Energy Policy 118 (2018) 474–481

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Mitigating the impact of personal vehicle electrification: A power generation perspective

Constance Crozier[a], Dimitra Apostolopoulou[b], Malcolm McCulloch[a]

[a] Department of Engineering Science, University of Oxford, Oxford OX1 3PJ, UK
[b] Department of Electrical and Electronic Engineering, University of London, London EC1V 0HB, UK

ARTICLE INFO

Keywords:
Electric vehicles
Charging
Power grid protection

ABSTRACT

The number of electric vehicles on the road in the UK is expected to rise quickly in the coming years, and this is likely to have an impact on the operation of the power grid. This paper first quantifies the consequences of allowing a completely electric fleet to charge freely, then considers whether there is a practical way in which the impacts can be mitigated. We predict that, with an entirely electric fleet, the UK power generation capacity would need to increase by 1/3. We show that it is possible to completely mitigate this with controlled charging, although substantial infrastructure would be required. However, we propose a simple scheme which could largely avoid the negative effect and does not require the creation of new infrastructure. We show that this reduces the projected increase in peak electricity demand by 80–99%.

1. Introduction

This paper considers whether there is a practical way in which we can prevent the increase in peak power demand resulting from a large fleet of electric vehicles (EVs).

Electric vehicles (EVs) have the potential to drastically reduce the national carbon footprint; as well as having zero tail-pipe emissions, the electricity required to power them can be produced through renewable sources. Van Vliet et al. (2011) confirm that regardless of the source of the electricity, EVs produce fewer CO_2 emissions than both conventional and hybrid vehicles. It is the general consensus that EVs could also increase the amount of renewable energy that is brought online without negatively impacting the grid (Richardson, 2013). This is particularly true with relation to solar (Birnie, 2009) and wind (Short and Denholm, 2006).

The 2008 Climate Change Act commits the UK to a reduction target of 80% by 2050, and this has led the government to introduce grants to encourage people to purchase EVs. Coupled with the decreasing price of lithium ion batteries this has lead to a rapid increase in the adoption of EVs in the UK, as shown in Fig. 1. More recently, a ban on the production of diesel and petrol vehicles after 2040 was announced (Asthana and Taylor, 2017) so the move to all-electric now seems extremely likely.

However, a large-scale adoption of EVs will present significant challenges to the power grid. Electric vehicle chargers draw a large amount of power relative to standard household appliances (see Table 1). Unlike other high-power appliances vehicle chargers will be on for several hours, meaning that there is a much larger chance that many in the same area will be on at the same time. This stands to increase the current peak power demanded from the grid. As well as the peak power, the amount of electricity required in a day by households will be larger; (National Grid, 2017b) predicted a maximum increase of 11% in household electricity demand due to charging by 2050, while (Andrews, 2016) estimated that the UK electricity needs would grow by 36% if all vehicles were electric. Both of these studies were simplistic, and their disparity highlights the sensitivity of predictions to the underlying assumptions in such models. The latter assumes that electrification will not change the number of vehicles on the road, while the former uses sales and scrappage projections to arrive at an updated number.

In the UK, power generation is limited to 78 GW (Department for Business, Energy and Industrial Strategy, 2016), meaning if all power generators operate at full capacity this power is produced. In practice this is not possible as 9 GW of this is from wind and solar power which are variable, and tend to be negatively correlated with each other (Widen, 2011).

If the peak demand regularly exceeds the available supply, more generation will need to be built. For exampled, the Hinkley Point C nuclear power plant currently under construction will add a capacity of 3.2 GW at a cost of up to$21 billion (UK Government, 2016).

The high cost of building additional generation places a large value on shifting demand to off peak times. While the amount of electricity required is not changed, by spreading it throughout the day the demand can be met though increased operation of existing power stations.

E-mail addresses: constance.crozier@eng.ox.ac.uk (C. Crozier), dimitra.apostolopoulou@eng.ox.ac.uk (D. Apostolopoulou), malcolm.mcculloch@eng.ox.ac.uk (M. McCulloch).

https://doi.org/10.1016/j.enpol.2018.03.056
Received 11 October 2017; Received in revised form 25 February 2018; Accepted 25 March 2018
0301-4215/

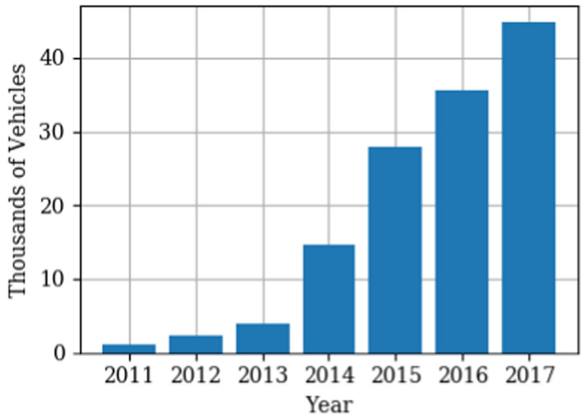

Fig. 1. The number of vehicles eligible for the plug in electric grant on the road in the UK.

