Aspects Regarding the Impact of Electrical Vehicles' Charging on Power Quality

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***Abstract* - A major problem with the increased penetration of electric vehicles is the preparation of the power supply system to accommodate the increasing number of charging stations. Possible problems include exceeding the rated power of distribution equipment and electrical systems components, changing the voltage profile and altering the quality parameters of electricity. In these scenarios it is important for the grid operators to have an accurate information on present grid status, as well as the effects of EVs charging facilities interaction with the hosting grid. This knowledge will help the operators to more efficiently manage their grids while the e-mobility is expanding. This paper addresses issues related to the challenges of large-scale implementation of electric vehicles in Romania and especially their estimated impact on the power quality in current distribution networks. The authors present some of the results of a monitoring and analysis study of the power quality parameters in the coupling buses of some electric vehicle models during their charging cycle. The results of the study are included in a database used as a reference for a larger project aimed at developing intelligent solutions for PQ-based control of load units.**

Cuvinte cheie: *calitatea energiei, monitorizare, rețea electrică de distribuție, vehicul electric, stație de încărcare.*

Keywords: *power quality, monitorization, power distribution grids, electrical vehicle, charging stations.*

I. INTRODUCTION

According to Directive 2010/31/EU last amendments, the EU Member States must establish the requirements for the installation of a minimum number of recharging points for electric vehicles for all non-residential buildings with more than twenty parking spaces up to 1. January 2025.

In Romania, the electric car transportation is currently in a pioneering phase, the lack of infrastructure of large capacity recharging stations being the main obstacle in its deploying. Nevertheless, the official figures show that e-mobility is in increasingly local demanding and the national policies are yet to appear. Still, there are some initiatives worth mentioning, as "Green Charging infrastructure program" launched in 2017 by the Ministry of Environment, Waters and Forests to support the acquisition of electrical vehicles (EVs) charging stations (CSs). In this respect, the authorities have created a scheme to finance 6000 EV charging stations by 2020. According to the Direction of Driving Licenses and Vehicles Registration (drpciv.ro) less than 2000 electric vehicles are currently on the roads in Romania. They can access about a 434 public charging points [1]. In order to accommodate the EVs charging loads in the actual Romanian distribution system, it would be necessary for utilities to invest in and reinforce the grid infrastructures in heavily loaded areas. As the local power grid operator wanted to be prepared for the growing needs of EVs charging industry, it only made sense to choose a smart service that has the capability to be flexible and manage the growing load from EV charging and its impact on the grids. An intelligently integration of EVs can also partially solve the power quality (PQ) problems. For the expected increasing number of private or home charging stations (CSs), a comprehensive assessment of these loads' behaviors and impacts, as well as smart approaches that actively operate the grids can help to reduce the grid connection costs.

II. STATISTICS REGARDING THE EV'S IN ROMANIA

A. *Hybrid electric vehicles*

The three main types of electrical vehicles are generally known as hybrid electric vehicles (HEV), plug-in hybrids (PHEV) and battery electric vehicles (BEVs).

Although hybrids are not loaded from the distribution network, they are important as a reference for determining the degree of market penetration of BEVs and PHEVs.

There are several hybrid configurations. Modern hybrid electric vehicles use new technologies, such as regenerative braking, which, instead of dissipating the kinetic energy of the vehicle into the environment in the form of heat, as conventional braking systems do, recovers it in the form of electric energy, which is stored in batteries.

Some hybrid electric vehicles use their internal combustion engine to drive an electric generator, the current produced being stored in batteries or powering the electric propulsion motors directly.

Other hybrid electric vehicle technologies reduce emissions when idling by shutting down the internal combustion engine instead of letting it idle and restart it at start-up, a method known as the start-stop system. No mechanical gearbox is required in all configurations, as the speed and torque of an electric motor can be adjusted without problems by varying the frequency and actual current. The main advantage of the electric drive system is the bidirectional flow of energy. While the vehicle is in braking mode, the electric car operates in generator mode, and much of the vehicle's kinetic energy is converted into electrical energy stored in the battery.

Table I presents the technical specifications of the hybrid car models that dominated the market in Romania at the end of 2018.

B. *Hybrids plug-in*

Plug-in hybrid electric vehicles (PHEVs) have a propulsion system with a gasoline engine and an electric motor similar to HEVs, but with a larger battery that can be charged by both the own systems and power grid by plugging in. Lithium-Ion batteries are usually used for this purpose. Most PHEV devices are designed so that the owner can travel the longest distances in the city, using only battery power, the combustion engine being used only over long distances.

