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Evaluation of commercial building HVAC systems as frequency regulation providers

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ABSTRACT

The heating, ventilating and air-conditioning (HVAC) systems of large commercial office buildings consume a significant amount of electric power. Instead of passively consuming energy, these systems can provide frequency regulation (FR) services to the electric grid by adjusting the power consumption in response to a signal sent by the electric grid operator. This paper has four primary goals: First, it provides the theoretical support and states the need for using HVAC systems to provide FR. Second, it proposes two methods of using HVAC systems for providing FR – a direct method and an indirect method; these two methods are developed as models and tested in simulation. Third, it addresses the challenges of using commercial building HVAC systems for FR; this motivates the development of a new supervisory control method to support the HVAC system for providing FR service. Fourth, it evaluates the simulated results based on the performance based regulation (PBR) rules proposed by the PJM regional transmission organization; thus, it provides the reference for the future field-testing

1. Introduction

The electric power system in the United States delivers power at a frequency of 60 Hz. This must be strictly maintained within a very narrow range or serious system reliability problems will occur. However, the frequency constantly fluctuates around 60 Hz because of variations in both supply and demand. If the demand is greater than the supply, the frequency drops below 60 Hz. If the demand is less than the supply, the frequency rises above 60 Hz. In order to maintain frequency, the independent system operators (ISOs) and regional transmission organizations (RTOs) not only need to dispatch power supply for substantial variations from load valleys to load peaks throughout the day; but also need to direct dedicated FR resources up or down to track the smaller scale demand variations on a second-to-second basis. FR typically uses certain amount of generators (e.g., 1% of total generation in PJM) equipped with automatic generation control (AGC) and the information gathered through the supervisory control and data acquisition (SCADA) system to continuously track the demand variations automatically [1,2]. However, when the frequency deviation is out of the controllable range of FR, system operators may also manually change the setpoint of all generation units synchronized on the grid for balancing the demand [2]. Here, the supply can be generated by generators and also be imported from the neighboring interconnected areas; whereas, the demand can be consumed in loads, losses on transmission lines and be exported to the neighboring interconnected areas [2]. The energy balance of supply and demand is the key to maintain frequency and the reliability of the grid. A real-time value, area control error (ACE), is used to quantify the energy balance at each moment [1,2]. ACE is measured in MW and is calculated by the mismatch between the actual and scheduled power interchange between the neighboring interconnected areas along with the frequency bias caused by generators governor control and the reactive load response [2]. The ISOs and RTOs must monitor and carefully control ACE in a limited range in order to fulfill their obligations to the National American Electric Reliability Corporation (NERC) for system reliability [2,3].

Therefore, FR provides the continuous, rapid and automatic corrections that fine tunes ACE and is the most important ancillary service for maintaining energy balance and system reliability [2]. Typically, large generators are used for FR; however, these generators operate most efficiently with constant output and are not able to track the second-to-second changes of ACE. Providing FR not only adds wear and tear on a generator but also consumes more fossil fuel. A possible solution for providing FR in a more efficient way is to use demand side resources (DSR). The Pennsylvania–New Jersey–Maryland Interconnection (PJM)

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recently investigated the use of DSR for frequency regulation, using electric water heaters, wastewater treatment pumps, manufacturing facility battery banks, ceramic thermal energy storage bricks in residential communities, and plug-in electric vehicles [4]. These resources typically have much smaller capacity than generators; however, they can ramp much faster and provide improved ACE correction. On October 1, 2012, PJM officially launched the performance based regulation (PBR) rule that enables DSRs to participate in FR and receive the correct payment for their better ramping capability. Commercial buildings are the major loads on the demand side. Instead of passively consuming energy, buildings may actively participate in the FR market with proper management and control of the HVAC systems. As large commercial buildings dominate the urban core, the availability of these buildings' HVAC systems provides the opportunity for FR participation without additional equipment investment; on the other hand, buildings can also compensate their energy expenses with the payment received for providing FR service to the grid.

This paper explores using commercial building HVAC systems as FR resources based on PJM's PBR rule, and is organized as follows: Section 2 presents the literature review and relevant background information; Section 3 describes two proposed FR methods and a supervisory control method; Section 4 presents and evaluates the simulation results and then analyze the results for each FR method; and Section 5 offers conclusions.

