Applied Energy Symposium 2019: Low carbon cities and urban energy systems
October 16-18, 2019, Xiamen, China
Paper ID: 0144

AN IMPROVED FAST DEMAND RESPONSE STRATEGY OF BUILDING HVAC SYSTEM WITH LOW COST MEASUREMENT SENSORS FOR SMART GRID APPLICATIONS

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ABSTRACT

The grids are facing the critical issue concerning the power imbalance. Demand response (DR) program are increasingly promoted to encourage the end-users to change their load profiles under a specified pricing policy or request of the grid. For buildings, the supply-based fast demand response strategy has been demonstrated that it can quickly response to the urgent request from smart grid and can reduce the load demand within very short interval. However, flow sensors are required for each air conditioning terminal equipment. In view of the high cost of flow sensors and the large number of air-conditioning terminal equipment, there are few cases of installing flow sensors for air-conditioning terminal equipment in existing large public buildings. Therefore, it hinders the application of this method in practical projects. This study aims at developing an improved fast demand response strategy of building HVAC system with low cost measurement sensors for smart grid applications. The virtual flow meter was modelled to estimate the water flow rate of each AHU based on the air side measurements. Meanwhile, a modified self-adjustment chilled water distribution method was developed to realize the balanced distribution of cooling capacity in different indoor zones, which does not require additional work to offline identify the key parameters prior to application.

Keywords: fast demand response, smart grid, virtual sensor

1. INTRODUCTION

In recent years, distributed renewable energy sources have been widely used in buildings. Meanwhile, random fluctuating power users such as large-scale electric vehicle charging piles have gradually increased in buildings. These intermittent and random disordered power consumption in buildings poses a severe challenge to the stability, reliability and economy of the traditional power grid. These factors aggravate the peak-valley difference of grid load, increase the difficulty of grid control, and become an urgent problem for power energy system. In response to those challenges faced by traditional grid, smart grid technology provides promising solutions for enhancing the reliability of grid by regulating the contradiction between power supply and demand through incentive mechanism.

In the smart grid environment, demand response (DR) has become an essential action promoted to encourage the end-users to change their load profiles under a specified pricing policy or request of the grid. Buildings are the major energy end-user in the world and have a significant impact on peak load of power grid. Therefore, it is necessary to take buildings into the scope of demand response resources.

At present, large amounts of studies paid more attention to building demand response in terms of modulating the HVAC load. The global temperature adjustment (GTA) strategy is a frequently used measure that modulates the temperature set-point of air-conditioned spaces to result in a flexible building load. Motegi[1] pointed out that the power savings using GTA strategy consists of two parts: the transient savings and the steady-state savings. Xu[2] performed in-situ case study of demand shifting with thermal mass in two large commercial buildings by GTA strategy. Results show that precooling has the potential to improve the demand responsiveness of commercial buildings while maintaining acceptable comfort conditions.

Compared with the GTA strategy, fast demand control method realizes demand response by directly limiting the power consumption of building electrical equipment, such as reducing the number of units and

Selection and peer-review under responsibility of the scientific committee of CUE2019

loads of fans, pumps, chillers, etc. The system regulation method can achieve rapid energy consumption reduction, but it has a potential impact on the stability of the system. Xue and Wang[3] conducted a simulation study on the stability of the system after closing part of the chillers. The results showed that serious hydraulic imbalance occurred in the air conditioning hydraulic network and uneven indoor air temperature rises among individual airconditioned spaces would be achieved. In order to handle the serious problem, Tang and Wang proposed a novel supply-based feedback control strategy that employs global and local cooling distributors based on adaptive utility function to reset the set-points of chilled water flow and air flow for each zone and space online[4,5].