TABLE I.
TECHNICAL SPECIFICATIONS OF THE HEVS IN ROMANIA

Car model	Capacity of gas engine (l)	HP gas engine	HP electric engine	Fuel consumption (l/100 km)	Sold units
Toyota C-HR	1.8	98	72	3.8	355
Toyota Auris Hybrid	1.8	99	82	3.5	242
Toyota Yaris Hybrid	1.5	75	61	3.5	239
ToyotaRAV4 Hybrid	2,5	155	140	5.0	159
Toyota Prius	1,8	98	72	3.3	140

Table II presents the technical specifications of the dominant plug-in hybrids on the Romanian market in 2018. The Mercedes model falls into the exclusive category, less accessible. Nevertheless, it was introduced in this statistic as one of the models that has been available for testing in INCESA laboratory.

TABLE II.
TECHNICAL SPECIFICATIONS OF THE PHEVS IN ROMANIA

Car model	Capacity of gas engine (l)	HP gas engine	HP electric engine	Battery storage capacity (kWh)	Fuel consumption (l/100 km)
VW Golf GTE	1.4	150	102	8.7	1.7
Volvo v60 hybrid	2.4	215	68	11.2	1.8
BMW 225xe iPerformance	1.5	136	88	7.6	2.0
Mitsubishi Outlander	2.0	117	80	12.6	8.1 – 12.0
Porsche Cayenne E Hybrid	3.0	320	95	14.1	3.3 – 3.4
Mercedes-Benz GLE 500 e 4MATIC	3.0	333	116	8.8	3.7

C. *Battery electrical vehicles*

Battery electric vehicles (BEVs) do not have combustion engines, being driven only by energy stored in large capacity batteries (Lithium-Ion) that are charged from the electricity distribution system. The specifications of the best-selling electric cars in Romania are presented in Table III.

At the time of the study, the Solaris Urbino 18 electric model bus was put into circulation by the City Hall, for the performance tests prior to a future acquisition. It was also introduced in this statistic being another model that has been available for testing with INCESA laboratory's equipments.

D. *User experience regarding electric vehicles*

The EVs have certain advantages compared to classic fuel vehicles. They are designed to develop the power to cover the average daily distance up to 50 km. In addition to the fact that they do not need to access the services of a petrol station, EVs owners will never change their oil, thus meeting the criteria of a low-maintenance car.

TABLE III.
TECHNICAL SPECIFICATIONS OF THE BEVS IN ROMANIA

Volkswagen e-Golf	
Engine	100 kW (134 HP)
Battery capacity	35.8 kWh
Loading power	7.2 kW AC
Supply voltage	120V 240V
Autonomy	300 km (NEDC)
Speed	150 km/h
Loading time	5h15m
Average energy consumption	12.7 kWh/100 km
BMW i3	
Engine	127 kW (170 CP)
Battery capacity	33.2 kWh
Loading power	3.7 kW AC
Supply voltage	120V 240V
Autonomy	200km (NEDC*)
Speed	150km/h
Loading time	7h30m
Average energy consumption	13.1 kWh/100 km
Renault Zoe	
Engine	68 kW (92 HP)
Battery capacity	41 kWh
Loading power	22 kW AC
Supply voltage	120V 240V
Autonomy	403 km (NEDC*)
Speed	135 km/h
Loading time	2h15m
Average energy consumption	13.7 kWh/100km
Smart	
Engine	52 kW (71 HP)
Battery capacity	17.6 kWh
Loading power	4.6 kW AC
Supply voltage	120V 240V
Autonomy	155 km (NEDC*)
Speed	130km/h
Loading time	4h30m
Average energy consumption	11.5 kWh/100 km
Kia e-Niro	
Engine	64 kW (85 HP)
Battery capacity	67.1 kWh
Loading power	7.2 kW AC
Supply voltage	120V 240V
Autonomy	375 km (NEDC*)
Speed	167 km/h
Loading time	10h30m
Average energy consumption	17.1 kWh/100km
Solaris Urbino 18 electric	
Engine	160 kW (214 HP)
Battery capacity	125 kWh
Loading power	30 …200 kW
Supply voltage	120V 240V
Autonomy	200 km
Loading time	< 6h

**New European Driving Cycle (NDEC)*

However, the disadvantages of EVs are significant. While the technical features of the latest EVs allow owners to use them in the city, their use for travel outside the city is not advantageous due to the lack of a distributed and easily accessible charging infrastructure. Being forced to access certain charging points, the drivers may be limited to a driving distance of half the total driving mileage of a fully loaded EV.

Many infrastructure changes have been proposed to allow EV owners to drive longer distances, but unfortunately all of these are accompanied by significant problems. In Romania, more than 400 charging stations are installed, of which 161 station (almost 37%) are fast charging points. Unfortunately, there are areas in Romania discovered. In addition, even for a high availability of fast charging stations, they remain less attractive compared to filling a gas tank because they need even 30 minutes to charge the battery to a capacity of 80%

Although the high cost of the batteries remains the main barrier when it comes to the price competitiveness of electric cars, it has decreased significantly in recent years. An analysis by Forbes shows that Lithium-Ion battery cell cost $1,100/kWh in 2010, and by 2019 the cost dropped to $156/kWh (with almost 86%) and things do not stop there. Considering that most EVs on the market have a battery capacity of 16… 28 kWh, the battery pack cost between $3000 and $7000, relatively easing the financial efforts to replace them.

