DEVELOPMENT OF A PRACTICAL TECHNIC-ECONOMIC METHODOLOGY FOR THE DESIGN STAGE OF EV CHARGING STATIONS INTEGRATED IN POWER DISTRIBUTION GRIDS

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As the electrification of our transport system gains speed, it becomes clear that the impact that Electric Vehicles (EV), be they Hybrid Plug-in vehicles (HPV) or Battery Electric Vehicles (BEV), generate on the power distribution networks cannot be ignored anymore. The main goal of this paper is to analyse the impact generated by the charging stations which will continue to be installed throughout the world on the power distribution networks, both from the energy efficiency point of view and from a power-quality one and develop a technical-economical method that can help decision-makers and site managers.

Keywords: Electric Transportation, Power Distribution Networks, Energy Efficiency, Power Quality, Economic assessment, Energy management

1. Introduction

In 2020, Tesla became the world's most valuable car company with a market value of $208 billion [1]. Numerous other car manufacturers are also pledging allegiance to the electrification effort, which heavily impacts the number and installed power of EV Charging Stations throughout the European Union (EU).

As [2] and [3] mandate, by 01.01.2025 every EU Member State must ensure that for every nonresidential building with more than twenty parking spots at least an electric vehicle (EV) charging station will be installed for every five parking spots. Local Public Administrations of cities with more than 100,000 inhabitants have the obligation to ensuring at least five public charging stations

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with a capacity of at least four vehicles each, no later than 31.12.2020. Gas / Petrol stations which have more than sixteen fuel pumps are also required to have installed at least two public charging stations, with a capacity of at least two vehicles each, no later than 31.12.2020. In Romania, as of 2018 the creation of the Inter-ministry Council for Alternative Fuels Market Development Coordination (CC DPCA) was decided [4]. The CC DPCA aims at developing a long-term strategy regarding the transition of the transport sector, from a highly polluting to a clean approach.

The Romanian legislation also states that, whenever technically possible and economically reasonable, public charging stations should be equipped with smart metering systems [5], as defined by [6]. Romania is situated just a little over the European average regarding electrical vehicle ownership, with 300 registered vehicles for every 1,000 inhabitants and with a strong increase in electric vehicle registrations [7], reaching a market share of 6.7% in the first quarter of 2020, a great increase compared to the previous year, when the electric vehicle share was 3.8% [8].

The number of newly registered EVs in Romania increases exponentially on a yearly basis [9]. The continuous increase of the EV market share, at a global level, led to a 60% increase in the total number of public charging stations worldwide [10]. The exponential growth of the available public charging stations was also observed in Romania, increasing from approximatively 209 charging stations in 2018 to approximatively 400 in the last quarter of 2019 with an average increase rate of 30%/semester [11].

As [12] has proven, the presence of single charging stations in the local Power Distribution Grid poses no serious threat to the voltage quality at the point of common coupling because the stations have a low short-circuit power compared to the grid. However, as [13] pointed out, several power quality problems were identified when analyzing the behavior of the charging station – EV's battery link. Power factor variations (correlated with the steady state of the battery) and increased values of the Current Total Harmonic Distortion Factor (THD_I) were observed. In [14] some additional issues are revealed, mostly related to the balancing of the supply grid and the connection mode of power transformers, identifying the fact that YYn0 connection mode combined with the presence of single-phase on board chargers led to the highest amount of unbalances and thus power quality issues in the power distribution network. Some mitigation methods are proposed [15], based on the joint integration of charging stations and renewable energy sources (small scale photovoltaic plants).

In this paper, the Power Quality and Load Indicators of an energy boundary consisting of four wall-mounted charging stations will be analyzed and an assessment methodology proposed. The charging stations are installed in one of Bucharest's largest shopping center, which has a total of 10,000 parking spots.

The development of both European and national legislation and the continuous increase of EVs registered in Romania will lead to a considerable increase in the number of such charging stations. A realistic approach would lead to a total number of 2,000 charging stations installed in this commercial building alone. Power Quality Indices (PQI) and Load Curve Indices (LCI) problems will then become a real threat to the internal power distribution grid of the commercial user.

The paper aims at highlighting the most important issues generated from the operation of charging stations and at proposing several mitigation strategies, so that users can timely prepare for the inevitable. The authors measured and mathematically determined the PQI and LCI for one of the four charging stations for a period of four relevant days from 26th of July 2019 to 30th of July 2019 (over the weekend period), in order to record as much activity as possible. The measurement methodology will be presented in Chapter 2.

In Chapter 3, the data resulted from the measurement campaign will be processed and the main PQI and LCI will be evaluated and presented. Chapter 4 will present the methodology and the results of technic and economic calculations of complex LCIs and Chapter 5 is focused on PQIs. Chapter 6 summarizes the paper's conclusions, recommendations and the required further research.

The analyzed charging station has two Alternating Current (AC) plugs with the main characteristics presented in Table 2. The EV station has a Wi-Fi connection and is operated via a touchscreen. It is remotely serviced by technical staff 24/7. It is compatible with all the BEV / HPEV available on the Romanian market. The station also has a Bluetooth connection.