It can be found from the above existing studies that the supply-based fast demand response strategy can quickly response to the urgent request from smart grid and can reduce the load demand within very short interval. However, in [4], the presented method requires water flow sensors for each air handling unit (AHU). Actually, in most of existing buildings, there are normally no flow meters installed for each AHU due to their high cost. In this situation, the application of previously presented fast demand response strategy would be difficult for the large number of existing projects. Aiming at solving this limitation and extending the application scope of the fast demand response strategy, this study proposes to develop a low-cost method that does not require the water flow sensors for each AHU

However, in this study, flow sensors are required for each air conditioning terminal equipment. In view of the high cost of flow sensors and the large number of air-conditioning terminal equipment, there are few cases of installing flow sensors for air-conditioning terminal equipment in existing large public buildings. Therefore, it hinders the application of this method in practical projects.

The purpose of this study is to develop an improved fast demand response strategy of building HVAC system with low cost measurement sensors for smart grid applications. The virtual flow meter was modelled to estimate the water flow rate of each AHU based on the air side measurements. Meanwhile, a modified self-adjustment chilled water distribution method was developed to realize the balanced distribution of cooling capacity in different indoor zones, which does not require additional work to offline identify the key parameters prior to application. The proposed method provides technical support for the implementation of rapid demand response in existing large public buildings.

2. OVERVIEW OF EXISTING FAST DR AND POWER LIMITING CONTROL STRATEGY

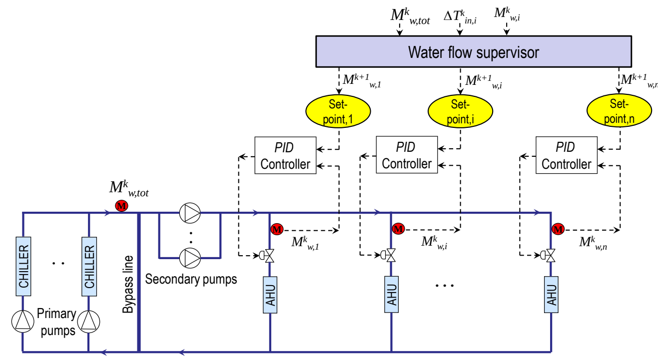

Fig 1 Existing chilled water flow control strategy. [4]

In [4], the existing fast DR and power limiting control strategy can be illustrated as Fig.1. A "Water flow supervisor" was developed to continuously adjust the set-points of chilled water flowrates of individual zones. For each group of AHUs, a feedback (PID) control is employed to control the water flow rate of the AHU at the set-point by modulating the flow control valve. However, in each PID control loop, a real water flow meter is required to monitor the real-time water flow through the associated AHU coil.

3. PROPOSED FAST DR AND POWER LIMITING CONTROL STRATEGY

3.1 Overall structure of the control strategy

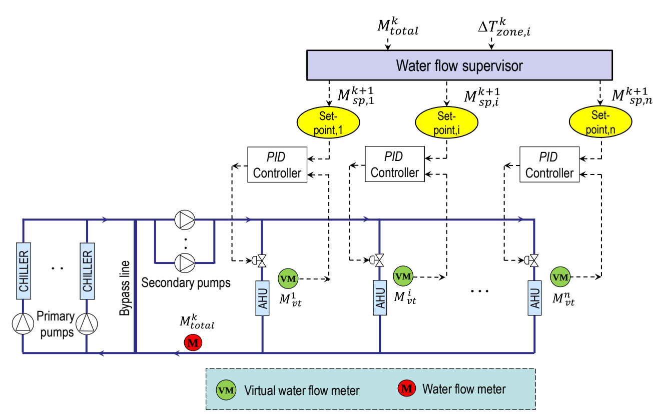

Fig 2 Proposed chilled water flow control strategy.

In this study as shown in Fig.2, an improved fast demand response control strategy is developed by developing the virtual sensor for online determination of the water flow of each AHU coil. During DR event when some of active chillers are switched off, the proposed DR control strategy would still solve the imbalance water flow distribution among AHUs and achieve the similar thermal comfort variation among different zones while not requiring the actual water flow meters of each AHU.

