Electric Vehicle Charging and Power Grid Issues Scenarios versus PV-powered charging stations

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Abstract* – The contribution of electric vehicles (EVs) in reducing greenhouse gas emissions depends on the energetic mix of the public grid. On the other hand, the public grid may become vulnerable when EVs number drastically increase, as predicted in many worldwide scenarios. Considering several scenarios, i.e., passenger EVs number, charging power values, EV consumption, and average daily urban/peri-urban trip of 20 - 60 km, and based on French power grid data, this paper investigates the power grid issues regarding the EVs charging. The results show that the total required energy for EVs charging can be assumed by the grid while the total required power may represent an issue. In order to overcome this issue, a photovoltaic (PV) powered EV charging station, including stationary storage and public grid connection as power source backups, is introduced. Based on a classic real time power management (rule-based algorithm), three case studies are analyzed. The simulation tests show that for an average daily urban/peri-urban trip of 20 - 40 km and a daily EV charging based on a slow charging terminal associated with PV-powered charging station may bring large advantage for the public grid as well for the environmental footprint.

Keywords: Charging station, driver profile, electric vehicle, power grid, microgrid, photovoltaic energy, storage.

I. INTRODUCTION

Based on the growth in the number of electric vehicles (EVs) around the world and the realistic future scenarios released recently by the International Energy Agency [1], it looks like EVs, especially passenger cars, are really becoming the norm for transportation. In 2020, the EVs number reaches 10 million and considering several policies and targets announced recently by governments and the private sector, the prevision for 2030 is around 140 million and 245 million in view of a sustainable development scenario. However, if nowadays there is an important number of charging stations, mostly slow charging (private or public) and fast charging public, new trends and developments are required regarding EVs charging stations as well as end-users' behaviour.

The expected massive penetration of EVs leads us to wonder about the charging process, energy and available power offered by a public grid and the possible solutions in the event of vulnerabilities by considering the same power and energy capacity of the public grid. Indeed, the charging process of EVs is generally done by drawing electrical power through a point of common coupling with the public grid. If the energy capacity offered by a public grid does not seem to pose a problem, however, the simultaneous charging of several million of EVs may cause a locally public grid congestion leading to severe issues on power grid especially during the peak hours. However, EVs are considered a flexible load unlike uncontrollable loads; therefore, the charging of EVs can be controlled and shifted to other times to prevent the peak load by implementing a smart charging framework [2].

Different charging frameworks of EVs exist:

- Uncontrolled charging happens when the EV starts charging immediately until its battery is fully charged. Thus, there is not any interaction between the EV users and the electrical grid. This is the worst scenario since it charges the EV with the maximum power in the shortest time imposing difficulties on the grid and peak load [3], [4], [5], [6].
- Delayed charging occurs when the park time (time duration for an EV parked in a station) is longer than the actual required time of charging, therefore, the EV charging can be delayed taking into account the time of use price and can be charged during the low-cost and off-peak energy period [3], [4]. However, the park time must be known by the charging terminal in advance.
- Average charging is considered when the EV is charged at constant power depending on the park time in which the EV is able to meet the requested state of charge (SOC), partial or full, where it is not necessary to charge with full power [4], [5], [6]. This charging operation requires data from the EV's user and abilities to run the terminal with the calculated constant power with respect of the limited power of the charging terminal.
- Smart charging: the EV users provide the charging station management with information regarding the park time and the requested charge that must be supplied before leaving the station. Therefore, energy is used to supply the EVs while the public grid may control and shape the EV charging profiles and minimize the charging costs. In addition, the smart

charging may be done combined with renewable energies production, local or remote, [3].

This generic classification implies however other comments. Delayed charging can be considered also as a smart charging framework, since it changes the charging start time, charging end time, and charging power, yet most importantly delivering the requested energy to the EV. Additionally, the average charging can be considered as an uncoordinated charging framework, since it starts charging immediately when the EV is plugged-in but with limited power [6]. The delayed charging profile is similar to the uncontrolled charging profile but the peak load is shifted to overnight/dawn (around 5:00 am and 9:00 am). Whereas, in average charging, the profile is flattened instead of having a peak [4]. Uncoordinated charging of EVs may increase the peak load, imposing a heavy burden on the public grid leading to more losses. Therefore, through smart charging or coordinated charging, EVs can be an asset for the grid by helping to increase penetration of renewable energies, balancing the energy system, and improving the efficiency of the system while satisfying EV user demands [7]. Coordinated charging is classified into two types, time coordinated charging and power coordinated charging as in [8]. In time coordinated charging, the number of EVs that can charge is controlled to ensure the total load demand within the available power for EV charging. Whereas, in power coordinated charging, the power of EV charging is controlled to ensure the total load demand within the available power for EV charging.

