Design of Control System of Water Source Heat Pump Based on Fuzzy PID Algorithm

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Abstract—This study aims to enhance the control and energy efficiency of the central air conditioning system by integrating frequency conversion fuzzy control and advanced control strategies. The focus is on optimizing the motor operation of the central air conditioning system with the help of a frequency converter and improving the system's performance through adaptive control mechanisms, which is an important part of intelligent control. The research adopts frequency conversion fuzzy control for high - power motors in the central air conditioning system, using a pure proportional controller. The system's response is analyzed, including the rise time (tr = 339.3s) and peak interval (Ts = 633.19s) based on unit step response data. The study also addresses the integration of cooling water heat exchange systems, such as heat pumps and plate heat exchangers, to facilitate energy recycling, achieving the goal of energy saving. System identification is performed using MATLAB's toolbox for deep well water pump frequency conversion data, forming a basis for further simulation and optimization. The study incorporates a hybrid PID, fuzzy, and neural network - based control strategy to handle the system's time - varying, nonlinear characteristics. The results indicate that the hybrid control strategy significantly improves the system's dynamic response. With a rising time of tr = 611s, peak time of tp = 830s, adjustment time (±5%) of ts = 1140s, and an overshoot (Mp) of 16.08%, the system exhibits better performance than conventional PID controllers, particularly in handling large lag and nonlinear behaviors. This work presents an innovative approach by combining frequency conversion fuzzy control with adaptive PID and neural networks for a more efficient air conditioning control system. The integration of cooling water heat recycling and advanced control mechanisms provides a novel solution for enhancing energy efficiency and operational performance in central air conditioning systems, which is highly relevant to energy saving and intelligent control.

Keywords—Central air conditioning system; frequency converter; fuzzy PID control; intelligent control; energy saving

I. INTRODUCTION

According to statistics, in 1995, the percentage of building energy consumption was 10.7%, and in 2006, the percentage was 23.1%, building energy consumption showed a rapid rising trend. With the acceleration of urbanization, buildings and facilities will increase exponentially, and it is expected that their proportion to the total energy consumption of the society will eventually be close to the level of developed countries [1, 2]. Therefore, building energy conservation has become a key factor affecting the optimization of energy structure and improving energy efficiency, and become the focus of sustainable development strategy. Building energy consumption includes energy use of building materials, this trend will continue to rise due to improving people's living standards [3, 4]. With the development and maturity of ground source heat pump technology, ground source heat pump technology has gradually become an effective means to curb this trend. The flow rate to stabilize the temperature difference between the supply and return water of the air conditioning system at the set value. This method can make the system at low load fixed temperature difference small flow operation, save the transmission power of the secondary pump group, and achieve the purpose of energy saving [5, 6]. The total flow rate of pipe network is only related to the set value of real-time load, which also has some defects [7]. In recent years, water source heat pump systems have gained significant attention as an efficient and environmentally friendly solution for heating, ventilation, and air conditioning (HVAC) applications. These systems leverage the stable thermal properties of groundwater or other water sources to provide reliable heating and cooling, making them particularly suitable for regions with moderate climate conditions [8]. It can meet the requirements of temperature and humidity of the user; and the system operation cost is lower, which is convenient to realize the variable flow is unchanged, which meets the requirements of indoor temperature and humidity, and is suitable for the temperature difference flow control [9, 10].

High efficiency refers to that, compared with the existing conventional HVAC system of the same scale, It has a higher energy efficiency ratio; Environmental protection means that, when compared to conventional HVAC systems, it reduces the environmental pollution from the large number of pollutants. The replacement is that the ground source heat pump system can partially replace or completely replace the conventional energy [11, 12]. Understand the identification process, such as the system operating conditions, working processes, the physical laws of the dominant process, some prediction experiments, etc. According to different purposes, such as for design, forecasting, control, etc., using different model types, different identification methods and requirements, and different precision requirements, etc. [13]. Traditional control strategies, such as differential pressure control, often fail to address these challenges comprehensively, leading to inefficiencies, energy waste, and suboptimal performance. To overcome these limitations, this paper proposes a control system design based on a fuzzy PID algorithm, which integrates the advantages of fuzzy logic and proportional-integral-derivative (PID) control to enhance system stability, adaptability, and energy efficiency [14].

Through the experimental collection of input and output data, in the data collection due to the influence of the environment and unit, the inevitable existence of different degrees of interference, exist in the data often contains the dc component and some high frequency components, some of the data collection dimension even different, these will affect the accuracy of the identification system, therefore, before the identification to identify data for data pretreatment. The commonly used data preprocessing methods mainly include data resampling, desteady state value, detrending value and data filtering, etc. which can improve the accuracy of identification and the availability of the identification model [15, 16]. And the ground source heat pump system in the building cooling or heating has obvious energy saving effect, clean energy, good environmental benefits, multi-purpose, high efficiency and energy saving, air conditioning system industry in our country has broad prospects for development, and application in our country building [17]. With the development of control technology and water pump variable speed technology, the variable flow technology of air conditioning system has also been greatly developed. According to the size of the actual load to each room to change the cold-water flow, and according to the actual flow required by the system, adjust the pump speed or the number of running units, so as to save the energy. In China, due to the gradual maturity of the frequency converter technology and the decreasing price, designers and engineers began to use the frequency converter in the air conditioning water system and achieved certain economic and environmental benefits [18]. The follow-up work of this article will focus on the variable flow control scheme of the groundwater source heat pump air conditioning system, and explore in detail the application of fuzzy control technology in it. Based on the fuzzy PID algorithm, the control system of the water source heat pump central air conditioning unit will be designed. Subsequently, the experimental results were analyzed to verify the effectiveness of the proposed scheme and algorithm. Finally, the research results were summarized to clarify the contribution and future development direction of this study in improving system energy efficiency and control performance.