Experts forecast that the price will reach $100/kWh by 2023, level at which the electrical vehicles will reach a price parity with those with conventional engines [2].

In addition, new technologies are expected to appear, such as solid-state batteries, which will bring cheaper, faster-charging batteries to the market and have a longer service life, with a higher density.

Until then, however, the all-electric cars are used in Romania only as secondary cars. For people who can't afford a second car, a plug-in hybrid might be a better option. A potential new buyer who wants a "green" car without range restrictions can choose between a hybrid and a plug-in hybrid.

III. EVS CHARGING UNITS DEPLOYMENT AND GRIDS IMPACT

Since EVs require the use of batteries with high storage capacity, a large deployment of this concept is expecting to impact considerably the power grid design and operation [3]. Chargers are in general connected to the low-voltage (LV) grids, and their operation is characterized by electromagnetic perturbations affecting the PQ level. The uncoordinated charging can result in for instance in slow voltage deviations, rapid voltage variations (flicker), harmonics, phase voltage imbalance, grid losses and overloading, fluctuation of grid frequencies, which disturb end-users including more and more sensitive loads [4-8]. An intelligent integration of EVs and their CSs units can partially solve the existing and future power quality (PQ) problems. For the expected increasing number of private or home charging stations (CSs), smart approaches that make use of currently available excess capacities and actively operate the grids can help to reduce the grid connection costs.

A wide spectrum of charging management algorithms is proposed in literature. While PQ issues are solved by designing a new charging connector or charging station with PQ compensation [9, 10], some algorithms have been proposed to move EV charging load to off-peak hours or to react in real-time on changes of the different local or global parameters of the grid [11]. Other EV charging policies [12] consider voltage support for the distribution network to increased penetrations of distributed PV systems. There are also solutions proposing local smart charging algorithms based on *droop* controller [12, 13] to reduce line voltage drops and voltage unbalances. These solutions estimate the voltage locally, but ignore the overall state of the LV grid. Decentralized approaches considering wider grid areas are developed based on traffic light estimation model of the voltage variation parameter and assets loading [14].

A better understanding of these PQ issues specific to EVs will aid power operators in the design of their distribution systems and provide guidance for asset planning. Consequently, more online monitoring and active interventions during grid operation are necessary to maintain critical boundary conditions such as bus voltages and asset loading within permissible limits. As the local power grid operator wanted to be prepared, it only made sense to choose a smart service that has the capability to be flexible and manage the growing load from EV charging and its impact on the network.

IV. RESEARCH PROJECT FOR ASSESMENT OF EV'S IMPACT REGARDING POWER QUALITY

By regarding the present national politics and the state of hosting power grids, any action and project which aims to integrate and develop an optimal management of the publicly accessible EVs charging infrastructure in the region should take into account the following challenges: (1) Existing local distribution grids are made of long-life assets and equipment which cannot be removed or easily upgraded; (2) The development strategy of the local power distribution grid operator (DGO) envisages improving the level of safety and quality in the distribution of electricity and reducing energy losses; (3) When it comes to e-mobility infrastructure at least three players emerge: the electricity supplier, the charge point operator (CPO - responsible for the installation, service and maintenance of the CSs), and even an e-mobility provider (EMP - enables access to the complex charging infrastructure), which should see “CS operation” as a business model, but as an additional service for customers considering a minimal negative impact on the local hosting grid; (4) The technical, economical, societal and regulatory context for distribution grids and their customer significantly varies has particular specificity in Romania in comparison with other European countries with more advanced e-mobility initiatives; (5) The operational policy of the local DGO and the specific nature of the networks that it operates require the identification of potential risk hotspots associated in the immediate perspective with the expansion of large commercial areas and the acquisition of the EVs fleet of local public transport.

One of the projects (METROPOLITANER) developed within Smart Grids Laboratory of INCESA (Research Hub for Applied Sciences of University of Craiova) aims to develop and validate in a laboratory environment a smart control system architecture for different EVs charging typologies connected to the local power distribution grid in order to reduce the impact on the asset loading and quality of voltage.

For reaching the overall purpose, the project is planning to achieve the following objectives: (1) To assess the present PQ perturbation background and the individual emissions of the EVs charging units in the power distribution grids by data measurements; (2) To assess the impact of EVs on PQ and assets operation of power distribution grids by measurements and numerical simulation; (3) To perform studies to evaluate the e-cars impact on the distribution network; (4) To identify the needs/requests of different stakeholders regarding concerning an optimal management of the EVs charging infrastructure; (5) To evaluate the efficiency of the adopted charging control system architecture; (6) To develop and test the laboratory-scale prototype for a smart PQ-based control system architecture.

