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Making legacy thermal storage heating fit for the smart grid

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ABSTRACT

Thermal storage heaters, charged using overnight off-peak electricity, have been used for domestic space heating in the UK and other countries since the 1980s. However, they have always been difficult for consumers to manage efficiently and, with the advent of a high proportion of renewables in the electricity generation mix, the time of day when they are charged needs to be more flexible. There is also a need to reduce peaks in the demand profile to allow distribution networks to support new sources of demand such as electric vehicles. We describe a trial of a smart control system that was retrofitted to a group of six dwellings with this form of heating, with the objectives of providing more convenient and efficient control for the users while varying the times at which charging is performed, to flatten the profile of demand and make use of locally-generated renewable electricity. The trial also employs a commercially-realistic combination of a static time-of-day tariff with a real time tariff dependent on local generation, to provide consumers with the opportunity and incentive to reduce their costs by varying times of use of appliances. Results from operation over the 2015–16 heating season indicate that the objectives are largely achieved. It is estimated that on an annualised and weather-adjusted basis most of the users have consumed less electricity than before intervention and their costs are less on the trial tariffs. Critical factors for success of this form of system are identified, particularly the need to facilitate hands-on control of heating by thrifty users and the importance of an effective and sustained user engagement programme when introducing the technology, to ensure users gain confidence through a readily-accessible source of support and advice.

1. Introduction

In March 2016 the UK's National Infrastructure Commission (NIC) published a report [1] entitled "Smart Power" arguing that investment in interconnection, storage, and demand flexibility "could save consumers up to £8 billion a year by 2030, help the UK meet its 2050 carbon targets, and secure the UK's energy supply for generations." These attractive benefits arise from the urgent need faced by many national electricity systems to adapt to an increasing level of intermittent and geographically distributed renewable generation on the supply side, while meeting rising demand from increasing adoption of technologies such as heat pumps and electric vehicles. Similar findings have been documented elsewhere, for example Pudjianto et al. [2] identify a potential value of up to £30 Bn in deferred or avoided network reinforcement costs up to 2050 that can be obtained from demand flexibility that reduces the peak load on local distribution networks. The regulatory changes needed to realise these benefits are now being actively pursued [3].

In this paper we report on a practical trial that realises part of the vision for storage and demand flexibility described in the NIC report. It exploits electrically-charged thermal storage heating (generally known as storage heating) – a form of electric space heating that is found in 1.3 million homes in England [4] and is employed in other temperate countries such as France and New Zealand. Storage heating appliances comprise an insulated enclosure containing high thermal capacity ceramic bricks that are heated by a resistive heating element. The heat energy held in the bricks is then progressively released depending on the setting of vents in the insulating enclosure. Figs. 1 and 2 illustrate a typical appliance. Conventionally in the UK these appliances are used in combination with an electricity tariff known as 'Economy 7' which

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Fig. 1. Storage heater.

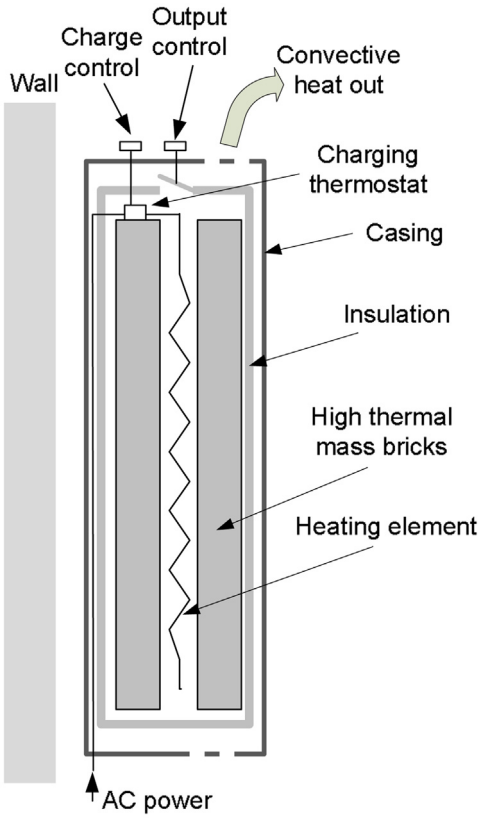

Fig. 2. Storage heater simplified cross-section.

allows them to be charged overnight during a fixed 7 h interval at a low tariff. The majority of dwellings with this form of heating are rented and relatively small [4] as is the case for those in this trial. This implies that users are more likely to suffer from poverty, while fuel poverty, a more specific measure of fuel costs in relation to income, currently arises in 16% of electrically-heated English households, compared with 11% for all households [5]. The cost impact is therefore an important factor in the trial.

There are two major disadvantages in this system of heating as currently employed:

- The appliances are actually quite difficult to use efficiently because energy charge and discharge are regulated by separate manual controls (seen at top right of the unit in Fig. 1) whose interaction and weather dependence are hard to comprehend.
- There is no flexibility to vary the time of day when charging is performed to reflect the dynamic availability of electricity supply, particularly from renewable generation.

A form of "smart" control that can be retrofitted to these legacy appliances[1] is therefore needed that addresses these weaknesses by providing user-friendly controls and allowing the charging time to be shifted throughout the day in a responsive way that reconciles the comfort needs of the user with grid and generation opportunities and constraints. We describe a control system which provides these features and report results from a trial. The rest of the paper is organised as follows. Section 2 provides more detail on the technical and human factors relating to storage heating. Section 3 describes our control system and the form of prototype trial that has been undertaken, then Section 4 summarises results from the trial. The implications of results are discussed in 5 and conclusions presented in 6.

2. Background

2.1. Storage heating

In the UK storage heating tends to be deployed in smaller dwellings such as flats or maisonettes, motivated by the low installation and maintenance cost compared to gas central heating (which also gives rise to more stringent building construction requirements particularly for multi-storey buildings). This results in a typical installation of one large and two or three smaller heaters having a total input power of about 8 kW and thermal storage capacity of 56 kWh. So the 1.3 M households in England have an aggregate capacity in the region of 73 GWh. As a resource for grid management it compares favourably with the UK grid's total pumped storage capacity of 30 GWh [6]. This potential, combined with the need to avoid the network impact of large numbers of storage heaters switching on simultaneously, was recognised in the 1970s leading to the introduction of the Radio Teleswitch system [7] in 1984. This makes use of the BBC Radio 4 long wave transmission on 198 kHz to carry a very low data rate signal to receivers linked to 'Economy 7′ meters that record consumption on a two-band tariff that provides for cheap electricity during seven night-time hours. The signal causes the meter to adjust the time window over which the connected storage heaters are charged. However, the time variations are limited to the overnight period and constrained to 256 options by the signal format, while the introduction of an electricity market enabling consumers to switch suppliers easily has caused the contractual basis for operation of

[1] A trial of new-generation, smartly-controlled storage heaters is under way in Ireland, German and Latvia, in the EC-funded project RealValue. The project runs from 2015 to 18.