Table 2

Technical Characteristics of the EV charging station

Plug	Connector Type	Manufacturer	Rated Power, P_r [kW]	Rated Current, I_r [A]	International Standard
1	Type 2	Wallbox	22	32	IEC 62196-2
2	Type 2		13	18	

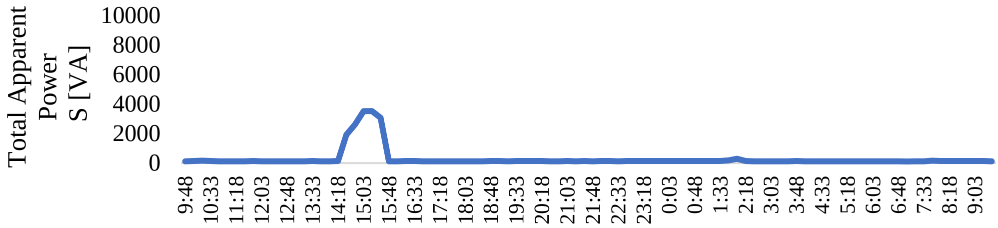
2. Measurement methodology

The average working-day and weekend load of the energy boundary and the average number of clients per day were analyzed in order to determine the optimal measurement period. It has been concluded that the most relevant period is Friday to Tuesday, as it covers the weekend (peak number of clients and peak load) and Monday-Tuesday period which registers the lowest number of clients.

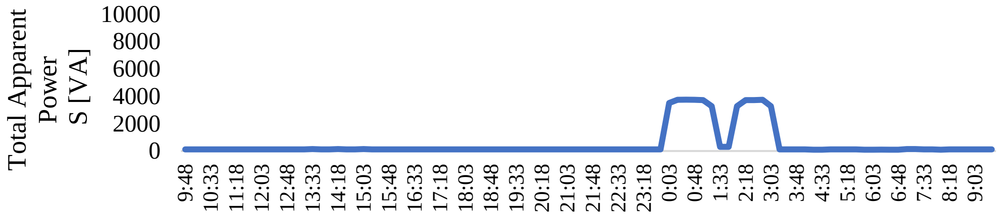
The measuring frequency was set at one second, well below the requirements of IEC 61000-4-30 (10 seconds). The measurement results were then aggregated at a quarter of an hour and used for the determination of the analyzed LCI.

3. Load Curve Data

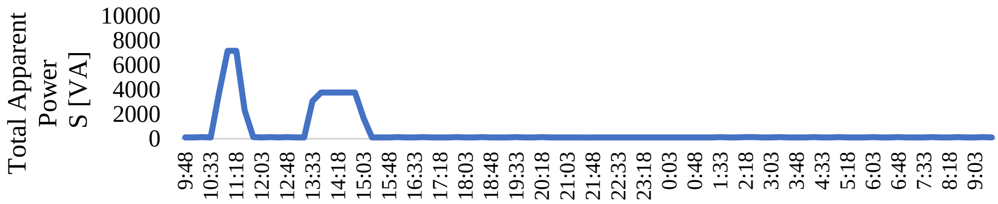
The four days measurement campaign and 15 minutes-aggregated load curve results are presented, divided into four 24 hours periods in Fig. 2.



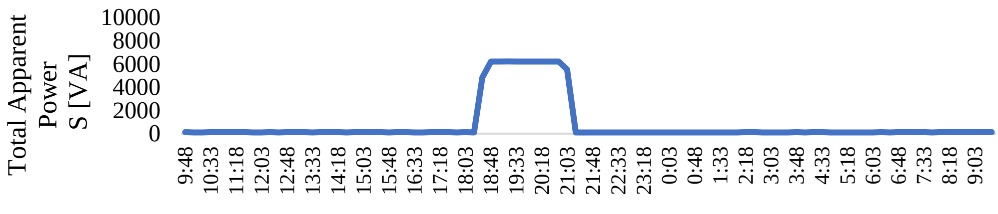
a) Friday to Saturday load curve



b) Saturday to Sunday load curve



c) Sunday to Monday load curve



d) Monday to Tuesday load curve

Fig. 2. The 15-minute aggregated apparent load curve

The first aspect to be observed is that the charging station has a constant auxiliary service demand amounting to approximatively 133 VA, for the touch screen and for the Wi-Fi and Bluetooth connections used for communication.

On Friday, the charging station was only used during the middle of the working day/lunch break (approximatively one hour of charging – corresponding with an average food-court period of 45 minutes per customer / client). Over the weekend, on Saturday night, three hours of charging were recorded. The only open business in the commercial center during those hours is the Casino. Sunday, when the shopping center is operating at peak load, multiple charging sessions were recorded, as expected, this being the busiest day of the week. On Monday, the electricity consumption of the charging station was registered close to the closing hours, for a period of little over three hours.

Upon analyzing the load curves, some consumption patterns (correlated with the energy boundary's destination) can be identified:

- At the beginning of the week, after the working hours (18:00), EV owners are using the charging stations to fully charge their vehicles for the working days to come; the middle of the last working day of the week and during the weekend are chosen by drivers for recharging their EVs; Saturday nights are the optimal days for Casino's clients to charge their EVs – this also implies that people with a high living standard afford to own electric vehicles, more expensive than conventional, fuel-based, ones;
- The minimum charging time was one hour; all the recorded charging sessions were used for HPEVs, with charging currents ranging from 13 to 16 A; peak loads were recorded when two cars where charged simultaneously.

4. Technic-economic methodology

The first step consisted in determining the LCI values. The LCI calculation is presented in the following paragraph, with the main LCIs being presented in Table 3. Based on that, a technic-economic methodology useful at the project development stage is presented.