The objectives are feasible and can be done in the framework of this project by taking into consideration that:

- The local municipality has a viable perspective for becoming one the biggest “green city” of Romania by implementation of *Green City Action Plan*. The local authorities launched the procurement procedure for 46 electrical buses, 46 normal charging stations and 11 fast charging stations. This city accommodates the largest commercial complex in the area, with a parking spaces for around 2700 cars, with the prospect of installing 27 CSs.

- The local power distribution grid operator (DGO) is a supporter of the e-mobility initiatives and mainly stakeholder regarding the effects of EVs integration into the actual power grids.

- There is a traditional project-based collaboration between university and the local power distribution company and urban transport authority in the area of energy efficiency and process control and optimisation.

The first phase of the METROPOLITANER project aims the PQ data acquisition and analysis of the EVs charging stations impact on power distribution grids. Some results of these monitorisation sessions are presented in this paper, outlining mainly the features of the acquisition procedures: type and parametrisation of measuring equipments, EV’s types, charging type, monitorisation period and time, charger location.

V. PQ MEASUREMENTS AND DATA ANALYSIS

This study includes the results of PQ monitoring for the charging process of two types of EVs: Mercedes-Benz GLE 500 e 4MATIC (HPEV) and Solaris Urbino 18 (BEV). A specific attention was paid to the PQ parameters: voltage deviations, harmonics and flicker. There were also noted the loading variation. The objective is to define and test a measurement and analysis procedure to be extended at whole grid level and develop a database useful for further understanding and forecasting of the CSs behavior regarding PQ issues.

In order to analyze the impacts that the two EVs types have on the local distribution system, the data sets were collected directly at the LV buses of the supplying transformer substations, as well as on the individual charging circuits of EVs batteries.

In order to monitor the electrical parameters that describe the charging process of the batteries of the two vehicles considered, a power quality analyzer FLUKE 435 was used. FLUKE 435 is a PQ meter class A, in accordance with EN 50160. The measurements were performed during whole charging period, with a RMS sampling of 5000 samples on 10/12 cycles according to IEC61000-4-30 (50 Hz). The recordings include voltage and current waveforms, as well as recording of MIN, MAX and AVG readings of PQ parameters user-configurable at 1 min. The data was stored by the equipment in a .odn file type database that can be opened with the proprietary Fluke Power Analyze software and exported as .xls file type. The characteristics of the monitorization sessions are given in Table IV.

TABLE IV.
CHARACTERISTICS OF THE MONITORIZATION SESSIONS

Characteristics	Values	
	Mercedes-Benz GLE 500 e 4MATIC	Solaris Urbino 18
Charging time duration	4h 15 min (10:00 – 14:15)	2h (15:45-17:45)
Battery charging power (kW)	1.25	83
Battery charging current (A)	5.9	108
Supplying voltage (V)	230 a.c. (1 ph)	400 a.c. (3 ph)
Supplying voltage variations (V)	236.9…241.0	410.5…420.3
Range of voltage harmonic content (VTHD %)	1.73…2.30	5.13…57.36
Range of long-term flicker (Plt)	0…0.562	0…0.448

The results of the monitorization sessions are given in Fig. 1-12 (according to Table V).

TABLE V.
LIST OF RESULTS OF THE MONITORIZATION SESSIONS

Recording	Correspondent figures	
	Mercedes-Benz GLE 500 e 4MATIC	Solaris Urbino 18
Active & reactive power time variation	Fig. 1	Fig.7
RMS voltage time variation	Fig. 2	Fig. 8
RMS current time variation	Fig. 3	Fig. 9
Statistics of voltage variation	Fig. 4	Fig. 10
Statistics of THD variation	Fig. 5	Fig. 11
Statistics of flicker variation	Fig. 6	Fig. 12

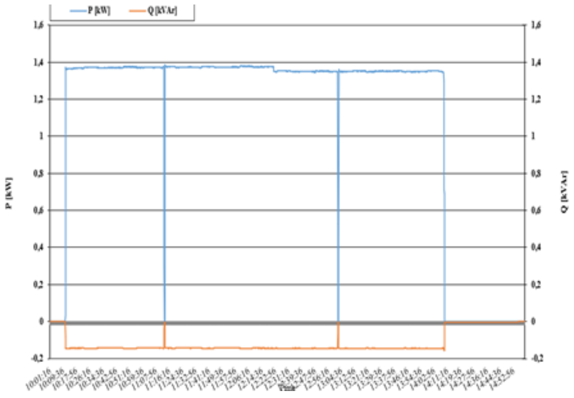


Fig. 1. Power time variation on Mercedes battery charging circuit: active power (blue), reactive power (red).