II. The Variable Flow Control Scheme of Underground Water Source Heat Pump Air Conditioning System

A. Control of Differential Pressure Variable Flow of Underground Water Source Heat Pump

As Formula (1) and Formula (2). In winter, the low-taste energy present in the water is "extracted", which absorbs the heat stored in the groundwater through refrigerant evaporation.

$$\frac{2}{T_{c/2}} = \frac{1+M\sin\omega_1 t_A}{t_2} \tag{1}$$

$$\mathrm{L}(e) = max(0,(1-f(e))^2-1) \tag{2}$$

Heat in the condenser to the building for heat; in summer, the energy in the building "takes" out, that is, absorb the heat through the evaporation of refrigerant, as shown in Formula (3) and Formula (4), and release the groundwater heat in the condenser, thus realizing the indoor temperature regulation. In this way, it can basically take cold and heat from underground in summer and cold from underground in winter, so as to achieve heat balance in a sense, and there will be no heat pollution.

$$t_2 = t_2^{'} + t_2^{''} = \frac{T_c}{2}[1+\frac{M}{2}(\sin\omega_1 t_A + \sin\omega_1 t_B)] \tag{3}$$

$$f(e_i) = tag - thr_i = \begin{cases} malicious, \text{if } f(e_i) < 0 \\ benign, \text{otherwise} \end{cases} \tag{4}$$

Stored by the earth water as a cold and heat source, as shown in Formula (5) and Formula (6), and carries out energy conversion for heating and cooling. The surface soil and water is a huge solar collector, collecting 47% of the solar radiation energy, more than 500 times the annual human energy utilization.

$$t_2 = t_2^{'} + t_2^{''} = \frac{T_c}{2}(1+M\sin\omega_1 t_e) \tag{5}$$

$$\frac{\partial tag_{n'}}{\partial a_n} = \begin{cases} 1, \text{if } n' = n \\ 0, \text{if } n' \neq n \end{cases} \tag{6}$$

As shown in Formula (7) and Formula (8), in the winter into the underground cooling, can help the summer system, and in the summer to release heat to groundwater, can help the winter of heating system, which not only realize the balance of cold and cold underground environment, but also realize the energy recycling between soil and water.

$$t_1 = t_2 = \frac{1}{2}(T_c - T_2) \tag{7}$$

$$Loss = \sum_{e\in E}\mathrm{L}(e) + \alpha\,||A-A_0||_2 + \gamma\,||G-G_0||_2 + \tau\,||T-T_0||_2 \tag{8}$$

Therefore, this technology is considered to be an advanced technology that only uses clean and renewable geothermal energy. As shown in Formula (9) and Formula (10), so the evaporation temperature of the heat pump cycle can be improved, and the performance coefficient can also be greatly improved.

$$t_{a2} = \frac{T_c}{2}(1+M\sin\omega_1 t_e) \tag{9}$$

$$\frac{\partial Loss}{\partial a_n} = \frac{\partial \mathrm{L}}{\partial f}\cdot\frac{\partial f}{\partial a_n} + \alpha \tag{10}$$

As shown in Formula (11) and Formula (12), the condensation temperature of cooling can be reduced, and the cooling effect is better than air cooling and cooling tower, and the efficiency of the unit is improved. According to the EPA estimate, designing well-installed water source heat pumps can save 30 to 40% of the operating costs of heating, cooling and air conditioning on average.

$$t_{a2}+t_{b2}+t_{c2}=\frac{3T_c}{2} \tag{11}$$

$$\frac{\partial tag_{dest}^{new}}{\partial a_n}=(1-g_e)\frac{\partial tag_{dest}}{\partial a_n} \tag{12}$$

B. Frequency Conversion and Speed Regulation of Underground Water Source Heat Pump

Underground water source heat pump uses electric energy, electric energy itself is a clean and pollution-free energy, as Formula (13) and Formula (14), does not emit carbon dioxide, do not need coal yard, that is to say, the pollution of the equipment itself is small. The power consumption of the underground water source heat pump unit, compared with the air source heat pump, is reduced by more than 30%, and compared with the electric heating, it is reduced by more than 70%.

$$t_{a1}+t_{b1}+t_{c1}+t_{a3}+t_{b3}+t_{c3}=3T_c-(t_{a2}+t_{b2}+t_{c2})=\frac{3T_c}{2} \tag{13}$$

$$\frac{\partial tag_{dest}^{new}}{\partial a_n}=g_e\frac{\partial tag_{src}}{\partial a_n}+(1-g_e)\frac{\partial tag_{dest}}{\partial a_n} \tag{14}$$

The refrigerant used by underground water source heat pump can be R22, R134A and other alternative working medium, as shown in Formula (15) and Formula (16), can avoid the destruction of the ozone layer by commonly used refrigerant. When the heat pump unit is running.

$$\mathrm{E_g}=4.44\mathrm{f}_1\mathrm{N}_1\mathrm{K_{Nl}}\Phi_\mathrm{m} \tag{15}$$

$$p_{new}=p_{old}-l\cdot\frac{\partial Loss}{\partial p_{old}} \tag{16}$$

As shown in Formula (17). The temperature of groundwater is relatively stable throughout the year, and its fluctuation range is far smaller than the change of air. The constant characteristic of water temperature can ensure the more reliable and stable operation of the heat pump unit, and make the system more economical and more efficient.

$$\mathrm{P_L}=\mathrm{T_L}\mathrm{n_L}/9550=\mathrm{K_P}\mathrm{n_L^3} \tag{17}$$

The heat pump unit is under the stable working condition for a long time, so it can be more convenient to use the computer for automatic control, which can be easy to manage, and at the same time, the stable operation of the system can make its life greatly increased. As shown in Formula (18).

$$S=\frac{Q}{h(T_s-T_a)}=\frac{Q}{50} \tag{18}$$

For the buildings requiring heating and cooling at the same time, underground water source heat pump has great advantages, that is, one machine, reduce the initial investment of equipment, and easy to install, as shown in Formula (19).

