

Real-time performance assessment and adaptive control for a water chiller unit in an HVAC system

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Abstract. The paper proposes an adaptive control method for a water chiller unit in a HVAC system. Based on the minimum variance evaluation, the adaptive control method was used to realize better control of the water chiller unit. To verify the performance of the adaptive control method, the proposed method was compared with an a conventional PID controller, the simulation results showed that adaptive control method had superior control performance to that of the conventional PID controller.

1. Introduction

Although traditional PID controllers have been most commonly used in HVAC(Heating Ventilation and Air-conditioning) systems, it has sometimes been difficult to compensate fully for load disturbance and to keep controlled variables close to set point values within the prescribed range [1-3], especially for water chiller units, the most important unit in HVAC systems, whose control performance will have a great impact on the whole operation of an HVAC system. In order to obtain good control performance, an adaptive control method based on control performance assessment for a water chiller unit was proposed in this paper.

Currently many adaptive control methods have been applied in various engineering areas , such as robots, industrial chemistry, power system operation, military weapons, etc., and they normally have better control effect [4-6]. Although these adaptive control methods have many advantages, the water chiller unit has complex and time-delayed characteristic, frequently adjusting controller parameters will reduces its stability. In the paper, a control performance assessment criteria was used combined with the adaptive control method for control of the water chiller unit. When the control performance is lower than the threshold[7], the adaptive control will be implemented to update controller parameters. Otherwise, the controller parameters will be kept unchanged.

In the paper, the minimum variance was chosen as the control performance assessment benchmark, which has been widely used in the control area. Many scholars have conducted in-depth study on the method, which was first put forward by Harris in the 1960s [8], it provides a scientific basis to the assessment of the controller performance in the engineering area.

2. Modeling of a water chiller unit

An water chiller unit contains four major components (Figure1): evaporator, compressor, condenser, throttle valve [9-10]. The main function of the unit is to produce enough refrigerating capacity, and complete heat transfer with chilled water in the evaporator, so the mathematical model of the loop can be obtained by the law of energy conservation and thermodynamics equations. The evaporator's heat



exchange procedures can be decomposed into three parts: the change of chilled water temperature, the heat transfer between refrigerant and cooling water, the heat transfer between chilled water and external environment, just as shown in Figure 2.

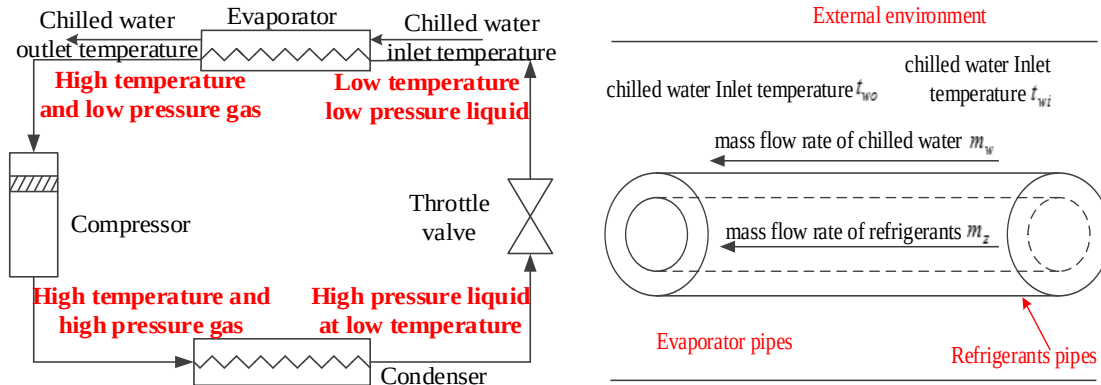


Figure 1.Water chiller unit working process. **Figure 2.** Heat exchange in the evaporator.

So the thermodynamics equation of the water chiller unit can be deduced, as shown in Eq.(1).

$$C_1 \frac{dt_{wo}}{dt} = c_w m_w (t_{wo} - t_{wi}) + m_z r_z + \frac{t_b - t_{wo}}{r} \quad (1)$$

In Eq.(1), C_1 is the capacity coefficient of the chilled water in the evaporator; t_{wo} is the outlet temperature of chilled water in the evaporator (°C); t_{wi} is the inlet temperature of chilled water in the evaporator(°C); m_w is the mass flow rate of chilled water in the evaporator(kg/s); t_b is the temperature of external environment(°C); r is the thermal resistance between external environment and evaporator ($K \cdot m^2$)/W; c_w is the specific heat capacity of the chilled water(J/(kg·K)); m_z is the mass flow rate of refrigerants(kg/s); τ is the running process time(s); r_z is the latent heat of vaporization of refrigerant(kJ/kg).

