ELECTRIC HEATING AS FLEXIBLE DEMAND FOR ENHANCED NETWORK OPERATION

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ABSTRACT

Electrical distribution networks are facing a number of network challenges, which combined with the anticipated transition towards a Distribution System Operator model will place increased emphasis on network and demand flexibility.

The use of direct or storage electric heating to facilitate demand side management and/or response services address a number of these emerging distribution network operation and performance challenges, particularly in relation to increasing distributed generation and system support services.

The ability to deliver such services rests on the implementation of robust, resilient, prioritised and co-ordination control and communication functionality and capabilities.

1: INTRODUCTION

Electrical heating is an established component of the UK's electrical system demand, control and operation, primarily in the form of existing residential direct or storage electrical heating [1]. The desire to decarbonize the UK's heat energy demand has led to a focus in recent years on electrified heating as a potential solution with heat pumps as the preferred technology replacement for existing heating systems with associated provision of network services [2]. However with the ongoing improvements in the operational performance and control capabilities of direct and storage electric heating, this technology has the potential to emerge as a rival candidate for electric heating and the provision of flexible demand. [3].

This paper considers how modern direct or storage electric heating can be used to address a number of the challenges that electricity distribution networks by acting as flexible demand.

In Section 2 an overview of electric heating usage and distribution network is provided, Section 3 focuses on the technology options, Section 4 highlights the network challenges with Section 5 addressing the role of electric heating as flexible demand followed by a discussion in Section 6, conclusions in Section 7 and references in Section 8.

2: ELECTRIC HEATING AND DISTRIBUTION NETWORKS IN SCOTLAND

Scotland differs from the majority of the UK in a significant proportion of domestic households (16%) are off-gas grid which means that they are unable to use natural-gas fuelled boilers as their primary heat source. This lack of gas infrastructure has contributed to the levels of domestic electric heating in Scotland (13% of households) being significantly higher than the UK average (9% of households) [4].

The Scottish Government's Heat Policy Statement [5], while it has a focus on decarbonising heat, recognises the role that electric heating could play in increasing renewable generation capacity, extending distribution network asset life and providing operational flexibility.

The large levels of Distributed Generation (DG) currently connected or planning to connect to the electricity distribution networks in Scotland means that are presently subject to significant planning, operational and performance constraints [6, 7]. Such constraints could be eased by increased levels of network and demand flexibility within the existing demand base, including electric heating.

The anticipated paradigm shift from the current passive Distribution Network Operator (DNO) basis towards the pro-active Distribution System Operator (DSO) is being actively considered nationally [8] and within Scotland [9]. Such a transition provides a forum, incentive's and opportunities for existing, replacement or new direct or storage electric heating to provide demand side response (DSR) and associated services at lower installation costs and timescales than the future installation of heat pumps.

A number of projects have been developed and implemented within the Scottish Islands [11 - 13], to use domestic electric heating to ease network constraints while providing network ancillary and balancing services. Such projects provide a mechanism to establish what is technically and commercially possible while also addressing the social acceptability of alternative heating control and operating regimes and as such are vital in demonstrating effective flexible demand service provision.

The scale of the electric heating demand, combined with

the extent of the distribution network issues presented by the substantial level of distributed generation indicates that there can be significant role for modern electric heating technologies in the progress towards decarbonisation of heat [10] and development of the DSO role within Scotland.

3: ELECTRIC HEATING TECHNOLOGIES

While domestic heat pumps are seen as emerging electric heating technologies that will have an increasing presence and impact on the UK's electrical networks [2], they still face a number of potential economic, behavioural, technical and supply-side barriers [14, 15], as summarised in Table 3.1. These barriers may contribute in various ways to preclude heat pumps from being the preferred technology choice under a number of circumstances.

Category	Potential Barrier
Economic	Higher Lifetime Costs than conventional alternatives
	Financing of installation can be diffcult
Behavioural	Lack of consumer knowledge and confidence
	Increased space requirements and reduced visual amenity compared to conventional alternatives
	Increased time needed for understanding technology and installation
	Mismatch of investment incentives between landlord and tenants
Technical	Suitability of Building (ground space, noise, water storage)
	Regulatory barriers to uptake
	Technical challenges in installation and operation to deliver acceptable heating comfort
Supply-Side	Inability of supply chain capacity to match growing demand
	Ineffective supply chain co-ordiation across installers, service and spares etc

Table 3.1: Potential Heat Pump Deployment Barriers [15]

Direct or storage electric heating is an established technology which is beginning to receive renewed attention across a range of customer applications (e.g. rural off-gas-grid, urban high density dwellings) where heat pumps may be not be viable or appropriate [16]. Their technology, controls and communications are such that they have the potential for efficient, flexible and responsive demand services as well as meeting customer heating needs [11, 12]. It is possible with appropriate aggregation, co-ordination and prioritization of individual residence heating system controls

