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Demonstrating demand response from water distribution system through pump scheduling

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HIGHLIGHTS

- Water distribution systems can profitably provide demand response energy.
- STOR and FFR are financially viable under a wide range of operating conditions.
- Viability depends on the pump utilisation and peak price of the electricity tariff.
- Total GHG emissions caused by the provision of reserve energy are <300 gCO_2/kW h.
- These are lower than those from the major reserve energy provision technologies.

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ABSTRACT

Significant changes in the power generation mix are posing new challenges for the balancing systems of the grid. Many of these challenges are in the secondary electricity grid regulation services and could be met through demand response (DR) services. We explore the opportunities for a water distribution system (WDS) to provide balancing services with demand response through pump scheduling and evaluate the associated benefits. Using a benchmark network and demand response mechanisms available in the UK, these benefits are assessed in terms of reduced green house gas (GHG) emissions from the grid due to the displacement of more polluting power sources and additional revenues for water utilities. The optimal pump scheduling problem is formulated as a mixed-integer optimisation problem and solved using a branch and bound algorithm. This new formulation finds the optimal level of power capacity to commit to the provision of demand response for a range of reserve energy provision and frequency response schemes offered in the UK. For the first time we show that DR from WDS can offer financial benefits to WDS operators while providing response energy to the grid with less greenhouse gas emissions than competing reserve energy technologies. Using a Monte Carlo simulation based on data from 2014, we demonstrate that the cost of providing the storage energy is less than the financial compensation available for the equivalent energy supply. The GHG emissions from the demand response provision from a WDS are also shown to be smaller than those of contemporary competing technologies such as open cycle gas turbines. The demand response services considered vary in their response time and duration as well as commitment requirements. The financial viability of a demand response service committed continuously is shown to be strongly dependent on the utilisation of the pumps and the electricity tariffs used by water utilities. Through the analysis of range of water demand scenarios and financial incentives using real market data, we demonstrate how a WDS can participate in a demand response scheme and generate financial gains and environmental benefits.

1. Introduction

Electricity storage schemes and grid management methods are becoming ever more important as the landscape of the electricity grid changes to more decentralised renewable production. The intermittent nature of these sources and the unavailability of contemporary technology for storing large quantities of electrical energy efficiently and cost effectively has led to a demand for new energy storage systems and more intelligent electricity demand management [1]. Edmunds et al. [2] highlight significant reductions in greenhouse gas (GHG) emissions from future UK

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power grids when storage technologies are implemented, while Lau et al. [3] show considerable GHG emission savings can be achieved through a range of demand response programs. Demand response schemes have also been shown to enable a larger integration of wind power generate [4,5].

In demand response, an electricity consumer reduces or shifts its power consumption when requested to do so in exchange for compensation. For an electricity consumer with an electricity demand that is predictable into a future operational horizon, demand response (DR) is provided by reducing its electricity consumption compared to the predicted consumption [6]. Different DR mechanisms may impose requirements on how long the power reduction must last, how large it has to be, at what rate it must be reduced and within what time frame it must be achieved. A detailed summary of possible mechanisms and their properties is provided by Ma et al. [7]. Despite the potential of active demand management to increase renewables penetration [8], a large share of demand response services are currently provided through backup generators instead of demand shifts by consumers [9]. Moreover, the increased utilisation of renewable energies to power a water distribution system (WDS) has been shown to reduce the GHG emissions considerably [10].

This paper shows for the first time how a WDS can provide reserve energy through demand response by optimising the pump schedules.We quantify the environmental benefits of demand response compared to alternative reserve energy systems as well as the financial profits that can be generated for the water network operator. In the literature, electricity usage management of a WDS has been considered employing time of use tariffs and maximum demand charges [11,12]. Demand response is a more dynamic and flexible service than maximum demand charges and time of use tariffs are part of the reality for a water utility in the UK, therefore Demand Response services must be provided additionally and not alternatively to these methods. The key challenges we address include the formulation of an optimal scheduling problem with demand response and its solution through model relaxations and state-of-the-art global optimisation tools. Furthermore, we validate our findings through simulation of the optimal operation of the WDS using real data from National Grid in a Monte Carlo simulation. Using this data, we show the potential application as an additional revenue stream that is new to water distribution companies, which could simultaneously provide the grid with more demand side response potential at low GHG emissions and competitive cost.