3.2 Modelling of the virtual flow meter

In this study, a virtual flowmeter is modelled to online estimate the water flow rate of each AHU based on the air side measurements. For the ith AHU, the water flow rate can be estimated using Eq. (1)-Eq. (6).

$$M_{w,vir,i} = M_{w,total} \cdot Rat_{w,i} \tag{1}$$

$$Rat_{w,i} = \frac{M_{w,i}}{\sum_{i=1}^{n} M_{w,i}} \tag{2}$$

$$M_{w,i} = \frac{M_{a,i}(H_{ra,i} - H_{sa,i})}{4.19(T_{w,r} - T_{w,s})} \tag{3}$$

$$H_{ra,i} = 1.005T_{ra,i} + 0.001S_{ra,i}(2500 + 1.84T_{ra,i}) \tag{4}$$

$$H_{sa,i} = 1.005T_{sa,i} + 0.001S_{sa,i}(2500 + 1.84T_{sa,i}) \tag{5}$$

where, for ith AHU, $M_{w,vir,i}$ is the estimated water flow rate, $M_{w,total}$ is the measured total water flow rate of the main pipe, $Rat_{w,i}$ is the ratio defined, $M_{w,i}$ is calculated rough water flow rate, $H_{ra,i} / H_{sa,i}$ are the calculated return/supply air enthalpy, $T_{ra,i} / T_{sa,i}$ is the measured return/supply air temperature, $S_{ra,i} / S_{sa,i}$ is the measured return/supply air humidity.

3.3 Self-adjustment method for determining water flow rate set-point

A self-adjustment method is developed for determining water flow rate set-point. Different from the corresponding method in reference [4], the main characteristics of this proposed method is that it does not require additional work to offline identify the key parameters prior to application.

The basic principle for determination the water flow rate set-point of each AHU is to ensure that the temperature rise of each zone is basically the same.

$$M_{w,i}^{k+1} = M_{w,total}^{k} \cdot (\alpha_i^k + \beta_i^k) \tag{6}$$

$$\alpha_i^k = \frac{M_{w,vir,i}^k}{M_{w,total}^k} \tag{7}$$

$$\Delta T_{zone,i}^k = T_{zone,i}^k - T_{sp,i} \tag{8}$$

$$TR_{zone,i}^k = \frac{\Delta T_{zone,i}^k}{\sum_{i=1}^{n} \Delta T_{zone,i}^k} \tag{9}$$

where, for ith AHU, $M_{w,i}^{k+1}$ is the water flow rate set-point at time (k+1), $M_{w,total}^{k}$ is the measured total water flow rate of main pipe at time k, α_i^k is the coefficient indicating the water distribution proportion at time k, $M_{w,vir,i}^k$ is the estimated water flow rate from the virtual sensor at time k, $T_{zone,i}^k$ is the measured zone temperature, $T_{sp,i}$ is the zone temperature set-point, $\Delta T_{zone,i}^k$ is the zone temperature rise, $TR_{zone,i}^k$ is ratio of individual zone temperature rise to total zone temperature rise.

4. TEST PLATFORM

4.1 Setup of test platform

Computer-based dynamic simulation is adopted, as an effective mean, to test and validate the online control strategies (Wang 1998). In this study, a virtual test platform is built to test the proposed fast DR and power limiting control strategy using dynamic models developed on TRNSYS. This test platform employs

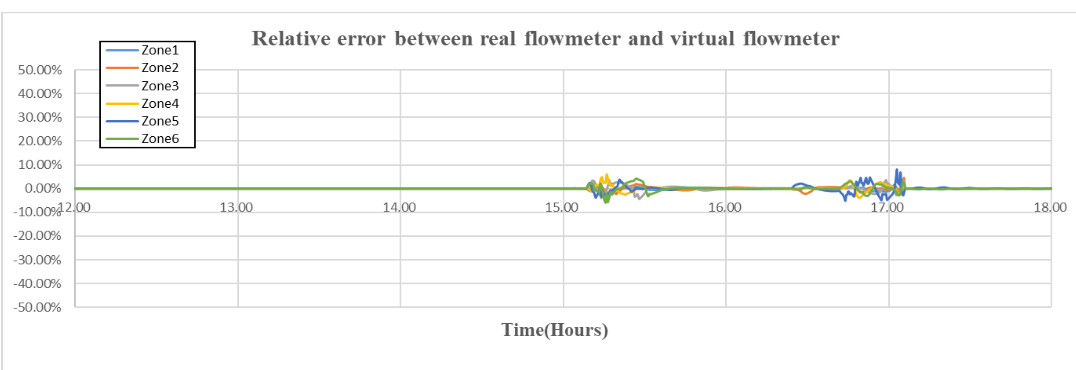

Fig 3 Relative error of real flowmeter and virtual flowmeter.

