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Cooling Supply-based HVAC System Control for Fast Demand Response of Buildings to Urgent Requests of Smart Grids

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Abstract

Shutting down part of operating chillers in HVAC (heating ventilating and air-conditioning) is a direct and effective mean allowing immediate responses of buildings to the power reduction requests of a smart grid.This paper presents a summary on the demand response control strategies and the problems when using the current conventional demand-based air-conditioning control strategies for fast demand response as well as the reasons of rebound problems after a DR event. The proposed cooling supply-based strategy aims at properly controlling air-conditioning systems when the cooling supply is not sufficient to fulfil the cooling demand of a building. This strategy can effectively solve problems of immediate power demand limiting control in response to the urgent requests of a smart grid as well as the rebound problems after the demand response event.

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Keywords: fast demand response;adaptive utility function;air-conditioning control;demand limiting;smart grid

1. Introduction

Power imbalance in power grid operation has become one of the most critical issues. Smart grid technology provides a promising solution for enhancing the balance of power grids by improving the ability of electricity producers and consumers to communicate with each other and make decisions about how and when to produce and consume electrical power [1].Demand response (DR) program is promoted to encourage the end-users to actively alter their load profiles during peak times. Buildings, as the primary

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energy end-users, could play an important role on power demand response in smart grids. The interaction between buildings and the power grids could be very effective due to elastic nature of building energy use [2]. The building demand management for demand response aims at minimizing the impact of peak demand charges and time-of-use rates on the service quality of buildings. The HVAC system is an excellent demand response resource as the consumption of HVAC systems accounts for the largest part in buildings [3] as well as their elastic nature. Load shifting and load limiting are the two major means for peak load management. Demand limiting is the practice of restricting the peak power load of a building in such a way that the total power does not exceed the pre-defined peak load during periods of time where power is at a premium cost.

In smart grids, users can be informed of pricing changes or DR requests one day ahead, hours ahead or even minutes ahead depending on the prediction accuracy and the degree of emergency. When pricing changes are notified some hours ahead, rescheduling the system operation, such as resetting the indoor air temperature is a preferable alternative to reduce the air-conditioning power demand. When adding additional generation capacity is extremely expensive or at times of supply shortage, however, sudden pricing changes or urgent incentives are desirable alternatives to achieve the demand reduction within a very short time, i.e. minutes. In such a case, conventional building demand management strategies would not be sufficient.

In fact, shutting down some of the chillers can achieve immediate demand reduction [4]. However, simply shutting down chillers at the cooling supply side will result in disorder of the entire air-conditioning system control. Extremely serious operational problems would be caused, such as chilled water pumps running too fast, imbalanced chilled water distribution among AHUs (air-handling units), and imbalanced air distribution among VAV (variable air volume) terminals. This would cause extremely large difference of indoor air temperatures among different air-conditioned zones. This is because almost all the conventional control strategies used today for centralized air-conditioning systems are “demand-based” control strategies, in which the cooling supply by chillers is set to be enough to fully satisfy the requirements of the terminal units (e.g., AHUs). The water valve opening of individual AHU is modulated to maintain the supply air temperature at the preset set-point. The speeds of secondary pumps are adjusted to ensure the measured pressure drop of the main supply side (or the remote critical loop) at its set-point. For the individual AHU severing different rooms by different VAV boxes, the opening of each VAV box will be adjusted to maintain the air temperature of the room it serves. The chiller sequence/capacity will be properly controlled to meet the cooling load required. When the cooling supply is not enough, all cooling demand side users will compete for the limited cooling supply. The reductions in thermal comfort among different zones will not be even and the indoor environment in some zones will be sacrificed to unacceptable levels much more quickly. In addition, some other extremely serious operation problems would also be caused. For instance, secondary chilled water pumps would be over-speeded and the over-supplied chilled water flow rate of secondary loop would exceed that of primary loop (i.e. deficit flow in the bypass line).

This paper proposes a novel cooling supply-based control strategy that is able to properly control the air-conditioning system under the limited cooling supply conditions when shutting down some of chillers in commercial buildings in respond to short-term pricing changes/urgent requests from smart grids.

2. The proposed cooling supply-based control strategy

“Cooling supply-based” means that the control strategy aims at modulating the loads of the components (cooling demand side) properly in accordance to the reduced cooling supply from chillers (cooling supply side) during demand response event while providing the solutions to the inherent operation problems of commonly used control strategies. By introducing the concept of utility, an important concept in economics and game theory, a water flow distribution scheme and an air flow distribution scheme are developed.