When the operation condition of the water chiller unit changes, Eq.(1) can be converted into the formula below:

$$C_1 \frac{dDt_{wo}}{dt} = c_w m_w (Dt_{wo} - Dt_{wi}) + Dm_z r_z + \frac{Dt_b - Dt_{wo}}{r} \quad (2)$$

Combined the actual parameters of air conditioning system with Eq.(2), the mathematical model of water chiller unit can be calculated, and the adaptive control method with performance evaluation proposed in this paper can be used to complete the simulation.

In order to verify the validity of the water chiller unit mathematical model, assign the same input signal to the simulation model and the water chiller unit of an HVAC system, and comparing the simulation results with the experimental results, the following are respectively the output curves under 30%, 40%, 50% power of compressor, as shown in Figure 3.

The simulation and experimental results under 30%, 40%, 50% power of compressor show that the gap between mathematical model data and experimental data is not greater than 0.5 °C. With the increase of the compressor power, the gap is becoming more and more smaller. As mentioned above, the mathematical model is accurate generally, it can represent the water chiller unit under normal working conditions, and also can be used for the research of advanced control algorithm.

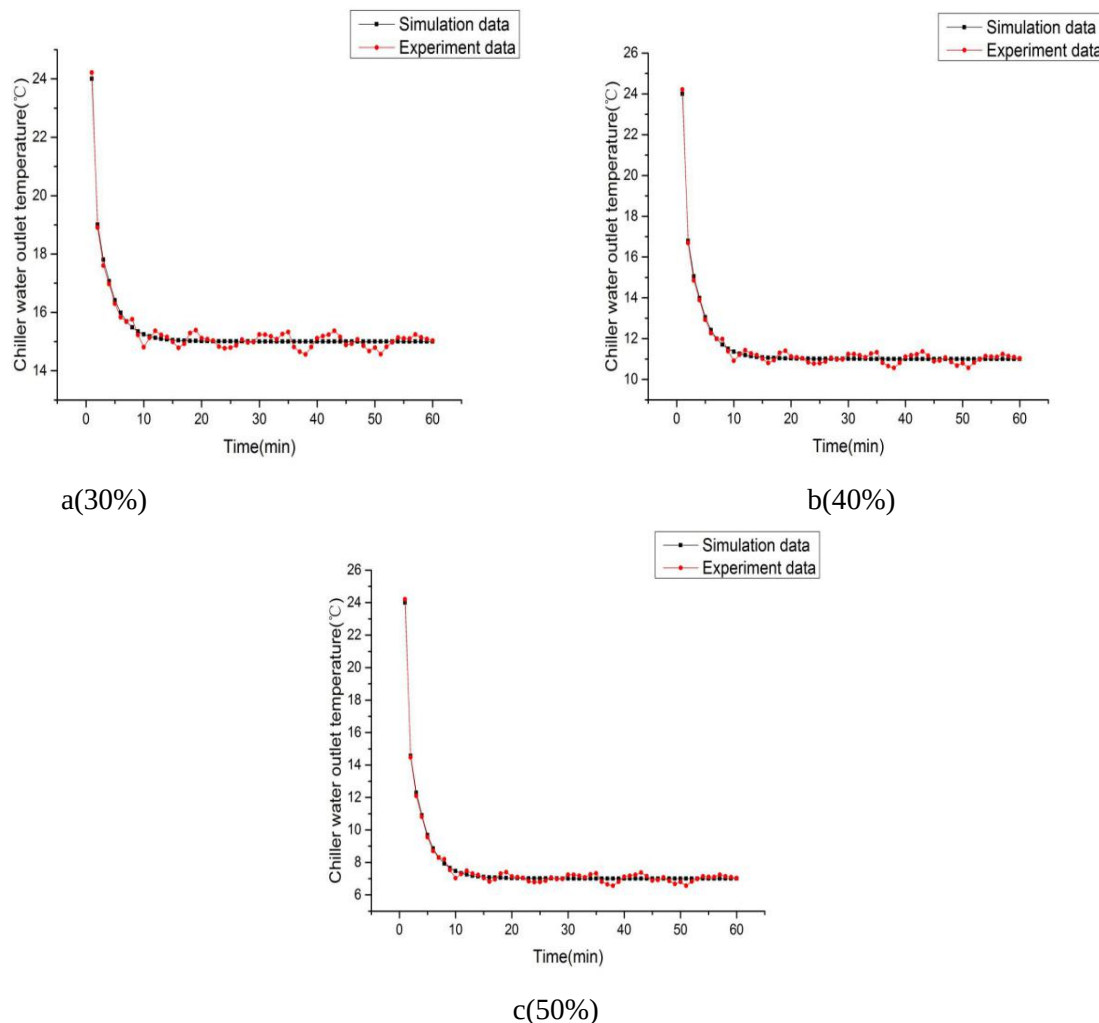


Figure 3. Chilled water outlet temperature curve under different power of compressor.