The most important parameters in EV modeling are the charging/discharging rate, initial SOC, battery capacity, charge depleting distance, and user behavior, which is hard to predict in advance. In addition, the arrival time at the charging station, the departure time, and the driving distance of the EV are variables, depending on user habits. They can, however, be assumed and follow probability distribution functions [5], [9]. For this purpose, probability distribution functions are generated to determine the arrival time at the charging station, the departure time, and the driving distance of the EV. Then, the energy needed to fully charge the EV is calculated and the total charging time of the EV is the energy needed to fully charge the EV over the charging rate [5], [9], [10].

Following the literature review, scheduling the charging process of EVs is compulsory and the demand response highlights the off-peak hours as the best choice. Nevertheless, it will be difficult to reconcile the incentive to switch from an internal combustion internal combustion vehicle to an EV with the constraints imposed on users regarding the hourly charging possibilities [11]. On the other hand, the literature does not reveal studies on the public grid impacts with scenarios calculated or estimated from a power point of view. Hence, it is less pertinent to analyse if the proposed smart charging will meet the users' requirements and the public grid needs without a major enhancement of the grid's infrastructure. To overcome this issue an alternative may be the use of renewable energies and thus avoid calling on the public grid spinning reserve, which is composed mainly of fossil fuel-based power plants [12].

Therefore, the electromobility requires EVs charging infrastructures based on renewable energies. In urban/peri-urban districts, photovoltaic (PV) panels are the mostly used renewable energy sources. However, the intermittency nature of the PV energy production makes less efficient the direct use of the PV power. Thereby, for local production-consumption, a microgrid, based on PV sources, storage devices, loads, real time power management, optimization subsystem, data collection system, and interfaces' communication system, becomes a solution for EVs charging.

This paper introduces firstly several scenarios regarding the French public grid impacts. After there, it is presented a PV-powered EV charging station including stationary storage and public grid connection as power source backups and, through three case studies, the conditions under which the PV energy production can relieve the public grid, especially during peak hours, while the end-user demand may be satisfied are investigated.

The main contributions of this study are: the public grid vulnerability for several scenarios based on passenger EVs number, charging power, EV consumption, average daily urban/peri-urban trip of 20 - 60 km, and French public grid data (I; the conditions for which the PV energy production involved in EVs charging may mitigate the public grid issues (ii).

The article is organized as follows, Section 2 describes the public grid impacts when passenger EVs number drastically increases, Section 3 introduces the PV-powered charging station, and Section 4 presents the simulation results for three case studies regarding the EV charging characteristics and drivers' profiles. Finally, Section 5 concludes this paper and gives perspectives.

II. Public grid impacts considering electromobility

The development of electric mobility, according to all forecasts, will be particularly sustained by 2035, everywhere in the world. In France, EVs have known sustained growth in the first half of 2020, with nearly 70 000 units sold in France, i.e., twice as many as over the same period in 2019, despite the health crisis. This strong growth is accompanied by a densification of the network of charging stations across the French territory. In December 2021 there were nearly 32 000 charging stations open to the public, directly or indirectly connected to the public grid and it is expected 100 000 charging stations in France by the end of 2022. Mechanically, this increases in the number of EVs and charging stations will induce an increase in power demand due to new charging needs. The electrical system must therefore adapt.

A. French transmission and distribution system operators' considerations

Regarding the French public grid, in [13] the French electricity public grid operator claim that the integration of the EVs into the French electricity system does not present particular difficulties for the public grid, both at the local level and at the national level, from an energy point of view. In addition, it is highlighted that the possibility of controlling EVs charging will facilitate a better integration of EVs in the medium term and also make it possible to promote local and / or green energy supply for extra-economic reasons, in particular by synchronizing the charging of EVs with the production of renewable energy. From a power point of view, in [13] it is considered that the end-users can schedule the recharge / discharge by smart communicating metering control functions leading to the adjustment of its charging power according to that of the home / building electric network. Thus, the users of the distribution network are the main beneficiaries of the control of EVs charging. In fact, the more the charging is controlled, the integration of the EVs into the power grid will be better. The benefit, for the electricity system and the community, goes to all public grid users. Furthermore, the assessment of the charging control gain against existing time-of-use offers is based on the difference between the cost of controlled charging and "natural" charging. The control is optimized to minimize the cost of charging, as a function of the different price signals, which are the different elements of the invoice for charging. For a residential EV charging, by shifting charging during the off-peak period, when the home consumption is very low, the charging control can avoid increasing the contract subscription fee. For a fleet of a limited number of utilities charging, if the site does not have enough available power, the management of the charging may be operated by shifting it over time and over the different vehicles. However, in [13] the studies are limited at up to 11 kW charging power. Moreover, the power analysis is not deeply investigated as well as how to reduce the cost of upgrading electrical networks without constraints for the users such as that of differentiated tariffs.