$$P=\frac{Q\times 10^{-3}}{\rho C(T_0-T_a)} \tag{19}$$

As shown in Formula (20), due to its high degree of automation, the temperature and the number of hosts can be controlled according to the specific use of the room, and the energy saving effect is very obvious. In addition, geothermal energy is used in the winter, and the operating costs will be further reduced.

$$u(t)=K_p[e(t)+\frac{1}{T_i}\int_0^t e(t)dt+T_d\frac{de(t)}{dt}] \tag{20}$$

III. The Application of Fuzzy Control Technology

A. Fuzzy Controller

Simply increasing or reducing the power supply frequency will also cause changes in other parameters, such as the stator induced electromotive force, magnetic flux, etc., which will have a great impact on the performance of the motor. In the motor speed regulation, often will keep each pole magnetic flux constant as an important goal. In general, if the magnetic flux is weak, it means that the magnetic core of the motor is not wasted; but if the magnetic pass is large, the magnetic flux can be saturated, and a large excitation current will be generated [19, 20]. Fig. 1 is the block diagram of the fuzzy control system, which even increases the iron loss and burns the flow of the motors, so the power consumed by the valve control method is much higher than the frequency conversion speed regulation and control the frequency conversion speed control of the pump, which can greatly save power consumption [21, 22].

The basic principle of traditional differential pressure control in water source heat pump systems revolves around maintaining a constant pressure difference (P) between the two ends of the air conditioning system. This pressure difference is directly related to the impedance of the load-side piping network and the total flow rate of the system. While this approach ensures stable operation under certain conditions, it exhibits several critical shortcomings that limit its effectiveness in real-world applications [23, 24]. This method is based on the operation characteristics of the pump, which can improve the efficiency of the pump and is the most widely used control scheme in engineering. The differential pressure control system is mainly composed of pressure or differential pressure sensor, regulator (PLC or DDC controller), frequency converter, water pump and water supply and return pipe [25, 26]. The basic principle: the pressure difference between the two ends of the air conditioning system is P, the head of the pump is Y, the pressure difference P is related to the impedance of the load side pipe network and the total flow of the pipe network, that is to say, it is only related to the characteristics of the system pipe network, but also shows the defects of the control mode [27, 28]. Mainly reflected in: ignoring the thermal characteristics of the system, there is no involvement in the change of cold and heat load that reflects the user demand; For the system with high dehumidification requirements, it may affect its dehumidification effect; For the normal operation of the whole system, If the pressure difference required for the normal operation of each branch is different, And with the same certain pressure difference value control [29, 30]. However, the selected pressure difference value cannot enable the normal operation of all branches, Fig. 2 shows the relationship between motor power consumption and flow rate, then it is possible to make some users' air conditioning effect become worse or ineffective; For systems with high temperature and humidity requirements, Energy-saving effect is not good. For the ground water source heat pump air conditioning system, the impedance of the external circulation pipe network is relatively stable, which makes it difficult to realize the differential pressure change flow control. If the water temperature changes greatly, then the pressure of the system will also change, which is even more difficult to control, because it is very difficult to choose a Pm control value suitable for the characteristics of the system pipe network.