3. Control performance evaluation

With the rapid development of industrial technology, the research on industrial control systems becomes more and more deeply, especially for the control units in HVAC systems. HVAC systems normally have time-varying, nonlinear, time-delayed and multivariable coupling features and are often disturbed by load change[11-13].

Industrial controllers often can achieve good control effect at the beginning, but with the increase of the running years, the control performance will gradually decline. Therefore ,it is important to accurately evaluate the current performance of the control system [14].

The water chiller unit in an HVAC system was selected as the research object in this article, whose mathematical model can be obtained by combining with the mathematical model calculation methods in the 2nd chapter. To simulate the normal working condition of the chiller unit, the setting outlet temperature of chilled water will be changed from 24 °C to 7 °C in the 40 sampling time, the simulation model is shown in Figure 4.

The PID controller parameters of water chiller unit simulation model is $K_p = 10$, $K_i = 2.1$, $K_d = 2$. The assessment result shows that the current water chiller control loop performance indicator is 0.7. It usually selects 0.6 as the control performance threshold in engineering applications[15], so the current PID parameters can meet the demand of the current condition although they are not the optimal

parameters and the optimal PID control parameters are $K_p = 12$, $K_i = 1.65$, $K_d = 0.8$. The comparison with two groups of control parameters is shown in Figure 5.

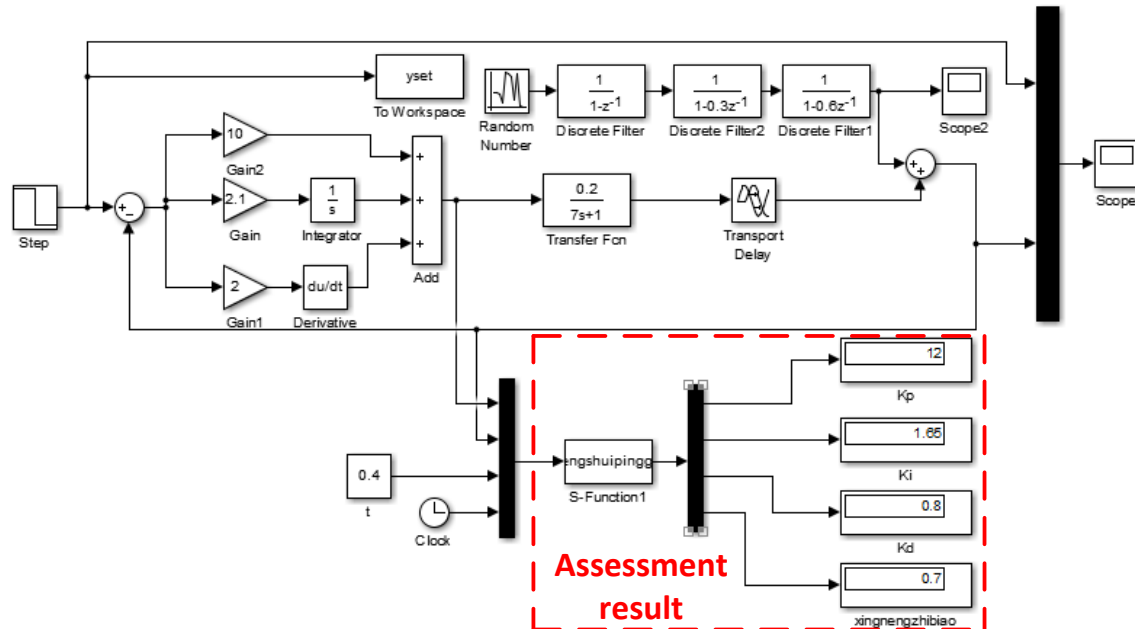


Figure 4. Performance evaluation simulation model for water chiller unit in Simulink.

