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Extending the envelope of demand response provision though variable speed pumps

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Abstract

Changes in power generation and supply and changes in water distribution systems are creating new opportunities for water utilities to enhance operational efficiency and income through the use of advanced control and optimisation. First, the increase in renewables penetration into the grid is causing a growth in energy storage schemes. Second, variable speed pumps are now fitted to most new systems and many existing water distribution systems are being retrofitted with variable speed pumps to improve the efficiency of the operation. We study how these trends can be jointly exploited to provide energy storage from a water distribution system. We investigate how variable speed drive pumps can enhance the ability of a water distribution network to provide demand response energy to the grid. We show that demand response provision from water distribution systems can be improved through the use of variable speed pumps. We also demonstrate that a network equipped with variable speed pumps can provide demand response profitably across a wider range of operating scenarios compared to a network equipped with only fixed-speed pumps. The results highlight another potential benefit of variable speed pumps in water distribution systems.

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Keywords: Demand response, variable speed pumps, Pump schedule optimisation

1. Introduction

Water distribution systems (WDS) consume a considerable amount of a cities energy, up to 5% of its total usage [1]. Variable speed drive (VSD) pumps can be used to reduce the energy used to operate a WDS through the increased variation in the performance. Reductions in energy cost of 35% in irrigation systems have been demonstrated through the use of variable speed pumps [2]. These savings have lead to retrofitting of VSD pumps to existing systems and increasingly new systems are being equipped with VSD pumps. On the energy supply side electricity storage schemes and grid management methods are becoming ever more important with the introduction of more decentralised renewable production [3]. 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 [4]. This work seeks to combine these two trends in the water supply and energy supply systems and to evaluate the mutual benefits that can be generated.

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The demand management scheme investigated here is demand response (DR). In demand response, an electricity consumer reduces or shifts its power consumption when requested to do so in exchange for compensation. An electricity consumer with an electricity demand that is predictable into a future operational horizon, providing DR is achieved by reducing and shifting its electricity consumption compared to the predicted consumption [5]. Different DR mechanisms impose different 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 in [6]. It has been shown that considerable GHG emission savings can be achieved through a range of demand response programs [7]. Demand response schemes have also been shown to enable a larger integration of wind power generate [8,9]. Demand response provision from a WDS with fixed pumps was first evaluated in [10]. Here we explore how a network equipped with VSD pumps could participate in a DR scheme and how the finer control of the VSD pump power consumption improves the potential of participation in a demand response scheme.

The optimisation of the pump schedule including the operating condition of the variable speed pump has been approached with a range of meta-heuristics such as ant colony optimisation [11], or genetic algorithms [12]. Other methods minimize the specific energy consumption of the system and solve an idealized WDS approximation evaluating a series of local optima [13]. The main limitation of these approaches lies in their inability to find certifiably optimal schedules. The optimal control of a WDS with VSD pumps can also be found using a mixed integer non-linear programming approach, using third order polynomial approximations for the VSD pump properties [14]. The problem can be reformulated as a mixed integer linear program (MILP), using a piecewise linear approximation. By linking the power consumption to the flow rate and head difference created by the pump the non-linear relations of power, head, flow and pump speed are approximated through a proxy variable. The non-linear equations describing the exact pump state are solved after the optimal schedule has been computed. The pump schedule optimisation method for a network with VSD pumps used here is described in [15,16].

2. Method

2.1. Modelling demand response

In the United Kingdom, National Grid operates the electricity grid maintaining the desirable frequency of 50Hz. To do this National Grid calls frequency reserve providers in case of a significant drop in frequency. This is followed by reserve energy providers to relieve the faster acting and more expensive to operate frequency services. However, frequency response services require sudden and fast switching of equipment, in this case pumps. As VSD pumps have no advantage over a fixed speed pump in such an operating regime, only reserve energy provision is considered here. Furthermore, analysis of DR from WDS showed that STOR services were more suitable as a DR scheme for a WDs to explore first [10].

The reserve energy provision service we consider is the Short Term Operational Reserve (STOR), which is brought on-line within 20-30 minutes [17]. A STOR provider offers a steady demand reduction and must deliver the reduction within 4 hours after being called and may be required to reduce the demand for up to 2 hours. However, the tender records show that the mean call duration in 2013 was 82 minutes and that National Grid prefers services that can respond within 10 – 20 minutes [4]. Since the minimum offered power requirement for STOR participation in the UK is 3MW, 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.

Table 1: Summary of the range of monetary rewards for STOR service options [4,18,19].

(Windows available)	Availability (£/MW/h)	Energy pay £/MWh	Total (£/ MW) (R)
1^{st} & 2^{nd}	7 – 9	75 – 200	30k – 45k
1^{st} only	1.8 – 2.5	75 – 200	15k – 30k