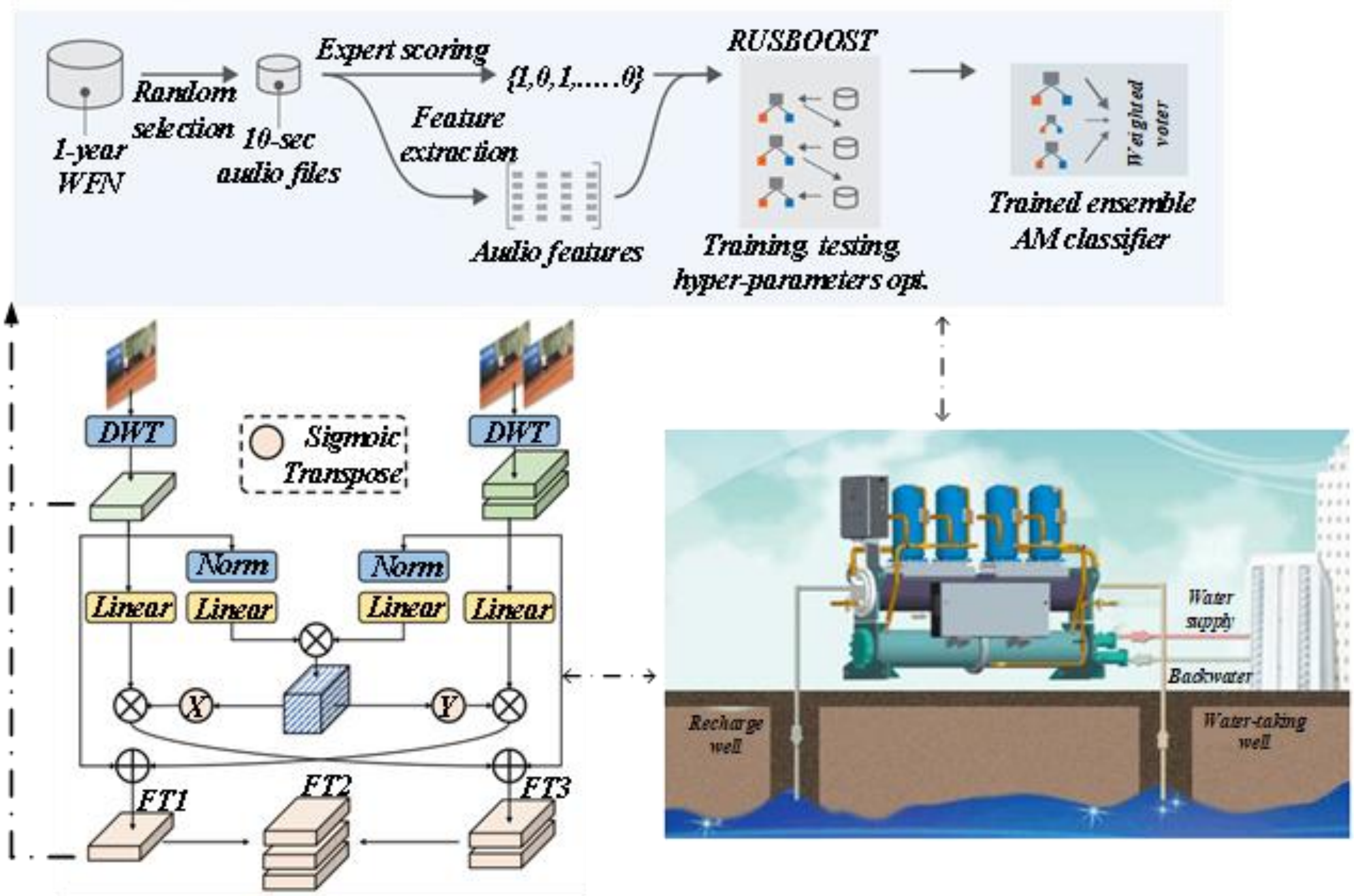

Fig. 1. Block diagram of the fuzzy control system.

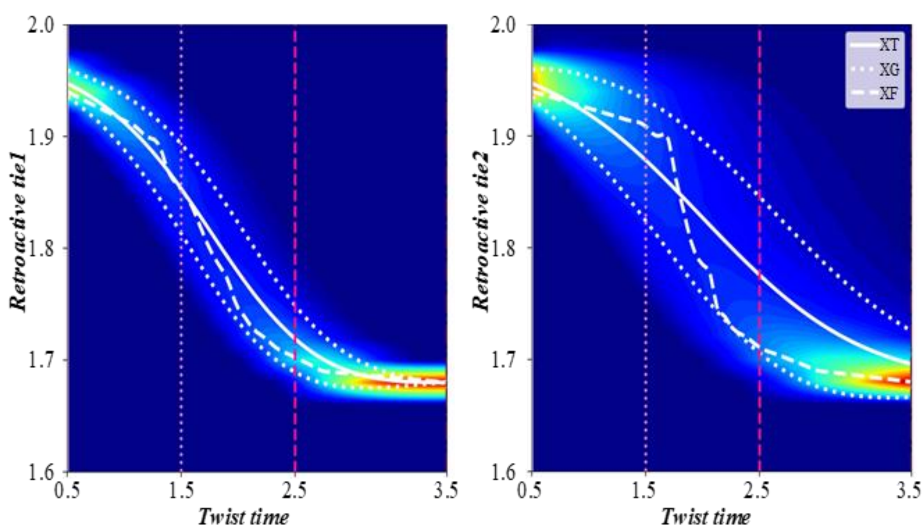

Fig. 2. Relationship between motor power consumption and flow rate.

B. Heat Recovery and Utilization in the Central Air-Conditioning System

Using heat pump technology, input a small amount of electric energy, to obtain more heat energy, in order to heat and cool for users and provide domestic water. The underground water source air conditioning system includes terminal system, power room system, water source system, indoor and outdoor pipe network system and metering system. The fan coil heat exchange system is adopted at the indoor end to realize the control and adjustment of the three-speed switch. The power room is centrally set in the underground power station in the middle of the community. The control strategy focuses solely on maintaining a predefined pressure difference, without considering the dynamic changes in cooling and heating loads that reflect user demand. As a result, the system may fail to respond adequately to fluctuations in thermal load, leading to discomfort for users and inefficient energy use. Second, for systems with high dehumidification requirements, maintaining a constant pressure difference can negatively impact the dehumidification performance. The indoor and outdoor pipe network system uses two different-range variable flow systems, and a self-propelled balance valve is installed on each branch pipe entering the room to ensure the hydraulic balance of the system. Table I shows the relationship between water pump, water quantity and power. The outdoor pipe network adopts four-way partition water supply to solve the adjustment problems under different use time and different loads. The pipe network outside the load side and the water source side is all directly buried with steel pipe. The insulation material of the directly buried pipe is polyurethane hard foam, and the protective shell material is high-density polyethylene outer protective pipe. The indoor pipes of the power station and the end are made of steel pipe, support and hanger installation, rubber and plastic insulation. The system is installed with household metering device, household metering meter is prepaid mechanical heat meter.

TABLE I. RELATIONSHIP BETWEEN WATER PUMP, WATER QUANTITY AND POWER

Frequency	Speed reduction	Water reduction	Power coastdown
45hz	10%	10%	27.1
40hz	20%	20%	48.8
35hz	30%	30%	65.7
30hz	40%	40%	78.4

This project uses the MWH water-water screw type water source heat pump (cold water) unit (C series), it is the world's relatively mature technology, perfect refrigeration unit. Mainly manifested in the following aspects: stable unit operation, high efficiency and energy saving. Groundwater temperature stable heat capacity, good heat transfer performance, so the unit operation is stable, not affected by seasonal temperature changes, operating condition is better than the traditional central air conditioning, and effectively solve the outdoor noise air cooling heat pump and bad operation problems, is high efficiency, energy saving and environmental protection products, its operation cost only traditional way 1 / 3-2 / 3. Using high quality semi-closed double screw compressor, the possibility of shaft seal leakage is zero. Fig. 3 is the schematic diagram of the conventional hybrid fuzzy controller. The shell is optimized and cast, with high accuracy and extremely strong, which effectively reduces the noise of the unit. The imported high efficiency fluorine resistant motor, high efficiency, energy saving, high reliability. Condenser and evaporator are shell tube heat exchanger, using new high efficiency heat exchanger structure, with good heat transfer performance and high reliability. In the case of partial load operation, it can still maintain a very high efficiency, and the operation energy consumption is small. Using the advanced controller, the control system with perfect protection measures is developed, which can monitor the operation state of the unit at any time.

