Evaluating the impacts of Electric Vehicles and Micro-Generation in Distribution Networks

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I. Introduction

The foreseen electrification of the transportation sector is being regarded as an important measure to reduce the fossil fuel consumption worldwide and, consequently, decrease the emission of greenhouse gases to the atmosphere. Despite these benefits, the extra electricity demanded by Electric Vehicles (EV) will represent a major challenge for the electric power systems operation and planning.

The large deployment of EV will change the power demand patterns, causing changes in the grids' voltage profiles, branches' congestion levels and energy losses, namely at the distribution level, where the EV will connect for charging purposes [1].

To maintain the quality of service and avoid jeopardizing the network normal operation, Distribution System Operators (DSO) will have to adopt a validation strategy to manage the EV load, that will be grouped and negotiated in the market through EV aggregating entities. This will require the exploitation of Smart Grid related technologies, involving the use of reliable and efficient metering and communication infrastructures. With such infrastructures available, the DSO and the EV aggregating entities can develop novel control and management strategies to make the EV charging coincide with the periods when the demand is lower or the electricity produced by renewable Micro-Generation (µG) units is higher [1]. The identification of such control and management strategies relies on a detailed evaluation of the impacts that EV charging and µG will have in the system operation.

This paper presents an innovative methodology to assess the referred impacts and the results regarding its application to the entire Portuguese distribution system (LV + MV networks). Different EV charging strategies will be considered, as well as several future µG and EV penetration scenarios.

II. Methodology

The main objective of this paper is to assess the impact of the µG and EV in the Portuguese distribution system. Due to the large extension of the network and consequent simulation complexity, some general assumptions were made, namely:

- Separate analysis of LV and MV networks;
- Only the LV and MV networks with the highest degree of representativeness of the Portuguese distribution system were selected;
- Load and generation diagrams are represented by a discrete time step of half an hour, being conducted one power flow for each time step.

Under these assumptions, the impact assessment studies were conducted for each selected network, using a simulation tool that provides a reliable and detailed characterization of the grid operating conditions. The outputs of this tool are voltage profiles, branches' loadings, grid peak power, energy losses and the identification of networks components that will possibly be operated near, or above, technical limits.

The general methodology adopted is shown in Fig.1. To obtain a detailed evaluation, three studies were performed considering: a) Only the connection of EV; b) only µG; c) both EV and µG connections. The developed tool combines a stochastic model based on a Monte Carlo method with the PSS/E simulation software. The Monte Carlo method is used to generate scenarios of µG production and EV load, whereas PSS/E is used to conduct power flow analysis and compute the algorithm outputs.

III. Characterization and modelling of EV and µG units

The deployment of EV requires new interface infrastructures, such as fast charging stations, public charging points, domestic charging points and private charging stations for charging EV fleets. With the exception of the fast charging stations, all the other infrastructures will only be capable of charging EV at relatively low power rates. In these cases, EV remain connected to the LV network during a long period (usually 4-8 hours), offering the possibility of performing load control.

When considering the presence of EV connected to the grid, three different charging strategies were considered, to assess the importance of controlling EV load:

- Dumb charging – EV may charge freely, regardless of their grid impact;
- Multiple tariff scheme – Electricity price is assumed to be lower in off peak hours, incentivising EV drivers to charge their cars during these periods;
- Smart charging – The EV aggregating entities are capable of managing EV charging according to the market negotiations, but always taking into account EV owners' requests [1].

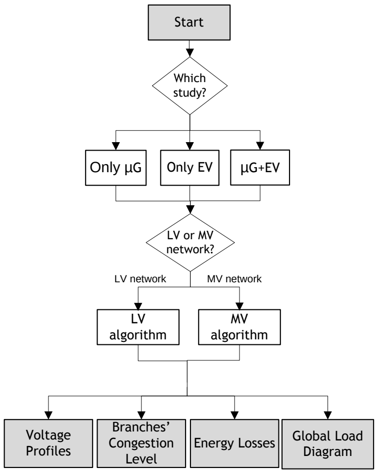


Fig. 1 – Methodology adopted for the µG and EV impact evaluation.

To study the impact of the EV, the adopted tool was based in [1] and is represented in Fig. 2. After evaluating the initial conditions of the grid under study, the stochastic model based on a Monte Carlo method is used to characterize the EV regarding different EV drivers' behaviours, EV charging strategies, battery capacities, charging rates and energy consumptions per distance travelled (kWh/km). Then, it simulates EV movement and charging for each half an hour period of a day. In [1] it is referred that if any voltage violation or line overloading is detected, when smart charging is considered, the DSO will request a reduction in the EV charging rates in order to solve the identified problem. However, as this study is focused on determining only the impacts that EV and µG will provoke, the DSO actions were not considered.

