Automation in Construction 85 (2018) 333–343

Contents lists available at ScienceDirect

Automation in Construction

journal homepage: www.elsevier.com/locate/autcon

Direct chiller power limiting for peak demand limiting control in buildings—Methodology and on-site validation

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ARTICLE INFO

Keywords:
Peak demand limiting
Chiller power limiting
Demand response
Model predictive control
Building thermal mass

ABSTRACT

Large electricity consumers are often charged of a high price for their peak demand for the purpose of reducing the capacity and cost, as well as the operation reliability of electricity transmission facilities. As a result, even one spike in the monthly demand profile would result in a significant increase in electricity bill. Peak demand limiting techniques provide an effective and efficient means to reduce such cost. For instance, the methods to utilize cooling/heating stored in building thermal mass by resetting space air temperature set-point have been proofed effective in many studies. This study proposes a direct chiller power limiting control strategy for peak demand limiting control in buildings, particularly during the period of chiller starting when the peak demand occurs mostly. Validation tests were conducted on-site in a super high rise building and on a dynamic simulation platform. Results showed the strategy was effective in reducing the peak demand during chiller starting periods.

1. Introduction

Large electricity consumers are often charged of a high price for their peak demand for the purpose of reducing the capacity and cost as well as the operation reliability of electricity transmission facilities. The electricity bill of a large consumer commonly consists of two major parts: the energy cost which is based on the total energy consumption in kWh over a billing period, e.g. a month, and the demand cost which is based on the peak demand in kVA during the billing period. Therefore, even one spike in the monthly demand profile could result in a significant increase in electricity bill. Actually, peak demand in commercial buildings lasts only for a short period of time, but its costs could be up to 50% of the overall bill [1,2].

Demand management techniques provide an effective and efficient means to reduce such high cost, particularly with the emerging technology of smart grid [3,4]. Demand limiting control targets at limiting power consumption over a certain period. Demand limiting control systems often reduce electricity bills by 15% to 20% in industrial buildings and commercial buildings [2].

Demand management methods are classified into three main categories, i.e. demand shedding (also named as demand cutting, demand curtailment, etc.), demand shifting and on-site generation [5]. Demand shedding refers to remove some of the non-essential loads during on-peak periods. Demand shifting is to shift loads from on-peak periods to off-peak periods. For instance, building thermal mass or thermal energy storage systems could be used to shift space cooling/heating loads. On-site generation is to generate electricity on-site instead of using grid electricity. Since on-site generation requires extra equipment and energy resources on-site, it can hardly be widely used. The demand shedding and demand shifting methods are the dominant approaches in real practice.

The control of energy systems in buildings for demand limiting mainly consists of three methods: global temperature adjustment, systemic adjustment, and schedule of equipment [5,6]. As the dominant method in literature and practice, global temperature adjustment method is to reduce building cooling/heating load by resetting room temperature to be closer to the ambient temperature during on-peak periods. Building thermal mass or thermal storage systems are used as buffers to alleviate the impact of such adjustment on thermal comfort in air-conditioned spaces [7]. Systemic adjustment method refers to those methods in which limits are directly placed on certain equipment in a HVAC system. Such methods provide a quick response to the grid, but should be carefully selected to avoid causing system imbalance or unstable to the entire system [5]. Schedule of equipment method means to dynamically schedule the operation time of equipment according to electricity price or the offered incentive during on-peak periods.

Many studies have addressed peak demand limiting in buildings. Studies on the use of global temperature adjustment method have been conducted based on simulation and on-site tests [7,8,9]. Dynamic inverse building model has been built for determining the proper zone

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http://dx.doi.org/10.1016/j.autcon.2017.10.029
Received 7 July 2017; Received in revised form 15 September 2017; Accepted 28 October 2017
Available online 05 November 2017

temperature set-points in global temperature adjustment method [10,11,12]. Some other studies have developed strategies that combined global temperature adjustment methods with systemic adjustment methods [13,14,15,16].

Most of those existing methods for HVAC systems targeted at reducing cooling supply during on-peak periods. However, according to the study based on the real operation data in a high-rise building, peak demand of chillers occurs mostly during the period when a chiller is starting. Such peak demand may be caused by the increase in cooling load, or the sudden starting of a constant speed chiller, or both. Reducing peak demand during chiller starting period has not yet been particularly addressed in literature. Therefore, a direct chiller power limiting control strategy is proposed in this study to reduce the peak demand that occurs during the short periods of chiller starting.

This paper is organized as follows: Section 2 highlights the issue of peak demand during chiller starting period based on real operation history data of a super large HVAC system for a high-rise commercial building. Section 3 describes the proposed direct chiller power limiting control strategy for peak demand limiting. Section 4 presents the arrangement of on-site and simulation validation tests, which includes the super large HVAC system, a dynamic simulation platform built based on the same super large HVAC system, and the electricity tariff used in electricity bill. Section 5 presents the validation test results and discussions. Section 6 presents the conclusions.