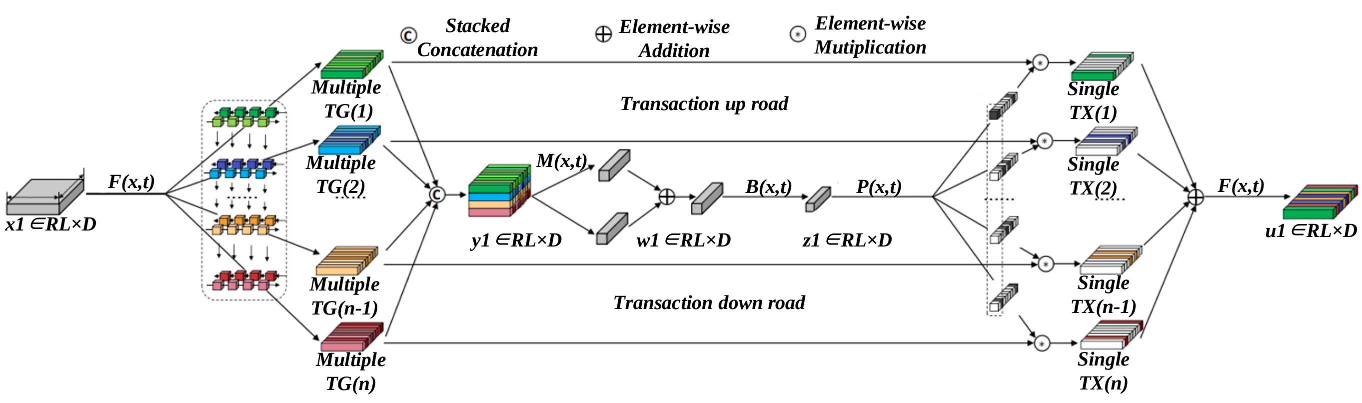

Fig. 3. Schematic diagram of the conventional hybrid fuzzy controller.

This is because the control strategy does not account for variations in humidity levels, which are critical for maintaining indoor air quality and comfort. Third, in systems where different branches require varying pressure differences for optimal operation, a uniform pressure difference control value may compromise the performance of certain branches. This can lead to uneven distribution of cooling or heating, causing some users to experience degraded or even ineffective air conditioning performance. Finally, traditional control strategies often fall short in achieving significant energy savings, particularly in systems with stringent temperature and humidity requirements. The inability to dynamically adjust to changing conditions results in suboptimal energy efficiency and increased operational costs. This is a model modeling method, the model is completely based on the input and output data, ignoring the real composition of the system, therefore, it can also be called "black box modeling". The resulting mathematical model is called either an identification model or an experimental model. The advantage of system identification is that there is no prior information available for use, little understanding of the relevant internal motion mechanism, the modeling is fast, and can create a good environment or noise dynamic characteristics, which is not available by other methods. Therefore, this method is particularly applicable for systems with a complex system mechanism.

IV. Design of Control System of Central Air Conditioner Unit of Water Source Heat Pump based on Fuzzy PID Algorithm

First the known movement mechanism as the basic quantity, and then they according to the experience and the prior knowledge of reasonable combination and as a model input, and then follow certain model selection rules, with some input structure that "optimal" model structure, finally using a series of identification method given model parameters, Table Ⅱ for the central air conditioning system before the gray box model. Gray box modeling is a method based on the physical relationship model of the system structure. This method takes into account the model uncertainty caused by process noise, utilizes the prior physical knowledge of the system, and compared with the mechanism modeling and black box modeling methods, gray box modeling can better grasp the nature of the actual system behavior, so this method is the most widely used in the current modeling.

The input and output data is the basis of identification; the equivalence criterion is the optimization goal of identification; and the model class is the scope of finding the model. Based on the above three elements can be concluded: system identification to experimental design, construct a suitable for the system contains rich frequency component input signal, using experimental input and output data, select a given model class, construct the error criterion function, continuous optimization, find a best fit with the data a model. In addition, because the data used is generally noisy, the model obtained by identification modeling is actually an approximate description equivalent to the characteristics of the actual process. For groundwater source heat pump systems, the impedance of the external circulation piping network is relatively stable, which complicates the implementation of differential pressure-based flow control. When water temperature changes significantly, the system pressure also fluctuates, making it challenging to select an appropriate pressure difference control value (Pm) that aligns with the characteristics of the piping network. This further exacerbates control difficulties and limits the system's adaptability to varying operational conditions. Fig. 4 shows the block diagram of the variable flow fuzzy control system of the central air conditioning system. Different parameter estimation algorithms are selected according to different model types and the complexity of objects. Comparing the actual measurement output with the model output, the model parameters shall ensure the proximity between the two outputs in a selected sense. If not, the hypothesis of the model structure was modified, the experimental design was modified, and the experiment was repeated. Model verification mainly includes two categories: prior knowledge test and data test. For the general person, the model validation mainly uses the method of data testing. Its model is a high-order complex nonlinear system. In actual use, we linearize and adopt the equivalent model to replace it. For the control object used in this paper, there are two main parts: heat pump unit and deep well water system. These two parts can be used for partial modeling to implement the overall model.