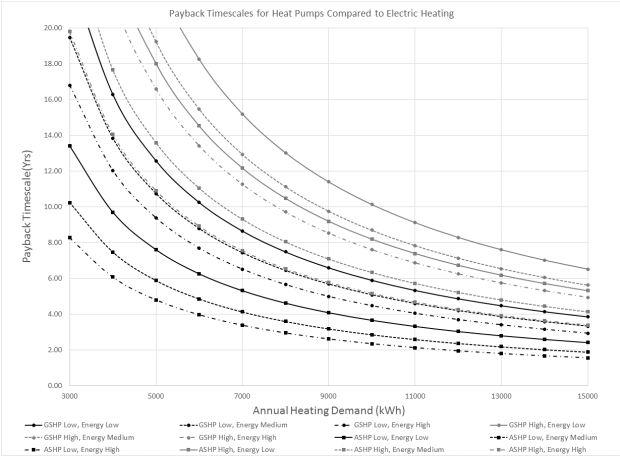

Figure 3.1: Payback Period for Heat Pumps Compared to Electric Heating

to deliver both network operational and optimisation benefits in conjunction with DSR while still maintaining satisfactory customer heating comfort levels [17].

A comparison of the capital[1] and operational[2] costs of electric heating with heat pumps and calculation of the payback period for heat pumps, as shown in Figure 3.1, shows that the payback period before heat pumps would begin to represent a viable economic heating system compared to electric heating but be prolonged (> 10 yrs.) particularly if the heat pumps capital costs are high, energy costs are low or annual heating demand levels are low.

The potential deployment barriers for heat pumps combined with their possibly 'longer' payback periods suggest that the replacement, refurbishment or new installation, of direct or storage electric heating still present a technically and economically advantageous domestic heating solution for a number of years.

4: NETWORK CHALLENGES

Electrical distribution networks are facing a number of challenges including:

i. Aging Asset base with high upgrade/replacement costs

ii. Divergence of operational basis and performance from intended design basis due to increasing DG penetrations

iii. Desire for increased levels of network and demand flexibility

iv. Emergence of Active Network Management (ANM) as a short-term or enduring

[1] Indicative capital cost range of £7000 – £11,000 for Air Sourced Heat Pumps (ASHP) and £13,000 - £20,000 for Ground Sourced Heat Pumps (GSHP) [18]

[2] Taken as 8p/kWh (Low), 12p/kWh (Medium), 16p/kWh (High)

operational and asset management approach

v. Emergence of new, complex, dynamic pricing structures and tariff's

The main focus of this paper is on (ii), (iii) & (iv) and the role that direct or storage electric heating acting as flexible/responsive network demand would provide.

4.1 Operational and Performance Impact of Distributed Generation

Ongoing increases in DG are having wide-reaching impacts on both the operation and performance of distribution networks. The utilisation of flexible demand which was either directly or indirectly controlled to respond to key aspects of network performance could increase and extend the networks operational capabilities to economically and efficiently accommodate DG.

4.2 Network and Demand Flexibility

There is a growing recognition of the extent, nature and importance that demand flexibility could play in the efficient and economic operation of both existing and future network operations [8].

Key areas where network, and by implication, demand flexibility are being sought include:

- Post-fault or outage demand response as part of a network operator's operational measures.
- Peak load lopping to avoid asset replacement due to breaching of thermal ratings and/or security of supply criteria. Deferment or avoidance of asset replacement would be expected to lead to cost savings and environmental benefits
- Off-peak load shaping for optimisation or limitation of key network performance parameters such as equipment thermal loadings, system losses, voltage regulation and profiles, generation unit scheduling and commitment, asset utilisation.
- Provision of existing ancillary support services such as frequency response (primary, secondary and enhanced).
- Increasing need for ancillary and balancing services, currently vested in large/centralised service providers or plants which are likely to move towards an increasingly decentralised provision via DSO's.

4.3 Active Network Management

As the transition towards ANM as 'business as usual' continues to gathering pace with alternative, managed or flexible generation connections becoming offered by all UK DNO's, the main focus to date has been on generation abatement or curtailment as the main mechanism of achieving the ANM management objectives [19].

The implications of such generation curtailment for low carbon generation which have no means to preserve or store fuel supplies such, as solar, wind, run of river hydro, is a direct loss of revenue. There is also the additional environmental disadvantage that the constrained low carbon generated energy is likely to be replaced by conventional fossil fuel generation energy.

The capabilities of ANM schemes in achieving their network management objective could be augmented by the introduction at scale of elements of flexible, controllable demand while reducing curtailment of low carbon generation sources.

In this case the challenges faced by the electrical distribution networks can be both exacerbated, and ameliorated, by the use of electric heating controlled to provide flexible and controllable network demand.

5 ELECTRIC HEATING AS FLEXIBLE DEMAND

The capability of electric heating to operate under direct or indirect control while operating under Demand Side Management (DSM) or as DSR to planned or unplanned network events, are summarised in Table 5.1.