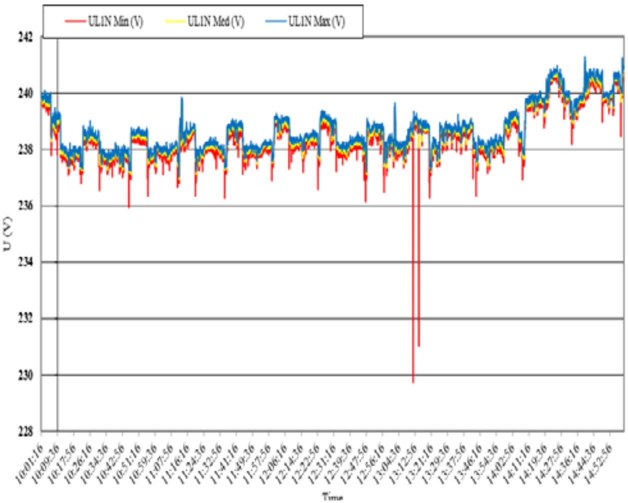


Fig. 2. RMS Voltage time variation on Mercedes battery charging circuit (MIN, MAX, AVG evolution).

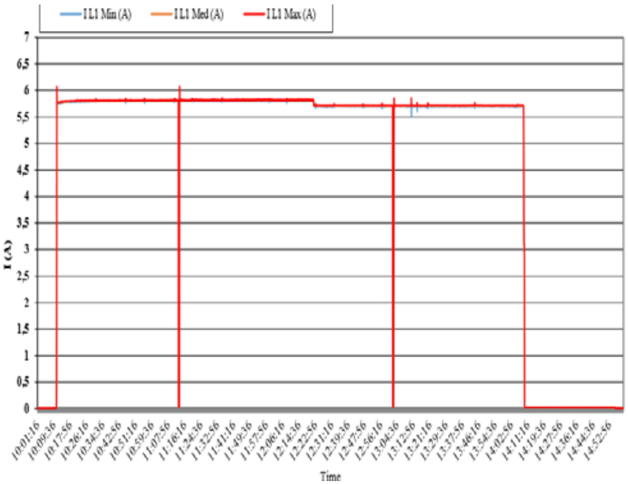
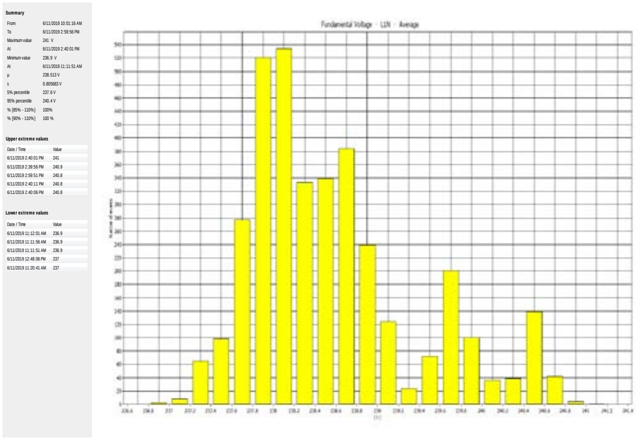
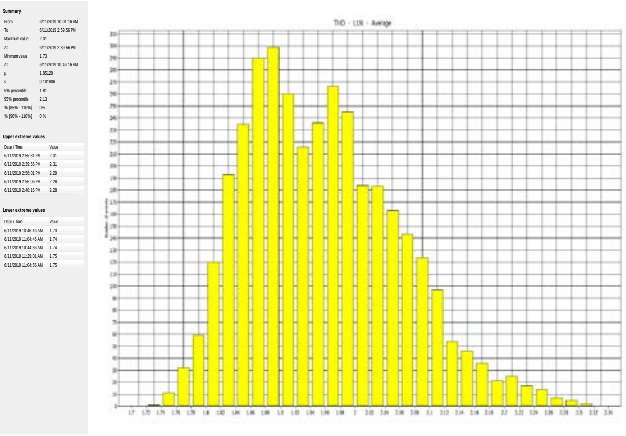


Fig. 3. RMS Current time variation on Mercedes battery charging circuit (MIN, MAX, AVG evolution).



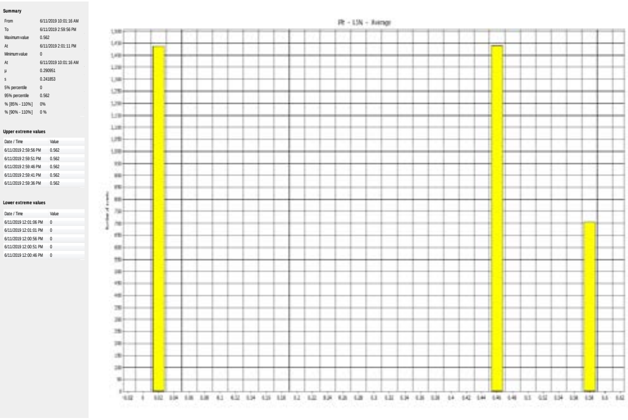
Maximum value	241 V
Minimum value	236.9 V
5% percentile	237.6 V
95% percentile	240.4 V

Fig. 4. Statistics of voltage time variation (fundamental voltage L1 average) on Mercedes battery charging circuit.



