), while the THDi exceeds the limit for all cases evaluated. This shows the need to implement harmonic mitigation strategies even when the transformer capacity is not exceeded. On the other hand, for all cases, the THDv remains under the limits.

Table 5 Estimation of harmonics parameters for scenario #1

Simulation Group	TDD [%] (P 95%)	THDi [%] (P 95%)	THDv [%] (P 95%)
1	7,4	9,0	1,8
2	9,5	13,2	2,3
3	9,0	13,9	2,2
*Ratio $Isc/Il = 32$ ** DSM no required			

Scenario #2: 70% of EVs penetration level

In this scenario, a total of 56 vehicles are connected to the grid, and they have a considerable impact on the operational conditions of the network. In this way, the total consumption of the users exceeds the capacity of the transformer between 6:00 pm and 8:00 pm. The total load curve presents a peak of demand of 90 kW, which reflects an overload of 15 kW, nearly 20 % of the maximum power of the transformer.

The harmonic limits defined for scenario 2 are the same as those for scenario 1, because the Isc/Il ratio is between 20 and 50. According to Table 6, the TDD, THDi and THDv values from the simulations exceed the reference values in all cases. This is the effect of the considerable penetration level of EVs into the grid.

Table 6 Estimation of harmonics parameters for scenario #2

Sim. Group	TDD [%] (P 95%)			THDi [%] (P 95%)			THDv [%] (P 95%)		
	NO DSM	DSM	Δ%	NO DSM	DSM	Δ%	NO DSM	DSM	Δ%
1	12,1	11,4	-0,7	16,9	16,9	0	4,3	4	-0,3
2	14,4	13,9	-0,5	18,1	17,8	-0,3	5,1	4,9	-0,2
3	15	14,4	-0,6	19,3	18,9	-0,4	5,4	5,1	-0,3
*Ratio $Isc/Il = 22.89$									

In this case, the DSM program manages the load curve demanded by the residential cluster, and keeping the total consumption below the network capacity and the operational limits of the transformer and conductors.

According to the results in Table 6, the columns DSM (when a DSM program is implemented) show that technical limits are met, while the TDD and THDi overpass the limits. However, there is a positive effect that causes a 0.5% reduction in these two parameters. It was also observed in simulation Group 1 and Group 2 that the DSM program reduces the THDv to values allowed. Finally, the THDi increases considerably in scenario #2 compared to scenario #1, since there is a greater number of EVs injecting harmonics into the grid. The results show that the grater the inclusion of EVs, the worse the operating conditions and the power quality in the grid.

Scenario #3: 100% penetration level of EVs

In this scenario, the 80 EVs are connected to the grid, showing a severe impact on the operational conditions of the grid. For this case, the consumption exceeds the maximum capacity of conductors and transformer for almost 4 hours a day. The power of the system with this penetration level reaches up to 105 kW, which corresponds a transformer overload of the 40%.

Later, implementing the DSM program, it is possible to shift the excess of power identified in the rush hours to a later during the night, preventing the transformer overload. This allows operate without exceeding the transformer capacity from 6:00 pm to 12:00 am as shown in Fig. 3. For the simulation groups, the DSM program allows managing the power required by the grid while adjusting the technical operating conditions of the network.

In this scenario, the harmonic limits are more demanding for current harmonics: (a) the TDD limit is 5% because the ratio Isc/Il is under 20; (b) the THDi limit is 4%; (c) the THDv limit remains at 8%. According to the simulations and the results presented in Table 7 the implementation of the DSM program reduces 4.3% the TDD levels, which is relevant and demonstrates that this program allows the improvement of power quality parameters. However, in this case, due to due to the demanding limits, the harmonic parameters exceed the values established by the technical standard.

Table 7 Estimation of harmonics parameters for scenario #3

Sim. Group	TDD [%] (P 95%)			THDi [%] (P 95%)			THDv [%] (P 95%)		
	NO DSM	DSM	Δ%	NO DSM	DSM	Δ%	NO DSM	DSM	Δ%
1	15,0	13,9	-1,1	22,6	22,2	-0,4	6,3	5,7	-0,6
2	16,7	15,6	-1,1	22,7	24,0	1,3	7,2	6,6	-0,6
3	21,2	16,9	-4,3	24,9	24,3	-0,6	8,6	7,0	-1,6
*Ratio $Isc/Il = 19$									

Conclusions

In this paper, the proposed scenarios confirm that the DSM program accomplished the main objective of ensuring the EVs recharging, and maintaining the operation limits of the electrical network. In addition, the results obtained confirm that higher penetration levels of EVs produce higher negative impacts on the operational conditions such as overload of the conductors and the transformer. However, this situation can be mitigated by implementing the DSM program proposed. The power quality indicators related to current harmonics exceed the values recommended by the IEEE-519 standard in all proposed scenarios, while the indicators related to TDD have an opposite behavior, reaching a reduction of 4% in the best case. Although the DSM program reduces the TDD as the penetration of EVs increases, the THDi does not show a reduction when increasing the number of EVs injecting harmonics to the grid, while the THDv improves in most of the proposed scenarios.