TABLE II. Conditions of the Central Air Conditioning System before the Renovation

Order number	Name	Power of motor	Quantity	Installation site
1	Air conditioning cooling pump	90kw	3	-the 4th floor
2	Air conditioning cold warm water pump	55kw	3	-the 4th floor
3	Cooling tower fan	30kw	3	-the 4th floor

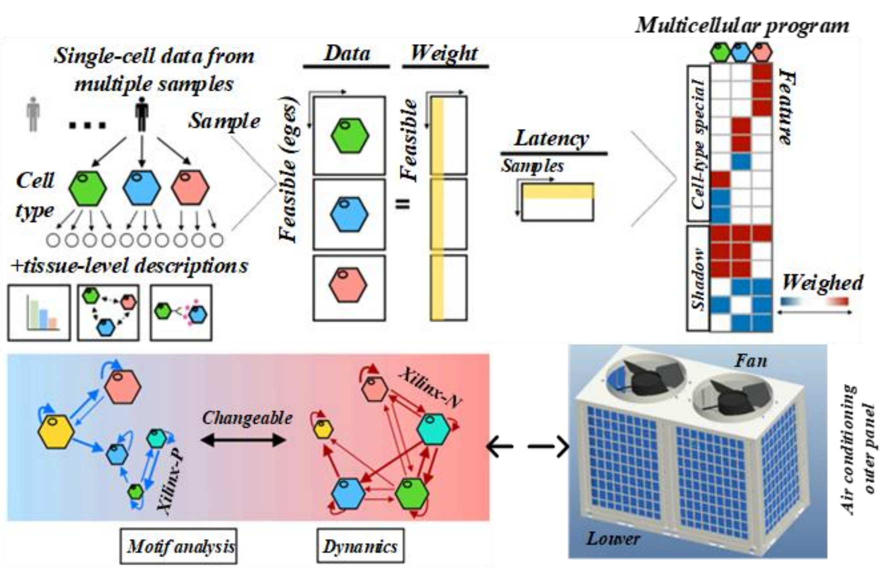

Fig. 4. Block diagram of variable flow fuzzy control system of central air conditioning system.

To address these challenges, the proposed control system leverages a fuzzy PID algorithm, which combines the robustness of fuzzy logic with the precision of PID control. Fuzzy logic is particularly effective in handling nonlinear and uncertain systems, as it can incorporate expert knowledge and heuristic rules to manage complex relationships between system variables. PID control, on the other hand, provides a well-established framework for stabilizing system dynamics through proportional, integral, and derivative actions. By integrating these two approaches, the fuzzy PID algorithm can dynamically adjust control parameters in response to real-time system conditions, thereby enhancing both stability and adaptability. Using the system identification toolbox for modeling can greatly reduce the computational amount and improve the work efficiency, and its graphical interface operation makes the modeling process more intuitive and convenient to apply. In the traditional air conditioning control system, the system return air temperature, humidity and pressure difference are generally taken as the controlled parameters, and the PID control of multiple circuits is used. However, the changes of temperature, humidity and pressure difference are non-linear and lagging, It difficult to make the control effect of conventional PID satisfactory. In addition, the conventional PID parameter setting method is more complicated, and the set parameters are often not better, so that the control effect is not good, and the adaptability to the controlled process is also poor. Fig. 5 shows the block diagram of differential pressure variable flow control. Generally speaking, a group of fixed parameters can only achieve better control effect within a certain range. When the parameters change beyond this range, it needs to be rearranged.

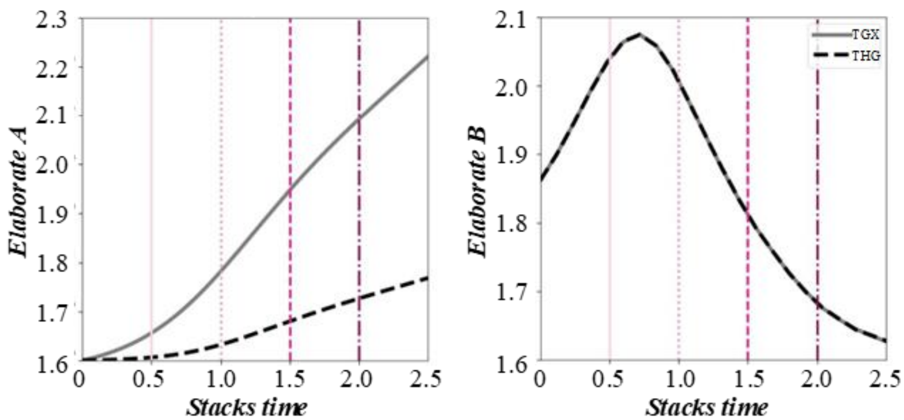

Fig. 5. Block diagram of differential pressure variable flow control.

The output of the control algorithm at each time contains all the previous control amount, that is, the e (k) amount, which is easy to saturation the integral and increase the workload of computer computing. If the computer fails or u (k) changes substantially, it may cause the execution device disorder and failure, and may even cause major production accidents. These disadvantages make the location PID controller very limited in the practical application, which also spawned the incremental PID controller. Control the increment u (k), depending on the sampling value of the nearest k times, so that a better control effect can be obtained by weighting processing. If misoperation occurs, these effects can be eliminated by logical judgment. When switching from manual to automatic, the valve receives little impact, thus achieving undisturbed switching. However, its integral cutoff effect is large, including static error and overflow. The fuzzy PID algorithm operates by first converting the system's input variables (such as pressure difference, flow rate, and temperature) into fuzzy sets through a fuzzification process. These fuzzy sets are then processed using predefined fuzzy rules that capture the system's behavior under various conditions. The output of the fuzzy inference engine is subsequently defuzzified to generate crisp control signals, which are used to adjust the PID parameters in real time. This dynamic adjustment ensures that the control system can respond effectively to changes in load, temperature, and other operational parameters, thereby maintaining optimal performance across a wide range of conditions.

V. Experimental Analyses

It does not need accurate model and can reflect some real situation of the system, so it is applicable to many occasions. The response curve must meet a S curve, Fig. 6 for the cooling water for the summer temperature difference data curve evaluation graph, attenuation curve method is according to the proportion P after integral I last D operation order, get the set parameter set on the regulator, fine tuning, until a satisfactory control performance.