Table 3

Main LCIs used

Load Curve Indices	Notation
Average active power absorbed from the power distribution network	P_{avg}
Average apparent power absorbed from the power distribution network	S_{avg}
The Maximum active duration power	P_{Md}
The Maximum apparent duration power	S_{Md}
The Maximum active duration power time	T_{PM}
The Maximum apparent duration power time	T_{SM}
The Laod curve form factor	k_f
The Load factor	k

The LCIs presented in Table 4 are used for sizing installations, calculation of electrical losses, electrical equipment procurement etc. By processing the measured data, the average (apparent and active) power over a 15 minutes period was determined. The load curves in Fig. 2 were built based on these values, which are presented in Table 4.

The average apparent power was determined by applying equation (1). A similar formula was used to determine the average active power:

$$S_{med} = \frac{\sum_{i=1}^{n} S_i \cdot t_i}{t_f} \ [VA] \tag{1}$$

where t_f – is the operating time, in this case is the characteristic period of 24 hours, expressed as 1,440 minutes; t_i – is the time frame *i*; the recommended value by design regulations being 15 minutes [16]; S_i [VA] – is the apparent power for the time frame *i*; it was calculated as average power over each time frame of 15 minutes, by processing the measured data; n-is the number of frames, in our case study is 96.

To determine the use time of the maximum duration power, the daily energy use was firstly calculated (apparent – W_S and active – W_P) using formula (2).

$$W_S = \frac{\sum_{i=1}^{n} S_i}{60} \cdot 15 = \frac{\sum_{i=1}^{96} S_i}{4} \left[\frac{kVAh}{day}\right] \tag{2}$$

The use time of the maximum apparent duration power, formula (3) was used [17], [18]:

$$T_{SM} = \frac{W_S}{S_{Md}} \left[\frac{hours}{day}\right] \tag{3}$$

Similar equations were used to determine the active power and use time values. The results are presented in Table 4.

Table 4

Load Curve Indices for each characteristic period of 24 hours, from 09:48 AM to 09:33 AM of the following day

Period	S_{Md} [kVA]	P_{Md} [kW]	T_{SM} [hours/day]	T_{PM} [hours/day]	S_{avg} [kVA]	P_{avg} [kW]
Friday to Saturday	3.513	3.513	1.90	1.87	0.278	0.274
Saturday to Sunday	3.752	3.752	3.31	3.27	0.518	0.511
Saturday to Monday	7.163	7.158	1.88	1.86	0.562	0.554
Monday to Tuesday	6.213	6.206	3.06	3.01	0.791	0.778

To determine the load curve form factor-k_f, relation (4) was used [19]:

$$k_f = \frac{S_{avg,sq}}{S_{avg}} \ [-] \tag{4}$$

where $S_{avg,sq}$ $[kVA]$ – is the apparent average square power, determined with formula (5).

$$S_{avg,sq} = \sqrt{\frac{\sum_{i=1}^{n} S_i^2 \cdot t_i}{t_f}} = \sqrt{\frac{15 \cdot \sum_{i=1}^{96} S_i^2}{1{,}440}} \tag{5}$$

The results for the load curve form factor are presented in Table 5.

Secondly, the ancillary power usage was evaluated. The contribution of the auxiliary services of the charging stations on the total energy losses in the Low Voltage (LV) connection cable supplying the station was also determined by applying relation (7).

Table 5

Load curve form factor

Period	k_f
Friday to Saturday	2.49
Saturday to Sunday	2.36
Sunday to Monday	2.61
Monday to Tuesday	2.58

A cable with perfect insulation and a constant voltage value was considered for the total active energy losses calculation with relation (6):

$$\Delta W = \frac{\rho}{s} \cdot \frac{S_{avg}^2}{U_r^2} \cdot k_f^2 \cdot t_f \cdot l \; [kWh/year] \quad (6)$$

where $\rho \; [\Omega mm^2/m]$ –resistivity of the cable material; $s \; [mm^2]$ – cross section of the cable; $l \; [m]$ – cable length.

By dividing the energy losses in the LV cable generated by the power absorbed by the auxiliary services to the energy losses generated by the total power supplied to the EV charging station, equation (7) resulted:

$$\Delta W = \frac{\Delta W_{as}}{\Delta W} = \frac{S_{avg,as}^2}{S_{avg}^2} \cdot \frac{1}{k_f^2} \cdot 100 \; [\%] \quad (7)$$

where $S_{avg,as} = 133 \; [VA]$ – average apparent power absorbed by the auxiliary services of the charging station.

By replacing k_f from equation (4) in equation (7), equation (8) is obtained:

$$\Delta W = \frac{S_{avg,as}^2}{S_{avg,sq}^2} \cdot 100 \; [\%] \quad (8)$$

Considering that $S_{avg,as}$ is practically constant, as can be observed from equation (8), the efficiency of the supplying service depends only on the power absorbed in each time period, S_i.

The results for the percentual energy losses determined by the auxiliary services in the total losses in the LV cable are presented in Table 6.

The EV charging station has two AC plugs, as presented in Table 2. The load factor (k) average and maximum values over the measurement period are presented in Table 6. The load factor was considered as a ratio between the average active power absorbed over the 15-minute period and the rated power of the plugs. In this way, EV station solutions can be ranked by their energy efficiency.

Regarding the symmetry over the three-phase connection of the charging station, one AC plug (32 A) is connected to the B phase and the other one (18 A) is connected to the C phase. This asymmetry is causing additional power and energy losses in the neutral wire of the network. The asymmetry will be analyzed, along other PQIs in the following paragraphs.

