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## A fault detection and diagnosis method for low delta-T syndrome in a complex air-conditioning system

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### Abstract

Low delta-T syndrome widely exists in the existing air-conditioning systems and results in increased energy consumption. This paper presents a fault detection and diagnosis method (FDD) to detect and diagnose the low delta-T syndrome resulted from the water fouling of cooling coils in a complex cooling system. Performance indices and adaptive thresholds are adopted in the FDD strategy to diagnose the health condition of the system. The adaptive threshold can effectively improve the prediction uncertainty of the reference models and the calculation uncertainty of performance indices under various working conditions. The proposed method was validated in a dynamic simulation platform representing a real complex HVAC system studied. The results show that the proposed FDD strategy can successfully detect the low delta-T syndrome and identify the faults.

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*Keywords:* Chilled water system; low delta-T syndrome; Deficit flow; Fault detection and diagnosis

### 1. Introduction

Heating ventilating and air-conditioning (HVAC) systems are the major energy consumers in the commercial buildings [1]. While in real applications, most of the primary-secondary chilled water systems, from time to time, do not work as efficiently as expected due to the excess secondary flow demand, which causes deficit flow problem (i.e. the required flow rate of secondary loop exceeds that of the primary loop). When the deficit flow problem exists, the water temperature difference produced by the air handling terminals is much lower than the design value, which is known as low delta-T syndrome [2-4]. Kirsner [2] pointed out that low delta-T chilled water plant syndrome exists in almost all large chilled water systems. In the last two decades, many researchers and experts in the HVAC field have devoted considerable efforts to deal with the low delta-T syndrome and deficit flow problem [5-10]. In primary-secondary chilled water systems, the low delta-T syndrome and deficit flow problem often occur when the

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performances of cooling coils in air handling units(AHU) or/and heat exchangers are degraded.

Because the water temperature difference produced by cooling coils varies with load conditions, it is hard to accurately estimate whether and to what extent the temperature difference is lower than what it should be only based on site observations. It is still necessary to diagnose whether and to what extent the cooling coils are degraded. Thus, this paper presents a fault diagnosis (FDD) strategy to quantitatively diagnose the low delta-T syndrome. The performance of this method is evaluated on a simulated dynamic system constructed based on a real system in a super high-rise building in Hong Kong.

## 2. Building and system description

The central chilled water plant concerned in this study is a complex primary (constant)-secondary (variable) system in a super high-rise building in Hong Kong [11]. The heat exchangers are employed to transfer cooling energy from chillers to some of occupied zones to avoid water pipelines and terminal units from suffering extremely high static pressure. One subsystem involving intermediate heat exchangers is selected as the example to be studied, as illustrated in Fig. 1.

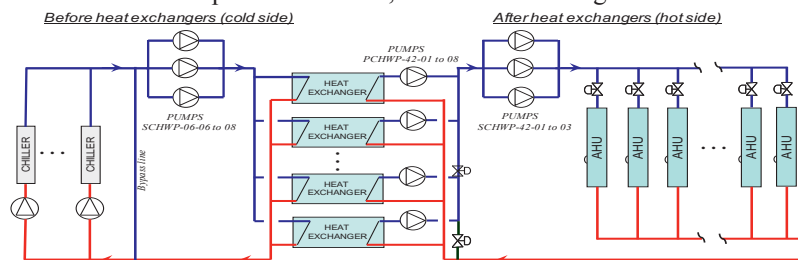


Fig. 1 The simplified schematic of chilled water system

## 3. Formulation of the method

### 3.1. Outline of the method

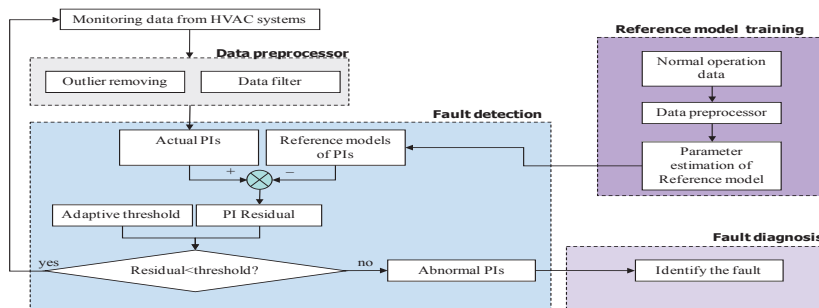


Fig. 2 Schematic of the FDD strategy integrated with energy impact evaluation

The FDD strategy for diagnosing low delta-T syndrome includes a data preprocessor, a fault detection scheme, a fault diagnosis scheme, as shown in Fig. 2. In the fault detection scheme, performance indices (PIs) are calculated using online measurements to characterize the current status of the system. The reference models of PIs are developed to determine the benchmarks of PIs, which are regressed in advance using the normal operation data (no faults). The residuals between the calculated actual PIs and their benchmarks are compared with their online adaptive thresholds to detect the faults. When the residuals of one or more PIs are located out of the thresholds, the corresponding PIs are considered in abnormal condition. The adaptive thresholds of PIs can be updated online, which consider both model-

fitting errors and measurement errors. Then, the abnormal PIs are further diagnosed and used to identify the specific fault in the fault diagnosis scheme.