When using the attenuation curve method, it must be noted that for the control system with fast response, it is difficult to distinguish the 4:1 attenuation curve and read out Ts. At this time, the recording pointer can be swung back and forth for two times to achieve stability as a 4:1 attenuation process. In the actual production process, when the load changes greatly, it must be re-adjusted to meet the new control requirements. If the 4:1 attenuation is considered too slow, the 10:1 attenuation process can be used. Fig. 7 shows the evaluation diagram of the frequency change data of the deep well water pump under summer working conditions. The method step is the same as the 4:1 attenuation ratio, but the calculation formula is different. It is worth noting that the critical shock occurs only when the order is at least 3, so the system that can use the critical scaling method should be at least third order.

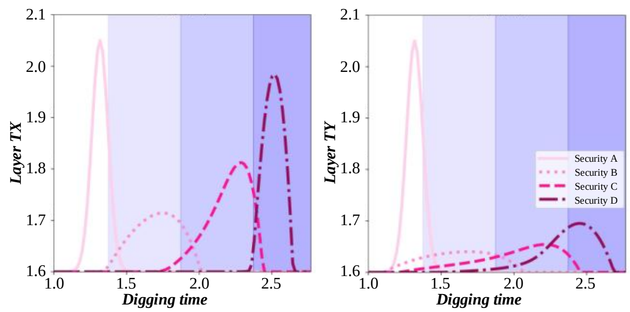

Fig. 6. Data diagram of the temperature difference between water supply and return water of cooling water under summer conditions.

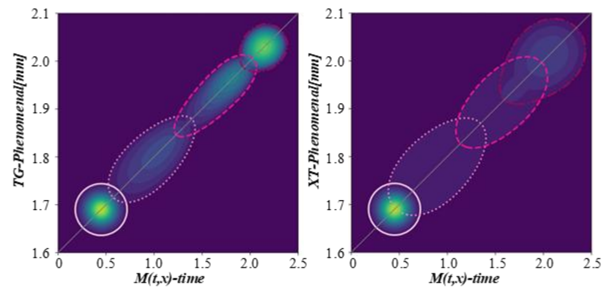

Fig. 7. Evaluation diagram of frequency change data of deep well pump under summer conditions.

These theoretical setting and engineering setting methods are a repeated and complex process. Choose the suitable setting method, grasp the setting law of PID parameters, and constantly adjust it repeatedly until the satisfactory adjustment effect is obtained. Fig. 8 shows the model curve fitting curve evaluation diagram.

During the parameter adjustment, the system model may be due to the health of the parameters and structure changes, and these changes in real-time, dynamic, the three characteristic parameter values of the PID controller are adjusted in real time. Fig. 9 shows the type response curve evaluation diagram to match the changing control environment.

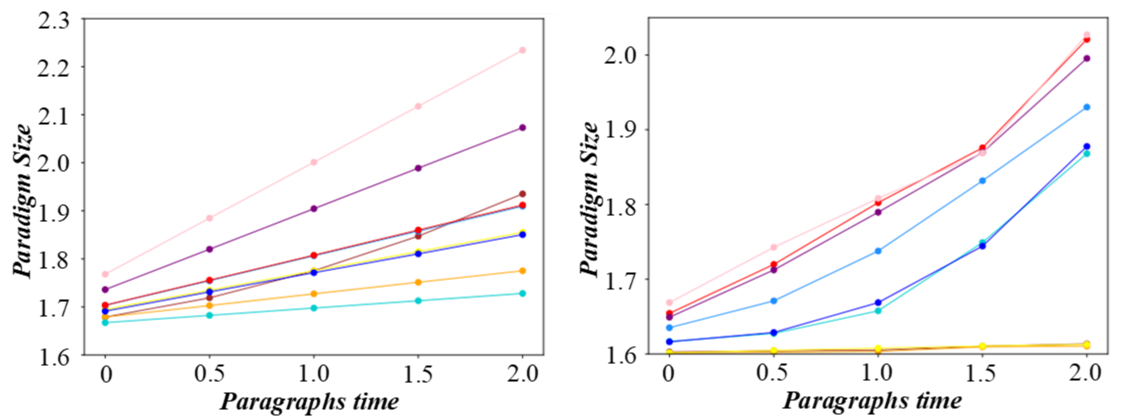

Fig. 8. Model curve fitting curve evaluation.

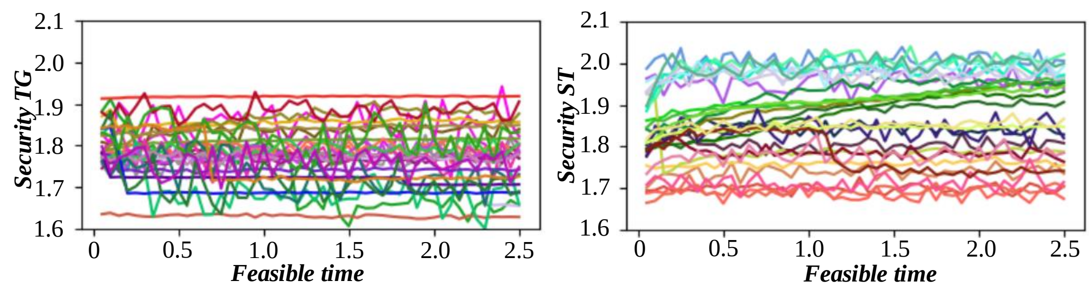

Fig. 9. Type response curve assessment.

It also provides ideas for the setting of PID parameters. Adaptive fuzzy PID control is based on the theory and application of fuzzy mathematics, the PID parameters in the form of fuzzy set, Fig. 10 for the decay curve evaluation diagram, and the initial parameters and PID information as knowledge elements and stored in the knowledge base of the controller.

Fig. 11 is the step response evaluation diagram of the controlled object, so that the system can not only maintain the characteristics of small calculation, strong robustness and strong real-time of conventional PID control, but also fuzzy control makes the system more flexible, more adaptable and more accurate.