The French public grid operator estimates that in 2035 there could be up to 15.6 million EVs circulating in France [13]. Each of them would travel 14 000 km per year with an average consumption of 15 kWh / 100 km. According to these assumptions, around 40 TWh of electricity would be needed to supply French EVs in 2035. This amount of energy represents approximately 7.5 to 8% of the 537.7 TWh of electricity produced each year in France (data from 2019), which it is not huge. However, these statistics remain limited to the energy consumption. However, regarding the power demand, for slow fast and ultra-fast charging terminals, considering also the case of simultaneous charging of several EVs, an analysis is necessary to identify the future issues that a public grid can have during the massive increase of EVs.

B. Impact of EVs energy and power demand on a public grid

In order to design a reliable model of power demand for EV charging, data estimated by learning methods (deep learning coupled with artificial intelligence) or measured are necessary. But, at present, to our knowledge, these models are not developed and / or published. Therefore, for a public grid, the suggested analysis, considering the demanded energy as well as the demanded power, may be carried out according to several parameters:

- the total number of EVs in circulation, N_{EVs};
- the daily distance in kilometers, D;
- the available power of the charging terminals, P_{CHARG_TERM};
- the simultaneous connection of some EVs.

Based on a daily urban/peri-urban trip within an average consumption in kWh / 100km, the total energy demand of EVs is calculated in kWh following (1):

$$E_{EVs\_DEM\_TOT}\,[\text{kWh}] = (C \times D \times N_{DAYS} \times N_{EVs}) / 100 \qquad (1)$$

where $E_{EVs\_DEM\_TOT}$ is the total EVs energy demand in kWh, C is the average consumption in kWh / 100km, N_{DAYS} is the considered number of days, and N_{EVs} is the number of EVs.

Regarding the power analysis, the theoretical total power demand of EVs is calculated in kW following (2).

$$P_{EVs\_DEM\_TOT}\,[\text{kW}] = P_{CHARG\_TERM} \times N_{EVs} \qquad (2)$$

where $P_{EVs\_DEM\_TOT}$ is the theoretical total EVs power demand in kW. Assuming that a number of EVs charge simultaneously, then this simultaneous demanded power is calculated in kW following (3) or (4).

$$P_{EVs\_SIM}\,[\text{kW}] = \gamma \times P_{EVs\_DEM\_TOT} \qquad (3)$$

where γ is the simultaneity coefficient during the peak hours in % and the P_{EVs_SIM} is the simultaneous demanded power in kW.

Knowing that the charging power may be very different depending on EV model, traveled distance, user needs and behavior, and so on, several charging powers may be considered. To simplify, in this study it is consider only simultaneity under a charging power distribution for slow, fast, and ultra-fast charging. In this case, the simultaneous demanded power is calculated in kW following (4).

$$P_{EVs\_SIM}\,[\text{kW}] = \gamma \times ((\sigma_s \times P_{CHARG\_TERM\_S}) + (\sigma_f \times P_{CHARG\_TERM\_F}) + (\sigma_{uf} \times P_{CHARG\_TERM\_UF})) \qquad (4)$$

where σ_s, σ_f, *and* σ_{uf} are the number of EVs charging in slow, fast, and ultra-fast charging respectively and the $P_{CHARG\_TERM\_S}$, $P_{CHARG\_TERM\_F}$, and $P_{CHARG\_TERM\_UF}$ are the charging power terminal for slow, fast, and ultra-fast charging respectively in kW.

Knowing that for an EV the energy consumption is very often between 10 kWh / 100 km and 20 kWh / 100 km, an average consumption of 15 kWh / 100 km may obviously be considered. Hence, based on a daily urban / peri-urban trip within C = 15 kWh / 100 km, the total energy and power demand of EVs are calculated in following for domestic, slow, fast, and ultra-fast charging terminals.

Considerations on the French public grid are also required: the French public grid is characterized by a total yearly energy production of 537.7 TWh, noted with E_G, with 135.328 GW as total installed power, noted with P_G (data from 2019 before Covid-19 crisis). Regarding the EVs number increase, three different stocks of EVs are considered in following.

1) Impact of EVs on French power grid for $\gamma = 10\%$

Table I summarizes the impacts on energy of three scenarios regarding the EVs stocks and considering 60 km as distance. Following these assumptions, the EVs charging induces a minor impact on the total produced energy.

TABLE I.