Frequency response and reserve energy mechanisms available in the UK are used as case studies to evaluate the financial and environmental implications of a WDS participating in DR. The financial and environmental benefits of participation are assessed by comparing the operating cost and GHG emissions when participating in DR to those of operations that minimise only the operating cost in a time of use tariff. To ensure this comparison is valid, we solve both schedules to a sufficiently small certifiable optimality gap; an optimality gap that is smaller than the model uncertainty is chosen [13]. When assessing the ability of a WDS to curtail its electricity usage at request to participate in the demand response market, we separate the hurdles to implementation into system and operational hurdles. The system constraints considered are the available financial rewards, the given electricity price structure and the water network's pump utilisation rate. These dictate whether a demand response program can be considered financially viable. Examples of operational constrains are ramp rates, pump switching constraints or minimum network pressure constraints. This investigation focusses on the system hurdles using quasi steady state modelling and simplified operating constraints; we assume the operational hurdles can be met with available control and monitoring technologies and design expertise.

2. Demand response

2.1. Service description

In the United Kingdom, National Grid operates the electricity grid, maintaining it as tightly as possible around the desirable frequency of 50 Hz. In case of a significant drop in frequency, as illustrated by Fig. 1, National Grid recognises two mechanisms relevant for this work, frequency response and reserve energy. Within two seconds of an incident that causes the frequency to drop, the frequency response services are brought on-line to stabilise the grid. Reserve energy providers are then brought on-line to enable the fast responding frequency services to be switched off so they could be used again at future events. The services considered here that can provide frequency response (*FR*) through demand response are the Firm Frequency Response (FFR) and Frequency Control by Demand Management (FCDM). The reserve energy provision service considered here is the Short Term Operational Reserve (STOR), which is brought on-line within 20–30 min [14]. The faster reacting fast reserve service is not considered since the 50 MW minimum power delivery is prohibitively large for a typical WDS.

The first demand response service considered for the WDS case studies is STOR since the technical requirements suggest that it can be implemented in a WDS more readily. A STOR provider offers a steady demand reduction and must deliver the reduction within 4 h after being called and may be required to reduce the demand for up to 2 h. However, the tender records show that the mean call duration in 2013 was 82 min and that National Grid prefers services that can respond within 10–20 min [9]. Since the minimum offered power requirement for STOR participation in the UK is 3 MW, only large WDSs would be able to participate in a STOR scheme directly. However, through an aggregator, a company that aggregates several consumers and bids their capacities to National Grid, a smaller WDSs could participate in these mechanisms by sharing the profits generated with the aggregator. To offer STOR National Grid recognises a range of pathways to suit the wide range of suppliers. The pathways modelled here are based on offering STOR services during both availability windows or just in one, this can be achieved through tendering either a committed or flexible service. The STOR windows and tariff structure is described in further detail in Section 2.2 and in Fig. 4.

The second method for demand response energy provision considered here is the provision of frequency response services through FFR or FCDM. National Grid requires that an FFR provider is able to deliver a minimum of 10 MW response power; smaller users can offer FFR through an aggregator. For the secondary response service, which is considered here, the response must occur within seconds and be maintained for a few minutes. The service may be tendered for any time period, with National Grid preferring tenders that can offer and deliver the service most times. Furthermore, there are requirements detailing the metering and communication systems in place as well as pre-qualification assessments that need to be performed [15,16]. FCDM is a bespoke service arranged through bilateral agreements with National Grid. In general an FCDM provider must provide the demand reduction within 2 s of instruction and deliver for a minimum of 30 min. The minimum demand reduction to be delivered is 3 MW, which may be achieved by aggregating a number of smaller loads at same location. FCDM calls occur only ten to thirty times per annum [17].

For our analysis, the frequency response services FFR and FCDM are approximated by removing the minimum power delivery constraint and requiring the WDS to be able to deliver demand response throughout the day. The event duration for which water must be supplied to customers with reduced pump power is set to 30 min. For the analysis of the financial viability of DR the