Maximum value	2.31 %
Minimum value	1.73 %
5% percentile	1.81 %
95% percentile	2.13 %

Fig. 5. Statistics of voltage THD (THD L1N average) time variation on Mercedes battery charging circuit.



Maximum value	0.562
Minimum value	0
5% percentile	0
95% percentile	0.562

Fig. 6. Statistics of long-term flicker (Plt L1N average) time variation on Mercedes battery charging circuit.

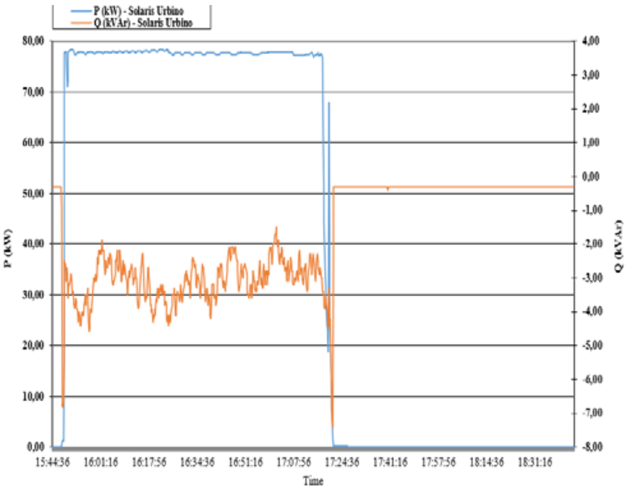


Fig. 7. Power time variation on Solaris battery charging circuit: active power (blue), reactive power (red).

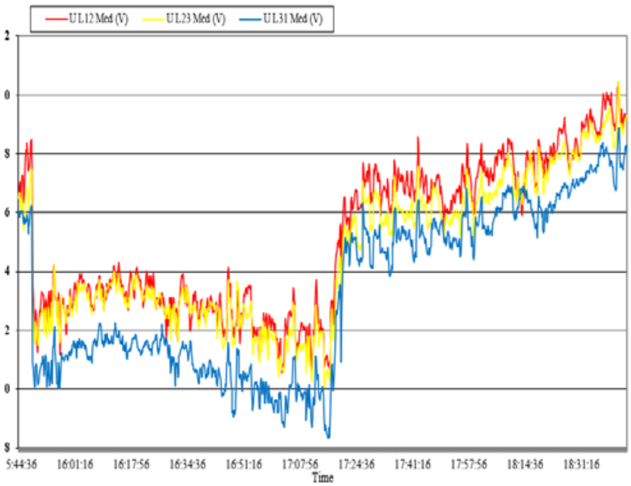


Fig. 8. RMS Voltage time variation on Solaris battery charging circuit (MIN, MAX, AVG evolution).

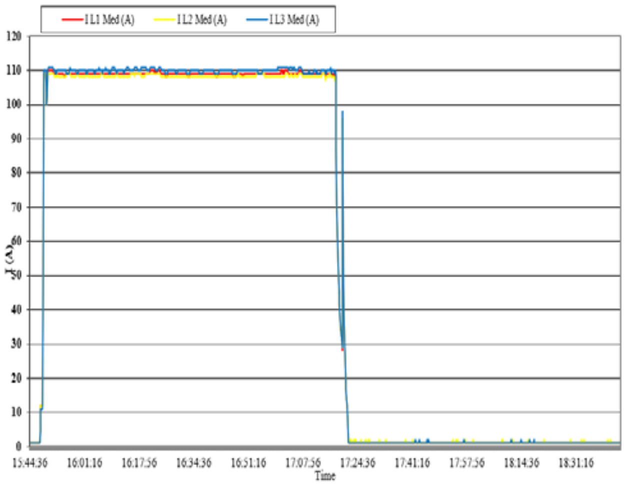
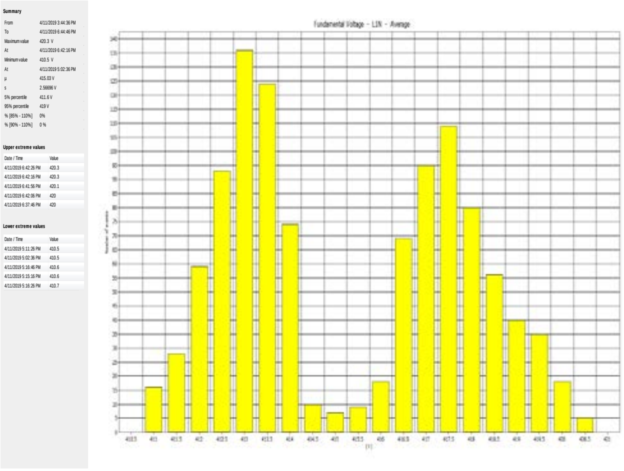
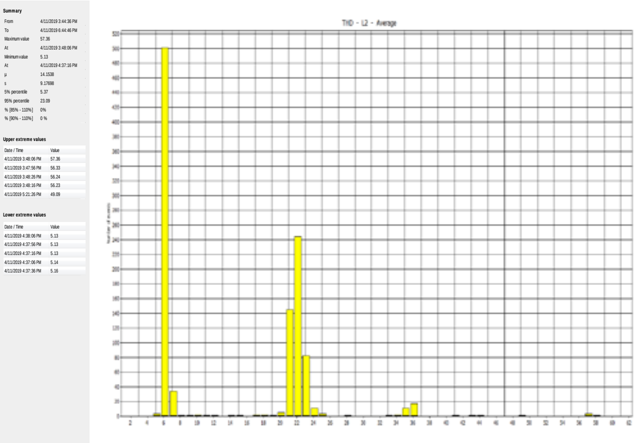