EVs data		Energy	
N_{EVs}	*D (km)*	$E_{EVs\_DEM\_TOT}$ *(GWh/year)*	$E_{EVs\_DEM\_TOT}/E_G$ *(%)*
1M	60	3285	0.61
5M	60	16425	3.05
15M	60	49275	9.16

Table II and III summarize the impacts on power with 10% of possible simultaneous charging of EVs.

TABLE II.

N_{EVs}	$P_{CHARG\_TERM} = 2.3$ kW, *Domestic terminal*			$P_{CHARG\_TERM} = 7$ kW, *Slow charging terminal*		
	$P_{EVs\_DEM\_TOT}$ GW	P_{EVs_SIM} GW	P_{EVs_SIM}/P_G %	$P_{EVs\_DEM\_TOT}$ GW	P_{EVs_SIM} GW	P_{EVs_SIM}/P_G %
1M	2.3	0.23	0.17	7	0.7	0.52
5M	11.5	1.15	0.85	35	3.5	2.59
15M	34.5	3.45	2.55	105	10.5	7.76

TABLE III.

N_{EVs}	$P_{CHARG\_TERM} = 22$ kW, *Fast-charging terminal*			$P_{CHARG\_TERM} = 50$ kW, *Ultra-fast charging terminal*		
	$P_{EVs\_DEM\_TOT}$ GW	P_{EVs_SIM} GW	P_{EVs_SIM}/P_G %	$P_{EVs\_DEM\_TOT}$ GW	P_{EVs_SIM} GW	P_{EVs_SIM}/P_G %
1M	22	2.2	1.63	50	5	3.69
5M	110	1.1	8.13	250	25	18.47
15M	330	3.3	24.39	750	75	55.42

One notes that for the most critical case of 15 million EVs charged by a slow charging terminal with required power of 7 kW, EVs charging induces a minor impact on the total installed power; however, the demand response management must be involved. Conversely, for 15 million EVs charged by a fast-charging terminal with required power of 22 kW, EVs charging induces a major impact on the public grid (near 25% of the total installed power) and a huge impact (more than 55% of the total installed power) for EVs charged by ultra-fast charging terminal with required power of 50 kW. The demand response management, even strongly implemented, will be not enough to maintain the correct supply of the French territory.

Considering only fast-charging terminals with power up to 50kW and only 10% of possible simultaneous charging during the peak hours, the installed power is highly impacted when connecting millions of EVs.

2) Impact of EVs on French power grid for $\gamma = 10\%$ and distributed charging power

This third scenario would become more realistic considering that by 2035 most of users have already integrated the controlling of the EV charge by shifting charging during the off-peak period, by charging avoiding exceeding the subscribed power, or by the management of the EVs charging operation by shifting it over time and over the different vehicles. Among the supposed 15.6 million of EVs in 2035, it is assumed that 30% are always under charging control while the other 70% may be charged depending on the users' needs at public charging stations. Thus, the scenario focuses on these N_{EVs} = 10.9 millions of EVs that 10% are charging simultaneous at slow, fast, and ultra-fast power during the peak hours (meaning that a global γ at 10% is taken into account). To differentiate the different charging operation, the following distribution of the number of EVs charging in slow, fast, and ultra-fast charging respectively is taken into account: σ_s = 3,27 million (30% of N_{EVs}), σ_f = 5.45 million (50% of N_{EVs}), and σ_{uf} = 2.18 million (20% of N_{EVs}). This is an arbitrary choice for the charging power distribution during peak hour, but it makes sense given the assumptions made at the beginning of this third scenario. The P_{EVs_SIM} in kW is calculated following (4) and the result is given in (5).

$$P_{EVs\_SIM} = 25.18 \text{ [kW]} \qquad (5)$$

According to (5), one notes that even under an optimist scenario and without consideration on the already existing ultra-fast charging terminal between 100 kW and 400 kW there is always a major impact on the public grid with more than 18.5% of the total installed power. Therefore, although the electricity grid operator considers that the overconsumption of electricity generated by EVs should be absorbed without difficulty by the current infrastructure, this study shows that the growth of the EV must be considered keeping in mind the issue of the power demand and peak demand with different charging types. In addition, robust EVs charge controlling and power management solutions are required.

Furthermore, it could be worthy to ensure that users are able to charge the EVs everywhere in the territory and not only at their homes. The traditional tariff control systems, based on the peak-hour / off-peak hours, combined with smart metering signal, could be strengthened to encourage EVs to charge automatically during periods of low power demand.

On the other hand, the local photovoltaic (PV) energy production combined with efficient energy management permits to reduce the impacts of EVs on the electrical system by decreasing the power demanded from the grid [14] and consequently to increase PV energy portion in charging EVs. Concretely, it is necessary therefore, a charging control system based on a microgrid that prevents the saturation of the power grid.