Table 6

Percentual active energy losses determined by the auxiliary services of the charging station and the average and maximum values of the load factor

Period	ΔW [%]	$S_{avg,sq}$ [kVA]	k	
			Maximum	Maximum
Friday to Saturday	3.69	0.69	0.10	0.10
Saturday to Sunday	1.18	1.22	0.11	0.11
Sunday to Monday	0.82	1.47	0.21	0.21
Monday to Tuesday	0.42	2.04	0.18	0.18

Over the measurement period, only HPEVs were charged, loading the plug on the B phase at a maximum level of 0.5 of its capacity and the other plug at a maximum level of 0.8 of its capacity. There were periods when both plugs have simultaneously had HPEVs connected. This leads to the best use of the charging station, with demand factors of around 0.4 (a product between the simultaneity and the load factor).

At the project development stage, we give designers a straightforward methodology for the technic-economic evaluation of each solution for the EV station (see the flow chart in Fig. 10).

5. Power Quality Analysis

The third step consisted in the evaluation of the PQI. In order to properly analyze the Power Quality influence of the charging station, without overlapping electromagnetic perturbances and multiple PQI values in the point of common coupling, the PQI analysis was done over a period of time in which only one of the two plugs was operational and charging.

As it can be observed in Fig. 3, the voltage levels (both line and phase ones) of the energy boundary were situated in the admissibility band of ± 5% of the rated voltage of 400 V, throughout the measurement period [20].

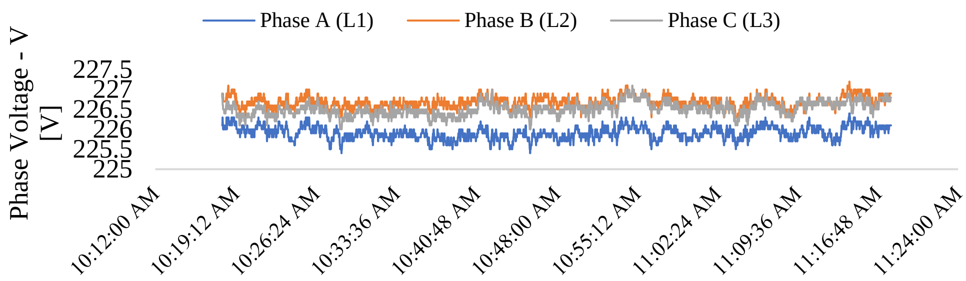


Fig. 3. Phase Voltage levels

A short disconnection of the battery was also recorded, which lasted a couple of dozen milliseconds. The frequency of the power distribution network was also analyzed, and it was observed that its values respected the ± 1% of the rated frequency variation limit [22].

The analyzed EV charging station is supplied from the B phase (L2), thus heavily contributing to the unbalancing of the local power distribution grid, with an unbalance level of 200%, as per [21].

As it can be seen in Fig. 4, during this period, the EV that was charging was limited by its own charging processor to absorb approximatively 3.45 kW. The charging station was being used at a demand factor of less than 0.5. However, an injection of reactive power into the power distribution network was recorded (see Fig. 5), proving that the battery was slightly contributing to the compensation of the power factor in the point of common coupling (LV substation).

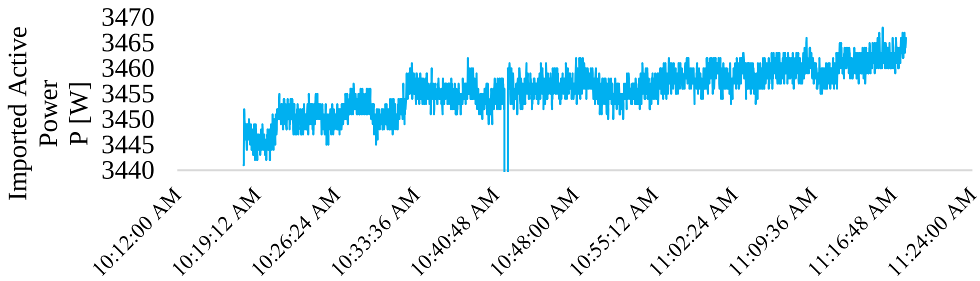


Fig. 4. Absorbed Active Power on the B phase (L2)

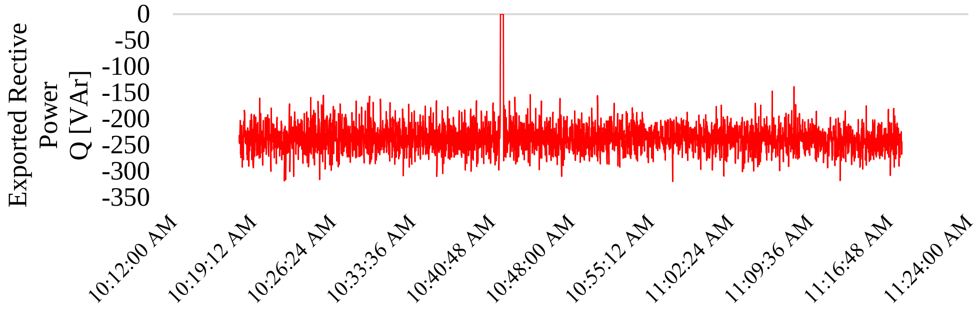


Fig. 5. Transited Reactive Power on the B phase (L2)

This hypothesis is confirmed by the extremely high values of the Power Factor in the LV power supply cable, as it can be observed in Fig. 6. Thus, it can be concluded that EV charging stations can be used as a mean to ensure a peak demand in reactive power needed for mitigating the total power factor at the point of common coupling (PCC) / measurement point. A large enough number of EV's that are simultaneously charging can easily replace an existing Automatic Power Factor Correction (APFC) system. However, a severe risk of ending up in an over-compensating regime exists. In this case, the energy boundary may end up exporting reactive power into the public distribution network, thus being taxed by the Distribution System Operator (DSO) as per the national legislation [23]. Caution is advised and as the charging stations are installed, a continuous process of verifying the value of the TPF (Total Power Factor) at the PCC is required. Thus V2G (Vehicle to Grid) technologies represent the future of a free carbon economy.