Fig. 9. RMS Current time variation on Solaris battery charging circuit (MIN, MAX, AVG evolution).



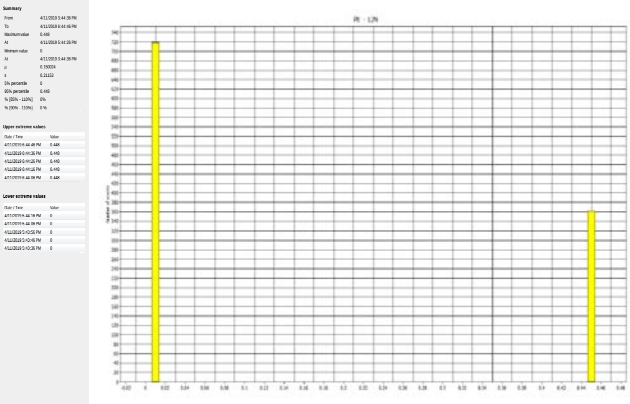
Maximum value	420.3 V
Minimum value	410.5 V
5% percentile	411.6 V
95% percentile	419 V

Fig. 10. Statistics of voltage (fundamental voltage L12) time variation on Solaris battery charging circuit.



Maximum value	57.36 %
Minimum value	5.13 %
5% percentile	5.37 %
95% percentile	23.09 %

Fig. 11. Statistics of voltage THD (THD L2 average) time variation on Solaris battery charging circuit.



Maximum value	0.448
Minimum value	0
5% percentile	0
95% percentile	0.448

Fig. 12. Statistics of long-term flicker (Plt L2) time variation on Solaris battery charging circuit.

The further observations allow to extend the characterization of PQ parameters’ evolution during the entire charging cycle as a set of singleton values.

Mercedes-Benz GLE 500 e 4MATIC

- Variation of voltages on the supply bars in the permissible range (U_{nom} ±10%): 236.9… 241 V (Fig. 4);
- Harmonic distortion on the feed bars in the permissible range (THD <8%): 1.73…2.31 (Fig.5);
- Plt flicker index on feed bars is in the allowable range (Plt <1): 0…0.562 (Fig.5);
- There are registered 2 periods of approx. 1 min in which the active power decreases to close to 0, with corresponding increases in the reactive power value; the charging cycle shows no other oscillations.
- The variation of the power on the charging cycles of the EV battery, powered on phase B causes variations of reactive power on phase C.

Solaris Urbino 18

- Variation of voltages on the supply bars in the permissible range (U_{nom} ±10%): 410.5... 420.3 V, with cumulative probability 95% of 10 min samples CP95% of 419 V;
- Harmonic distortion on the supply bars very high, exceeding the allowed limit (THD < 8%): 5.37…57.36%, with CP95% of 23.09%;
- Plt flicker index on feed bars in the allowable range (Plt <1): 0…0.448, with CP95% of 0.448;
- Symmetrical system of voltages and currents (zero asymmetry factor);
- The power absorbed from the grid during charging process does not show major variations, except for the end of the period, characterized by multiple oscillations that precede the ending of the charging process.

VI. CONCLUSIONS

The widespread use of electric cars, both cars and trucks and buses, is likely to significantly reduce the pollutant emissions prevented by transport.

The ambitious plan of European countries to drastically reduce emissions from transport by using millions of electric cars could be blocked by the lack of supply capacity of new charging stations in large cities.