III. PV-Powered Electric Vehicle Charging Station

The PV-powered charging station (PVCS) is based on a microgrid grid-connected with PV integrated on a car parking shade as presented in Fig. 1. The considered system consists of 84 fixed-angle PV panels, capable of producing 29.8 kW at standard test conditions (STC), i.e., 29.8 kWp, including a stationary storage (electrochemical batteries), whose characteristics are 185 Ah and 96 V giving an energy capacity of 17.76 kWh. These technical data are chosen as in [15]. In addition, to limit the maximum charging power from the stationary storage, its power limit is chosen at 7 kW while the public grid power limit is set at 22 kW corresponding at the fast-charging mode.

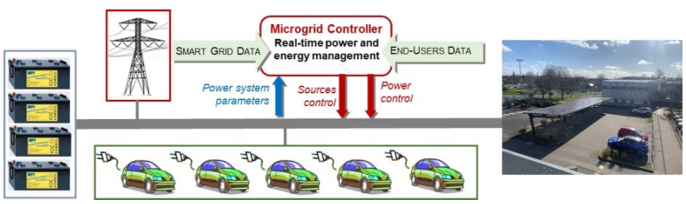

Figure 1. Microgrid grid-connected based on PV-powered car parking shade

The PVCS has five charging terminals, each one equipped with two sockets, one for slow charging limited to 2 kW and one for fast charging limited to 22 kW. Based on smart grid data as well as end-users' data, the microgrid controller operates the whole system considered constraints while performing power balancing as described by the algorithm presented in [14]. The main role of this algorithm rule-based is the microgrid control dispatching the power's sources in real time. However, it is designed also to control the EVs' charge responding efficiently to the desired final state of charge (case studies 1 and 2 presented in Sections 4.A and 4.B respectively) and/or to adapt the charging power to the parking time (case study 3 presented in Sections 4.C). The algorithm is based on the following rules: PV panels are first involved to charge EVs, after PV energy, the second source is stationary storage, and finally, only if there is not enough energy, the public grid is concerned to charge the EVs. In case of excess energy produced by PV panels, the stationary storage is charged first and only if the stationary storage reaches its maximum limits (power or state of charge), the remaining excess energy is sold/injected into the public grid. It is considered that this system is installed in North of France.

The simulation output, calculated with PVGIS tool [16], given in Fig. 2, shows that the lowest PV production occurs in December with an average daily PV production of 36.22 kWh. Based on the assumptions described above, the following section presents three case studies whose results show that the PVCS can mitigate the power demand from the public grid and, therefore, to overcome public grid impacts.

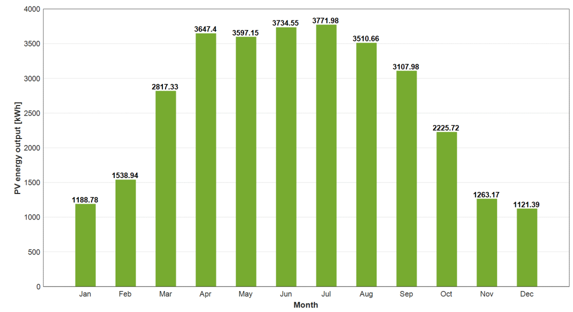

Figure 2. Monthly energy output from fix-angle PV system

Moreover, a comparative analysis identifies some preliminary conditions to be able to solve the power impact on the public grid by using the PV local production and make benefits for EV passenger car.

IV. Case Study

In this section three case studies are presented. All EVs make a daily average urban/peri-urban trip deduced as 20 km – 40 km from [17]. Generally, for urban/peri-urban areas, two driving modes are observed: eco-responsible drive with around 10 kWh / 100 km and normal drive with around 15 kWh / 100 km. Consequently, for an eco-responsible drive mode, the daily energy consumption rate is between 2 kWh and 4 kWh while this consumption rate becomes between 3 kWh and 6 kWh for a normal drive. In addition, it is assumed that initial and desired final EV SOC for each vehicle are known; these data are supposed to be entered by the user throughout the system's interface and therefore considered by the microgrid controller. The arrival of each EV is arbitrary chosen for all three cases. Regarding the EVs, it is assumed that all five EVs are equipped with the same battery capacity of 50 kWh, which represents the average EV's battery nowadays on the market. The simulation results are obtained under Matlab-Simulink following the control algorithm presented in [14]. The goal is to analyse the quantity of PV energy in comparison with that of the public grid and to be able to discuss the conditions under which the PVCS really allows full benefit from renewable energies.

