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Vehicle-to-grid systems for sustainable development: An integrated energy analysis

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Abstract

Vehicle-to-grid (V2G) systems represent a means by which power capacity in parked vehicles can be used to generate electricity for the grid. This paper describes the first detailed and global analysis of the potential of V2G technologies over the long-term (to 2100) using a comprehensive energy-systems model. In this analysis we explore the potential for V2G systems to supply a number of electricity submarkets and concomitantly accelerate the diffusion of advanced vehicle technologies, including hybrid-electric and fuel cell drivetrains. We also examine the potential impact of V2G on the global energy system, particularly in terms of investment in conventional capacity, and the possible role of V2G-enabled vehicles in increasing the market penetration of renewable electricity generation technologies. Importantly, however, V2G technologies represent a paradigm shift in how the energy and mobility markets are related, and a number of possible barriers to the widespread adoption of this technology are also discussed.

Keywords: Fuel cell vehicles; Hybrid vehicles; Ancillary services; Vehicle-to-grid power; Greenhouse gas emissions; Technological change; V2G

1. Introduction

New technologies represent an important means by which challenges facing the energy system can be overcome. Current global challenges include, among others, the need to reduce greenhouse

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gas emissions, manage energy security and reduce local and regional pollution, while providing access to cheap and safe energy needed for development [1,2]. These challenges are particularly pronounced in the transport sector, where the current dependence on internal combustion engine vehicles (ICEVs) fuelled with petroleum from politically volatile regions remains a major threat to energy security, climate change mitigation and urban air pollution. However, a number of alternative technologies exist that may ameliorate some of the risks emerging in the transport sector through their higher efficiencies and potential to utilize non-petroleum fuels [3]. These technologies include hybrid-electric vehicles (HEVs), fuel cell vehicles (FCVs) and battery electric vehicles (BEVs), although there exists some debate about the suitability of these different options [4–6]. Collectively, these options can be categorised as electric-drive vehicles (EDVs), because they all have the capability to produce motive power from electricity, rather than from the internal combustion engine.

However, these technologies currently suffer to different degrees from a lack of market experience and high costs. Moreover, even if and when these current barriers are overcome, the transition to EDV technologies may span long periods of time, due to the large inertia resulting from the current dominance of the ICEV and related technologies and social systems [4,7,8].

In this paper we explore whether vehicle-to-grid (V2G) technologies represent a potential opportunity to bring forward and accelerate a transition towards EDVs by improving the commercial viability of new vehicle technologies. The V2G concept involves using parked vehicles to supply generation services to the electricity grid [9–13]. In simple terms, vehicles are plugged in to the grid, and then feed in electricity generated from the vehicle engine (in the case of FCVs) or stored in an on-board battery system (HEVs and BEVs).[1]

However, V2G systems are only likely to change EDV deployment and diffusion patterns if there are benefits associated with providing energy from parked cars. One factor which suggests such benefits may exist relates to the fact that private vehicles are parked on average 93–96% of their lifetime, during which time each represents an idle asset [11,14]. Each parked vehicle contains underutilised energy conversion and fuel (or battery) storage capacity, and may actually create negative value due to parking costs. Accordingly, generating V2G power from parked vehicles can better utilise an expensive investment (particularly in the case of new and alternative vehicle technologies), thereby enabling cars to provide both mobility and energy services.

Nonetheless, the question remains as to whether vehicles, via V2G, can provide electricity services competitively compared to conventional electricity generation technologies. Electricity services can be characterized according to specific power markets, which differ in terms of control method, response time, duration of the power dispatch, contract terms and price. V2G power generation has already been analysed in several studies [14–16] which showed that although EDVs may be less suited to base-load electricity generation, they may be suitable for providing regulation services, spinning reserves and peak power demand. These services are described below:

- *Peak power* is required at times of day when high levels of demand are expected (e.g., hot summer afternoons when air conditioning demands are large). Typically, peak power is generated

[1] Of course, electricity could be produced onboard HEVs by operating the internal combustion engine to run a generator, but this would merely provide an inefficient way of generating electricity from the vehicle's primary fuel—petroleum—contributing little to the main challenges outlined above.