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Potential of demand side response aggregation for the stabilization of the grids frequency

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HIGHLIGHTS

- New Balancing services are a necessary requirement for smart grids.
- Dynamic frequency control is applied to the heat pumps and fridges.
- Aggregation of assets provides rapid frequency response service.
- Reduction of spinning reserve generators is achievable.

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ABSTRACT

The role of ancillary services related to the frequency control have become increasingly important in the smart grids. Demand Side Response is a competitive resource that can be used to regulate the grid frequency. This paper describes the use of heat pumps and fridges to provide ancillary services of frequency response so that to continuously balance the supply with demand. The power consumption of domestic units is usually small and, therefore, the aggregation of large numbers of small units should be able to provide sufficient capacity for frequency response. In this research, dynamic frequency control was developed to evaluate the capacity that can be gathered from the aggregation of domestic heat pumps and fridges for frequency response. The potential of frequency response was estimated at a particular time during winter and summer days. We also investigated the relationship between both loads (domestic heat pumps and fridges) to provide Firm Frequency Response service. A case study on the simplified Great Britain power system model was developed. Based on this case study, three scenarios of load combination were simulated according to the availability of the load and considering cost savings. It was demonstrated that the aggregation of heat pumps and fridges offered large power capacity and, therefore, an instantaneous frequency response service was achievable. Finally, the economic benefit of using an aggregated load for Firm Frequency Response service was estimated.

1. Introduction

In a power system, frequency deviation is the main indicator of the momentary imbalance between supply and demand. The grid's frequency fluctuates continuously due to the practical difficulty of controlling generation to instantaneously track all changes in demand [1]. In real power systems, frequency response services are traditionally classified into the following three categories [2]:

- Primary service, which is provided by frequency-sensitive generators and a load that responds within a few seconds to a change of grid frequency.
- Secondary service, which is provided by generators and a load responding to the frequency signal within 5–10 min and which can be continued until the frequency is restored to the nominal value.
- Tertiary service, which is an emergency control action that is applied when there is a serious power mismatch between supply and demand. This service is typically provided by stand-alone generators.

In the Great Briain power system, uncertainty in demand forecasting is met by ensuring a sufficient amount of spinning reserve from large scale generating units driven by nuclear and fossil fuel sources. These generators alter their active power output in response to a frequency

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Nomenclature

DSR	demand side response
FFR	firm frequency response
T_{in}	temperature of building
T_{Co}	temperature of fridge's cooler
T_{min}	minimum temperature of a building/cooler
T_{max}	maximum temperature of a building/cooler
ALR_{hp}	availability of low-frequency response from heat pumps
AHR_{hp}	availability of high-frequency response from heat pumps
ALR_{fr}	availability of low-frequency response from fridges
AHR_{fr}	availability of high-frequency response from fridges
SAL_{winter}	seasonal availability of low-frequency response in winter
SAL_{summer}	seasonal availability of low-frequency response in summer
SAH_{winter}	seasonal availability of high-frequency response in winter
SAH_{summer}	seasonal availability of high-frequency response in summer
NHP	number of heat pumps
NFR	number of fridges
$NALR_{hp}$	number of heat pumps that have ON states
$NAHR_{hp}$	number of heat pumps that have OFF states
$NALR_{fr}$	number of fridges that have ON states
$NAHR_{fr}$	number of fridges that have OFF states
Fhp_{ON} and Fhp_{OFF}	upper and lower trigger Frequency of a heat pump unit
Ffr_{ON} and Ffr_{OFF}	upper and lower trigger Frequency of a fridge unit
Shp_f and Sfr_f	final switching signal of a heat pump and a fridge
ST_{in}	temperature control signal of the building
ST_{Co}	temperature control signal of the cooler

change. However, continuing to rely on fossil fuels to produce electricity has two main problems: the potential shortage of fossil fuels at reasonable prices and the emissions that come from burning the fuel. It is predicted that changes in environmental legislation and other government policies will result in a higher generation diversity. More electricity will be generated from renewable, low-carbon resources such as wind and solar. In the Great Britain (GB), it is projected that wind generation may contribute up to 30% of the total generation capacity by 2020 [3]. However, increasing the reliance on renewables causes two challenges:

i. Increasingly intermittent sources provide a large proportion of variable and less flexible generation. Hence, maintaining an instantaneous balance between supply and demand is becoming a real challenge in the GB power system [4].
ii. System inertia is reduced when converter-connected generators displace the conventional generation sources.