A. *Case 1: slow charging mode operation for all EVs*

The slow charging mode is mostly ranged between 1.8 kW, for domestic use, and 7 kW. In this study, the slow charging mode is supposed to be at 1.8 kW, i.e. the lowest power corresponding to the eco-driving profile described above. Fig. 3 and Fig. 4

present the EVs charging power and respectively the EVs SOC evolution for case 1.

It is observed that EV3 and EV4 are charged with the higher PV energy quantity, due to their time arrival corresponding to the high solar irradiation, while EV1 and EV5 are charged with the lower PV energy quantity, due also to their time arrival corresponding to the low solar irradiation. Thus, for these two EVs, i.e. EV1 and EV5, the stationary storage brings its contribution following the solar irradiation fluctuations.

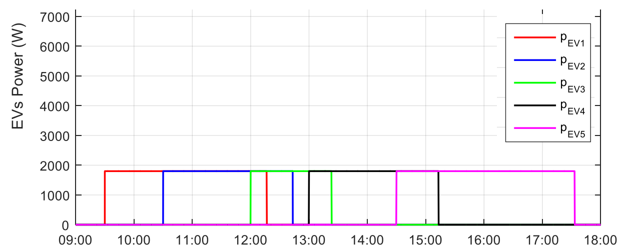

Figure 3. EVs charging power evolution for case 1

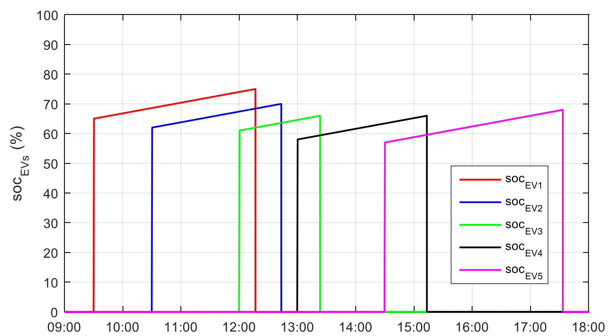

Figure 4. EVs SOC evolution for case 1

The obtained results regarding the energy's contribution of each considered source for each EV are presented in Table IV.

TABLE IV.

EVs energy flow									
EVs	EV energy demand	EV energy received		PV energy		Storage discharging energy		Grid supply energy	
	kWh	kWh	%	kWh	%	kWh	%	kWh	%
EV1	**5**	**5**	**100**	**3.79**	**75.80**	**1.21**	**24.20**	**0**	**0**
EV2	**4**	4	100	3.31	**82.75**	0.69	17.25	0	**0**
EV3	**2.5**	2.5	100	2.28	**91.20**	0.22	8.80	0	**0**
EV4	**4**	4	100	3.72	**93.00**	0.28	7.00	0	**0**
EV5	**5.5**	5.5	100	2.70	**49.10**	2.80	50.90	0	**0**

System energy flow				
PV energy (kWh)	Storage discharging energy (kWh)	Storage charging energy (kWh)	Grid supply energy (kWh)	Grid injection energy (kWh)
21.81	5.20	6	**0**	**0**

The energy from the public grid is not required, and the desired EVs' final SOC is reached for all five EVs. Regarding the system energy flow, the PV sources and stationary storage are able to operate without public grid solicitation. Thus, the PV benefits are greatly highlighted, but the end-user behavior must be compliant with an eco-responsible driving / charging mode.

B. *Case 2: slow and fast charging mode operation*

The case study considers that only three EVs make a daily average urban/peri-urban corresponding at eco-responsible drive mode rated at 2 kWh – 4 kWh, while two other EVs are supposed to require the fast-charging mode. One of this latest EV is supposed also to make a full charge, i.e. 42% as difference between the initial SOC and the final desired SOC. In this case, the fast-charging mode is considered at 22 kW. Fig 5 and Fig. 6 present the EVs charging power and respectively the EVs SOC evolution for case 2. The EV1, EV3 and EV4 are supposed to connect at the slow charging electrical outlets while the EV2 and EV5 are supposed to connect at the fast charging ones.

