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Smart control for minimizing distribution network reinforcement cost due to electrification

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HIGHLIGHTS

- Growth of electricity loads driven by electrification of transport and heat will be significant.
- It will increase the electricity peak demand up to 2–3 times and cost tens of billion pounds if we maintain Business as Usual approach.
- A coordinated application of smart demand technologies can significantly reduce this cost.
- It requires sets of policies and regulations to facilitate timely deployment of such technologies.

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ABSTRACT

Electrification of transport fleets and heating sectors is seen as one of the key strategies to further reduce the use of fossil fuels and the resulting greenhouse gas emissions. However, it will potentially cause a significant increase of electricity peak demand and have adverse consequences on the electricity system, in particular on distribution networks. This paper will address the benefits of various applications of smart network control and demand response technologies for enhancing the integration of these future load categories, and for improvements in operation management and efficient use of distribution network assets. A range of numerical simulations have been carried out on different distribution network topologies (rural and urban networks) to identify the need and the cost of network reinforcement required to accommodate future load under various operating strategies such as Business as Usual (passive demand and passive network) against the smart grid approach. Applications of smart Plug-in vehicle (PiV) charging, smart heat pumps, and optimised control of network voltage regulators to reduce network investment have been studied, and selected key results of our studies on evaluating the benefits of implementing these technologies for Great Britain's distribution networks are presented and discussed in this paper.

1. Introduction

In its development of a sustainable energy system, the UK government has set a clear target in its Renewable Energy Strategy (RES) (The UK HM Government, 2009) that by 2020, more than 35% of the UK electricity demand will be met by renewable generation and the electricity sector would be almost entirely decarbonised by 2030. Reduction of greenhouse gas emissions from other energy sectors can also be achieved by switching from fossil fuels used in transport and for heating towards electricity supplied by renewable and low-carbon electricity generators. However, this electrification may potentially act as a significant driver for an increase in peak demand that is disproportionately higher than the increase in energy consumption. This will have negative impacts on the electricity system as it increases demand for more generation and network capacity with low utilisation levels. In order to alleviate these negative impacts of the electrification, there are unprecedented opportunities for improving energy efficiency and utilising demand-side response facilitated by inherent storage capabilities present in electric car batteries and thermal storage associated with buildings, not only to optimise electricity production capacity but also to enhance the efficient provision of network capacity.

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However, delivering the carbon reduction targets cost-effectively through demand-side response optimisation will require a fundamental shift from a passive to an active philosophy of network control in addition to social behavioural changes. This shift, enabled by the incorporation of demand response into system operation and design, can be facilitated by the application of a smart metering system supported by an appropriate information, communication and control infrastructure. Development of such a system has to be facilitated and stimulated by appropriate government policies that remove barriers for the development and deployment of such technologies.

Our analysis demonstrates that optimising responsive demand has the potential to reduce considerably the system peak demand and subsequently, the need for system reinforcement. In the UK, full penetration of Electric Vehicles (EVs) and Heat Pumps (HPs) could increase the present daily electricity consumption by about 50%, while doubling the system peak. By optimising demand response the increase in the peak demand could be restricted to only 29%, resulting in massively improved utilisation of generation and network capacity, and significantly reduced network investment. At the local distribution network level, which is the focus of this study, significant benefits of optimising demand response in relation to the network capacity are observed even for very low levels of penetration of electric vehicles and heat pumps.

In order to understand how the impact of increased electricity load in the future can be evaluated, we present and discuss our modelling approach of electric vehicles and domestic heat pumps in Section 2, followed by our modelling framework for distribution networks in Section 3. Section 4 presents a range of numerical studies evaluating the impact of demand projection scenarios elaborated in three Transition Pathways on the UK distribution networks, and quantifying the value of various applications of smart control in reducing the network reinforcement cost required to accommodate the additional future loads. Finally, our conclusion is presented in Section 5.