Increasing demand is another challenge that is facing the power system. The level of electricity consumption will increase as a result of electrification of heat, such as electric heat pumps, and electrification of transport, such as electric vehicles [4,5]. The electricity sector is becoming more diverse with a transition from a small number of large companies to a wide range of smaller aggregators and innovators [4]. To accommodate this level of variable generation and demand, additional conventional frequency response (acting in seconds) is required, which will significantly increase the operational cost [6]. However, a considerable portion of the frequency response required to balance the grid frequency could be obtained by the demand at low cost through demand side response (DSR) mechanism. DSR is a process that can deliberately change the users' natural pattern in response to a signal from other parties. Businesses and consumers can turn up, turn down, or shift their flexible demand in real-time to provide a frequency response service after receiving a frequency signal [7].

1.1. Brief description of frequency control strategies

This section aims to describe the latest strategies that use the demand to provide ancillary services of frequency response to continuously balance supply with demand. Recent studies have demonstrated the concept and benefits of DSR, although they have not directly referred to a specific load technology. For example, Refs. [2,8–11] summarize the technical features and economic benefits of using demand control algorithms. These studies use a stochastic control algorithm and they have applied it to the load to stabilize the system frequency. The responsive load in these studies has the potential to provide a considerable operating cost saving and they can reduce carbon emissions by replacing the spinning reserve service of generators with the frequency response service of demand. The authors in [12,13] studied large battery applications for frequency response provision. Battery storage systems can be installed to store electricity when solar generation exceeds the demand or when electricity is cheap. This stored electricity can then be used when needed. However, the use of large batteries for frequency response provision requires a large investment cost. Electric vehicles (EVs) may be used for the same purpose with less investment cost. In [5,14–17], a population of EVs were used a source of demand response to regulate the grid frequency and provide rapid frequency response with the presence of large scale of intermittent wind generation. A dynamic EV frequency control algorithm that considered the travelling behavior of the EV users was developed to drive the EVs charging/discharging in response to changes in the grid frequency [5]. The authors in [17] developed an estimation tool to estimate the 24- hour EV charging load for frequency control study based on statistical analysis and according to EV type.

Thermostatically Controlled Loads (TCLs), such as fridges, heat pumps, water heaters, bitumen tanks, and so on, are also flexible candidates for DSR [18–21]. The normal operation of these appliances can be temporarily interrupted without a noticeable effect on the temperature. Because there are a large number of thermal loads connected to the grid and their thermal storage characteristics, the TCLs could potentially provide a significant economic value throughout the provision of various forms of ancillary services [2,22–24]. Two main dynamic TCLs frequency control algorithms have been used for the provision of a frequency response service, namely: centralised and decentralized control. For example, in [25] and [26], a comprehensive DSR strategy based on central load control was developed to regulate the system frequency by controlling the aggregation of electric water heating and air conditioning units. However, the centralised load control algorithm requires the support of a high- performance communication system between the load and the system operator. The system operator operates the central controller, which monitors the ON/OFF state conditions of all thermostats and decides to turn them ON or OFF to balance demand with supply and restore the grid frequency to the nominal limits. Ideally, the load controller should not use real-time communication between the system operator and millions of TCLs connected to the grid because of the expensive infrastructure requirements and the possibility of communication failures.

Decentralized control algorithms have also been used for frequency regulation and they are installed locally [27,28]. Hence, they do not need two- way communication with the system operator. Decentralized