Flexible Demand Service	DSM		DSR			
			Planned		Unplanned	
	Direct Control	Indirect Control	Direct Control	Indirect Control	Direct Control	Indirect Control
Voltage Controlled						
Peak Lopping						
Load Shapping						
Post-Fault Response						
Frequency Response						
STOR						
DG Curtailment Reduction						
Dynamic Tariff						

Key: N/A; High Potential; Limited Potential

Table 5.1: Flexible Demand Capabilities

The use of direct or storage electric heating to provide the capabilities in Table 5.1 have a number of potential advantages over the use of heat pumps:

- The extent of the flexible demand per installation would be greater due to the increased demand levels of direct or storage electric heating
- If demand flexibility can be provided at individual room heater level the degree of controllability can be extended whilst maintaining consumer comfort.

The use of storage in the form of either energy or thermal

storage or a combination of both can extend both the scope and range of flexible demand services offered [16]. Typically this would increase the control complexity but it may increasingly form part of the capabilities offered by the expanding number of domestic energy and environmental control systems.

While a number of the demand flexibility services can be complementary, there is the potential for conflict between the services and their responses characteristics with the need for a hierarchy, prioritization, optimisation and co-ordination of services and characteristics [20]. One option would be for an aggregator to deliver the demand flexibility capabilities but they may not be able to provide all functions within the required network event response times. There is therefore the need for a combined control approach between and aggregator and the DSO, with the DSO having some form of direct control capabilities to support time-critical network operational demand response.

The means by which the various control responses would be implemented and regulated also needs to be considered. In some cases these may be set (e.g. voltage/frequency response) and broadcast regularly, while in others more direct action with associated control and communications requirements (e.g. load matching) may be required. If electric heating is to provide flexible demand then reliable, secure, resilient communications are essential, with appropriate interfaces with external parties (i.e. aggregators, ANM, DSO management system) [21]. The nature and type of communication and control infrastructure may be dependent upon the services offered and would need to control not just positive actions (e.g. load reduction or increase), but also regulate/mitigate the impact of negative actions (e.g. electric heating all switching on simultaneously) following reduction, to avoid any adverse network interactions/impacts [22].

The provision of secure, reliable, timely communications will present installation, operational and economic challenges with the need for careful consideration as how they are to be provided, since poor or slow communications are likely to restrict the flexible demand services that are offered [21].

The extension of an ANM scheme to include generation, demand and, if available storage would increase the potential range and extent of network management activities with a move from a reactive network management approach towards a more proactive approach. For example, if a network has ANM managed constrained wind or PV based DG inclusion of electric heating based flexible demand could allow the ANM controller to determine and schedule electric heating load profiles to minimise generation constraints. Information used would typically include weather forecasts, estimated generation output and demand levels based on load profiles and characteristics. The use of ANM for DSM has been demonstrated as part of the Low Carbon London project [23].

6 DISCUSSION

Electric heating based flexible demand can take differing roles within different network topologies, such as urban and rural networks, the key characteristics of which are shown in Table 6.1

Characteristic	Urban	Rural
Load Density	High	Low
Circuit Distances	Short	Long
Dominant Circuit Construction	Cable	Overhead Line
Typical DG Density	Lower	Higher
DG Types	PV, CHP, EfW	Wind, PV, Hydro
Key Network Issues	Thermal, Voltage	Thermal, Voltage, Constraints

Table 6.1: Key Characteristics of Urban and Rural Networks

Within urban networks, it may be network demand based thermal loading issues which dominate, therefore peak lopping or load shaping may be the desired flexible demand response. Alternatively, with increasing levels of urban PV generation and potential to increases in other forms of urban DG (e.g. Energy from Waste (EfW), Combined Heat and Power (CHP)) then other flexible demand services such as constraint relaxation or the introduction of Virtual Private Wire (VPW) to facilitate trading, with time can become desirable features of urban networks.

In a rural network context, it may be that the prime advantage of electric heating as flexible demand would tend to be realised in the aspects associated with DG based network effects, primarily easing of voltage and thermal constraints. Although peak lopping or load shaping flexible demand capabilities may also be beneficial, especially if expensive or contentious network reinforcements or upgrades were being considered.

The retrofitting or replacement of existing electric heating systems with modern heating systems would be expected to be accommodated within distribution networks with minimal, if any network upgrades since the network capacity and infrastructure is already in place.

7 CONCLUSIONS

The use of Demand Side Management and/or Demand Side Response services offers solutions to a number of distribution network operation and performance challenges, particularly in relation to increasing distributed

generation levels and system support service requirements.

The retrofitting or replacement of existing electric heating with modern direct or storage heating systems and/or control and communications could introduce significant levels of flexible demand into distribution networks within existing asset bases while providing increased consumer heating comfort and reduced energy costs.

The use of direct or storage electric heating based flexible demand may provide a suitable platform for Distribution System Operator and wider network flexibility services from which future approaches for the wide scale deployment of heat pumps or increases from existing direct or storage electric heating levels could be supported.

A critical factor in the ability to deliver such services would rest on the implementation of robust, resilient, prioritised and co-ordination control and communication functionality and capabilities that would need to take into account both direct and indirect control regimes with potential conflicting or competing objectives from multiple service providers and/or users.

ACKNOWLEDGEMENTS

This work has been supported through the EPSRC Centre for Doctoral Training in Future Power Networks and Smart Grids (EP/L015471/1)

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