Development Status of Dynamic Distributed Transmission and Distribution System in Chinese

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Abstract

This paper reviews the studies on dynamic distributed transmission and distribution system and traditional heating distribution system in aspects of mathematical model, structure of pipe network, hydraulic stability of the dynamic distributed system and regulation and control strategy; comparatively analyses the characteristics and difference between each kind of system and summaries the progress and deficiency of existing researches. It is remarkable that pumps should be equipped with various frequency devices to achieve the optimal energy saving effects and regulating efficiency. Many achievements have been realized in each aspect, but there are still disadvantages in the dynamic distributed heating system. All the deficiencies will be the research directions about the dynamic distributed heating system in the future.

Keywords: Dynamic distributed transmission and distribution system, Mathematical model, Structure of pipe network, Hydraulic stability, Regulation and control strategy

1. Introduction

According to the traditional design methods in the district heating systems, pumps located close to the heat sources offer energy to overcome the flow resistance of water circulating in the whole networks. In order to meet
heating load requirements, the selection of the pumps is based on the total pressure drop in the most unfavorable loop in the heating systems. Branches near the heat sources always use valves to keep the hydraulic balance [1]. With the development of the heating technology more and more mature, the district heating area is larger and larger. With the head of the circulating pumps increasing, the pressure head taken by valves in the branches close to the heat sources is bigger, which is not good for energy savings. The heat load in the most moments in the heating season is lower than that under the design conditions. Most of the running system under the conditions with the existence of "little load with great power", thus under the traditional network form of the heating system, it not only wastes useful work of water pumps, but also affects the working efficiency of the heating system.

With the development of the water pump frequency conversion technology entering the mature stage, applying variable frequency pumps instead of the regulating valves in the dynamic distributed heating system not only has important significance for energy saving, also plays an important role in the operation of the heating system network adjustment.

Researches have been achieved in the renovation of traditional networks for energy saving in foreign countries [2]. In the early 1950s Gil Carlson put forward a new theory in the primary - secondary system which divides the whole big system into several small and relatively independent ones to solve the traffic problems. Somchai Parporn put forward the idea of applying variable frequency pumps instead of the regulators in the end of the heating system with analyzing the energy loss of traditional systems with throttle valves and the energy saving effect in the new system [1].

It was until the 90s that the dynamic distributed heating systems were introduced into Chinese. The prototype of the dynamic distributed heating systems was to apply pumps in return pipes when the traditional heating system network is transformed to solve the effect of insufficient flow rate at the users. With the understanding of malpractice of traditional network design, Yi Jiang and Hongfa Di [10] put forward the idea of the dynamic distributed heating system with variable frequency pumps with using variable speed pumps instead of the regulating valves in the late 90s. Then many researchers studied and certificated all respects of the dynamic distributed heating system. This paper mainly analysis the current status and the relative findings in the dynamic distributed heating systems with the mathematical models, the development of network form, the hydraulic stability, the mixed water systems, the effect of energy saving, the application and control strategies on operation adjustment.

2. Mathematical Model

Rongjian Shi [4] and other researchers put forward the mathematical models of the dynamic distributed heating system based on the basic mathematical model of heating pipe network. A distributed power system network count for B, the number of nodes is \(N+1\) and \(Q\) is the flow of the distributed power system to meet the following matrix equations:

\[
\begin{align*}
AG &= 0 \\
B \Delta H &= 0 \\
\Delta H &= S \cdot |G| \cdot G + Z - DH
\end{align*}
\]

Where \(\Delta H\) is the column vector of pressure drop of two nodes in the branches. \(S\) is the diagonal matrix. \(S_j\) is the resistance characteristic coefficient of each section. \(|G|\) is the absolute value of flow in each branch. \(Z\) is the column vector. \(DH\) is the column vector. When the pumps are not in the branches, \(DH=0\). The method to solve the model is MKP with fast convergence speed and high precision.
3. Forms of networks

There are 3 basic forms of the dynamic heating systems [5]. The first one is as followed. The circulation pumps located close to the heat sources bear the internal pressure drop and the users' head in each branch. The pumps in the main pipes in the system bear the pressure drop in pipe sections.

![Fig. 1. Distribution of pumps and water pressure in the dynamic distributed heating system](image1)

The second form is as followed. The circulating pumps located close to the heat sources bear the internal pressure drop. The pumps in the main pipes in the system bear the pressure drop in pipe sections. The circulating pumps located close to terminals bear the pressure drop in each branch.

![Fig. 2. Distribution of pumps and water pressure in the dynamic distributed heating system](image2)
The third form is as followed. The circulation pumps located close to the terminals bear the pressure drop of internal. The pumps in the branches in the system bear the pressure drop in pipe sections and in the heat users'. The circulating pumps located close to heat sources bear the pressure drop in the internal.

![Distribution of pumps and water pressure in the dynamic distributed heating system](image)

**Fig. 3. Distribution of pumps and water pressure in the dynamic distributed heating system**

### 4. Energy saving analysis

The traditional heating systems consume extra pressure head through the regulator to adjust the hydraulic balance in all loops. While the dynamic distributed heating systems reduce the power input to keep hydraulic balance. Therefore power consumption in the dynamic distributed heating system is greatly reduced especially under the off-design operations. The effect of energy saving in the dynamic distributed heating systems is remarkable.

The main factors for energy saving to determine whether the distributed variable frequency pumps are the selection of pressure difference control points and back pressure of the system. When the pressure difference control points in the central heat supply network is near the heat source, the energy consumption of the system is the lowest. The effect of energy saving decreases while back pressure of the system increases. The effect of the frequency conversion adjustment is greatest in the heating systems without back pressure. When the back pressure in the system increases to a certain degree, the energy consumption of the distributed variable frequency pumps will be greater than that of pumps in the system with throttling valves [6].