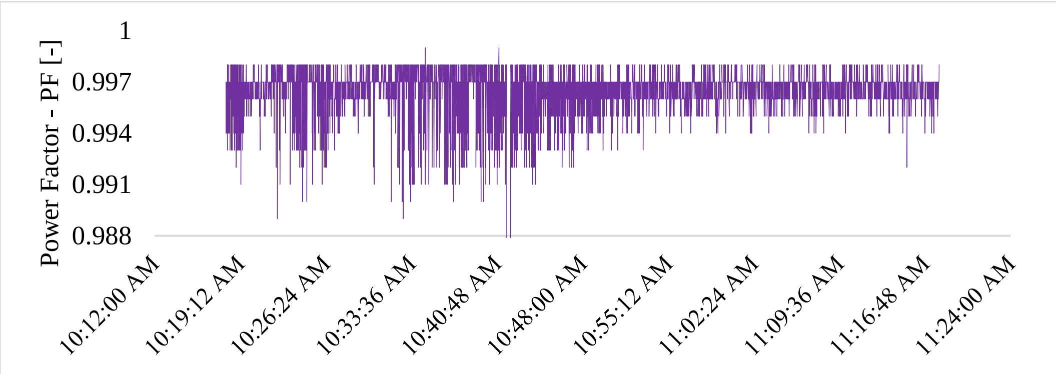


Fig. 6. Total Power Factor on the B phase (L2)

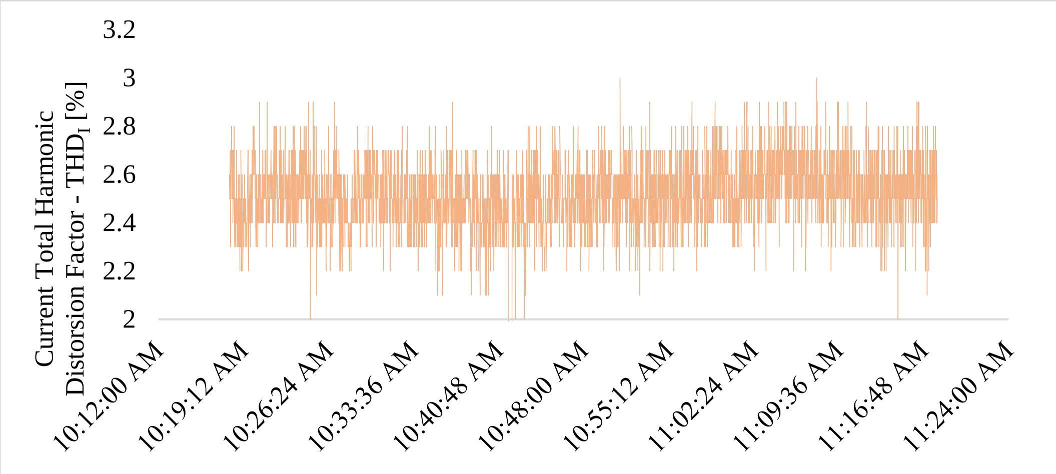


Fig. 7. Current Total Harmonic Distortion Factor on the B phase (L2)

The fact that the analyzed charging station does not have an AC-DC link leads to a low level of electromagnetic perturbances emissions, as proven by the low values of the Current Total Harmonic Distortion Factor (THD_I) presented in Fig. 7, which registered an average value of 2.55 % of the fundamental current component. Furthermore, as the Short-circuit current (I_{SC}) – Maximum demand load fundamental frequency component current (I_L) ratio in the PCC is greater than 1,000, the limit set by this ratio (20) is also respected [24].

It is expected that the value of the THD_I will be significant in the case of using fast-charging stations, with an active AC-DC link, because of the rectifiers used to convert the voltage.

High levels of short-term voltage flicker were recorded on all three phases of the energy boundary, as it can be observed in Fig. 8.

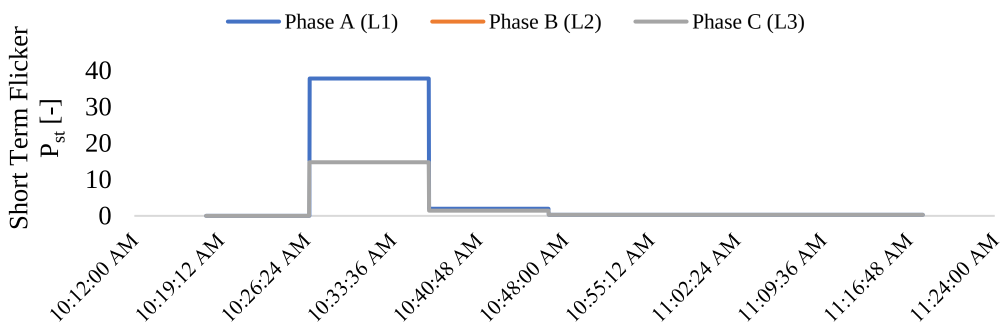


Fig. 8. Short term Flicker Variation

Even though this phenomenon is not related to the analyzed charging station, it's source being upstream (as the values recorded are on all three phases of the power supply network) it is worth mentioning as flicker could lead a fast charging station into an abnormal operational mode. Also, fast charging high powered stations can contribute to the flicker, as proven by [25]. Further measurements on fast charging stations are required in order to evaluate the long-term flicker contribution of EVs. The overall results of the PQI analysis will be presented in Table 7.