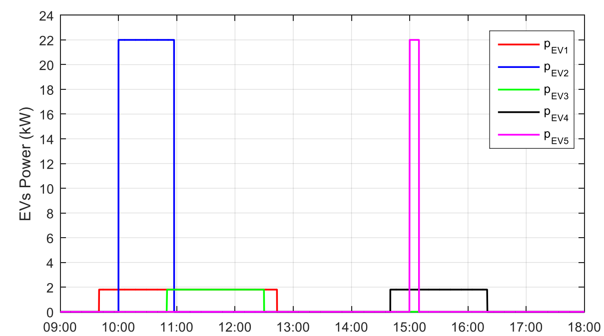

Figure 5. EVs charging power evolution for case 2

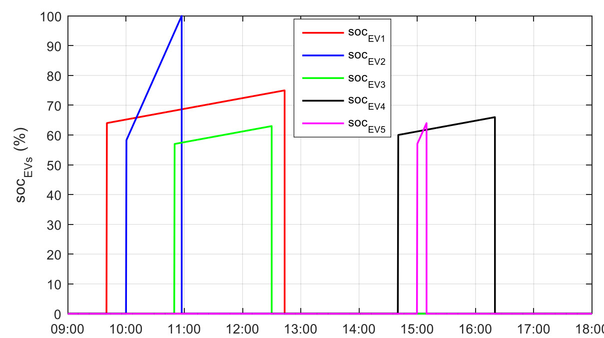

Figure 6. EVs SOC evolution for case 2

The obtained results regarding the energy's contribution of each considered source for each EV are presented in Table V.

TABLE V.

EVs energy flow									
EVs	EV energy demand	EV energy received		PV energy		Storage discharging energy		Grid supply energy	
	kWh	kWh	%	kWh	%	kWh	%	kWh	%
EV1	5.50	5.50	100	3.52	**64**	0.80	14.54	1.18	21.45
EV2	**21**	**21**	100	1.52	**1.24**	4.99	**29.76**	14.49	**69**
EV3	3.00	3.00	100	2.58	**86**	0.23	7.67	0.19	6.33
EV4	3.00	3.00	100	2.09	**69.67**	0.74	24.66	0.17	5.67
EV5	3.50	3.50	100	0.41	**11.71**	1.03	**29.43**	2.06	**58.86**

System energy flow				
PV energy (kWh)	Storage discharging energy (kWh)	Storage charging energy (kWh)	Grid supply energy (kWh)	Grid injection energy (kWh)
21.81	7.78	11.65	**18.10**	**0.05**

It is observed that EV3 and EV4 are charged with the higher PV energy quantity, due to a better time arrival corresponding to a highest solar irradiation, while, as expected, EV2 and EV5 are charged with the lowest PV energy quantity, due to fast charging mode and desired final SOC. The EV2 and EV5, use the energy from the power grid and stationary storage. One notes that the desired EVs' final SOC was reached for all five vehicles.

Regarding the system energy flow, the PV sources and stationary storage are involved as well as the public grid. In contrast with the case 1, the PV benefits are impacted by the end-user behavior (fast charging and/or a high final SOC).

C. *Case 3: Slow and fast charging with adapted power*

The case 3 considers almost the same conditions as in case 2, but for this third case the charging power for the EVs is adapted by the algorithm [14] to the parking time in the charging station; this duration is supposed known by the microgrid thank to information given by the user. In addition, in contrast with the case 2, in this third case only one EV requests a charge with 22 kW. Fig 7 and Fig. 8 present the EVs charging power and respectively the EVs SOC evolution for case 3, where the arrival of each EV is the same as in case 2.

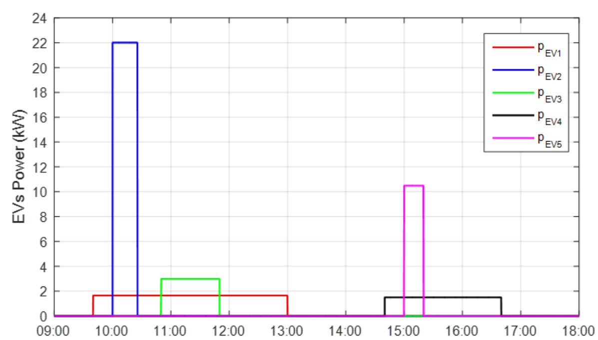

Figure 7. EVs charging power evolution for case 3

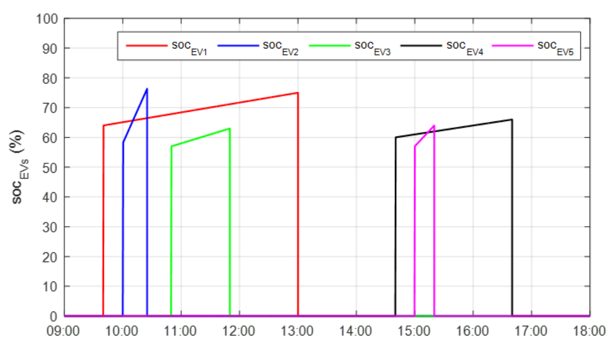

Figure 8. EVs SOC evolution for case 3

The obtained results regarding the energy's contribution of each considered source for each EV are presented in Table VI. It is observed that EV3 and EV4 are charged with the higher PV energy quantity, due to a better time arrival corresponding to a highest solar irradiation, while, as expected, EV2 and EV5 are charged with the lowest PV energy quantity, due to fast charging mode and desired final SOC.

