Integration of the Electric Vehicle into the Electrical Grid of the Future

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Abstract. Environmental issues are a major concern in society. To solve them, new technologies have appeared in the las few years, such as Renewable Energy Sources (RES) or Electric Vehicles (EVs). Nevertheless, all these technologies have a huge impact in the Electric System, and especially, in the electric grid, due to their technical characteristics. In this sense, the grid needs to evolve to assume the new electric scenario. In this context, this paper is focused on summarizing how the grid should evolve to correctly integrate these new elements into de system with a special focus on EVs, as they will be the ones with the greatest affection on the load profiles. Hence, how to integrate EVs into the grid considering charging profiles will be explained in order to design the electric grid of the future.

Key words. EV integration, charging profiles, Smart Grids, V2G.

1. Introduction

Greenhouse gas emissions are the major cause of climate change and global warming. The apparition of unpredictable and extreme meteorological phenomena, ocean acidification, loss of biodiversity, land degradation, etc. can be found among their effects [1], [2]. Therefore, it is essential to make an energy transition towards a more sustainable and carbon-free model.

One of the ways to achieve this goal relies on the replacement of traditional sources of electrical energy with Renewable Energy Sources (RES) [3]. Likewise, it is equally important to electrify sectors that depend on fossil fuels. In this sense, the electrification of road transportation will play an important role [4]-[6]. Electric Vehicles (EVs) improve air quality of cities, facilitate RES integration, have higher efficiency than Internal Combustion Engine Vehicles (ICEVs), have lower maintenance due to fewer mechanical elements, enable Electrical Energy Storage (EES) integration, etc. [7], [8].

Apart from these environmental and technical advantages, EVs are gaining importance due to the following factors [9], [10]:

1) Reduction of EV prices (especially due to the reduction in the price of batteries).
2) Increase of the number of charging points.
3) Public perceptions and subsidies.
4) Favourable regulation.
5) Increase of social environmental awareness.

It should be noted that in order to achieve a massive integration of the EV, electric grid must also be taken into account [11]. Otherwise, an uncontrolled integration would affect the power quality and would bring many associated problems like [12], [13]:

1) Congestion of the distribution networks.
2) Power losses.

3) Compromising the safety and reliability of the power system.
4) Frequency and voltage deviation.
5) Harmonic distortion.

This inefficient management of recharging would imply an increase in the cost of energy, for both the end user and the owners of the electricity system infrastructure.

In case the EV charging is carried out in a controlled manner, it would be beneficial for the power grid, favouring proper management of power flows, minimizing power losses, and avoiding unnecessary investment in new infrastructure [14].

Considering that EVs remain parked around 96% of the time, the Vehicle-to-Grid (V2G) concept is starting to make sense [15]. V2G is an EV charging strategy with an integrated view of power, information and money flows between EV owners, the grid, and, where applicable, the aggregator.

It aims to use the energy stored in EV batteries to support the grid. To do this, EVs are charged during off-peak hours when electricity is cheap, and that energy is returned to the grid when it is needed due to technical reasons [16], [17].

As a consequence of the fluctuating nature of RES and their increasing integration into the power system, grid ancillary services are becoming more and more important. In this sense, V2G is seen as one of the possible techno-economic solutions, since the natural gas power plants that have traditionally been used for this task, as they are working less and less hours, are becoming less profitable [18].

2. Evolution of the electric grid

Historically, power grids have been a key component of social and economic development. Nowadays, the world is facing an energy transition, and once again, the power grid is at the spotlight, as it is the integrating element of the new ways of generating and consuming electricity.

The power grid is the core of the electric system. Therefore, while new agents are being integrated into the system, the grid must be adapted to the new needs and characteristics. Thus, to make the penetration of RES and the integration of EVs possible, the grid must be developed oriented towards digitization and automation. This scenario is favorable for the development of Smart Grids (SGs) [19], [20].

SGs integrate in an intelligent and efficient way the actions of energy producers, consumers, and prosumers, optimizing the production, distribution, and consumption of electricity. They are characterized by [19], [20]:

1) Enabling controlled bi-directional flow of electricity and information.
2) Enabling active demand management in real time.
3) Being fully sensorized, monitored and automated.

4) Having a decentralized architecture and being autonomous and intelligent, with adaptive protections.
5) Allowing the insertion of distributed generation (DG).
6) Managing resources efficiently and focusing on Power Quality (PQ).

All this makes SGs an essential part of the smart cities of the future, where the end users will no longer be just consumers but will become active agents that participate and interact with the grid.

