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Plug-in hybrid electric vehicles and smart grids: Investigations based on a microsimulation

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ABSTRACT

The introduction of plug-in hybrid electric vehicles (PHEVs) and electric vehicles (EVs), commonly referred to as plug-in electric vehicles (PEVs), could trigger a stepwise electrification of the whole transportation sector. However, the potential impact of PEV charging on the electric grid is not fully known, yet. This paper presents an iterative approach, which integrates a PEV electricity demand model and a power system simulation to reveal potential bottlenecks in the electric grid caused by PEV energy demand. An agent-based traffic demand model is used to model the electricity demand of each vehicle over the day. An approach based on interconnected multiple energy carrier systems is used as a model for a possible future energy system. Experiments demonstrate that the model is sensitive to policy changes, e.g., changes in electricity price result in modified charging patterns. By implementing an intelligent vehicle charging solution it is demonstrated how new charging schemes can be designed and tested using the proposed framework.

1. Introduction

These days, fossil fuels are the most important primary energy source in most countries of the world. The transportation sector and individual transport in particular is highly dependent on fossil fuels. For several reasons, endeavors are undertaken to break this dependence. Reasons include concerns about the economic and political implications of the current unsustainable use of limited fossil resources or the impact of greenhouse gases on climate change. One solution to these problems could be the electrification of vehicles. It has been estimated that electrifying the whole transportation sector could shrink energy consumption to one fifth of current consumption (MacKay, 2009). Moreover, driving with electricity is currently far less expensive than driving with gasoline (IEEEUSA, 2007). In addition, electrifying the transport sector would promote sustainable ways of generating electricity, such as wind and solar energy (Short and Denholm, 2006). Also, there are advantages for the air quality and human health, such as reduction of particulate pollution and acid rain (Sovacool, 2010).

1.1. Plug-in hybrid electric vehicles

Although EVs have been around for quite some time, their limited range has hindered their widespread use. Plug-in hybrid electric vehicles (PHEVs) can run on both electricity and gasoline. The batteries of these vehicles can be charged at

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home or at other locations by means of an ordinary plug. As most people generally drive short distances during the week (BFS, 2006), the vehicles would mainly run on electricity. Only during longer trips would gasoline be used when the vehicles' batteries became depleted.

The introduction of PHEVs might also create the demand needed for companies to invest in electric fuel stations (Bradley and Frank, 2009). This would also foster the introduction of EVs, which vitally depend on such an infrastructure.

1.2. Smart grid

For electric power generation and distribution utilities, the ability to predict the demand for electricity during the day is vital, because this ability directly influences the operation of the system and hence revenues as well as the security of supply. A shift to electric vehicles would increase the demand for electricity. Furthermore, the demand for electricity from these cars would be dynamic in terms of time and location. This can lead to several challenges for the electricity system. An increase in peak load demand could cause the need to utilize more expensive generation units, if available. Furthermore, presuming the electricity generation capacities are sufficient, the electricity network's physical constraints could be violated by the additional PEV demand at the medium- and low-voltage levels (Peças Lopes et al., 2009). A possible solution to this problem could be offered by a future *smart grid* (National Energy Technology Laboratory, 2007).

The idea of a smart grid is to use advanced information and communication technologies in order to intelligently manage the provision of electrical energy to consumers. This means that by consolidating data from different sources (e.g., conventional generators, renewable energy producers, consumers, network operators and PEVs), the demand and supply are matched in a way to ensure network security and system sustainability. For instance, PEV owners and electric utilities could sign an agreement according to which vehicle charging could be stopped for a few minutes during demand peak times. In turn, the vehicle owners would receive compensation from the utility company or responsible entity. The general role of PEVs in such a future smart grid environment is elaborated in Galus et al. (2012a,b).

1.3. Vehicle-to-Grid technology

Through the use of a smart grid, the Vehicle-to-Grid (V2G) concept could become reality (Kempton and Tomic, 2005). A V2G implementation allows PEVs to act as resources to the grid. There are various potential applications for V2G technology (Kempton and Kubo, 2000; Galus et al., 2012a,b): If the demand for electricity in the grid exceeds the supply during peak hours, PEVs could supply peak power. There are also applications in which the vehicles are used to balance the power in feed prediction error of renewable energy generators (Kempton and Dhanju, 2006; Galus and Andersson, 2012), or where they provide ancillary services to the electric grid in order to stabilize the network (Galus et al., 2011).

Our paper presents the initial version of a framework, which helps to analyze the interaction of emerging technologies in connection with PEVs (e.g. smart grid). This framework is able to uncover limitations of existing electricity grids for potential future electricity demand of PEVs. The developed framework is able to analyze differing charging policies and their impact on transportation and electricity networks. Therefore, this framework can also be used to design charging policies for PEVs, which help balancing the electricity demand and planning of PEVs infrastructure (e.g. charging stations).

In the following section, related work is presented together with the two systems on which the framework is based. Then, the methodology and subsequently the experiments are described. Before presenting the conclusions, an outlook on possible future research is given.

2. Related work and background information

Several studies have been conducted regarding the energy consumption of PEVs and their influence on the electric grid. Some of the most recent and relevant work to the topic of this paper is summarized in the following.

Peças Lopes et al. (2009) demonstrate the impact of electric vehicle charging on medium voltage distribution grids. The results point to the appearance of various bottlenecks in the electrical network, such as excessively low voltage and transformer and line capacity violations. In their study, fixed durations (e.g., 4 h) are assumed for electric vehicle charging.

In Letendre et al. (2008) and Letendre and Watts (2009) an accumulated energy model is used to show that a large number of PEVs could be accommodated by the utility grid in Vermont, USA if PEVs are charged during the night. Furthermore, the potential number of cars which could be accommodated by a smart grid is estimated. For the experiments, the charging time of the PEVs is fixed to 6 h. The arrival times of the cars are uniformly distributed between 8 a.m. and 9 a.m. at work locations and between 6 p.m. and 8 p.m. at home locations.

The paper at hand also presents several PEV charging schemes. In contrast to the above-mentioned papers, the charging times and locations of the vehicles are based on an activity model of people. Therefore, the vehicles' energy consumption and charging durations are not constant. Furthermore, an electricity grid and a gas network are interconnected and model a possible future energy infrastructure that offers much flexibility and diversity. The electric networks incorporate physical constraints for the power flow. In the following two sections, both, the mobility model used for the transportation simulation and the energy system are described.