TABLE VI.

EVs energy flow									
EVs	EV energy demand	EV energy received		PV energy		Storage discharging energy		Grid supply energy	
	kWh	kWh	%	kWh	%	kWh	%	kWh	%
EV1	5.50	5.50	100	4.34	**78.91**	0.71	12.91	0.45	8.18
EV2	21	9.17	76.82	0.62	**6.76**	2.71	**29.55**	5.84	**63.69**
EV3	3.00	3.00	100	2.47	**82.33**	0.53	17.67	0	0
EV4	3.00	3.00	100	1.85	**61.67**	1.05	35	0.10	3.33
EV5	3.50	3.50	100	0.74	**21.14**	2.04	**58.29**	0.72	**20.57**

System energy flow				
PV energy (kWh)	Storage discharging energy (kWh)	Storage charging energy (kWh)	Grid supply energy (kWh)	Grid injection energy (kWh)
21.81	7.12	9.66	**7.26**	**2.11**

These last EVs, i.e. EV2 and EV5, use the energy from the power grid and stationary storage. One notes that the desired EVs' final SOC was reached for all five vehicles. However, EV2 user stopped charging the EV before he was supposed to do it, therefore it is not fully charged as originally asked. Regarding the system energy flow, the PV sources and stationary storage are involved as well as the public grid. In contrast with the case 1, the PV benefits are impacted by the end-user, whilst, in contrast with case 2, the charging power is adapted to the parking time set by the EV users.

D. *Results analysis and discussion*

The simulation results highlight that the EVs charging demand is not constrained and the EV user can charge in slow charging mode as well as in fast charging mode, and the charging demand is satisfied. However, the case 1 clearly indicates that the impact to the public grid decreases and the PV benefits increase for an eco-responsible driver profile considering a daily EV charging instead of weekly one. In addition, for a PVCS correctly sized, if all EVs are charged within these conditions, energy from the public grid is not required because the stationary storage capacity is sufficient to compensate PV power fluctuations.

Contrarily, the case 2 involves power from the power grid for all five EVs. This is due to the time arrival of both EVs that demand a fast charging mode. For example, the EV1 requires energy from the public grid more than 21% because during its charging time duration the EV2 demands a high power. Thus, the case 2 shows that the fast charge impact on slow charge. Although fast charging is allowed, the impact on slow charging must be limited. Knowing that the stationary storage is charged by the PV sources, therefore, the maximum power of the discharge of the stationary storage must be limited to the value of the slow charging power. This condition will further promote the slow charging of EVs with PV energy and storage energy.

Whereas, the case 3 shows that the grid share of energy for the EVs charging in eco-mode is reduced in comparison with the case 2. Even more, for EV2 charging in fast mode, the share of grid energy is reduced from 58.86% to 20.57% and the share of PV energy is improved to 21.14%. Therefore, charging EVs with power adapted to the parking time can reduce the share of grid energy and improve PV benefits.

V. Conclusion and Perspectives

The public grid impact' study shows that the EVs' energy consumption is not an issue for a well-developed power grid while the EVs' power demand, especially during the peak hours, is the major impact. Even under the scenario calculated under the most optimist conditions, and without consideration on the already existing very ultra-fast charging terminal for greater than 100 kW, a major impact still remains with more than 18.5% of the total installed power. Despite the electricity grid operator opinion, which is quite optimist regarding the current infrastructure, this study shows that the growth of the EVs implies the charging control and the peak power demand management with less users' constraints as much as possible. However, in all scenarios, users' behavior is shown as a key parameter for this issue.

Nevertheless, the local PV energy production combined with efficient energy management permits to reduce the impacts of EVs on the electrical system by decreasing the power demanded from the grid and consequently increasing PV energy portion in charging EVs. In this case, the charging control system based on a microgrid may prevent the saturation of the power grid.

Therefore, it is shown that the PVCS properly sized and combined with an eco-responsible drivers' profile represents one of the realistic solutions for the electromobility. The obtained results show that the EV charging demand is not constrained during the daylight and the EV user can charge in slow or fast mode, depending on the time duration and/or desired final SOC. However, for an average daily urban/peri-urban trip of 20-40 km the public grid impact decreases and the PV benefits increase for the daily EV charging instead of weekly one, and for slow charging mode instead of fast charging.

Admittedly, additional studies are necessary to set up this charging operation. Thus, further works will focus on social acceptance, incentive business models, new services associated with PVCS such as vehicle-to-grid or vehicle-to-home as well as the possible flexibility that these services offer to public grid.

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