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A Novel Air-Conditioning System for Proactive Power Demand Response to Smart Grid

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Abstract

This paper presents a novel air-conditioning system with proactive demand response to smart grid. The system consists of a chilled water storage system (CWS) and a temperature and humidity independent control (THIC) air-conditioning system. Using this system, building power demand can be flexibly controlled as desired by implementing two demand response strategies: demand side bidding (DSB) strategy and demand as frequency controlled reserve (DFR) strategy, in respond to the day-ahead and hour-ahead power balance requirements of the grid, respectively. Considerable benefits can be achieved for both power companies and end-users under incentive pricing mechanisms. A case study concerning on the demand response performance of the proposed system is also conducted in an office building.

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Keywords: Proactive demand response; load factor; smart grid; demand side bidding; chilled water storage;

1. Introduction

One of the biggest challenges encountered by electric grids is the power imbalance between the supply side and demand side. The control of power demand of end-users according to variable electricity pricing is known as Demand Response (DR) and has become an essential part for reducing the imbalance in the smart grid vision [1, 2]. Buildings, as a primary end-user of the electricity grid, can play an important role in demand response. Chilled water storage (CWS) is a commonly used technique in buildings for load shifting and demand management. However, the low cold storage density due to the low storage temperature difference of the system is a huge obstacle for its application. In conventional air-conditioning systems by which air is cooled and dehumidified simultaneously, the supply and return temperatures of chilled water are usually fixed as 7°C and 12°C, respectively. However, in temperature and humidity independent control (THIC) air-conditioning systems, the indoor air temperature and humidity can be regulated independently using a separate temperature control subsystem and a humidity control subsystem, respectively. As a result, the return water temperature from the temperature control subsystem can be considerably increased, e.g., from 12°C to 21°C. If the CWS is used for temperature and

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humidity independent control, the cold storage density can be significantly increased. In addition, the sensible cooling load can be separated from the latent load. If only the sensible cooling load (about 50%~60% of the total cooling load) is stored in the chilled water system, the volume of the required tank can be further reduced.

In order to effectively make use of the demand response potentials of the chilled water system and reduce the required storage volume simultaneously, a novel air-conditioning system, which consists of a chilled water storage system (CWS) and a temperature and humidity independent control (THIC) air-conditioning system, is proposed in this paper.

2. System configuration

Fig.1 illustrates the schematic of the proposed air-conditioning system. The cold source of the system consists of chillers and a chilled water storage tank. The terminal system consists of a dedicated fresh air system (e.g., AHUs (air handle units)) and a room terminal system (e.g., dry FCUs (fan coil units)), which are used to control the humidity and temperature of indoor air, respectively.

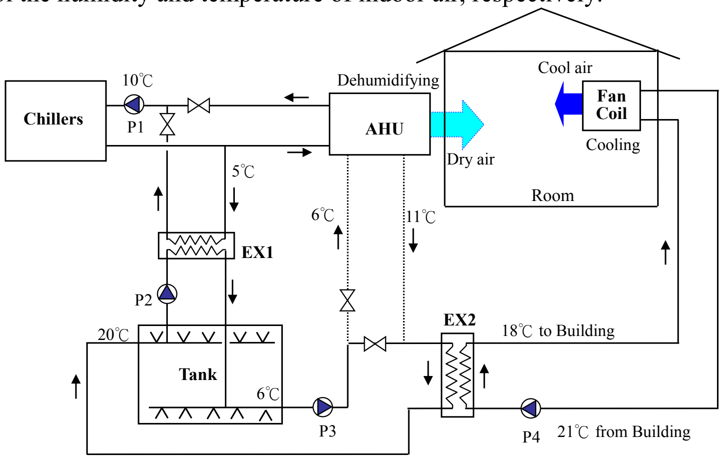


Fig.1. Schematic of independent control of temperature and humidity using cold water storage

During the power off-peak periods (e.g., nighttime), the cold energy is produced by chillers and stored in the water tank with a temperature about 6°C. During the peak demand periods, the stored cold energy is extracted from the tank through heat exchangers (i.e., EX2 in the figure) to handle the sensible cooling load (18/21°C) in the temperature control subsystem. Meanwhile, chillers are switched to supply the chilled water (5°C) to handle the latent cooling load (moisture load) and fresh air load through the AHUs in the humidity control subsystem. By doing this, the power demand during the peak period can be reduced greatly since only about half of the total cooling load need to be handled during this period.

In case that the building power demand needs to be immediately reduced in respond to the real time requirement from the smart grid (i.e., for hour-ahead peak alteration), all chillers can be shut down if necessary and the cold energy for handling the cooling load in the humidity control subsystem can be provided by the tank (through the branch indicated by dotted line in Fig.1).