In order to achieve government goals of becoming carbon neutral by 2045, EU countries should have several million plug-in hybrids and electric vehicles by the end of the next decade. While many of these will be powered at home for shorter journeys, a network of stations for longer journeys is needed, as are cabs and commercial trucks. The predicted "explosion" of electric cars could lead to a major problem: excessive growth in electricity demand, with proportional impact on the performances, losses and power quality of supplying grid. In order to accommodate the EV charging loads in the actual Romanian distribution system, it would be necessary for utilities to reinforce the grid infrastructures in heavily loaded areas. In order for electric vehicles to be manageable despite the lack of supply capacity or PQ emissions there should be developed extensive assessments of EVs impact on the power grids preceding their intelligent integration.

These solutions can partially solve the existing grid operational and infrastructure problems, and even future power quality (PQ) problems.

In this paper there were presented certain aspects related to the impact on the power quality of the EV charging stations in the supplying distribution grids, as part of an extended research project. The study presented in the paper is based on information obtained through direct measurements for two types of electrical vehicles during their normal charging process.

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REFERENCES

[1] *** European Alternative Fuels Observatory - Charging infra stats, “Normal and fast public charging points (2020). Romania”. Available at: https://www.eafo.eu/alternative-fuels/electricity/charging-infra-stats#.

[2] A. J. Hawkins, “Tesla’s Elon Musk said a $25,000 electric car with next-gen battery in the works”. In the Verge, Sep 22, 2020. Available at https://www.theverge.com/2020/9/22/21450916/tesla-battery-pack-elon-musk-price-kilowatt-hour-ev-cost-tabless

[3] J.A.P. Lopes, F.J. Soares, P.M.R. Almeida, “Integration of electric vehicles in the electric power system,” in Proceedings IEEE 99(1), 2011, pp. 168–183.

[4] G.A. Putrus, P. Suwanapingkarl, D. Johnston et al, “Impact of electric vehicles on power distribution networks,” in Proceedings of the IEEE vehicle power and propulsion conference (VPPC’09), Dearborn, 2009, pp 827–83.

[5] J. Taylor, A. Maitra, M. Alexander, “Evaluations of plug-in electric vehicle distribution system impacts,” in Proceedings of the IEEE power and energy society general meeting, Minneapolis, 25–29 Sept 2009, pp. 1-6.

[6] J. Chynoweth, C.-Y. Chung, C. Qiu, P. Chu, R. Gadh, “Smart Electric Vehicle Charging Infrastructure Overview,” in 2014 IEEE PES Innovative Smart Grid Technologies (ISGT) Conference Washington, DC, USA, 2014. Available at: https://smartgrid.ucla.edu/pubs/Smart%20Electric%20Vehicle%20Charging%20Infrastructure%20Overview.pdf

[7] M. Takagi, K. Yamaji, H. Yamamoto, “Power system stabilization by charging power management of PHEV with LFC signal,” in Proceedings of IEEE Vehicle Power and Propulsion Conf (VPPC’09), Dearborn, 2009, pp 822–826.

[8] L. Kutt, E. Saarijarvi, et al, “A review of the harmonic and unbalance effects in electrical distribution networks due to EV charging,” in Proceedings of 12th Internat. Conf. on Environment and electrical eng. (EEEIC’13), Wroclaw, 2013, pp 556–561.

[9] A. Cortes, S. Martinez, “A hierarchical algorithm for optimal plug-in electric vehicle charging with usage constraints,” Automatica 68:119–131. Available at https://doi.org/10.1016/j.automatica.2016.01.060, 2018.

[10] Z. Fan Z, “A distributed demand response algorithm and its application to PHEV charging in smart grids,” in IEEE Transactions Smart Grid 3(3), 2018, 1280–1290.

[11] L.G. Manescu, D. Rusinaru, et.al, “Complex Software System for Data Management and Analysis of Power Distribution Grids,” 2017 4th Internat.Conf. on Mathematics and Computers in Sciences and in Industry (MCSI), Corfu, Greece, 2017, pp. 51-56.

[12] F. Kong, X. Liu, Z. Sun, Q. Wang, “Smart Rate Control and Demand Balancing for Electric Vehicle Charging,” in Proceedings of 2016 ACM/IEEE 7th Internat. Conf. on Cyber-Physical Systems (ICCPS). IEEE, Vienna, 2016, pp 1–10.

[13] M. Faschang, F. Kupzog, R. Mosshammer, A. Einfalt, “Rapid control prototyping platform for networked smart grid systems.,” In Proceedings of IECON 2013 - 39th Annual Conf of IEEE Industrial Electronics Society. IEEE, Vienna, 2013, pp 8172–8176.

[14] Martinenas, K. Knezovi´c, M. Marinelli, “Management of power quality issues in low voltage networks using electric vehicles: Experimental validation, ” in IEEE Transactions Power Delivery 32(2),2017,pp.971–979.