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Water Supply Operation and Scheduling System with Electric Power Demand Response Function

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Abstract

A water supply operation and scheduling system with a power demand response (DR) function was proposed and evaluated in a case study. The system has two operation modes achieved by the DR function, that is, a power smoothing operation mode that seeks to smooth electric power use in ways that cut the basic tariff by cutting or shifting demand peaks and a DR operation mode that earns incentives by reducing demand in response to requests. The benefits of using the system for electric power management were assessed for a medium-sized water supply system. In an operation using both DR and smoothing operation modes at once, the scheduling system succeeded in reducing peak demand during the time period covered by DR requests (1 PM to 4 PM) by approximately 60%, from 1372 kW under existing practices to 545 kW. Moreover, peak daily demand was also reduced by approximately 16 %, from 1772 kW to 1492 kW.

Keywords: Water supply operation system; Scheduling, Electric power; Demand response; Mathematical programming; Optimization

1. Introduction

The water industry is an energy intensive sector. In the United States, about 3–4 percent of annual electricity is consumed by water and wastewater systems [1] [7]. Moreover, energy costs tend to increase due to population growth and rising energy prices. The operation of pumps used for water transmission and distribution accounts for a large

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proportion of energy consumption. In order to reduce energy costs and greenhouse gas emission, it is significant for the water industry to achieve cost-effective and energy-efficient operation of pumps.

DR has attracted attention in recent years as a way to control the consumption of electric power during periods of peak demand to ensure a reliable supply. DR is an incentive scheme that encourages users to reduce their demand when needed to maintain the balance of supply and demand. DR comes in the form of both tariff-based and incentive schemes. Tariff-based schemes use electricity pricing options to encourage users to shift peak demand, such as critical peak pricing and time-of-use (TOU) tariffs that vary depending on the time of day. Incentive schemes request users to reduce their power use at times when the supply of electric power is constrained and pay them for doing so in the form of a bonus. Effective pump operation for earning greater incentives or for reducing the basic tariff in the DR incentive scheme will lead to significant energy cost savings.

To reduce energy costs, various pump scheduling techniques have been proposed and evaluated in the last decade. A pump scheduling optimization software package was applied to four US cities [1]. To seek cost reduction, it featured moving energy use into cheaper tariff periods, reducing peak demand charges by limiting the maximum number of pumps, and reducing the energy required to deliver water by running a group of pumps closer to their optimal efficiency. Pump operation optimization techniques based on a genetic algorithm (GA) were proposed to reduce operation costs such as energy consumption and water leakage [2] [3]. Multi-objective optimization for a water supply system achieved the trade-offs of multi-objectives including energy costs [4] [5]. A real-time pump scheduling methodology using GA and an artificial neural network was applied to a large demand zone in the United Kingdom, indicating significant savings in energy costs [6] [7]. A decentralized model predictive pump scheduling technique realized a fast solution by dividing a wide water supply zone into several sub-zones [8] [9].

In this paper, a water supply operation and scheduling system with an electric power DR function is proposed and evaluated in a case study. This is an enhanced version of a water supply control system [10] that optimizes multi-objectives such as energy savings and a stable water supply. A new function for a DR incentive scheme, that is, a power DR function, has been developed and incorporated into the water supply control system. This function plans an optimal operation schedule of pumps to maximize earned incentives or reduce the basic tariff as much as possible in a DR incentive scheme.

In the following sections, the details of the water supply operation scheduling system and the DR function are explained. Finally, the benefits of using this function are demonstrated in a case study.

2. Water Supply Operation and Scheduling System with Power DR Function

The overall structure of a water supply operation and scheduling system is shown in Fig. 1. The system is configured as a sub-system of supervisory control and data acquisition (SCADA), and it plans a daily schedule of water production and transmission on the basis of forecasted water demand. An optimal schedule is made by minimizing objective functions such as power consumption and operational costs under constraints imposed on flow, tank level, and filtration speed, meeting daily demand. The functions of the water supply scheduling system are shown in Fig. 2. A new function, that is, a power DR function that contributes to reducing power costs in the DR incentive scheme, was developed. This function plans an optimal operation schedule of pumps to minimize peak power during time periods of tight supply-demand balance. The water supply scheduling system has two operation modes that are achieved by the power DR function. One is a power smoothing operation mode that seeks to smooth electric power use in ways that cut the basic tariff by cutting or shifting demand peaks. The other is a DR operation mode that earns incentives by reducing demand in response to requests. The power smoothing operation mode reduces the basic tariff as far as possible while the DR operation mode maximizes incentive income.

A snapshot is shown in Fig. 3. A schematic of a water supply system to be operated and a diagram of power consumption by water supply scheduling are indicated respectively on the left and right sides.