Although a complete reduction of the harmonic pollution of the network is out of the scope of this study, other types of advanced demand management strategies can be proposed and analyzed in future works. These strategies should consider power quality restrictions and include other mechanisms to mitigate the worst effects of the harmonics on the electrical network.

References

[1] R. Carter, A. Cruden, A. Roscoe, D. Densley, and T. Nicklin, “Impacts of harmonic distortion from charging electric vehicles on low voltage networks,” 26th Electric Vehicle Symposium 2012, EVS 2012, vol. 1, pp. 757–762, 2012.

[2] X. Gao, S. Dong, W. Gao, and S. Cui, “A Composite Control Strategy for Suppressing the Current Harmonic at the Grid Side of V2G Charger,” 2018 2nd IEEE Advanced Information Management,Communicates,Electronic and Automation Control Conference (IMCEC), no. Imcec, pp. 1038–1042, 2018.

[3] L. Li, B. Wang, and Y. Deng, “Model establishment and harmonic analysis of electric vehicle charger,” 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA), pp. 2204–2209, 2018.

[4] S. H. Berisha, G. G. Karady, R. Ahmad, R. Hobbs, and D. Karner, “Current harmonics generated by electric vehicle battery chargers,” in Proceedings of International Conference on Power Electronics, Drives and Energy Systems for Industrial Growth, IEEE, 1996, pp. 584–589. doi: 10.1109/PEDES.1996.539678.

[5] C. Kattmann, K. Rudion, and S. Tenbohlen, “Detailed power quality measurement of electric vehicle charging infrastructure,” in 24th International Conference on Electricity Distribution, Glasgow, 2017, pp. 12–15.

[6] J. P. Trovao, P. G. Pereirinha, L. Trovao, and H. M. Jorge, “Electric vehicles chargers characterization: Load demand and harmonic distortion,” in 11th International Conference on Electrical Power Quality and Utilisation, IEEE, Oct. 2011, pp. 1–7. doi:

10.1109/EPQU.2011.6128871.
[7] V.-L. Nguyen, T. Tran-Quoc, and S. Bacha, “Harmonic distortion mitigation for electric vehicle fast charging systems,” in 2013 IEEE Grenoble Conference, IEEE, Jun. 2013, pp. 1–6. doi: 10.1109/PTC.2013.6652435.
[8] S. Müller, J. Meyer, P. Schegner, and S. Djokic, “Harmonic Modeling of Electric Vehicle Chargers in Frequency Domain,” Renewable Energy and Power Quality Journal, no. 13, pp. 396–401, Mar. 2015, doi: 10.24084/repqj13.337.
[9] A. Camacho, L. Cortez, J. Cortez, G. Hernandez, R. Gonzalez, and P. Garcia, “Characterization of Harmonic Distortion on the Electric Network Caused By a Battery Charger for Electric vehicles,” Asian Journal of Empirical Research journal, pp. 1331–1342, 2013.
[10] D. Saker, S. Millward, M. Vahdati, and E. Essah, “Characterising and Managing Domestic Electrical Demand : A Literature Review,” TSBE Engineering Doctorate Conference, no. i, p. 14, 2012.
[11] A. M. Vega Escobar, “Gestión de la energía eléctrica domiciliaria con base en la gestión activa de la demanda,” Universidad Distrital Francisco José de Caldas, 2018.
[12] A. D. Quevedo, F. Santamaria, and J. A. Alarcon, “Analysis of plug-in electric vehicles penetration in residential buildings under deterministic and stochastic scenarios,” in 2016 IEEE PES Transmission & Distribution Conference and Exposition-Latin America (PES T&D-LA), IEEE, Sep. 2016, pp. 1–6. doi: 10.1109/TDC-LA.2016.7805648.
[13] C. Mendoza, A. Quintero, F. Santamaria, and A. Alarcon, “Estimation of electric energy required by electric vehicles based on travelled distances in a residential zone,” Tecciencia, vol. 11, no. 21, pp. 17–24, 2016, doi: 10.18180/tecciencia.2016.21.4.
[14] L. Kutt, E. Saarijarvi, M. Lehtonen, H. Molder, and J. Niitsoo, “Harmonic distortions of multiple power factor compensated EV chargers,” in 2014 16th European Conference on Power Electronics and Applications, IEEE, Aug. 2014, pp. 1–7. doi: 10.1109/EPE.2014.6911035.
[15] D. Committee of the IEEE Power and E. Society, “IEEE Std. 519 - 2014,” New York.