INTEGRATION OF ELECTRIC VEHICLES INTO TRANSMISSION GRIDS: A CASE STUDY ON THE GENERATION-LOAD ADEQUACY IN EUROPE IN 2040

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Overview

Electric vehicles are currently seen as an opportunity to reduce greenhouse gases and other local polluting emissions of the transport sector, which is nowadays mainly reliant on carbon-intensive fuels. As a result, many governments are incentivizing electric vehicle use. Some regions of the world have even planned to ban the sales or the use of thermal powered vehicles in the mid-term. In addition, battery costs are expected to decrease in the coming decades. Therefore, the share of electricity-powered vehicles in the transport sector is forecasted to accelerate in the following years [1].

The prospective integration of a large fleet of electric vehicles between 2020 and 2050 could be seen as both a challenge and as an opportunity for power systems, and thus needs to be further studied. Simultaneous uncontrolled charging of a large number of electric vehicles close to peak demand time could overload the electricity grid and reduce its capacity to match the total demand. On the other hand, electric vehicles are also seen as a source of demand side flexibility, which could be offered on various electricity markets, and could help further decarbonize the electricity generation system, in addition to the transport system.

Electric vehicle recharge could interact with several aspects of the electricity sector: hourly dispatch and supply-demand adequacy, grid flows (at the distribution scale as well as at the national scale in case of EV diffusion and usage, as well as the renewable energy sources are not geographically uniformly distributed), intraday balancing markets and frequency regulation. In this work, we focus on the interaction between electric vehicle recharge and the electricity supply-demand adequacy at the hourly time scale.

This paper aims at describing a methodology to study the economic impacts of the charge of electric vehicles according to several connection behaviors of EV owners (referred to as systematic, when necessary and when convenient) and the range of recharge modes available (uncontrolled, time of use tariff, smart-unidirectionnal charging, vehicle-to-grid). Subsequently, this framework is applied to a case study of high penetration of electric vehicles and renewable energy sources in Europe at the 2040 time horizon, in line with the European electricity generation mix evolution scenario “National Trends” of the ENTSO-E Ten-Year Network Development Plan.

Methods

The methodology presented in this paper is divided into two consecutive steps.

First, an electric vehicle load curve model is presented. In the electric vehicle modelling literature, this approach belongs to the class of statistical models using data from travel surveys.

Using data from the French National travel survey, and hypotheses taken on the development of electric vehicle and their parameters (battery capacity, consumption, Full electric EV / Plug-in hybrid EV ratio, etc.), the model generates aggregated connection and demand data of a fleet of electric vehicles. The model is composed of five consecutive steps : generation of the parameters of the vehicles in the simulation, generation of their mobility planning, computation of the energy consumption and location of the vehicles, computation of the power demand of those vehicles, synthesis of the results. Results are then extrapolated to other European countries from the French EV load curve and in line with results from [2], based on the time difference, and a projection of the number of EVs in European countries at the 2040 time horizon.

Secondly, we propose a methodology for the integration of the data from the previously introduced mobility model into Antares-Simulator. This open-source simulation model studies the adequacy of interconnected electricity systems and estimates the total cost of electricity production (for a more detailed description of this tool, see [3]). Electric vehicles are considered aggregated as a single battery per charging approach. The model enables to study many smart charging approaches : time-of-use tariff, unidirectional dynamic smart charging, bidirectional vehicle-to-grid. The key features of this approach compared to the majority of studies in the literature are that electric vehicle charging has impacts on the electricity generation mix and thus the electricity prices. Additionaly, it includes a model of the electric system in 17 Western European countries in order to take into account the flexibility of cross bordered exchange. The use of several yearly meteorological data sets allow for deeper analysis of the generation-load adequacy with EVs depending on the weather, compared to using a standard single meteorological data, and take into account extreme weather situations.

In order to make the simulation of all electric vehicles more realistic when aggregated as a single battery in the simulation (with time-varying capacity, connected power and state of charge), constraints are built from the outputs of the EV model.

Results

We show that, in the case of a development of electromobility leading to 24 Million EVs in France in 2040 (more than two thirds of French personal vehicles), the induced electricity demand of those vehicles could range up to 50 TWh annually in France (more than 10% of 2020 total electricity consumption). In the case of uncontrolled charging of these vehicles, there is an additional 10 GW of demand close to peak demand times in the evening.

In order to mitigate the impacts on power systems, we compute the value of different smart charging strategies: time-of-use tariff, smart unidirectional dynamic smart charging and V2G ; sorted in ascendant order of flexibility potential revenue. We also show that the behavior of EV owners in terms of plug-in frequency of their vehicles has a significant effect on the smart charging potential. The more frequent the EVs are plugged in, the more flexible the charge of their cars is for power systems, and the less costly the recharge of vehicles is for the whole electromobility ecosystem.

Additionally, we identify that in 2040, optimal EV recharge periods occur not only at night, but also at mid-day, simultaneous with peak photovoltaic production. As a result, the connection of EVs in the middle of the day might be incentivized for reduced impacts on power systems and support the integration of more distributed renewable energy sources.

Conclusions

In this paper we show the forecasted impacts of electric vehicle recharge on the European power system in 2040.

Four charging strategies are compared : uncontrolled charging, time-of-use charging, dynamic unidirectional charging and V2G.

We identify three major recommendations to get the maximum value from EV demand flexibility. First, tariff-based, dynamic smart and V2G charging modes should be developed, depending on user acceptance of these technologies. Second, is seems important to incentivize mid-day charging, especially with charging stations at the workplace for daily commuters or at home for prosumers, to better synchronize charging with peak solar production. Lastly, EV flexibility is maximized by encouraging systematic connection, in order to enlarge the accessible charging window and even allow EV charge to be postponed to following days (weekly flexibility). We also identify that smart charging value is highly dependent on parameters exogenous from the transport sector such as gas prices and carbon tax.

We conclude that the European electricity generation system could withstand the conversion of a large share of the transport sector vehicles to electric, under the condition that a share of the EV recharge is controlled. Secondly, indivual recharge behavior and smart charging diffusion offers a flexibility source for electricity supply-demand adequacy, and could significantly reduce the cost of the electricity generation and transmission systems.

References

[1] International Energy Agency, 2019. Global EV Outlook 2019: Scaling-up the transition to electric mobility. OECD.

[2] Pasaoglu, G., Thiel, C., Martino, A., Zubaryeva, A., Fiorello, D., Zani, L., European Commission, Joint Research Centre, Institute for Energy and Transport, TRT Trasporti e Territorio Srl, 2013. Projections for electric vehicle load profiles in Europe based on travel survey data. Publications Office, Luxembourg.

[3] Doquet, M., Fourment, C. and Roudergues, J., 2011, Generation & transmission adequacy of large interconnected power systems: A contribution to the renewal of Monte-Carlo approaches. IEEE Trondheim PowerTech, Norway, 2011, pp. 1-6, doi: 10.1109/PTC.2011.6019444.