detailed physical models including the building envelop and major components (e.g., chillers, pumps, hydraulic network, AHUs) of a central air-conditioning system. The dynamic processes of heat transfer, hydraulic different cooling load profiles. There are several operating chillers before the start of DR event, and only two chillers remain to operate in DR event.

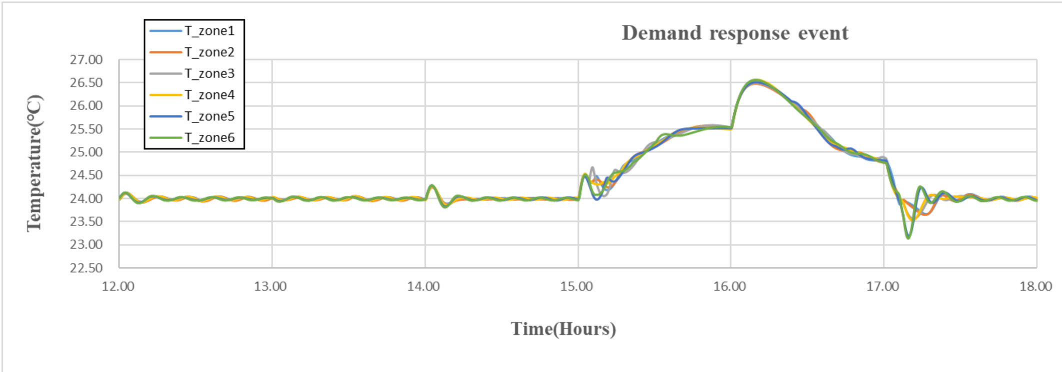

Fig 4 Real flowmeter for control.

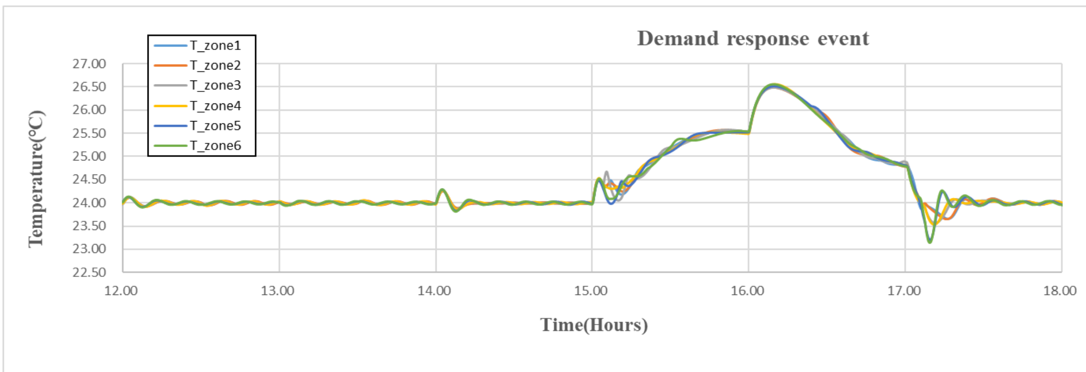

Fig 5 Virtual flowmeter for control.

