Design of Building Heating System Based on Distributed Variable Frequency Pump

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Abstract: With the continuous development and progress of society, people's requirements for living conditions have gradually changed. They begin to pursue the comfort and personalization of the living environment, while also pay more and more attention to the problems of energy and environment. In order to build a suitable living environment, the implementation of central heating is bound to consume all kinds of resources. In the heating process, the efficient use and effective saving of energy has become an important measure for the heating industry to achieve the coordinated development of energy and environment. Taking the central heating as the research object and the secondary side distributed variable frequency pump heating transmission and distribution system as the goal, this paper studies the energy saving of the distributed variable frequency pump heating transmission and distribution system. This paper provides a design method of distributed variable frequency pump heating transmission and distribution system, in order to provide some basis for the design of distributed variable frequency pump heating transmission and distribution system in the future, and solve the problem of high energy consumption in the traditional central heating transmission and distribution system.

1. Introduction

Central heating refers to the use of centralized heat sources to generate hot water or steam and other heat medium, heat medium pass through the heat pipe network to transfer heat to residents or other areas that need heat. In recent years, the living standards of urban residents are constantly improving, and the environmental requirements for living, learning and working have also increased continuously. At the same time, the state vigorously advocates the construction of a resource-saving society, and people's awareness of environmental protection is also constantly improving. At the same time, with rising pursuit of high-end comfortable living environment, more and more attention is paid to energy and environmental issues, efficient use of energy in the heating process, effective saving has become an important measure for the heating industry to achieve the coordinated development of energy and environment[1].

In order to solve the current heating problems, relevant experts put forward the development of distributed variable frequency pump heating transmission and distribution system. However, there are some different views on how to implement the distributed variable frequency pump heating transmission and
distribution system. Some scholars believe that if we try to explore the installation location and selection of pumps in the heating system, the benefits will be huge, and the power consumption may be reduced by 60% ~ 70%. Some scholars believe that the structure of distributed heating system is complex, it is difficult to implement in practical engineering, and the energy-saving effect is not particularly efficient. In view of the above content, the energy saving of distributed variable frequency pump heating transmission and distribution system is worthy of further study [2].

With the development of frequency conversion technology, the progress of water pump industry has driven the development of distributed heating transmission and distribution system. Rishel [3] proposed that through the use of frequency conversion technology, the water pump can adjust the speed at any time to adjust the flow of the pipe network, so as to reduce the operation energy consumption. At the same time, it can meet the time-varying flow water supply of different pipe diameters, and realize the design of heating pipe diameter according to the most economic specific friction. Professor Green [4] studied the variable frequency speed regulating pump instead of throttle valve, and concluded that the flow regulation effect of variable frequency pump is better than throttle valve, and the system energy consumption is reduced, and the system stability is improved. Lingireddy. S. and Wood D J. [5] through the actual case, the frequency conversion pump is used to replace the traditional power frequency pump to reduce the system energy consumption and investment cost, so that the application of frequency conversion pump in heating system has been widely concerned.

For a heating transmission and distribution system, energy saving is mainly reflected in two aspects: one is to reduce the generation of invalid heat supply, that is, to reduce the heat loss caused by boiler, external network and uneven heating; The second is to reduce the power consumption in the process of transmission and distribution. Among them, the invalid heat loss caused by the imbalance of heating system and the invalid power consumption in the transmission process are directly related to the unreasonable layout of circulating water pumps. According to statistics, the invalid heat loss caused by the uneven heat and cold of the heating transmission and distribution system can account for 30% ~ 40% of the total heat supply of the heating transmission and distribution system, and the invalid power consumption of the transmission and distribution network during the operation of the heating transmission and distribution system accounts for about 30% ~ 60%. Combined with the current national energy saving and emission reduction initiative, the traditional heating transmission and distribution mode gradually shows disadvantages in energy saving, which can not meet the current heating demand. Some scholars put forward the implementation of efficient and energy-saving distributed variable frequency pump heating transmission and distribution system [6].

