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Simulation of electric vehicle driver behaviour in road transport and electric power networks ☆

Charalampos Marmaras *, Erotokritos Xydas, Liana Cipcigan

Cardiff University, United Kingdom

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ABSTRACT

The integration of electric vehicles (EVs) will affect both electricity and transport systems and research is needed on finding possible ways to make a smooth transition to the electrification of the road transport. To fully understand the EV integration consequences, the behaviour of the EV drivers and its impact on these two systems should be studied. This paper describes an integrated simulation-based approach, modelling the EV and its interactions in both road transport and electric power systems. The main components of both systems have been considered, and the EV driver behaviour was modelled using a multi-agent simulation platform. Considering a fleet of 1000 EV agents, two behavioural profiles were studied (Unaware/Aware) to model EV driver behaviour. The two behavioural profiles represent the EV driver in different stages of EV adoption starting with Unaware EV drivers when the public acceptance of EVs is limited, and developing to Aware EV drivers as the electrification of road transport is promoted in an overall context. The EV agents were modelled to follow a realistic activity-based trip pattern, and the impact of EV driver behaviour was simulated on a road transport and electricity grid. It was found that the EV agents' behaviour has direct and indirect impact on both the road transport network and the electricity grid, affecting the traffic of the roads, the stress of the distribution network and the utilization of the charging infrastructure.

1. Introduction

Environmental and energy security reasons are setting Electric Vehicles (EVs) as a major part in the future road transport networks (Element Energy, 2013). Integration of EVs will affect the road transport networks due to their particular characteristics, such as the frequency and the time needed for recharging the EV battery. Apart from being a major part in road transport networks, EVs are expected to influence significantly the electric power networks (Momber et al., 2013). Considering a typical battery capacity of 30 kW, the energy needs for recharging an EV is nearly double the average daily needs of a house. EV charging will affect significantly the load profiles unless smart grid control techniques are applied. Several studies indicate that uncontrolled charging of EVs will increase the peak demand of the power system, resulting in feeder voltage excursion and overload of the transformers and cables, especially in already stressed networks (Putrus et al., 2009; Clement-Nyns et al., 2010; Pieltain Fernandez et al., 2011; Papadopoulos et al., 2012). The integration of EVs will affect both electricity and transport systems, and consequently, research is needed on finding possible ways to make a smooth

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* Corresponding author.
E-mail address: marmarasc@cardiff.ac.uk (C. Marmaras).

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transition to the electrification of the road transport. To fully understand the EV integration consequences, the behaviour of the EV drivers and its impact on these two systems must be modelled.

Because of the limitations in the current battery technology, the EVs offer relatively low driving range. With no major changes in the following years, the EVs will need regular recharging periods depending on the average daily trip distances. Depending on the urban design, EVs are expected to recharge mainly at night, when the EV owners return home from their work (Putrus et al., 2009; Papadopoulos et al., 2012). However, this will not exclude recharging events during the day. Charging in public or street locations requires at least a parking space per charging point. Due to the finite number of parking spaces in a city, especially in the city centre, the number of EVs that are charging at the same time is limited. This will affect the road transport networks particularly the daily travel patterns and the congestion parameters (Rodrigue et al., 2009). Authorities should take into consideration this behavioural change and utilize proper mechanisms and parking schemes for the EV deployment.

The complexity of the dependencies between road transport and the electric power system is therefore likely to increase with higher EV market penetration. Coordination is essential to preserve a stable network operation and avoid unnecessary investments in infrastructure. Due to limits in power capacity within an electricity network, it might not be possible to serve all EVs that want to recharge their batteries. In order to protect the electric power network, and maintain a robust operation, the condition of the various components needs to be monitored. Future scenarios utilize advanced EV charging management mechanisms that use the available storage in the EV batteries and the flexibility of the charging demand to provide ancillary services to the grid operators (Karfopoulos et al., 2012; Lin et al., 2014; Marmaras et al., 2014; Karfopoulos and Hatziargyriou, 2016).

This paper proposes an integrated simulation-based approach, introducing the EV as an intelligent unit existing in both road transport and electric power systems. The main components of both systems have been represented in a single environment, and the EV driver behaviour was modelled using a multi-agent simulation platform. The proposed simulation-based approach serves as an enabling technology in order to understand the EV driver behaviour and its impact on both the road transport and electric power system. Section 2 presents a short literature review on modelling EVs in transport and electric power networks. Section 3 presents the architecture of the EV agent and the governing equations of its environment. Sections 4 and 5 present the battery characteristics and the behavioural profiles of the EV agent. An example case study is presented in Section 6, and conclusions are drawn in Section 7.

2. Related work

The route choice behaviour of the drivers and the characteristics of the road transport network are strongly correlated. The route choice behaviour of drivers is affected by various factors like traffic information, weather and route attributes. According to Arentze et al. (2012), the road accessibility characteristics have a substantial impact on route preferences. Raveau et al. (2011) defined an angular cost variable to reflect the directness of the chosen route, and used it to improve the explanation of route choices. On the other hand, the route choice behaviour of the drivers affects the road transport network (Bhat, 1997; Yao and Morikawa, 2005). Multi-agent models are often used to model the behaviour of drivers on road networks (Balmer et al., 2004; Doniec et al., 2008; Bazzan and Klügl, 2013). Traffic simulation tools like SUMO, OMNet++ and Veins are generally used by researchers in order to quantify the impact of the route choice behaviour.

EV drivers however, need to consider additional factors when deciding their route. Factors like energy consumption, charging station availability, charging duration are introduced in the route choice decision. Nicholas et al. (2013) investigated the charging behaviour of EV drivers by simulating EVs travelling and charging at public chargers. The results show that more than 5% of the trips would require recharging at a public charger for different driving range and charging assumptions. The location of the charging stations is directly related to the impact of driving behaviour in urban road transport networks. In Ghamami et al. (2016) a general corridor model is used to propose the optimal location of EV charging stations, while the authors of Li et al. (2016) propose a multi-period optimization model to expand the charging network. Similar studies for an urban environment can be found in He et al. (2015, 2016) and Cavadas et al. (2015). A spatial-temporal demand coverage location approach is used in Tu et al. (2016) to address the location problem of electric taxi charging stations. The shortest-path and trip planning problem is investigated in Strehler et al. (2017), where the authors designed an approximation scheme to compute the energy efficient shortest route for EV drivers. Some traffic simulator platforms offer EV support and give to the user the ability to run traffic simulations with all or partially electrified vehicle fleets. Such a simulation can be found in Coninx and Holvoet (2014), where EVs are simulated in highway networks with on-line charging. Another example is found in Bae and Kwasinski (2012), where a spatial-temporal model is build based on a poison-arrival-location-model (PALM) for EVs charging at public chargers on the highway. These models however ignore the impact of EV charging on the electricity grid.

The charging behaviour of the EV drivers not only at public but also at the home chargers affects the electricity grid. The charging fashion in particular has been the certain of interest, as it defines the magnitude of this impact (Clement-Nyns et al., 2010; Pieltain Fernandez et al., 2011). In Schücking et al. (2017), the authors evaluate different charging strategies through performance indicators, and show that three characteristics are essential to develop a sustainable charging strategy: the maximum charging power, the duration of a full recharge, and the shape of the charging curve. All three characteristics impact directly the electricity grid. To take this impact into account, integrated models have been developed, which combine