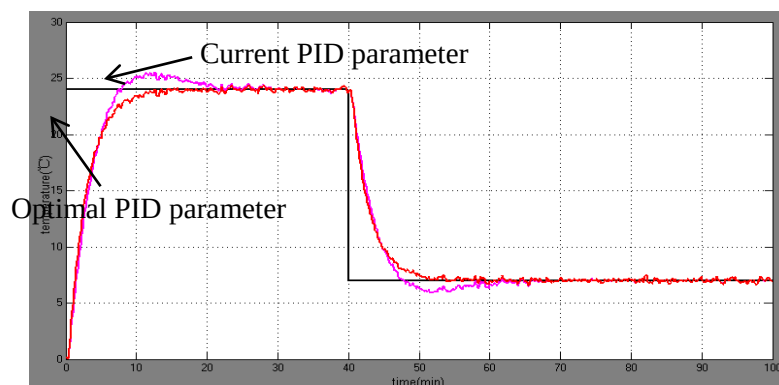


Figure 5. The contrast of current PID parameters and the optimal PID parameters.

4. Adaptive controller based on performance evaluation

In this paper, the adaptive control method determines whether to adjust the controller parameters according to the current control performance evaluation results. The control performance assessment result was calculated by the input and output of controlled variables. But the water chiller unit model parameters in the working process will continue to change because of outside disturbance and load change [16]. In order to realize the accurate control, the control system must have the online identification function, which selecting recursive least squares method to complete identification and establishing the adaptive control simulation model of water chilled unit to verify the control performance. The working principle of adaptive control method was shown as follows (Figure 6),

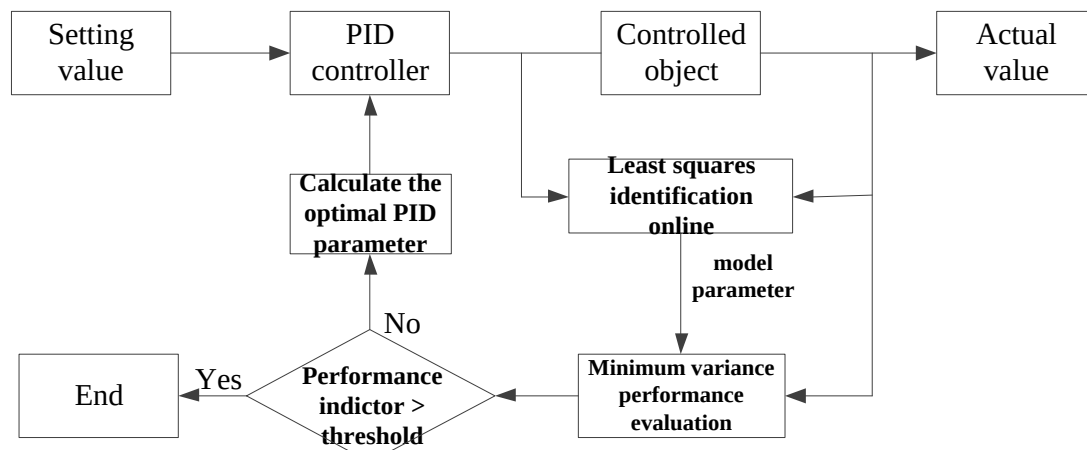


Figure 6. Working principle of the adaptive control method.

4.1. Recursive least squares method

Recursive least squares method complete the first time identification based on the given initial value. As time goes on, recursive least squares algorithm will continuously obtain new estimate values [17].

4.2. Adaptive control method simulation result

The water chiller unit of an air conditioning system was selected as the research object in this paper, the mathematical model and performance assessment process has been proposed. With the passage of time, the model of the water chiller unit was changing, associating with the online identification method, the simulation model can be shown in Figure 7.