Aiming at the problems of high energy consumption and large hydraulic imbalance caused by setting main circulating pump in traditional CCHP system, a CCHP system based on distributed frequency conversion is proposed. Through the cooperation of heat (cold) source pump and user pump, combined with the designed frequency conversion control strategy, the operation economy and energy saving of the designed system are improved, and the hydraulic imbalance degree is reduced. The research in this paper will contribute to the construction of CCHP system with low operation cost, low energy consumption, small hydraulic imbalance and high operation reliability, which is of certain significance to the engineering construction and application of CCHP.

2. Distributed Variable Frequency Pump Heating Transmission and Distribution System

2.1. Application of Trangen Theorem

The Trangen Theorem was proposed by B.H. Trangen in 1952, which is used to prove the reciprocity theorem and complex power balance theorem in the circuit. The current in the circuit can be regarded as fluid, and the heating transmission and distribution system is a kind of fluid network, and its topological
structure is consistent with the basic law of the electric network, so the Trangen Theorem can also be applied to the heating transmission and distribution system [7].

In the physical formula, the electric power is obtained by multiplying the voltage drop VbK in the branch and the current IBK in the branch. Therefore, the Trangen Theorem can be expressed as: in any given electric network with concentrated parameters, the sum of the electric power of the branch is zero. That is to say, the electric power provided by the active components in the electric network is completely absorbed by the passive components in the electric network. It can be understood that the electric power provided by the power supply is completely consumed in each branch.

Trangen's theorem is summarized as follows:

If there are n + 1 nodes and B branches in a lumped parameter network, both of them are given directional quantities, which can be expressed by the formula:

\[ \sum V_k I_k = 0 \] (1)

\[ \sum V_k I_k = 0 \] (2)

Trangen's theorem has been proved by strict mathematical formula, and detailed reasoning is not done here.

In the heat supply transmission and distribution system, the power consumed by a section of pipe is the product of the flow and pressure drop of the pipe section. According to the Trangen Theorem, the electric power of circulating water pump at each position in the heat supply transmission and distribution system is used to overcome the resistance in the pipe, and the two are equal in value without additional consumption. The establishment of this law has nothing to do with the number of pumps in the system, the installation position of pumps and the number of pipe sections.

\[ P_0 = \sum G \Delta H \] (3)

\[ P = \frac{P_0}{366 \eta} \] (4)

Among which: P0 is the pump power calculated by the Trangen Theorem, kW; G is the pipe flow, t/h; \( \Delta H \) is the pressure drop of pipe section,; P is the actual power of the pump, kW; \( \eta \) is the efficiency of the pump; 366 is the conversion coefficient [8].

The traditional central heating transmission and distribution system is designed according to the most unfavorable loop resistance, so there will be a maximum circulation flow in the system, which should meet the heating demand of the whole system loop from the nearest heat source to the most remote users.

According to the Trangen Theorem, if the power provided by the pump is greater than or equal to the power required by the pipeline, the pipeline can be adjusted; if the power provided by the water pump is less than the power required by the pipeline, the pipeline can not be adjusted. The maximum circulating flow should be distributed to each pipeline according to the actual demand to achieve the above requirements. However, in the traditional central heating transmission and distribution system, the excess pressure of the
near end users should be consumed through the throttling device, so the power must reach a certain value when the power is set. Only in this way can the power provided by the water pump be greater than the sum of the power required by the pipeline and the power consumed by the throttling device, so as to realize the purpose of adjustable pipeline [9]

2.2. Application of Pump Frequency Conversion Technology
Frequency conversion technology of water pump refers to the combination of frequency converter and power frequency pump or frequency conversion pump to regulate the rotation of motor through frequency converter. When the driving motor is power frequency motor, frequency conversion water pump can only operate in non power frequency state for a short time, otherwise the motor will be burned; if the driving motor is a variable-frequency motor, the frequency converter can adjust the motor at any time to realize variable-speed operation. The principle of water pump variable-frequency speed regulation is based on the frequency converter changing the power supply frequency of the motor. The motor rotor speed is adjusted through the change of power supply frequency, and then the water pump speed is changed to realize flow regulation [10]

\[ n = \frac{60(1-S)f}{p} \]  \hspace{1cm} (5)

In equation 5, \( n \) is the motor speed, r/min; \( f \) is AC frequency, Hz; \( p \) is the number of poles of the motor; \( s \) is the motor slip rate,\%.

