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Combining photovoltaic energy with electric vehicles, smart charging and vehicle-to-grid

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Abstract

Electric vehicles are expected to greatly increase their market share in the near future. Their impact on the energy system will depend also on the way electricity will be generated. Renewable energy sources and intelligent control strategies will offer relevant solutions to mitigate that impact. In this paper we study the combination of photovoltaic energy and electric vehicles under uncontrolled charging regime and under the application of smart charging and vehicle-to-grid strategies. The analysis assumes different levels of photovoltaic generation and different penetrations of the electric vehicles.

The assignment is carried out by means of an open source linear optimization model named EVLS, which simulates the interactions between the electric vehicles and the upstream energy system by considering market, technical and behavioral constraints. The results show that a high photovoltaic capacity could cover only a small portion of the transportation demand, if the charge is uncontrolled. In such a case, the non-photovoltaic generation would be required to severely ramp up in the late afternoon hours. An intelligent control of the charge could better accommodate the photovoltaic energy and reduce the ramps. The vehicle-to-grid could additionally help harnessing the photovoltaic energy to shave the peaks of the conventional load profile.

Keywords: Electric vehicle; Photovoltaic; Smart charging; Vehicle-to-grid; Energy system model; Linear optimization

1. Introduction

Two major energy issues are of great concern today: the emission of greenhouse gases and the use of peak resources. The former is mainly due to the combustion of fossil fuels and results in an asymmetric energy balance between Earth and space. The second is related to the limited nature of fossil fuels; it implies increasing costs and leads to unsustainable energy and economic systems.

Different technological and non-technological solutions have been proposed in order to mitigate these problems.

Abbreviations: ASE, amount of stored energy; BEV, pure battery electric vehicle; CLP, conventional load profile; EV, electric vehicle – meaning both the BEV and PHEV; PHEV, plug in hybrid electric vehicle; PV, photovoltaic; RS, renewable sources; RES, reference energy system; SCH, smart charging; UCH, uncontrolled charging; V2G, vehicle-to-grid.

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Within the transportation field we find electric vehicles (EVs), meaning both the pure-battery-driven (BEV) and the plug-in-hybrid (PHEV) types. EVs are efficient technologies able to substitute conventional inefficient vehicles and allow for substituting the main energy source on which transportation is based: the fossil fuels. A significant substitution of the existing fleet however would require more electric energy to be generated. The real benefits of electric vehicles would therefore strictly depend on the way that electricity is generated.

Renewable sources (RS) represent a suitable option to power electric vehicles. On the other hand most RS make new issues to arise: they do not allow for modulating or easily forecasting the generation. A big deployment of renewable sources could lead to curtailments, power drops and thus a general inefficiency and unreliability of the power system. Intelligent control strategies applied to EVs could be a key element for connecting the transportation needs and the generation of electricity from renewable sources.

The first key concept to be considered is the smart charging (SCH). With this term we mean all those control strategies that aim to charge the battery of the vehicles when convenient (it is worth noting that the convenience may depend on the point of view within the system). The adoption of the SCH could smooth the additional peaks that might be due to EVs reducing the need for additional power capacity. It could lower the costs and the emissions of the transportation sector by enabling a more efficient use of the generation technologies and by exploiting the cleaner ones when available (thus also avoiding curtailments).

The second key concept is the vehicle-to-grid (V2G). Its benefits lie even outside the transportation sector since it considers the vehicles as a distributed storage capacity that can serve the upstream grid. The V2G strategy, compared to the SCH, hence offers the possibility of reducing peaks that are not due to EVs.

1.1. Modeling electric vehicles within the energy system

As Richardson stated in his review (2013), modeling EVs is today the most effective way to study the impact they can have. Models can tell us which external conditions make them feasible, convenient or attractive in economical, technical or environmental terms. Several models have already been used or have been newly formulated to simulate the implication of EVs and smart control strategies on the energy system, throughout different techniques and formulations, and upon different temporal scales. A first interesting example can be found in Lund and Kempton (2008). They use a deterministic model of one year with a temporal detail of one hour to investigate the role of a large deployment of EVs at national scale in presence of wind and combined heat and power generation. In their analysis the generation is determined by historical data and three smart control possibilities are considered: the simple charging of the batteries at night, the charging when excess generation occurs and the V2G.

A contemporary but antithetic approach, with a lower temporal resolution and a 100-year horizon, is the one used by Turton and Moura (2008) who employed a global bottom-up model based on the optimization of the energy system to study the potential of the V2G. The economic and environmental benefits are investigated taking into account the spinning reserve, the regulation and the peaking margins.

In several other studies, the modeling of the EVs and the smart controls follows one of these two different approaches. Whichever strategy is used, their common challenge is to take into account those dynamics that occur or vary within short periods of time. Some examples deal with the adoption of the Balmorel model, used by Goransson et al. (2010), Juul and Meibom (2011) and Kiviluoma and Meibom (2011) or with the use of intelligent unit commitment combined with EV, considered by Saber and Venayagamoorthy (2010) and Wang et al. (2011). Further modeling approaches can be found in Kristofferson et al. (2011), Hartmann and Özdemir (2011), Rotering and Ilic (2011), Damiano et al. (2011), Darabi and Ferdowsi (2012), Rastegar et al. (2012) and Battistelli et al. (2012).

We created an open source model called EVLS (Electric Vehicles Learning Static model) able to simulate the relations between the EVs and the upstream energy system either in case of uncontrolled charging (UCH) or in presence of smart control systems: the SCH and the V2G. Its mathematical formulation is based on a linear programming problem that aims to satisfy the electricity demand for services at the lowest operating cost. The most important features of the model deal with its open source nature and its ease in use and adaptability. The time horizon can be adapted to use the desired time steps, according to the available information and the type of analysis. The model is available online, free of charge and can be expanded and detailed in each part of its structure.

1.2. Combining electric vehicles and photovoltaic energy

By means of the EVLS model, in this paper we investigate the integration of EVs and photovoltaic (PV) plants upon a broad range of combinations of the penetration of both technologies. The combination of EV and PV has not yet been fully explored by the researches dealing with the integration of EVs and renewable sources, which mostly focus on wind energy. This is well documented by Richardson in his review (2013), where a comprehensive list of the studies and a discussion can be found.

Among the few that relate EVs and PV, an interesting analysis is the one of Munkhammar et al. (2013). They use a stochastic model to investigate how home-charged EV can modify the coincidence between the profiles of the PV output and the households load. Their results show that an improvement exists although little. The same conclusion is more recently obtained by ElNozahy and