### 3.2. Description of the FDD strategy

#### 3.2.1. Faults modeling

Shown in Table 1, performance degradation of heat exchangers is introduced by reducing the overall conductance–area product ( $UA_{HX}$ ) artificially in two quantities (i.e.,  $UA_{HX}$  is reduced by 20% and 30%). The water temperature difference ( $\Delta T_{w,bhx}$ ) before heat exchangers and  $UA_{HX}$  are selected as the performances indices (PIs) to identify the fault. When  $UA_{HX}$  is reduced, more chilled water will be required at primary side of heat exchangers. Consequently, the water temperature difference at primary side of heat exchangers ( $\Delta T_{w,bhx}$ ) will be reduced.

Table 1 Faults, fault modeling and mathematical PI formulations

Fault	Means of introducing faults	Performance indices(PIs)	PIs formulation
Heat exchanger degradation	Decrease the heat transfer coefficient	Water temperature difference	$\Delta T_{w,bhx} = T_{w,out,bhx} - T_{w,in,bhx}$
		Overall conductance–area product	$UA_{HX} = \frac{Q_{tot,HX}}{LMTD}$

#### 3.2.2. Reference models of performance indices

Reference models of the PIs are proposed to characterize the operation of a fault-free chilled water system. For the heat exchanger system, the cooling load ( $Q_{HX}$ ), the inlet water temperature at the primary and secondary sides of heat exchangers ( $T_{w,in,bhx}$  and  $T_{w,in,ahx}$ ), and the water flow rates at primary and secondary sides of heat exchangers ( $M_{w,in,bhx}$  and  $M_{w,in,ahx}$ ) are selected to establish the reference model of the temperature difference of water at primary side of heat exchangers ( $\Delta T_{w,bhx}$ ), as shown in Equation (1). Equation (2) is used as the reference model of the overall conductance–area product ( $UA_{HX}$ ). The coefficients (i.e.,  $c_0$ – $c_5$ ,  $d_0$ – $d_2$ ) used in the reference models are constant, which can be determined by linear regression method using the fault-free operation data.

$$\Delta T_{w,bhx} = c_0 \cdot Q_{HX}^{c_1} \cdot T_{w,in,bhx}^{c_2} \cdot T_{w,in,ahx}^{c_3} \cdot M_{w,bhx}^{c_4} \cdot M_{w,ahx}^{c_5} \quad (1)$$

$$UA_{HX} = d_0 \cdot M_{w,bhx}^{d_1} \cdot M_{w,ahx}^{d_2} \quad (2)$$

#### 3.2.3. Estimation of threshold

The residual threshold is used to determine whether the performance indices are in abnormal conditions. When the residuals of performance indices exceed the threshold, it means the PIs are in abnormal condition. The uncertainty of residuals is highly affected by the prediction uncertainty of the reference models and the calculation uncertainty of performance indices under various working conditions. Adaptive thresholds are used that vary with working conditions when given certain confidence levels. The method to determine the adaptive thresholds are based on the study of Cui [12].

## 4. Validation of the FDD strategy

The dynamic simulation platform as Fig. 2 was used to generate operation data for validating the FDD strategy. Three typical days were selected to represent the chilled water system working under Spring, Mild-Summer and Sunny-Summer days. The residuals of PIs were calculated using the measured data and then compared with their thresholds. Only the results of the Mild-Summer case are shown in Fig. 3. The points located out of the two lines of the threshold means the abnormal points detected. Obviously, both the PI of  $\Delta T_{w,bhx}$  and  $UA_{HX}$  are sensitive to the degradation of heat transfer efficiency at two levels. Almost

all the measured points deviated obviously from their thresholds, which indicate the faults were successfully diagnosed. The distance deviated from the threshold is proportional to the fault severity.

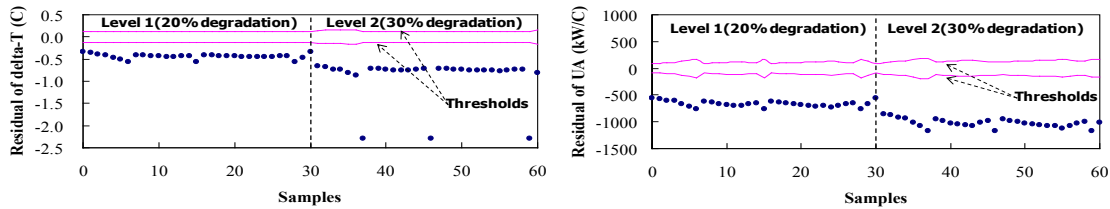


Fig. 3 Residuals of PIs (Delta-T and UA) in Mild-Summer case

## 5. Conclusion

A fault diagnosis strategy is presented, which is used for detecting and diagnosing the low delta-T syndrome resulted from the performance degradation of cooling coils in heat exchangers in chilled water systems. Performance indices and adaptive thresholds are adopted in the FDD strategy to determine the health condition of the system. The proposed FDD strategy was validated in a dynamic simulation platform representing a complex HVAC system. The results show that the proposed FDD strategy can detect the low delta-T syndrome and identify the faults.

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## Biography

GAO Diance received his PhD (2012) in building system diagnosis and optimal control in 2012 from Hong Kong Polytechnic University. He is the Post-doctoral Research Fellow in the department of Building Services Engineering, Hong Kong Polytechnic University. His research interests include building energy optimization, robust and optimal control strategies for building systems and smart grid.