According to the above formula, to change the motor speed, three parameters can be changed, namely alternating current frequency, motor magnetic logarithm and motor slip rate. However, in practical application, the change of motor magnetic logarithm is difficult to achieve, and the change of motor slip rate will increase the loss of rotation difference, and the adjustment range of the above two speed regulation modes is small and the efficiency is low. Therefore, variable current frequency speed regulation is generally adopted in the current project. Through the above formula, it is known that the motor speed \( n \) is proportional to the current frequency \( f \). When the motor drives the pump to work, changing the current frequency can quickly, efficiently and accurately realize the adjustment of the motor speed, thus regulating the water pump flow. There are many external environmental factors in the heating transmission and distribution system. When the system adjusts the flow rate, the flow in the pipe needs to be adjusted in real time according to the change of external environment temperature. With the support of frequency conversion technology, the heating transmission and distribution system can predict and control the load of the heating transmission and distribution system in advance through the design of temperature controller to realize accurate automatic control.

3. The Structure of the Heating Transmission and Distribution System of 3 Distributed Variable Frequency Pump
The distributed variable frequency pump heating transmission and distribution system is improved on the basis of the original traditional centralized heating transmission and distribution system, and the structure of the two is similar. The difference is that according to the Trangen Theorem, the variable frequency circulating pump is set at the end of the pipe network of the heating transmission and distribution system. The resistance in each pipe section can be overcome by the segmented pump drive medium, so as to achieve the heat on demand and ensure that the heat is evenly distributed and there is no energy loss caused by throttling. The distributed frequency conversion heating transmission and distribution system is to separate the heat source pump, external network pressure pump and hot user pump in the system, and the power step is transmitted to the heating network. The transmission and distribution is conducted on demand, and the push in the transmission system becomes the form of on-demand pumping.
Different from the traditional central heating system in structure, the distributed variable-frequency pump heat supply transmission and distribution system divides the resistance in the system by sections. According to the types of water pumps divided in the above contents, the variable-frequency pump is arranged at the heat source, the heat supply network pipeline and the heat user's place to overcome the flow resistance in the heat source, along the heat supply network and the heat user's equipment, the specific structure is shown in Figure 1

![Figure 1 Structure of distributed variable frequency pump heating transmission and distribution system](image)

When the distributed variable frequency pump heating transmission and distribution system works, the pipeline resistance to be overcome is the same as that of the traditional central heating transmission and distribution system. The main difference is that the distribution of pipeline resistance is different, and the installed power of motor is different either. When the latter is connected, the plate heat exchanger is generally used to complete the heat exchange. If there is a mixing pump in the indirect connection system, the system is also called the mixing system.

Different types of distributed variable frequency pump heating transmission and distribution system should be combined with the actual installation conditions when selecting the installation location of the water pump. Generally, the hot user circulating pump and heat supply network circulating pump are installed on the return pipe, the major concern is the low temperature of the return pipe and the better working environment of the water pump, which can relatively prolong the service life. The mixing pump is generally installed on the water supply pipe, which can ensure the full mixing.

4. Design of Distributed Variable Frequency Pump Heating Transmission and Distribution System

The distributed variable frequency pump heating transmission and distribution system is developed on the basis of the traditional central heating transmission and distribution system, but there are differences in the design steps between the two systems. In this part, the design differences between the traditional central heating transmission and distribution system and the distributed variable frequency pump heating transmission and distribution system will be compared, and the design steps of the distributed variable frequency pump heating transmission and distribution system will be introduced in detail.

Similar to the traditional central heating transmission and distribution system, the distributed variable frequency pump heating transmission and distribution system should first calculate the heating load to get the heating capacity. The calculation of pipe resistance and pipe diameter are also the same. The difference is that the distributed variable frequency pump heating transmission and distribution system should first select zero pressure. In terms of power configuration, the distributed variable frequency pump heating transmission and distribution system adopts the form of separate pumps, which directly determines the difference between the hydraulic calculation method, hydraulic balance method and pump selection and the traditional central heating transmission and distribution system, and the control mode.