Table 7

Overall PQI analysis results

PQI	Value		Pass Test
	Average	Limits	
Rated Voltage	392.08 V	400 ±10% V [20]	Yes
Frequency	49.99 Hz	50±1% Hz [22]	Yes
Power Factor	0.996	0.90*	Yes
Voltage Total Harmonic Distorsion Factor (THD_V)	0.77%	8% [26]	Yes
Current Total Harmonic Distorsion Factor (THD_I)	2.55%	20% [24]	Yes
Short term Voltage Flicker (P_{st})	5.5	1 [20]	No

* Limit set by the Organization in order to minimize the reactive energy bill

Also, the current unbalance was analyzed and evaluated as per [21]. A value of 200% current unbalance was identified. The value is considerably larger than the limit of 10% imposed by [21]. A need to balance the power supply was identified and the easiest and most convenient way to achieve it is to install a third charging plug.

6. Outcome analysis

Lastly, an advanced consumer behavior analysis is done in order to optimize the number and rated power of the charging stations from the client's point of view. The replacement of fuel-based cars with electrical vehicles needs a development strategy in correlation with the overall development of the economy and the power sector.

The consumer behavior impact on the load curve for the boundary in which EV stations should be included is key to the decision-making process. Lunch time, from 2:00 PM to 3:00 PM, when people choose to charge their EVs, is overlapping with the National Power System (NPS) peak hours during the day. The weekdays habit to take dinner after business hours and take advantage to recharge the EVs is also overlapping with the beginning of the system night peak (starting around 10:00 PM). Recharging EVs when out for late night entertainment is a massive advantage for NES, as it helps maintain large generation units in operation. Sunday morning activities give room for recharging EVs at the end of the morning dip hours.

Consumer Behavior Analysis should also include client opinion polls in order to determine the required number and installed power of EV Charging Stations. Because some consumer's behavior is congruent with the system peak hours, it is important for the overall efficiency of the power generation, transmission, and distribution system to develop a smart network of EV charging stations around Romania. This is a valid option even if large shopping centers and neighboring businesses will start building smart micro grids.

By developing the EV network, the system will benefit from the important consumption during the weekend, when most of the industrial and tertiary consumption are off. It basically creates an important consumer which will keep generation capacities in operation, thus being a key factor for new investment development decisions.

The maximum duration power has the highest value during the weekend on Sunday, as the families are crowding the shopping center; in the rest of the weekend, the maximum duration power has a much lower value – approximatively half of the Sunday one; during working days, the maximum duration power is in between the Sunday value and the rest of the weekend days value. The use time of the maximum duration power is between 7.83% and 13.79% of a day, giving less than 1,250 hours/year – a rather low value for the investment reimbursement. The load curve form factor has the highest value during working days, leading to a higher efficiency of electricity distribution. The load factor has a very low value (with a maximum of 0.234), leading to an inefficient use of the EV charging station.

The existing power supplying solution of the charging stations is inefficient as the unbalance reaches extremely high values, leading to an increase of the energy losses in the neutral of the network.

The electromagnetic emission of the analyzed charging station is low, mainly because it uses AC plugs. The impact of AC-DC conversion should be further analyzed in order to obtain a proper image of the impact of charging stations on the overall PQIs of their power supplying networks.

The power factor correction capabilities of EV’s has been proven. If properly used, the development of EV charging stations infrastructure could lead to a much finer tuning of the Reactive Energy transited trough the Power Distribution Networks, which could in turn lead to a significant reduction of active power losses and to postponing the resizing the electric cables and overhead lines as the electricity consumption continues to grow.

Voltage Flicker should be avoided as it can make fast charging stations operate in an abnormal manner and can be worsened by the presence of the stations.

It’s important to note that the design stage methodology discussed in this paper, alongside the following implementation and energy management stages are applied to existing office or commercial buildings, in which the consumer behavior analysis should already exist.

7. Proposed Methodology

The methodology proposed by authors rank solutions by their energy efficiency completed with the Power Quality Analysis results.

Following the theoretical and practical approach presented previously we are proposing the flow chart in Fig. 10 for ranking EV charging solutions at the design stage and for an efficient energy management at the operational stage.

The first step of the methodology requires that in the design stage, the installed capacity of all the auxiliaries of each EV station (touch screen, communication etc.) should be calculated and $S_{avg,as}$ should be determined.

The second step should be to forecast the electricity demand for each 15 minutes time frame; based on local statistics (EV cars by technology sold locally, sales forecast for EV, shopping center's own statistics on customer behavior etc.) and to determine S_i.

Afterwards, ΔW should be determined for each solution. Losses determined at this stage can be used for further financial indicators calculation (e.g., for the NPV-Net Present Value calculation).

The EV charging stations should be distributed evenly on the three phases, in order to minimize the additional unbalance in the PCC.

The third step requires that the values of relevant PQIs should be measured and analyzed, as presented in this paper, in the current situation, in order to determine reference values – used to properly determine the actual influence of the EV charging stations.