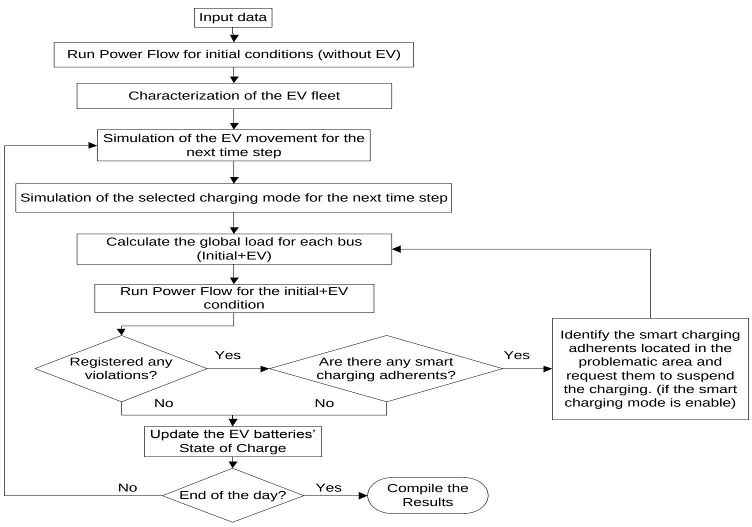


Fig. 2 – Algorithm to evaluate EV impacts.

Regarding the modelling of the µG units, the power produced by each µG unit is subtracted to the existing load at each bus for each time step of the simulation, as in

[2]. μG units are allocated to the buses proportionally to the residential load installed in each bus and it is considered that they have unity power factor. EV are distributed through the grid according to a set of probabilities, proportional to the residential load installed in each bus. Therefore, the buses with higher residential loads installed will have larger μG units connections and a higher probability of having EV parked [1, 2].

IV. Characterization of the data used

The performed evaluation required the definition of the integration scenarios of EV and μG, as well as a detailed characterization of the distribution networks. This section presents the data used for the assessment studies.

Integration Scenarios of μG

Similarly to [2], 80% of all the considered μG units are photovoltaic and the remaining 20% are micro-wind turbines technologies. They are considered to operate at a zero power factor and have specific generation diagrams. The Decree-Law No. 363/2007, [3], establishes the legal regime applicable to electricity production through μG units, stating for the year of 2008 a maximum power capacity of 10 MW that could be subsidized. This value is successively increased at a rate of 20% per year. Based on this legal frame and as in [2], two μG integration scenarios were considered:

- Scenario A – μG installed capacity at national level grows at a rate of 20% until 2015 and 3% from 2016 to 2030, reaching 250MW of installed capacity in 2030.
- Scenario B – μG installed capacity at national level grows at a rate of 65% until 2015 and 6% from 2016 to 2030, reaching 2000MW of installed capacity in 2030.

Integration Scenarios of EV

Since the aim of this study is to assess the impact of the EV in the distribution grids, it is of utmost importance to define a reliable set of hypothesis for EV integration until 2030. In this paper two scenarios of EV deployment were defined, considering two different automobile replacing rates and attending to the social and political circumstances. Additionally, the scenarios defined differentiate the growth of the two main types of vehicles that are expected to be deployed: the battery EV (BEV) and the plug-in hybrid EV (PHEV). The number of EV expected to be integrated in the Portuguese fleet by 2020 and 2030 is presented in Table 1.

Table 1 – Number of BEV and PHEV (thousands of units)

	PHEV		BEV	
	2020	**2030**	**2020**	**2030**
High variant (10^3)	168	444	84	1035
Low variant (10^3)	114	422	76	281

V. Portuguese MV and LV Distribution Networks

As it was previously referred, the presented studies were performed on a set of LV and MV Portuguese distribution networks based on real data. For the LV simulations, five typical LV networks were used, classified according to their MV/LV transformer rated power, which is a satisfactory approximation of load density. Regarding the MV networks existing in Portugal, six typical MV networks were chosen, representing approximately half the total consumption registered in the whole Portuguese MV distribution network. A detailed description of these networks can be found in [2].

In 2010, the annual consumption in the entire Portuguese distribution network was approximately 44.7 TWh. Considering the evolution of the Portuguese electricity consumption in recent years and the current economic and financial situation, a load growth rate of 1.5% per year was considered for a time horizon from 2010 to 2030.

The load diagrams adopted for this study were based in the diagrams used in [2]. The study considers two different periods in a year – winter and summer. For the MV, it is possible to distinguish three types of consumers: residential, commercial (both at the aggregate level of the MV/LV substation) and industrial (consumers fed directly at MV level). In LV grids only residential and commercial consumers were considered, since the number of industrial consumers does not have significant relevance.