Zero pressure difference is a special position in the distributed variable frequency pump heating
transmission and distribution system, where the pressure difference of supply and return water is zero. When designing the distributed variable frequency pump heating transmission and distribution system, the water pressure diagram of the heating transmission and distribution system should be drawn according to the hydraulic calculation, as shown in Figure 2.

![Water pressure diagram of distributed frequency conversion pump](image)

Figure 2 Water pressure diagram of distributed frequency conversion pump

Zero pressure difference can be accurately found on the water pressure diagram. The position of zero pressure difference is not the only constant point on the pipeline of heating transmission and distribution system. According to the configuration of power equipment, the position of zero pressure difference is constantly changing.

Affected by various objective factors, it is difficult to accurately find the location of zero pressure difference in actual engineering. In order to meet the needs of system work, the determination of zero pressure difference is generally reasonably selected within a certain range of the pipeline according to the site conditions, and it is usually set at the outlet of the heat source with the best economy.

5. Comparative Analysis of Simulation Experiment

5.1. Simulation Environment Settings

Considering the influence of energy conversion in throttling process on operation input, the operation cost of traditional central heating calculated based on the theory of fluid mechanics is higher than the actual operation cost, and there will be errors when comparing the energy saving performance of traditional central heating transmission and distribution system and distributed variable frequency pump central heating transmission and distribution system. The energy saving potential of distributed variable frequency pump heating transmission and distribution system is exaggerated. When calculating the operation input of the traditional central heating transmission and distribution system in this case, the operation cost is calculated based on the theory of fluid mechanics and thermodynamics respectively. It is verified that the pressure energy lost in the throttling process is converted into heat energy, which can reduce the operation input of the heating transmission and distribution system, and obtain the real energy consumption when using the central heating transmission and distribution system. The specific data are shown in Table 1.

| Calculation basis                  | Based on fluid mechanics | Based on thermodynamics |
|-----------------------------------|-------------------------|-------------------------|
| Thermal energy consumption (GJ)   | 1058765                 | 1055863                 |
| Electric energy consumption (kWh) | 172547.9                | 172547.9                |
| Thermal expenses ($10^3$)         | 364.5                   | 363.5                   |
Electricity consumption ($10^7$) & 12.55 & 12.55 \\
Operating investment per unit area ($) & 20.57 & 21.03 \\
Total operating cost ($10^7$) & 347.55 & 348.52 \\

When the operation of the central heating transmission and distribution system is calculated on the basis of thermodynamics, the power consumption of transmission and distribution is the same as that of hydrodynamics. However, considering that the invalid power consumption in the throttling process is converted into internal energy and reused by the heating transmission and distribution system, the thermal energy consumption can be reduced by 222.65GJ in a heating period, the operation investment can be reduced by 7570 RMB yuan, and the heating operation cost per unit area can be reduced by 0.04 yuan.

Based on the calculation data, the connotation of throttling loss of heating transmission and distribution system can be further elaborated as follows: in the operation process of traditional central heating transmission and distribution system, various valves are installed on the pipeline to realize the change of pipeline resistance to achieve the purpose of flow control, which increases the energy consumption of circulating water pump. However, in the throttling process, the medium pressure energy will be converted into heat energy, which will be absorbed and utilized by the heating medium again. Therefore, as far as the heating transmission and distribution system is concerned, the electric energy consumed in the throttling process is not invalid energy consumption, but the process of transforming high-quality energy into low-quality energy.

5.2. Comparative Analysis of Simulation System Operation

On the basis of the existing pipeline of the heat exchange station, the project case is transformed according to the design of the distributed variable frequency pump heating transmission and distribution system, the operation input required to complete the heating task under the set requirements is calculated, and the energy saving of the distributed variable frequency pump heating transmission and distribution system is obtained through comparative analysis.

