Chapter 17
Grid and Fleet Impact Mapping of EV Charge Opportunities

Niels Leemput  
KU Leuven, Belgium

Juan Van Roy  
KU Leuven, Belgium

Frederik Geth  
KU Leuven, Belgium

Johan Driesen  
KU Leuven, Belgium

Sven De Breucker  
VITO, Belgium

ABSTRACT
This chapter assesses the impact of different technical solutions and their impact on the ability of a fleet of plug-in hybrid electric vehicles to drive in electric mode as much as possible. The technical solutions covered in this chapter to attain this objective include: charging at low and medium power; charging at home, at work, and at other locations; and using fleets with small, medium, and large battery sizes. The driving behavior of the fleet is modeled using an availability analysis based on statistical data from Flanders and The Netherlands. The fleet itself is based on data of the Flemish vehicle segmentation, while the electric consumption of each segment is determined based on realistic vehicle data and driving cycles. This data is combined into different scenarios for which the utility factor, the energy consumption, the grid impact, and the battery utilization is investigated. Based on these scenario guidelines concerning the appropriate charge power at different locations and the distribution of charge locations, the expected grid impact and utility factor of different fleets are formulated.

INTRODUCTION
A whole range of electric vehicles (EVs) is introduced into the market in the present and the near-term future (Michaeli et al., 2011). Electric propulsion offers possibilities to reduce the consumption of greenhouse gas emitting fuels, e.g. gasoline and diesel (Tanaka, 2009). Furthermore, the local concentrations of harmful pollutants are reduced, due to the absence of tailpipe emissions (Duval and Knipping, 2007).

EVs, both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs), are charged with energy supplied through the electric power system. The increasing EV fleet size will impact the power system in terms of power consumption, load patterns, etc. It is generally concluded that uncoordinated charging of
EVs will significantly impact the grid voltage because of the simultaneity between the residential load peak and the plugging in of the vehicles when arriving at home, which starts the charge process (Clement et al., 2010). The impact of EVs on lower levels of the power system has also extensively been discussed, e.g. by Huang et al. (2012) and Pudjiarto et al. (2012). The impact for a household is significant, due to the relatively high energy and power consumption compared to other household loads.

Coordinated EV charging may avoid these grid problems, while respecting the primary objective of EVs, namely to provide a mobility service. Mobility behavior offers flexibility towards the charging of the EV, due to the long standstill times of vehicles, on average above 90% in Belgium, and relatively low distances driven, 41 km/day on average in Belgium (Mobiel Vlaanderen, 2013). The flexibility is determined by the EV users, by indicating the departure time of the next trip and required range, and by the battery (State of Charge, maximal (dis)charge current and voltage). This flexibility can be used to include an additional objective, to determine a unique charging pattern. A significant amount of research has already been performed on coordinated EV charging (Leemput et al., 2011). Generally, it is concluded that charging coordination strategies can reduce the impact on the power system, by making more efficient use of the capacity in the system (Heydt, 1983)(Lopes et al., 2011). Typically, the proposed coordination strategies optimize the charging behavior for objectives, such as minimal charging cost, valley filling, peak shaving and maximal penetration of intermittent renewable energy sources.

Although smart charging, such as defined by (Lopes et al., 2011), will have a beneficial impact on congestion management (Tran-Quoc et al., 2007), the mitigation of imbalance with increasing penetrations of intermittent RES (Tuffner et al., 2011) and other ancillary services (Rebours et al., 2007), the roll-out of electric vehicles has already started, while the wide-spread implementation of coordinated vehicle charging has not. This implies that uncoordinated charging will remain the conventional charging mechanism in the near-term future. Furthermore, the charging infrastructure should have a low cost in the initial roll-out phase of electric vehicles, to allow for a broad and widespread implementation (Cuellar and Gartner, 2012). In a later phase, the charging of the vehicles can gradually switch from uncoordinated charging to coordinated charging, whenever a sufficient amount of EVs is available to validate the benefits of coordinated charging. Additionally, locally high concentrations of EVs may occur before there is a significant penetration rate on the regional/national level (Huang et al., 2012). In that case, local grid constraints can be corrected with the implementation of grid interactive chargers, e.g. equipped with voltage droop control (Rei et al., 2010), while coordinated charging can achieve a socially fair solution in a later phase.

However, before coordinated charging can take place, significant infrastructure upgrades are required. As these upgrades come at a cost, the economic benefits of cost-optimal EV charging cannot be realized with all coordination strategies. For example, the time-of-use coordination strategy (Lyon et al., 2012) does not appear to justify investing in the smart grid infrastructure required to implement real-time pricing. Even though the vehicle-to-grid (V2G) potential is investigated in this chapter, this does not imply that the current state of battery cycle life justifies its implementation. For example, when considering coordinated EV charging for grid supporting objectives, the economic impact of increasing the battery lifetime through a suitable charging strategy, which benefits the vehicle owner, is approximately two times higher than savings due to coordinated bi-directional energy trading for cost minimization, which benefits the power system operators (Lunz et al., 2012). Thus, it is unlikely that vehicle owners will be prepared to participate in a coordination mechanism with V2G capability, because it pro-