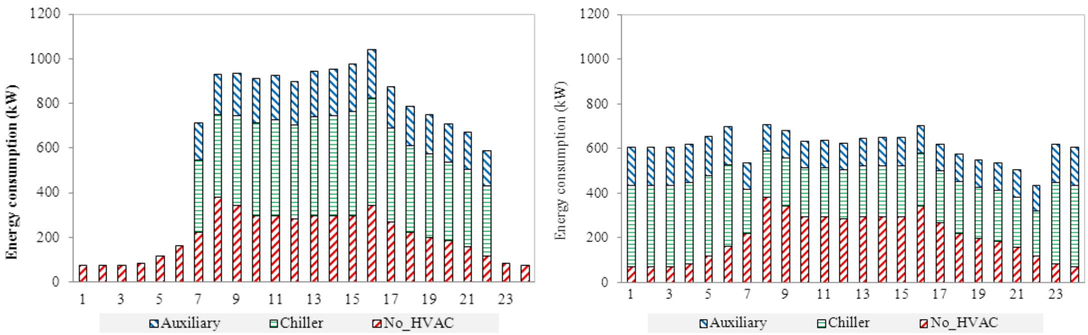
3. Implementation of proactive demand response strategies

Demand side bidding (DSB) is a competitive mechanism which enables the demand side of the grid to participate in electricity bargaining. The success of implementing demand response (e.g., DSB) is mainly dependent upon the capabilities of end-users in altering their loads with a favorable manner for both the power suppliers and end-users. Using the proposed system, a considerable amount of cold energy can be produced during the off-peak periods with a relative low price and stored in the chilled water tank. During the office hours with higher price, the stored cold energy can be discharged for handling the sensible cooling load while only the latent and fresh air loads need to be provided by chillers. This kind of arrangement can result a great power demand reduction during the peak periods, which can greatly reduce the operating cost of the building.

DFR strategies (e.g., emergency demand response programs) can be realized by immediately switching off all operating chillers in respond to the real time power reduction requirements while having no impact on the indoor thermal comfort. When the signal of power shortage of the smart grid is received by the building, chillers can be switched off at once. During this period, besides supplying cold energy for handling the sensible load (FCU loads) of the temperature control subsystem, the chilled water storage tank also overdraws cold energy for handling AHU loads. Conversely, when the power is predicted to be surplus on the grid, the overdrawn cold energy can be compensated by switching on more chillers.

4. Case study

A case study on the performance of the proposed air-conditioning system for demand response is conducted by comparing two air-conditioning systems in the same office building in Hong Kong. One is the proposed system. The other is a conventional air-water system, which does not use cold storage and therefore has no demand alteration ability, is used as the baseline for benchmarking.



(a) Using the conventional system (b) Using the developed system

Fig.2. Power demand of the building using two air-conditioning systems (only using DSB)

The performance when only using the day-ahead demand side bidding (DSB) strategy is shown in Fig.2. Due to the chiller load shifting, the power demand of chiller and auxiliary components are altered consequently. It can be observed that the original power demand (see Fig.2-(a)) is significantly improved by using the proposed systems. The power load factor is increased from 57.5% to 86.6%, which proves that the proposed system has satisfactory performance on the day-ahead demand response to the electricity grid. Great cost saving is also achieved in the building by shifting the power consumption from the peak period (with high price) to the off-peak period (with low price). The total energy cost of the building is reduced by 29.7%. In addition, the chiller capacity and the required storage tank volume can also be reduced by 24.0% and 64.3% respectively, which can greatly reduce the initial cost.

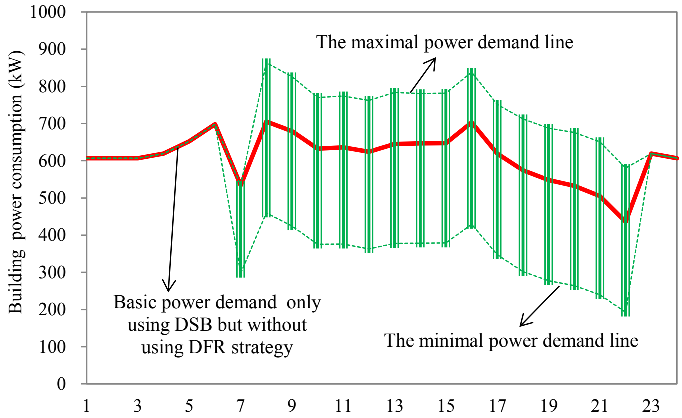


Fig.3. Potential of power alteration of the building using DFR strategy

Based on the day-ahead DSB strategy, building power demand can be further altered through the DFR strategy. The greatest power alteration potentials are shown in Fig.3. The maximal and minimal power demands occur when all chillers operate with the maximal capacity and when all chillers are switched off, respectively. In this case, the building can increase 23% or reduce 43% of its power demand if necessary.

5. Conclusion

A novel air-conditioning system that consists of a CWS and a THIC system is developed for proactive demand response to the smart grid. Two demand response strategies, i.e., the demand side bidding (DSB) strategy and demand as frequency controlled reserve (DFR) strategy, can be conducted in respond to the day-ahead and hour-ahead power balance requirements of the grid, respectively. The demand response performance of the developed system is validated in an office building in Hong Kong. Compared with conventional air-conditioning system, the power load factor of the building is increased from 57.5% to 86.6% by using the DSB strategy. The building can flexibly change (e.g., increase 23% or reduce 43% of) the power demand using the DFR strategy in response to the needs of the grid. The total operating energy cost is reduced by 29.7% and the chiller capacity is reduced by 24%.

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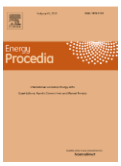

Biography

Chengchu Yan is a post-doctoral fellow, Xue Xue is a PhD candidate, Shengwei Wang is a chair professor in the Department of Building Services Engineering, The Hong Kong Polytechnic University. Building demand side management and smart gird are among the research interests of the authors.