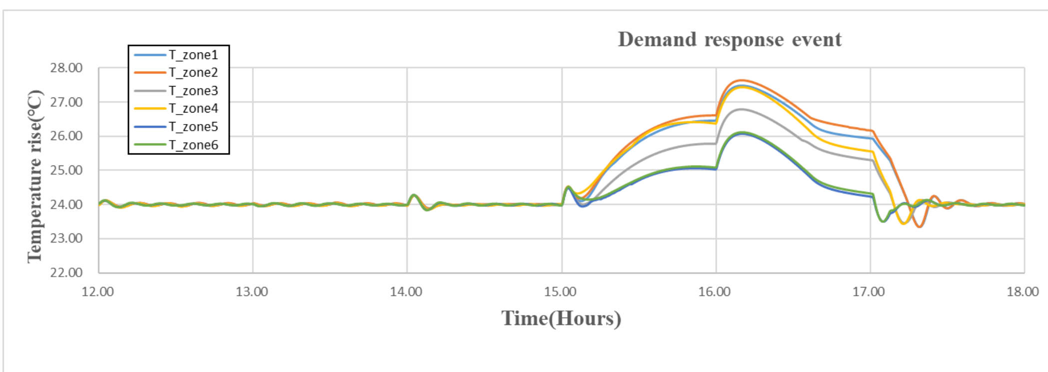

Fig 6 Indoor temperature with conventional control.

characteristics, flow balance, energy conservation, and controls among the whole system are simulated. The original indoor air temperature set-point before DR event is 24℃ The office time of the building is between 08:00 am and 6:00 pm. The DR period is between 3:00 pm and 5:00 pm. In this study, the DR event was conducted on August 1 in summer. Six air-conditioned zones in a commercial building have different sizes and

4.2 Case1: The verification of virtual flowmeter reliability

As shown in Fig.3, the difference between the virtual flowmeter and the real flowmeter used in this study is very, which means the virtual flow meter can be used to replace the real flow meter.

In DR event, the use of real flowmeter for control and the use of virtual flowmeter for control are shown in

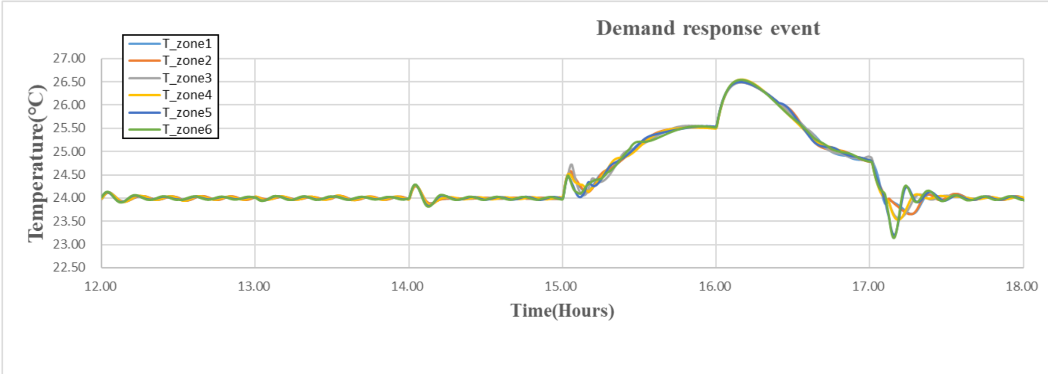

Fig 7 Indoor temperature using the proposed control strategy.

Fig.4 and Fig.5. It can be seen from the operation results that the error between the virtual flowmeter and the real flowmeter is within 1% in most time.

4.3 Case 2: the proposed control strategy VS uncontrolled DR

In the DR, only two chillers are working. If no control is applied, the temperature variation of the six rooms is shown in Fig.6. It can be seen that temperature difference among six rooms is large.

When the proposed control strategy using virtual sensor, the operation result is shown in Fig.7. It can be seen that temperature difference among six rooms tends to close to zero. The maximum difference is within 0.1 ℃.

5. CONCLUSION

This study proposes an improved fast demand response strategy of building HVAC system with low cost measurement sensors for smart grid applications. Test results show that the virtual flow meter can be used to online estimate the water flow rate of AHU with acceptable accuracy. Meanwhile, the proposed control strategy can effectively solve the disordered water distribution problem and achieve the uniform changing profiles of the thermal comfort among different zones under the limited cooling supply.

ACKNOWLEDGEMENT

This work presented in this paper is financially supported by a grant (No. 51778642) of National Natural Science Foundation of China.

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