In summary, Smart Cities will enable the coordinated and efficient collaboration of all infrastructures (energy, mobility, water, etc.) in a Smart Environment. Thanks to this, individual objectives will be unified at the physical infrastructure level to achieve an overall benefit that goes beyond the individual level. This overall benefit encompasses energy efficiency, sustainability, quality of life, safety and security, system resilience, etc. [20]-[22]

In this scenario, new agents such as Demand Response (to shift demand in a controlled manner), Electric Vehicles and their aggregators (as the effect of a single EV is negligible, the aggregator joins a group to have a real effect in the grid), Smart Meters (to reliably know the behavior of demand), Smart Homes (computerized homes to efficiently manage energy) and Smart Consumers (consumers who are self-aware of their actions), are going to emerge [20]-[22].

With the proliferation of DG and V2G services, more and more Virtual Power Plants (VPP) will be deployed. VPPs are systems composed of different DER and loads that operate together and can behave as a power plant or as a load. They are controlled by an aggregator and provide higher efficiency and more flexibility than the actual network configurations [23].
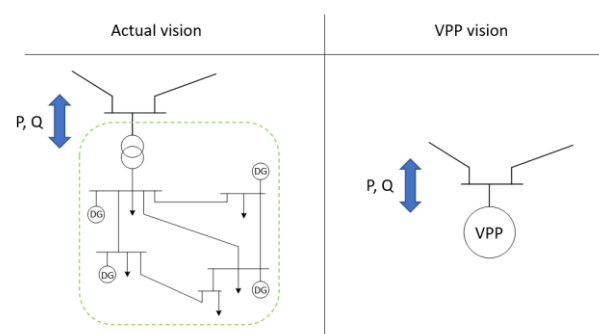

Fig. 1. System Operator's current vision of the DG vs. System Operator's vision under the VPP concept.

In this scenario, it is crucial to manage the energy in the most efficient way, not only in a macro scale, but also locally. In this sense, the Demand Side Management (DSM) is seen as a potential solution. In the DSM, the efficiency is obtained through a more active participation of the costumers, offering them more beneficial solutions. To achieve a proper implementation of DSM, it is essential to develop automation technologies and communication infrastructures [24].

In a near future, electric grids will not be a passive element just for carrying electricity as they have traditionally been. In this sense, they will be intelligent elements capable of real-time decision making and involving many different agents. However, to develop this electric grid of the future, it is necessary to know how the participants will affect it.

In this new situation, how the EV will be integrated into the grid plays a key role.

3. EV integration into the grid

In order to achieve the environmental objectives defined by the European Union (EU) [25], a huge insertion of EVs will be necessary. Considering the amount of energy they will demand, it is assumable that they will become one of the agents of the future that will most affect the traditional electricity consumption profiles.

But nowadays, there is almost no data available of how these EV charging profiles are. This is because the amount of operational EVs is still small and because the ones that are operational, are not monitored for this kind of studies.

So, in pursuit of solving this lack of information, scientific community is making previsions based on available information in databases. These databases generally include the following [26]:

1) Number of vehicles per home.
2) Departing and arrival time of vehicles.
3) Average travelling distance.
4) Differentiation between working days and holydays.
5) Driving patterns.

To extrapolate this data to EVs, some assumptions should be made. For example, it should be assumed that the behavior of EVs (arrival and departing time, travelling purpose, etc.) will be the same as the ICEVs. It should also be considered that while EVs are at home they will be plugged to the grid.

With this information and assumptions, it can be estimated how long EVs would be parked, how much energy they would consume, at which time they will be connected to the grid, etc. Considering all this information, EV charging profiles can be predicted [27], [28].

To perform this, the probability distribution of vehicle arrival times must first be obtained. Next, it is necessary to obtain the probability distribution of vehicle departure. Once these two curves are obtained, the times during which the EVs remain connected to the network can be obtained.

Then, the distribution of the distances traveled by the users is obtained. With this information, the energy expenditure during the trips can be estimated, and it can be deduced which level of the State of Charge (SoC) is available when

plugging in the EVs. Consequently, it can be estimated how the demand profile of the EVs will be like [29], [30].

This charging profiles may significantly vary from region to region. It is important to highlight the relevance of the social-demographic and cultural habits that will ultimately determinate the driving patterns, and hence, the EV charging profiles. In the same way, the patterns may also vary from winter to summer, from residential to commercial areas, from labor days to weekdays, etc. [31], [32].

4. Conclusions

The electric system paradigm is changing. Intermittent RES and DG are appearing. New consumption models are being introduced, such as prosumers, which can act as energy generators or consumers. In addition, the electrification process that many sectors are facing, will drastically increase the electrical demand. All this will completely change power flows through the electric grids, and hence, the network will need to evolve. This modernization will be achieved through the digitalization and automation of all agents participating in the electric system, giving rise to smart grids, VPP, DSM, etc.

However, to design the grid of the future, it is essential to know how the demand trends will be, especially, the ones that will most affect the power flows, such as EV charging profiles.

Mostly, these profiles are obtained through statistical analysis of databases, and they may vary depending on the season, geographical site, demography, cultural habits, weekdays and holydays, residential and commercial areas, travelling purposes, etc.

Understanding them will be a key factor for EV integration and for de development of the electric grid of the future.

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