The operation input calculation of the distributed variable frequency pump heating transmission and distribution system is the same as that of the traditional central heating transmission and distribution system. The operation input calculation of the distributed variable frequency pump heating transmission and distribution system also includes two parts: the heat cost to meet the needs of heat users and the power consumption cost to transport heating medium to complete the pipeline circulation.

5.2.1. Heat Cost Calculation

The distributed variable frequency pump heating transmission and distribution system can adjust the pump speed according to the outdoor temperature, and realize variable flow to adjust the heating temperature. The heating load is also related to the outdoor temperature, that is, the actual heating load is calculated according to the indoor and outdoor temperature difference, and then the total heat consumption of the heating transmission and distribution system is obtained. The calculation process is the same as that of the central heating transmission and distribution system.

The total heat consumption of a heating season is: \( Q = 104582 \text{GJ} \); The total heat cost is: \( Y = 364.5 \text{Y} \).

5.2.2. Calculation of Power Consumption Cost

The power consumption of distributed variable frequency heating transmission and distribution system mainly comes from the heat source circulating pump and the circulating pump at the hot user. According to the outdoor temperature, the frequency of the pump is adjusted by the frequency converter to achieve on-demand heating. The calculated outdoor temperature of each month is less than the design outdoor temperature, the actual heat load becomes smaller, and the circulating water pump operates below the rated
power under the regulation of frequency converter. Assuming that the efficiency of water pump after frequency conversion is reduced by 10%, the parameters of water pump after frequency conversion can be obtained as shown in Table 2.

Table 2 Statistics of pump operating parameters

| User location | Heat source pump | User 1 | User 2 | User 3 | User 4 |
|---------------|------------------|-------|-------|-------|-------|
| Trunk resistance(mH2O) | 0 | 0.45 | 0.47 | 0.46 | 0.42 |
| Branch resistance(mH2O) | 0 | 0.57 | 0.56 | 0.67 | 0.72 |
| User pressure(mH2O) | 0 | 9 | 9 | 9 | 9 |
| Required head(mH2O) | 7 | 10.47 | 10.54 | 10.88 | 10.21 |
| Actual flow (t/h) | 457.75 | 27.76 | 27.62 | 28.02 | 27.66 |
| Actual power of water pump (kW.h) | 11.75 | 0.92 | 1.01 | 1.05 | 0.98 |

5.2.3. Economic Benefit Analysis

The operation input of traditional central heating transmission and distribution system and distributed variable frequency pump heating transmission and distribution system in a heating period is compared, and the specific data is shown in Table 3.

Table 3 Comparison of operation input of heating transmission and distribution system

| Operation mode | Traditional system | Distributed system |
|----------------|--------------------|--------------------|
| Thermal expenses($10^3) | 357.5 | 360.1 |
| Electricity consumption($10^3) | 13.55 | 9.57 |
| Operating investment per unit area($) | 20.48 | 20.23 |
| Total operation investment($10^3) | 391.53 | 389.9 |

Combined with the data comparison, the operation input comparison of the traditional central heating transmission and distribution system and the distributed variable frequency pump heating transmission and distribution system in one heating period is drawn, as shown in Figure 3.

Figure 3 Comparison of heating system investment

By separating the water pump, it can effectively make the total head of circulating water pump close to
the total loss of pipeline resistance by overcoming the pipeline resistance in a staged manner, so as to reduce the total power of the pump and improve the energy saving of the transmission and distribution process.

6. Conclusion

In this paper, the design process and energy conversion in the throttling process of the traditional central heating transmission and distribution system are studied. This paper analyzes the design steps of distributed variable frequency pump heating transmission and distribution system, and analyzes the factors affecting its energy saving in detail. Through the experimental analysis, it is verified that the research content of this paper can reduce the power consumption, reduce the emission of sulfur dioxide, flue gas and other air pollutants, and achieve environmental protection.

In the next step, it is mainly about the initial investment and specific implementation scheme of the distributed variable frequency pump heating transmission and distribution system, as well as the research on the management and maintenance of each circulating water pump in the actual project.

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