Table 1
Power consumption of various household appliances.

Appliance	Power consumption (W)
Washing machine	700
Kettle	1800
Refrigerator	35
LCD TV	115
EV slow charger	3500

Smart charging refers to charging EVs in a controlled way so as to reduce the impact on the system. This is possible because vehicle charging represents an elastic demand; people don't mind whether their vehicle is on charge or not provided it has charged by the time they next need it. By contrast, normal household demand can be considered inelastic - appliances such as lights and microwaves require power at the instant they are turned on. While some trials are on-going, smart charging is not yet widely implemented in any country.

Here we focus on the case of the UK; although the methods could be used to repeat the research for a different area, the conclusions may not be the same. Only domestic vehicle use is considered, electrification of other transport (e.g. taxis and buses) would further increase electricity requirements. This paper focuses specifically on the national energy balancing problem, ignoring limits imposed at the local level by distribution system infrastructure.

Only currently available technology is included, meaning autonomous vehicles are not considered and neither are vehicle-to-grid schemes - where a vehicle can both give and receive power to and from the grid.

To consider a practical way of smart charging, this paper first (in Section 2) considers the charging infrastructure already available and outlines schemes previously proposed. Before assessing the success of smart charging the impact of a large electric fleet needs to be quantified; in Section 3 the methodology for doing this is presented, along with both an optimal and an approximate charging scheme. The proposed techniques are tested using data from the UK in Section 4, and the implications of the results are considered in Section 5.

2. Background

This section first considers the way in which people currently charge their vehicles, as a practical smart charging regime should not propose great deviation for standard practice and comfort of EV owners. Then an overview of the previously proposed schemes is given, and the reasons they are not practically implementable are explained.

Table 2
The types of vehicle chargers currently available to consumers, according to the terminology defined by Zap-Map (2017).

Charger type	Power (kW)	Charging time
Slow	3.5	6–8hrs
Fast	7	3–4hrs
Rapid	50	80% in 30–60 mins

2.1. Charging Infrastructure

Currently EV owners can choose to charge their vehicles from one of three types of charging points, summarised in Table 2. Given that their cars are parked there overnight, many customers have domestic chargers installed at their homes. These are predominantly slow chargers, but consumers can pay more to have a fast charger instead.

Once plugged in, EV batteries are charged under the *constant current, constant voltage* (CC-CV) scheme; chargers operate under a constant current until the battery is about 80% charged, when it switches to a constant voltage (decreasing current) until the battery is full. In power terms this means the charger runs at full power until 80% and then decreases exponentially to zero.

This charging profile is recommended by manufacturers in order to maximize battery lifespan, as empirical studies have observed lower levels of degradation compared to other methods (Zhang, 2006). A smart charging strategy would likely alter this profile, and the effect on the lifetime of car batteries would need be considered. However, this is beyond the scope of this paper.

The majority of drivers still see lack of public charging facilities as a reason not to purchase an EV (Office for National Statistics, 2016). This has led scientists to focus on ways to make charging more convenient, rather than minimising the charging impact; research into a cost-effective rapid charging network in the UK is already underway (Serradilla et al., 2017), despite this level of charging being the most potentially damaging to the grid.

2.2. Previously proposed strategies

An extensive array of smart charging strategies have already been proposed, and these can be broken down into three categories: time-of-use (TOU), centralised and decentralised schemes.

In TOU strategies a variable electricity price is introduced in order to incentivise charging at off-peak times. Charging is still under a CC-CV profile, and consumers have complete control over when they decide to charge. Lyon et al. (2012) conclude that TOU is the most cost effective way to shift charging, due largely to the low required infrastructure cost.

Cao et al. (2012) show that if every consumer acts to minimize the cost of charging their vehicle then valley-filling can be effectively achieved by appropriately setting the price. However, consumers are unlikely to work out their individually optimal charging strategy. In Langbroeka et al. (2017) a survey is conducted which attempts to gauge how consumers might change their charging habits in response to different pricing structure. However Hobman et al. (2016) note that historically the responses of consumers to cost-reflective pricing have not met expectation, and attribute this to psychological influences. Therefore, designing a tariff system which successfully shifts EV charging demand may be more complicated than it appears.

Another concern with TOU is that setting deterministic pricing bands may encourage all EVs to do the same thing, removing the natural diversity which the grid relies on. A possible extension to TOU which resolves this is to move to real-time pricing, where the price of electricity depends on the number of vehicles currently charging. However, Lyon et al. (2012) estimates that installing the infrastructure required to do this would be more expensive than increasing the