VI. Results Analysis

Following the methodology previously described, this section presents the results obtained regarding the different EV charging strategies as well as the future integration scenarios of EV and μG. For a matter of simplicity, only the most representative results will be shown regarding the resultant load diagrams, branches' congestion levels and energy losses. Although not presented in this paper, due to number of pages restrictions, voltage profiles and CO_2 emissions were also studied.

Load Diagrams

The daily load curve presented in Fig. 3 illustrates the consumption pattern for a typical winter day for the year of 2030 in a LV network with a 630kVA transformer capacity. In this scenario this network supplies approximately 63 plugged-in EV.

From Fig. 3(a) it is possible to compare the impact of the considered charging strategies on the daily load curve. As shown, adopting a dumb charging strategy will increase the peak power approximately 62 kW, since EV are likely to be charged at the end of the day. The multiple tariff will result in a new peak at 22:00h, which is when the period with a lower tariff begins. The smart charging takes advantage of the valley hours to charge the EV, contributing to keep the peak load almost unchanged.

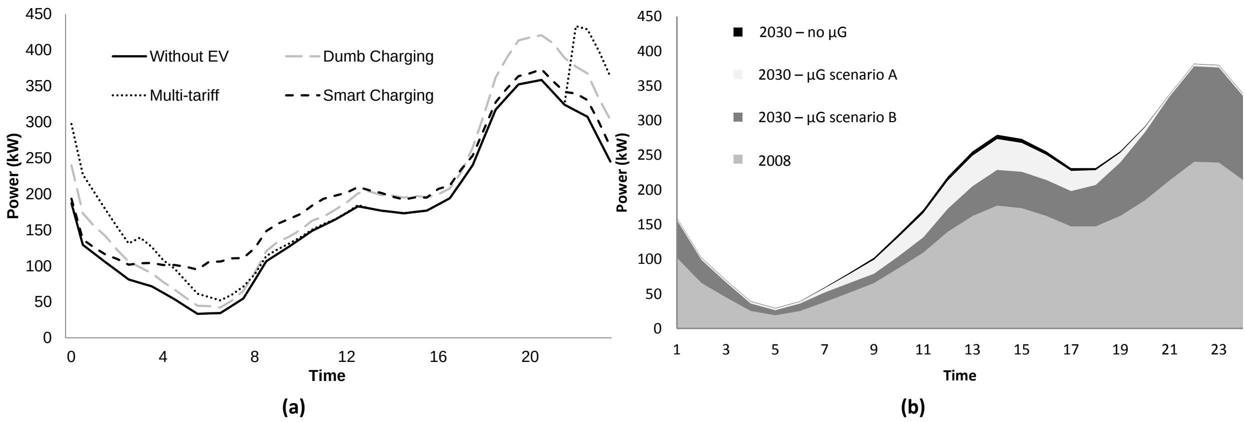


Fig. 3 – Winter day (a) and Summer day (b) in 2030 load diagram at the MV/LV substation of a LV network with 630 kVA transformer

Regarding the contribution of the µG units, in the Fig. 3(b) it is possible to see that during the hours with greater sunlight exposure there is a small reduction in the peak power at substations, since the majority of µG units are photovoltaic systems. It is important to state that in the figures above the EV and µG studies were presented separately, in order to assess more accurately their impacts.

Branches Congestion Levels

The evaluation of the branches overloading is also an important measurement of the adequacy of the Portuguese networks for future deployment of EV. In general, the branches' congestion levels increase in the scenarios without direct control of the EV charging. Fig. 4 shows an example obtained for a LV network with a 400kVA MV/LV transformer. The figures provide a comparison of branches loading in the peak hour of the scenarios without EV (upper-left picture) and with 14 EV, in order to provide a general overview of the three charging methods' impacts in this matter.

In this case the maximum branch loading detected increased 45% with the dumb charging, 56% with the dual tariff and only 11% with the smart charging.

Network Losses

Adopting different charging strategies is expected to increase the networks active power losses, since the power consumption increases. As shown before, uncontrolled charging strategies increase the peak power consumption, increasing also the current and consequently the active power losses. However, controlling the EV load though smart charging strategies, complemented by local generation from the µG units, contributes to avoid significant increases in the network losses.

The value of energy losses in the Portuguese distribution network (MV and LV) was 1782 GWh in the year 2008. This value represents approximately 4.14% of the total consumption in the entire Portuguese distribution network [2]. From the results obtained due to conventional load growth, in 2030, energy losses reach the value of 4394 GWh. When considering the future deployment of EV, losses could reach 5209 GWh if EV charging is not controlled. In this case, the integration of µG could reduce losses to 5175 GWh in scenario A and to 5011 GWh in scenario B. This value can be further reduced if the smart charging is adopted, as shown in Fig. 5, to 4863 GWh in scenario A of µG integration and to 4698 GWh in scenario B. As expected, the smart charging provides better results since it makes the load distribution along the day more uniform, consequently reducing the grid's peak demand.