2. Modelling of smart electrical demand

2.1. Modelling of electricity demand of electric vehicles

Electric vehicles are widely seen as one of the key policy instruments to enable shifting of transport demand from fossil fuels to the electricity sector that relies on renewable and low-carbon electricity generators. For the purpose of this study, a detailed National Transport Survey[3] (NTS) database is used. Data extracted from the NTS database contains detailed information on all journeys conducted by light vehicles including starts and ends of individual journeys grouped according to distances travelled. The NTS data is classified into 12 distance bands (e.g., less than 1 mile, 1 to 2 miles, 2 to 3 miles etc.). A small sample of the data set is presented in Table 1.

Based on these records, approximately 67.4 million journeys are undertaken daily on average, by around 34.2 million vehicles (i.e., on average, each car undertakes approximately two journeys per day). Based on the NTS data, each pattern of journeys is characterised by the number of vehicles involved along with start and end times of each journey, as well as the energy needed for each journey. The database created for the assessment undertaken in this study contains approximately 44,000 different combinations of journeys.

[3] National Travel Survey Database 2008, Department for Transport, UK, 2008, http://www.dft.gov.uk/.

Table 1
Driving patterns data.

Start time	End time	Distance band	No. of journeys (daily)
00:00–00:59	00:00–00:59	Under 1 mile	6,922
00:00–00:59	00:00–00:59	1 to under 2 miles	15,987
00:00–00:59	00:00–00:59	2 to under 3 miles	14,848
…	…	…	
00:00–00:59	01:00–01:59	2 to under 3 miles	1,277
00:00–00:59	01:00–01:59	3 to under 5 miles	4,938
00:00–00:59	01:00–01:59	5 to under 10 miles	3,209
…	…	…	
00:00–00:59	02:00–02:59	50 to under 100 miles	474
00:00–00:59	03:00–03:59	100 to under 200 miles	492
00:00–00:59	04:00–04:59	200 miles and over	388
…	…	…	
23:00–2359	23:00–23:59	25 to under 35 miles	7,750
23:00–2359	23:00–23:59	35 to under 50 miles	1,458
23:00–2359	23:00–23:59	50 to under 100 miles	923

With driving behaviour data prepared in this fashion, with an average of approximately two journeys carried out by each car per day, optimisation of alternative charging strategies has been formulated, specifying the energy consumed during the journey together with the times when vehicles are stationary and possibly connected to the electricity system. Our simulation/optimisation algorithms ensure that the state of charge of batteries would not compromise the ability of vehicles to carry out their intended journeys. In this exercise we assume 6 kW as the maximum power for charging EV batteries and each vehicle has a battery large enough to supply their daily energy requirement.

EV loads are particularly well placed to support network operation: given their relatively modest amount of energy required; the short driving times generally associated with small passenger vehicles (vehicles are stationary on average for 90% of the time); and given that the batteries have relatively high power ratings. Clearly, there is considerable flexibility regarding the time when the vehicles can be charged (providing the availability of charging infrastructure) and this can provide significant benefits both to the operation of distribution and transmission networks and to the efficient dispatch and utilisation of generation. In this work we have not explicitly considered vehicle-to-grid applications (discharging car batteries to support the grid[4]).

2.2. Modelling of domestic electric heat pumps

The heat sector is another area that has significant potential for decarbonising, both through replacing older gas-fired, and especially oil-fired or LPG-based domestic heating with electricity-based heating provided by electric heat pumps (HP), and by using heat pumps as a low-carbon space heating option for new housing (included for example in the construction of 'Zero Carbon Homes' starting from year 2016).

The UK residential heating market consists of approximately 26 million dwellings, with annual thermal demand typically in the range between 10,000 and 30,000 kW h (thermal), which is used for providing space heating and domestic hot water requirements. The data associated with the operation of heat pumps used in this work were derived from empirical studies and field trials of micro-CHP and boiler systems conducted by the (Carbon Trust, 2007).

[4] By excluding the explicit assessment of V2G concepts (which is still a controversial topic), our analysis provides conservative estimates regarding the benefits of incorporating EV demand response for real time network control facilitated by advanced smart metering functionality and corresponding communication network.