In the **fourth and last step**, after the EV charging stations installation, during the energy management stage, the site monitoring system helps the technical staff to maintain the energy efficiency of the EV charging network by continuously monitoring LFIs, PQIs and consumer behavior.

8. Conclusions

Authors presented a practical methodology that can be efficiently used by designers at the development stage for the decision-making process. The practical methodology for the design stage of EV charging stations integrated in Power Distribution Networks discussed in this paper can be also easily integrated into an existing Energy Management System, as defined by [27]. Furthermore, the periodic Energy Audit that larger than 1,000 tons of oil equivalent (t.o.e.) per year must do can offer the required LFI / PQI values for the design stage. It is of the uttermost importance that the EV charging stations are equipped with smart power quality analyzers to ensure the measurement loop required to maximize the benefits of the Energy Management Stage.

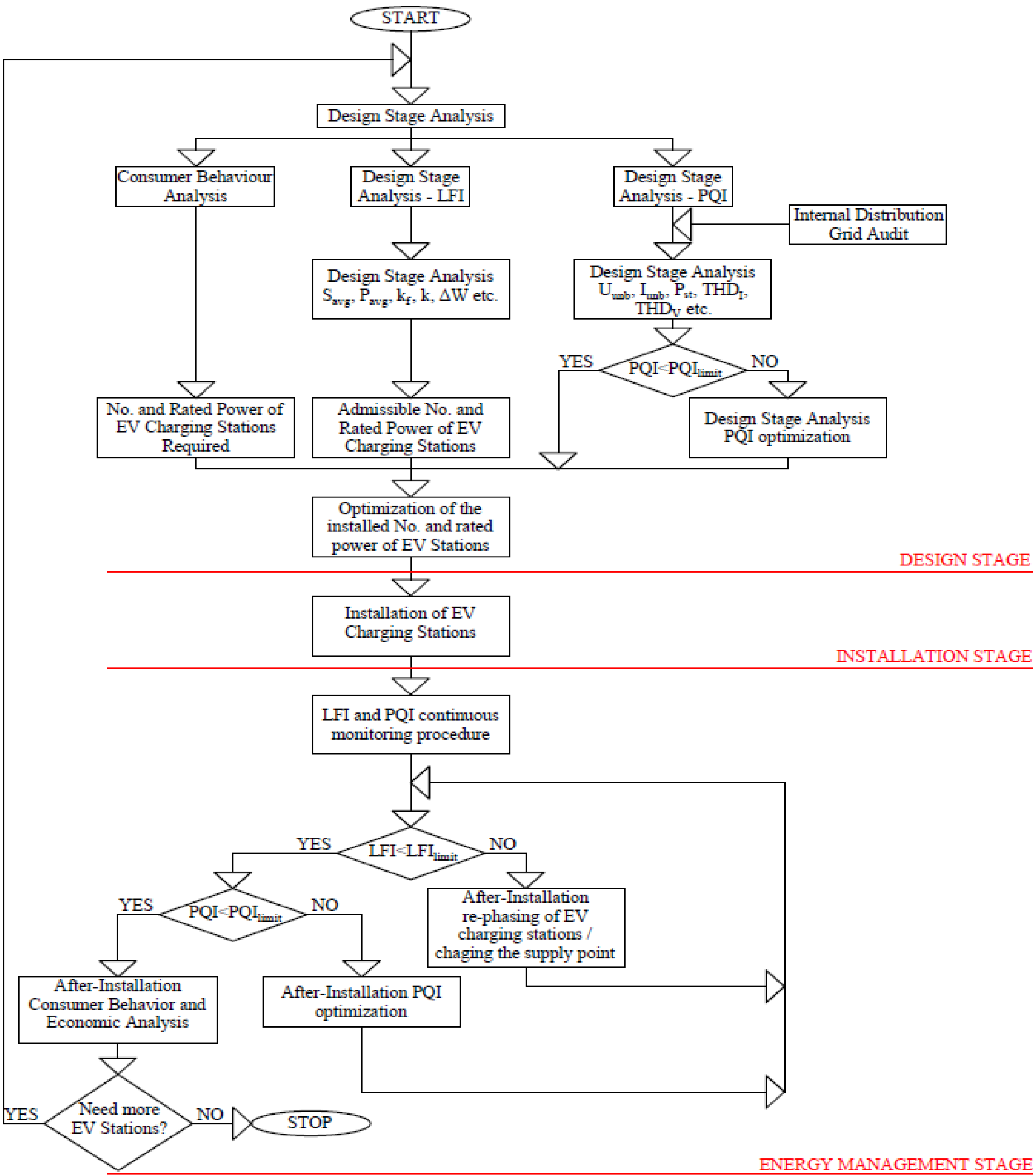


Fig. 10. Design and Integration of EV Charging Stations Methodology

The presented methodology is also a useful tool for site managers in the energy management activity. It is based on the installed capacity of the EV charging station equipment, the EV demand forecast and the impact that the EV charging station has on the overall PQIs on the PCC. At a first glance it seems that the consumer behavior component was completely ignored when picking out the installation point of the charging stations and their number, as proven by the low, inefficient values of the analyzed LFIs, as shown in Chapters 3 and 4.