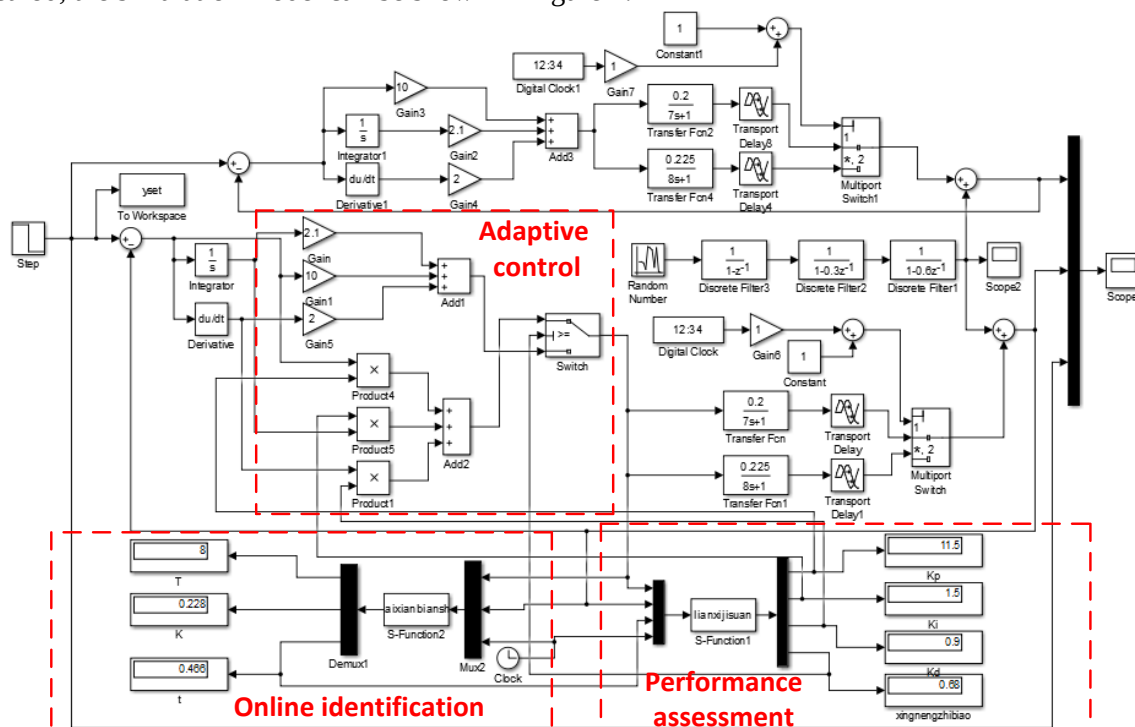


Figure 7. Adaptive control simulation model of water chiller unit.

In Figure 7, the water chiller unit simulation model is divided into three main parts: adaptive control, online identification and performance assessment. The identification result is shown as $T=8$,

$K=0.228, \tau=0.466$, which are very close to the actual parameters of the controlled object. And the performance result is shown as 0.68, the output of simulation model is shown in Figure 8.

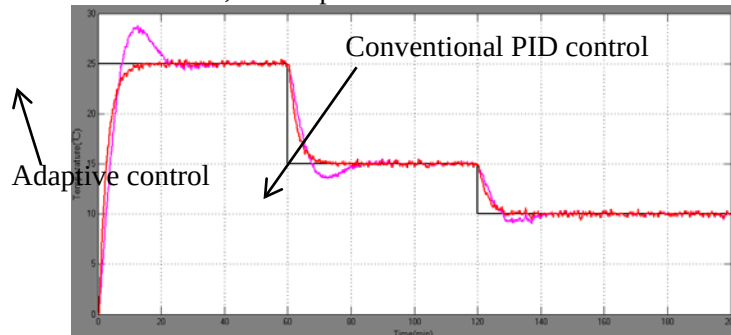


Figure 8.Chiller water unit simulation curve.

The setting value of outlet temperature was decreased first from 25°C to 15°C, and then to 10 °C. The black line is the setting value, the pink line show the control performance of the common PID control method and the red line shows the adaptive control method.

With the long-time use of chiller unit, the characteristic parameters will also change. So the conventional PID controller can't achieve good control effect, the chiller unit simulation curve after parameters changed is shown in the Figure 9, it can be seen that the performance of the proposed method is better than the conventional PID controller.

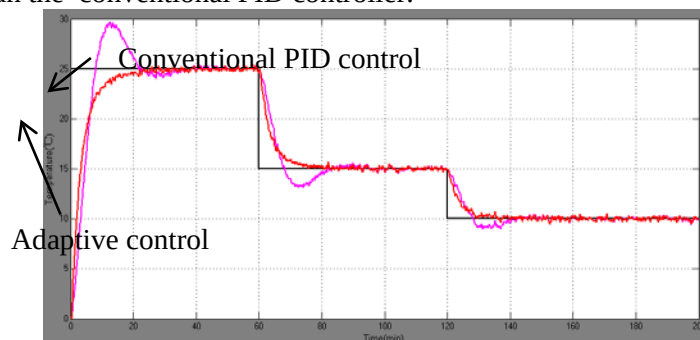


Figure 9.Chiller water unit simulation curve after parameters changed.

In a word, compared with the conventional PID control method, the adaptive control method based on the performance evaluation proposed in this paper has a faster regulation speed and more accurate control results.

5. Conclusions

In the paper, an adaptive control method based on the minimum variance performance assessment was proposed and a water chiller unit was selected as the controlled object. First, the adaptive control method identifies the current mathematical model according to the input and output values of the controlled object. Then, the method will calculate the current performance result based on the mathematical model. Third, the control performance was compared with the performance threshold and whether to adjust the controller parameters were determined. The simulation results show that the control method has better control performance than PID controllers. The proposed method can be used in HVAC systems.

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