2. Literature review

The federal energy regulatory commission (FERC) issued the final rule of FERC order No. 755 on October 10, 2011, where "the commission finds that the current frequency regulation compensation practices of RTOs and ISOs result in rates that are unjust, unreasonable, and unduly discriminatory or preferential. Specifically, current compensation methods for regulation service in RTO and ISO markets fail to acknowledge the inherently greater amount of frequency regulation service being provided by faster-ramping resources. In addition, certain practices of some RTOs and ISOs result in economically inefficient economic dispatch of frequency regulation resources" [5]. The new rule is usually referred to as "pay-for-performance" since it requires RTOs and ISOs to compensate the FR resources based on their actual amount of FR provided instead of FR expectation. The new rule requires the compensation to be based on two parts: (1) capacity, including lost opportunity cost (LOC), and (2) performance, which quantifies the performance of the resource following the FR signal [5]. In order to comply with the new pay-for-performance rule, PJM and the New York ISO launched their new rules on October 1, 2012 and October 25, 2012, respectively. The Midwest ISO and the California ISO will implement their final rules in 2013 and ISO New England scheduled the go-live date for January 2014 [6]. In this paper, the final rule of PJM is presented in detail and used to evaluate simulation results.

2.1. Overview of FR market within PJM territory

PJM launched the final rule with the name "performance-based regulation" (PBR) on October 1, 2012, which includes two-part offers and settlements – capacity and performance [4]. New concepts, including performance score, benefits factor, and mileage are developed in order to calculate adjusted market clearing prices. These prices are then used for selecting the most economical resources to provide FR and then for calculating the settlement payment to such resources [4]. PJM separates FR resources into two groups: ramp-limited and capacity-limited. The typical ramp-limited resources include gas or coal-fired steam power plants which have large capacity but respond slowly to FR signals. Typical capacity-limited resources include batteries, flywheels, plug-in electric vehicles, and responsive loads which have small capacity but respond quickly to FR signals. To fully utilize these two types of resources, PJM developed two types of FR signals: the traditional regulation A signal (i.e., RegA) and the dynamic regulation D signal (i.e., RegD). Ramp-limited resource should follow the slower moving RegA signal and get paid mostly for capacity. By contrast, capacity-limited resources should follow the faster moving RegD signal and get paid mostly for performance.

The RegA and RegD signals are derived from ACE and are designed to complement each other. PJM hired a consulting firm to determine the impact of various percentage levels of RegA- and RegD-following resources to the whole FR market [7]. In response, a new concept called "benefits factor" was introduced that converts RegD-following resources into traditional RegA-following resources in terms of the value to the FR market and the payment to FR resources [8]. The benefits factor is approximated by Eq. (1) [8]. Here, x represents the percentage of FR provided by RegD-following resources. When less than 41% of FR is provided by RegD-following resources, the benefits factor of each RegD-following resource is greater than 1. The FR offers of the RegD-following resources are then divided by the benefits factor; as a result, the adjusted FR offers become more competitive. However, the opposite occurs if there were too much FR provided by RegD-following resources. With the participation of fast moving RegD-following resources, NERC expects that the requirement for FR will be reduced by 10% [9]:

$$\text{Benefits Factor} = \begin{cases} 2.9 - 4.63x & 0 \le x \le 62.5\% \\ 0 & 62.5\% < x \le 100\% \end{cases} \quad (1)$$

As originally developed by ISO New England, PJM also employs the term "mileage" to describe the movement of FR signals, as defined in Eq. (2) [7,8]. Mileage is the sum of the absolute movement of the RegA or RegD signal and is calculated every hour [8]. Historical PJM data from January to June 2012 show that the RegD signal has a wider distribution of hourly mileage, ranging from 8 to 23 and centered at 16. The RegA signal has a narrower distribution of hourly mileage, ranging from 1.5 to 12 and centered at 6 [1]. Therefore, the average mileage of the RegD signal is almost three times more than that of the RegA signal – a significantly greater burden. Where a resource is capable of following either FR signal, the resource owner may need to think twice before switching their FR resources from RegA to RegD. The wear and tear on the resource could result in a higher maintenance cost offsetting extra payment for performance:

$$\begin{aligned} \text{Mileage}_{\text{RegA}} &= \sum_{i=0}^{n} \left| \text{RegA}_i - \text{RegA}_{i-1} \right| \\ \text{Mileage}_{\text{RegD}} &= \sum_{i=0}^{n} \left| \text{RegD}_i - \text{RegD}_{i-1} \right| \end{aligned} \quad (2)$$

The sale and purchase of FR in PJM is handled through a market-based system called eMKT [8]. The resource owners submit their specific FR offers (capacity and performance) to the eMKT. Then PJM processes these offers together with (1) energy offers, (2) benefits factors, (3) historical performance scores, (4) opportunity costs, and (5) resource schedules to determine the winning offers [8]. This process and the associated settlement calculations are available in [8–10].

2.2. Requirements for eligibility in PJM's FR market

To be eligible for providing FR, DSR must meet the following requirements: