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The investigation of the major factors influencing plug-in electric vehicle driving patterns and charging behaviour

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ABSTRACT

All major vehicle manufacturers now have, or plan to have, an electric vehicle model (EVs) on the market. Current EV take up rates are relatively slow, but the main factors that will determine take up rates are complex and unpredictable. A rapid and large increase in the take up rates over the coming years is therefore possible and probable. Such a rapid take up rate, if it occurs, would impact on electricity load and load profiles. Determining what the impacts will be, however, is made difficult as recharging behaviours of EV drivers are not well known or understood in advance. While a number of research studies have reviewed the methods that can be used to control the recharging profiles of EVs, this paper focuses on EV driver recharging behaviours and charging patterns and reviews and presents the major technical, environmental and economical factors that will influence these.

Contents

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1. Introduction

Electric vehicles (EVs) have started to appear on the market. All major vehicle manufacturers offer, or plan to offer in the near future, an EV model. This suggests that EVs could potentially represent a significant portion of the vehicle fleet in the future. High EV penetration rates would have a number of social, environmental and economic benefits, one major benefit being reduced oil consumption and reduced national reliance on imported oil products. Government policies are therefore likely to be geared to encourage accelerating EV take up rates. Accurately projecting EV take up rates at this very early stage in the market, however, is difficult and is made more difficult by the fact that the main determinants of take up rates, such as world oil prices and future battery costs, are unpredictable. This uncertainty of EV take up rates and the possibility of an unexpected surge in EV take up rates at any stage present major challenges for electricity distribution network operators. Rapid high EV penetration rates would result in EV recharging loads increasing to become a substantial part of the overall electricity load. It is not only the number of EVs in the vehicle fleet, but also the recharging behaviour of EV drivers that will determine the degree to which any sudden increase in load will be problematical for network operators. If, for instance, a large number of EV owners started to recharge their EVs at the same time in the day, and that occurred during peak load periods, it would have the potential to increase peak loads and to impact negatively on the reliable operation of the grid. It will therefore important to be able to predict the recharging behaviour of EV drivers, which will be determined in turn by vehicle technology as well as by recharging behaviour

This paper considers EV driver recharging behaviour in terms of time of day, duration and frequency of the recharging events and the electricity required to recharge the vehicle batteries. The major factors that could influence the recharging behaviour and driving pattern are grouped into three domains, named the transport domain (EV penetration rate, charging infrastructure), the vehicle technology domain (battery performance, cost) and the power system domain. These factors are discussed in terms of their likely impact on EV driving behaviour and charging patterns. The results of a trial used to study recharging behaviour are then presented.

2. Electric vehicle study overview

The driving behaviours or patterns of EV owners are likely to be very different to those of conventional internal combustion engine (ICE) vehicle owners, as they will be determined primarily by recharging and recharging management requirements. Currently, the driving behaviours and charging patterns of EV owners are unknown and this creates challenges for both transport planning and electricity planning. In order to manage these challenges it will be essential to obtain a better understanding of how EV drivers' mobility and driving patterns will differ from the current driving patterns of drivers of conventional ICE vehicles as these changes will determine EV recharging electricity loads and, therefore, the extent to which the other potential benefits of EVs, such as reduced emissions, will be achieved.

To address the fundamental concerns about the potential impacts that both Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs), together referred to in this paper as Plug-in Electric Vehicles (PEVs) or simply as Electric Vehicles (EVs), may have on the electricity grid as well as on environmental and climate impacts, assessing EV driving patterns and recharging is essential and will allow planners to manage the electricity grid to accommodate PHEVs and BEVs. Vehicle manufacturers and climate policy regulators also stand to benefit from a more thorough understanding of recharging behaviour, while battery manufacturers would benefit by being able to more accurately model battery life and cost. For energy planners, the charging behaviour of EVs is an important factor in the integration of EVs to the electric grid, as this will affect the recharging demand, which could become a major component of overall load on the electricity supply system.

The recharging behaviour of EV owners will be determined by various environmental, economical and technical factors, such as the number of EVs being charged (EV penetration trend), the availability of charging infrastructure, charging voltage and current levels, charging time, state of the battery technology, including battery specification, battery lifetime and capacity, which are all considered as technical aspects of EVs [1]. The interconnection between the power supply system, the transportation system and vehicle technology are shown in Fig. 1. Factors relating to each of these three domains will affect EV users' behaviours.

The study of electric vehicle integration and its impact on the electricity grid began in the 1980s. Several studies have been undertaken to estimate EV penetration growth rate in different regions and their potential impacts on electricity loads [2–6]. A common finding of these studies was that unmanaged charging demand is likely to coincide with the overall peak load on the grid [7]. These studies all focused primarily on the question of whether the existing and planned generation capacity would be sufficient to meet the resulting increase in load [8]. A thorough analysis of EV penetration into the regional power grid, for example, was undertaken by the Oak Ridge National Laboratory (ORNL) in the USA. That study found that all regions in the USA would need additional capacity to cover the increase in load.

Other studies have focused on the impact of EV penetration on the high voltage transmission supply infrastructure [6,9,10]. The majority of studies, however, have concentrated on the impact that EV recharging is likely to have at the distribution network level. An evaluation of the potential impacts of BEV and PHEV charging load on the distribution network components and its operation, however, requires a micro-level analysis that takes into account potential variations in spatial diversity of EVs throughout the network as well as temporal diversity in charging patterns and how these relate to the traditional system load [8,11]. The concepts of smart charging and demand response management have therefore been proposed, with the aim of optimising the recharging of EVs in terms of reducing the impacts on the distribution network [11–14].

A number of studies have found that the integration of distributed generation, such as small-scale renewable generators into EV charging infrastructure, could reduce the potential negative impacts that additional EV loads will have on the electricity network [15]. In more recent years, the focus of these studies of EV recharging has shifted towards analysing factors resulting from the EVs' extra load on the grid. The factors include driving patterns, charging behaviour, energy cost optimisation, and battery longevity [16–20].

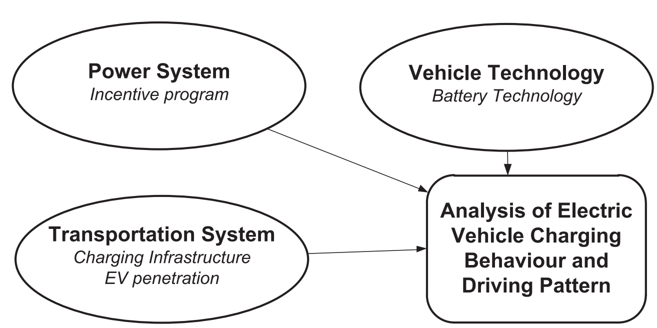

Fig. 1. EV charging behaviour and driving pattern analysis.