The analyzed case study, one of Bucharest largest and most visited shopping centers, pointed out that, at the design stage, the EV charging stations number, installed power and technological type were not optimized in order to minimize the impact on the internal power distribution grid, from the PQIs point of view, as proven in Chapter 5. As the reactive power recorded was insignificant, more determinations will be performed in various charging stations in order to draw relevant conclusions about the effect of the charging installation on the power factor at the PCC. This will lead to a more efficient model of V2G approach. To better highlight the influence of the voltage flicker on the charging stations, additional determinations will be performed, and the long-term flicker will be thoroughly analyzed.

The research will continue by analyzing fast charging stations with AC-DC link and PV-Charging Station hybrid solutions in order to determine their impact on the power distribution grid and to improve the design and integration methodology proposed in this paper. Furthermore, other office buildings and commercial centers will be analyzed in order to determine the variation scale of the consumer behavior impact on the energy usage of the charging stations.

R E F E R E N C E S

[1]. https://www.forbes.com/sites/sergeiklebnikov/2020/07/01/tesla-is-now-the-worlds-most-valuable-car-company-with-a-valuation-of-208-billion/#4ac907e15334, accessed in July 2020.

[2]. European Parliament, "Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency," Official Journal of the European Union, 2018.

[3]. European Parliament, "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings," Official Journal of the European Union, 2010.

[4]. Romanian Parliament, "Decision no. 87/2018 for approving the strategy regarding the national framework for alternative fuels market development in the transport sector and the development of the required infrastructure in Romania," National Gazette, Part 1, nr. 255 bis, 2018.

[5]. Romanian Parliament, "Law no. 34/2017 regarding the installation of the required infrastructure for alternative fuels," National Gazette, Part 1, nr. 214, 2017.

[6]. European Parliament, "Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure," Official Journal of the European Union, 2010.

[7]. https://www.automarket.ro/stiri/cota-de-piata-a-masinilor-electrice-aproape-6-in-romania-in-primele-trei-97443.html, accessed in May 2020.

[8]. https://www.zf.ro/auto/restrospectiva-pietei-auto-in-2019-cuvantul-de-baza-electric-industria-auto-resimte-pe-toate-planurile-trecerea-la-vehicule-electrice-18677459, accessed in May 2020.

[9]. ***, Periodical Romanian Automotive Register Reports, https://www.rarom.ro/

[10]. https://fingfx.thomsonreuters.com/gfx/editorcharts/azgvobxykpd/index.html?eikon=true, accessed in July 2020.

[11]. https://www.economica.net/cum-arata-piata-de-masini-electrice-in-romania-ce-modele-sunt-si-cate-statii-de-incarcare-sunt-disponibile-analiza_183336.html, accessed in April 2020.

[12]. *M. Auer, E. Kaffe and R. La Fauci, "*Impact of fast charging and home charging infrastructure for electric vehicles on the power quality of the Distribution Grid,*"* 25th International Conference on Electricity Distribution (CIRED 2019), June 2019.

[13]. *R. J. C. Pinto, J. Pombo, M. R. A. Calado and S. J.P S. Mariano*, "An Electric Vehicle Charging Station: Monitoring and Analysis of Power Quality," 9th International Conference on Compatibility and Power Electronics (CPE 2015), September 2015.

[14]. *Q. Li, S. Tao, X. Xiao and J. Wen*, "Monitoring and Analysis of Power Quality in Electric Vehicle Charging Stations, 1st International Future Energy Electronics Conference (IFEEC 2013), November 2013.

[15]. *A. K. Karmaker, S. Roy and R. Ahmed*, "Analysis of the Impact of Electric Vehicle Charging Station on Power Quality Issues," 2019 International Conference on Electrical, Computer and Communication Engineering (ECCE), February 2019.

[16]. ***, "NTE 007/08/00 – Designing and building electrical cables network," 2000.

[17]. *Energy National Regulatory Agency*, "Order for approving the measurement data correction procedure, with regard to the point of common coupling," National Gazette, Part 1, No. 307, 2005.

[18]. ***, "NTE 401/03/00 – Economic line section determination methodology for power distribution networks with rated voltages of 1 to 110 kV," 2000.

[19]. *N. Golovanov, I. Iordănescu, P. Postolache, C. Toader, S. Popescu, R. Porumb and L. Lipan*, "Electric installations and industrial energy audit elements,", N'Ergo, ISBN: 9731718109, Bucharest, 2008.

[20]. *International Electrotechnical Commission*, "IEC 61000-3-3 Electromagnetic Compatibility – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low voltage supply systems, for equipment with rated current 16 A per phase and not subject to conditional connection," 2013.

[21]. *Institute of Electrical and Electronics Engineers*," IEEE 112-2017 51000 Test Procedures for Polyphase Induction Motors and Generators," 2017.

[22]. *Energy National Regulatory Agency*, "Order no. 49/2017 for modifying the Power Distribution Services Performance Standard," National Gazette, Part 1, No. 535, 2017.

[23]. *Energy National Regulatory Agency*, "The methodology used to determine the payment obligations for reactive energy and the regulated price for reactive energy," National Gazette, Part 1, No. 408, 2014.

[24]. *Institute of Electrical and Electronics Engineers*," IEEE 519-2014 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems," 2014.

[25]. *S.M. Alshareef and W.G. Morsi*," Impact of Fast Charging Stations on the Voltage Flicker in the Electric Power Distribution Systems," 2017 Electric Power and Energy Conference (EPEC 2017), DOI: 10.1109/EPEC.2017.8286226, 2017.

[26]. *International Electrotechnical Commission*, "IEC 61000 group of standards" 2016.

[27]. *International Standardization Organization,* "ISO 50001:2018 – Energy Management Systems – General Guidelines," 2018.