2. The problem of peak demand during chiller starting period

The sequencing control of chillers is commonly based on real time cooling load and capacity of chillers [17]. Specifically, when cooling load increases and the current running chillers could not provide sufficient capacity to fulfill the required cooling load, the control system will start another idling chiller. This newly started chiller will run to its maximum capacity in the first few minutes in order to quickly achieve the supply chilled water temperature set-point. Considering the fact that the previously running chillers have already been fully loaded, all the operating chillers will be running at their maximum capacities during this period. This would result in a high power demand for a short period after the chiller started. Such problem exists particularly in HVAC systems installed with constant speed chillers.

An analysis was conducted based on one year operation data and electricity meter data of a high-rise building. The electricity cost of the whole building is divided into 23 bill accounts, each are charged separately. The bill account which costs most is the one consists of the six large constant speed centrifugal chillers for air-conditioning.

The analysis was focused on the peak days of two months in 2015, representing different weather conditions. The data of peak days in February and May are shown in Fig. 1. It can be seen that the total power demand of all running chillers always goes up dramatically after a chiller started. The peak demand occurred at 15:30 on the peak day in February, and at 8:30 on the peak day in May. There are two other small peaks in the power profile of the peak day in May when the chiller number did not change. But the two small peaks were lower than the one occurred in the morning after two chillers were added.

It can therefore be concluded that the electricity cost would be reduced if a proper demand limiting control strategy is applied during chiller starting periods.

3. Proposed direct chiller power limiting control strategy

3.1. Capacity control of centrifugal chillers

Because of the high capacity and efficiency they can provide, centrifugal chillers are typically used for large buildings, factories or even districts with large cooling load for space cooling or production processes. Since the cooling load is always varying, the amount of cooling provided by the chillers has to be controlled accordingly. As summarized below, three major methods are commonly used by centrifugal chillers to achieve the goal of capacity control.

(a) *Use inlet guide vanes*

Inlet guide vanes are located in the suction port of compressors. The refrigerant gas entry angle to the impeller changes with the change of inlet guide vane openings. Therefore, the refrigerant flow and cooling capacity varies as the vane opening changes. This method is generally used by constant speed centrifugal chillers.

(b) *Use variable speed drivers (VSD)*

The refrigerant flow can also be changed by varying motor speed of chillers by using VSD. Typically, the speed is only reduced to 60% of the maximum speed. Centrifugal chillers installed with VSDs also have inlet guide vanes. Inlet guide vanes and variable speed drivers are combined to control chiller capacity. Beside of capacity control, it is worth noticing that VSDs can be used as soft starters, which can avoid too high electric current during chiller starting periods.

(c) *Use hot gas bypass valves*

The hot gas bypass process is used to protect compressors by avoiding surging or stalling of compressors in low load conditions. The hot gas from compressor discharge port is recirculated back into the evaporator, and the hot gas bypass valve is used to control the amount of bypassed refrigerant. The use of this method should be avoided whenever possible, because the recirculated refrigerant gas generates no cooling effect, but has already consumed electricity in compression process.

3.2. Direct chiller power limiting control

By adopting an effective soft chiller starting method, the developed strategy in this study aims to reduce peak demand during chiller starting periods while have minimum impact on thermal comfort in the air-conditioned spaces.

Fig. 2 shows the concept of the proposed direct chiller power limiting control strategy. The strategy consists of three steps: (1) start a chiller normally, (2) limit the power consumption of the previously running chiller(s) while continuously checking supply chilled water temperature, (3) remove the limitation gradually.

Upon the request of adding a chiller, one of the idling chillers is put into operation immediately. Meanwhile, a limitation is added to all other previously operating chillers to reduce their power consumption. A coefficient α ($N_{pre}/(N_{pre}+1) < \alpha < 100\%$, where, N_{pre} is the previously operating chiller number) is used to measure the limitation, which is defined to be the ratio of the allowed maximum chiller power to the rated chiller power. In this way, the power of a previously running chillers will not be higher than $C_{rated}\,\alpha$ (where, C_{rated} is the rated chiller power). The limitation cannot be placed on the starting chiller, because it has to run at its full capacity in order to quickly attain the chilled water temperature set-point. However, the output capacity of the previously operating chillers can be limited to achieve a lower total demand of all chillers.

Because the priority of thermal comfort in the air-conditioned space is set to be higher than reducing electricity cost, the supply chilled water temperature is used as a constraint in the proposed control strategy. The temperature is frequently checked at a certain sampling period and compared with its set-point. If the measurement is higher than the set-point by ΔT, the constraint on chillers will be released by a certain degree which is determined according to the delay time and system characteristics. If the limitation is not completely released within a certain period (τ), it will be released gradually and completely. The τ is chosen based on the demand interval of electricity tariff and the