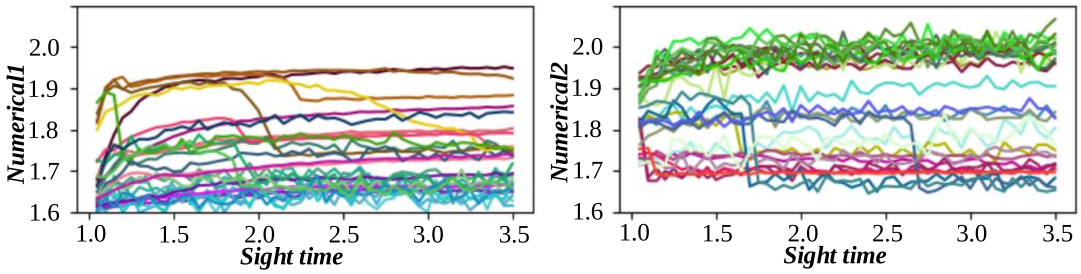

Fig. 10. Attenuation curve assessment.

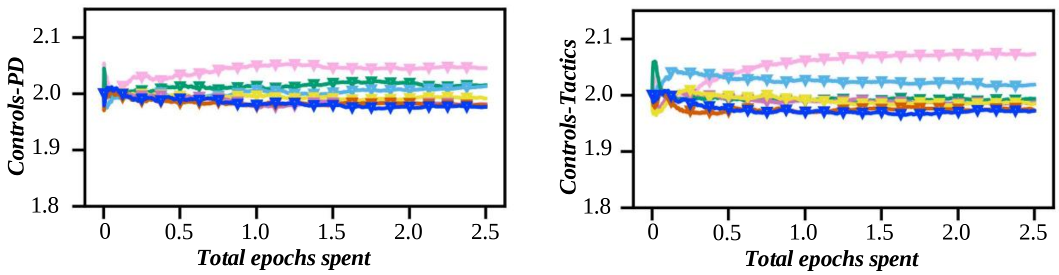

Fig. 11. Step response evaluation diagram of the controlled object.

VI. Conclusion

The paper firstly studies the energy saving mechanism and the application of variable flow control of underground water source heat pump in air conditioning system, and proposes the feasibility of variable flow control of underground complex control object with non-linear, large lag and time-variable characteristics. In the context of water source heat pump systems, the fuzzy PID algorithm is particularly advantageous. The algorithm can account for the thermal characteristics of the system by incorporating temperature-related variables into its control logic. This enables the system to adapt to variations in cooling and heating loads, ensuring that user demand is met efficiently. Additionally, the algorithm can optimize dehumidification performance by adjusting control parameters based on humidity levels, thereby maintaining indoor air quality and comfort. For systems with multiple branches requiring different pressure differences, the fuzzy PID algorithm can dynamically allocate resources to ensure that each branch operates within its optimal range, preventing performance degradation in any part of the system. Furthermore, the algorithm's ability to fine-tune control parameters in response to real-time conditions translates to improved energy efficiency, as the system avoids unnecessary energy consumption while maintaining stable operation.

They have been widely used in control systems because they do not require accurate mathematical models and have PID control of the conventional PID parameters are applied respectively, so that the intelligent algorithm and conventional PID are organically combined to learn from each other. The mathematical model simulation, in dynamic characteristics and steady state performance, the system comprehensive energy saving rate is 33.2%, including: sanitary hot water system 86.42%, including sanitary hot water system 88.9%, air conditioning system power saving rate 67.25%, equivalent to 133,200 kWh, the annual power saving is 553,200 kWh. After the cooling water supply of the central air conditioning system is 15t per day, and the intelligent control energy saving device is put into operation, the cooling water is equivalent to 13.33t daily water saving; that is to say, the cooling water heat discharge of the central air conditioning system is 16101 kJ / h, and the cooling water discharge of the intelligent control energy saving device of the central air conditioning system is 6441 kJ / h, that is, 60%, and the annual heat reduction of 150 days is 3.48107 kJ / h. Table III shows abbreviation name.

TABLE III. Abbreviation Name

PID	Proportion Integration Differentiation
HVAC	Heating, Ventilation and Air Conditioning
EPA	Environmental Protection Agency
R22	Dichlorodifluoromethane
R134A	1,1,1,2 - Tetrafluoroethane
PLC	Programmable Logic Controller
DDC	Direct Digital Controller
ARX	AutoRegressive with eXogenous inputs
ARMAX	AutoRegressive Moving Average with eXogenous inputs
BJ	Box - Jenkins

A. Related Work and Discussion

With the continuous increase in building energy consumption, the research on energy - saving control of central air - conditioning systems, a major part of building energy consumption, has drawn significant attention. Many scholars and research teams have conducted in - depth explorations from various perspectives, providing important references for this study. Some research focuses on the application of ground - source heat pump technology in central air - conditioning systems. In "Replacement Scenarios of LPG Boilers with Air - to - Water Heat Pumps for a Production Manufacturing Site", Carella et al. studied the replacement scenarios of LPG boilers with air - to - water heat pumps in production manufacturing sites, exploring their application potential and confirming the advantages of heat pump technology in improving energy efficiency. This is consistent with the research direction of this paper, which uses underground water - source heat pumps for building cooling and heating, providing a basis for the feasibility of the technology application.

In the aspect of system modeling and simulation, MATLAB is widely used. Some studies utilize MATLAB tools for system model establishment and analysis, which corresponds to the use of MATLAB Identification toolbox for system identification and modeling in this paper, indicating the universality and effectiveness of this method in relevant research. However, existing research still has some limitations. Traditional control strategies, such as simple PID control, struggle to cope with the non - linear, large - lag, and time - varying characteristics of central air - conditioning systems, resulting in unsatisfactory control effects and significant energy waste. In system optimization, some studies do not fully consider the characteristics of the system pipe network, the real - time nature of load changes, and the collaborative work among components, affecting the system's operational stability and energy - saving effect.

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