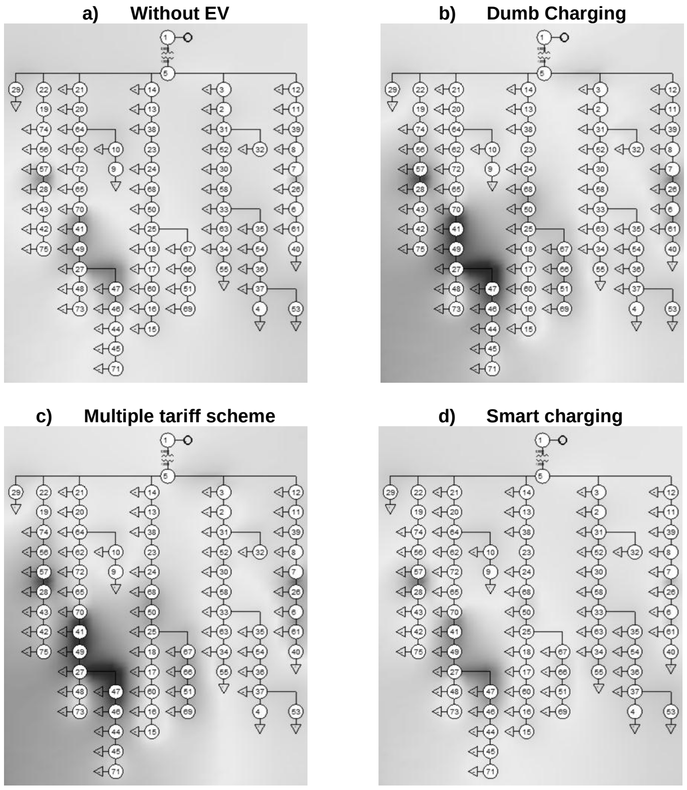
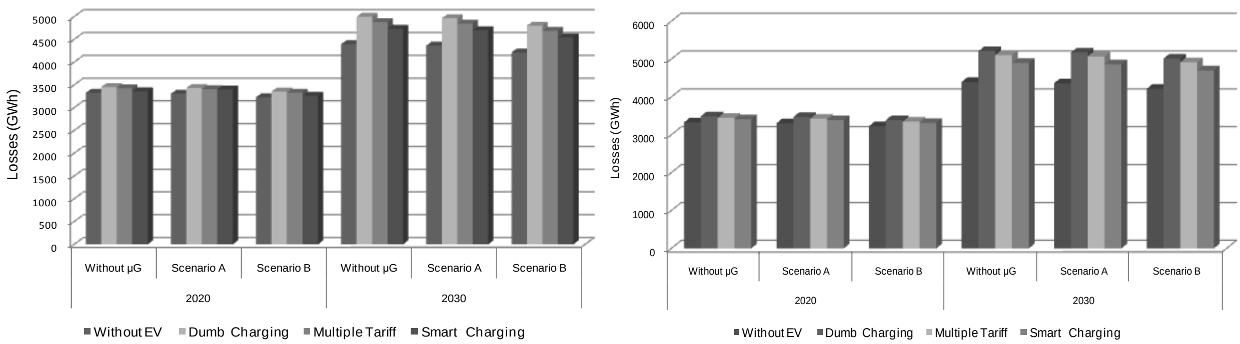


Fig. 4 – Lines loading for a LV network with a 400 kVA transformer (low EV scenario, Summer day, without µG and for the year 2030). Grading between light grey and black, stand for increasing values of congestion, from 0 to 100%.



a) Low EV Integration Variant **b) High EV Integration Variant**

Fig. 5 – Total distribution network losses (MV and LV) for 2020 and 2030, considering the Low and High EV integration scenarios and Scenario A and B of µG integration.

VII. Conclusions

The results presented proved that μG and EV integration might bring important technical benefits to distribution grids, namely if the EV deployment is accompanied with the implementation of controlled EV charging schemes. The major benefits are related with the reduction of branches overloading, grids' peak power and energy losses. Although not presented in the paper, μG and controlled EV charging also have a positive impact in the CO_2 emissions and voltage profiles. When comparing the EV charging schemes (μG not considered), the results obtained show that the the smart charging can avoid ~110 ktons of CO_2 emissions when compared to the dumb charging. The μG, in turn, can avoid 70 ktons when comparing Scenario B with the case without μG (EV not considered). Contrary to the EV charging strategy adopted, the μG has little influence in the grids' voltage profiles. Although not presented in the paper, the results obtained showed that the smart charging can avoid possible voltage violations that are likely to occur if other charging schemes are adopted.

VIII. References

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[3] Portuguese Decree Law Nº 363/2007, Diário da República – 1ª série – Nº 211 – 2 de Novembro de 2007.

IX. Acknowledgment

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