The parallel running with multi-pumps with variable speed regulation can save energy consumption and all pumps adopt the variable speed can work best. In the system parallel running with a constant speed pump and a variable speed pump, the efficiency of the two pumps reduce although more energy-saving than that parallel running with two constant speed pumps [10]. Especially when the flow is too small, the speed of variable frequency pumps is low. Two variable frequency pumps parallelly run in the system. When the flow changes, the speed of the two pumps adjusts at the same time to ensure the pumps always running in high intervals. Continuous adjustment is more smooth and safe.

Nan Xu and Shugang Wang [7] get several conclusions by analyzing all possible forms of the dynamic distributed heating networks with 6 branches. When the main circulating pumps locate close to the heat sources and pumps are in each of the rest of the branches in addition to the branch closest to the heat source, the installed power of the system is the minimum. Tangshan thermal company reform the Long Dong heating system to the dynamic
distributed heating system. The effect of energy saving in the new system is remarkable with its energy saving rate about 23%.

To reduce energy consumption to the greatest degree, Peng Wang [9] put forward the concept of the required power in dendritic network with single heat source, which is defined as the minimum power of the heat medium transmission system. The article also qualitatively analyzed the possibility to realize the minimum power in the dynamic distributed heating system with zero pressure almost located in the outlet of the heat source.

\[
N_{\text{min}} = \frac{2.78}{\phi} \left( \sum_{i=1}^{m} G_{ui} H_{ui} + 2 \sum_{j=1}^{b} h_{pj} + G_{pj} + \sum_{i=1}^{m} G_{ui} + H_{ui} \right)
\]  

(3)

Where \( N_{\text{min}} \) is the demand of the power in the heating system, \( W \). \( G_{pj} \) is the design flow of the No.\( j \) section, \( t/h \), \( j = 1, \ldots, b \). \( G_{ui} \) is the design flow of the number \( i \) users, \( t/h \), \( i = 1, \ldots, m \). \( H_{ui} \) is design head of the number \( i \) users, \( t/h \), \( i = 1, \ldots, m \). And \( m, b \) respectively represent for total heat users and pipe sections in the heating system.

Previous studies show that energy saving rate is affected by the structure and parameters of the dynamic distributed heating system. The problems should be specifically analyzed and the key factors for high energy saving rate in the heating system is as followed:

1. The users' are more and closer to the heat source;
2. Heat sources are near the distal trunk in the system. And the scale is small or the design head of pumps in branches near heat sources is lower;
3. The specific frictional resistance of the dendritic network is greater.

It is easy to know that the installed power in the dynamic distributed heating systems is much lower than that in the traditional network system. The effect of energy saving in the dynamic distributed heating systems is much more remarkable than that in the traditional network system under the operation condition. It is worth noting that variable frequency pumps should be applied in the dynamic distributed heating systems, only in this way the best effect of energy saving and the best regulation can be achieved.

**Hydraulic balancing**

With the structures of the heating networks more and more complex, the stability of the systems directly affects the heating quality of the users. Therefore the hydraulic balance in the district heating networks has been thoroughly studied in various countries and areas [8]. In the 1960s, the Soviet Union began to use the computer to study the hydraulic calculation in the heating systems. By the early 70s, many European countries built hydraulic calculation models of the heating system network. In some countries, the optimization design, the calculation of the initial investment and running costs are been done with computers. The study of the hydraulic balance in the district heating networks is relatively late in Chinese, but a lot of great progresses have been made in recent years.

The definition of \( K_s \) is introduced for more accurate analysis of hydraulic stability in the heating system [10]. All the hydraulic parameters in the control loop can be divided into two sets: \( D \) and \( F \). \( D \) is the circuit for analysis and \( F \) is a collection of all the other control circuits.

\[
K_s(D,F) = -\frac{\Delta G'_{DF}}{\Delta G_{DF}}
\]  

(4)

Based on the researches of characteristics of the circulating pumps and the location of the zero point, a lot of progresses in enhances the hydraulic stability has been made. The selection of pumps and control methods will have a significant impact on the hydraulic stability in the system. Therefore both aspects should be considered to achieve smooth running in the heating system.
Mixing water system

Owe to the traditional design methods of the heating system, the head of the user close to heat sources are fundamentally too great. Hydraulic disorder with uneven water temperature in the system is easy to happen. A platform for the phenomenon with small temperature difference and big operation flow is provided. In order to avoid this happening in the secondary loop, the development of mixed water heating system is a solution. Although indirect connection technology is mature and widely applied, the system is complex and the workload for maintenance is great. Therefore it is suitable for heat medium temperature adjustment in large heating and heat source of central air conditioning system. And when the size of the heating and air conditioning system is relatively small or the demand flow of lower temperature is smaller, it is suitable to apply the direct connections for the heating systems.

The heating system with mix water is refers to set mix water devices in the heat exchange stations or at the entrance of the buildings in the conventional central heating systems, including the mix or jet pumps which blend water with high temperature in the primary network with part of water with low temperature in the secondary network into lower temperature water in the secondary network for heating system. The mix water pumps can be set in the supply and return pipes in the secondary heating system and also can be placed on the by-pass pipe.

Based on the researches in mixing ratio and muddy water properties, Zhaoyu Shi [5] put forward the deficient of installed power of the circulating pumps in the mix water heating system.

\[ N_{\text{min}} = \Delta H'_{1}G'_{1k} + \Delta H'_{2}G'_{2k} + \Delta H'_{b}G'_{p} \]  

The installed power of the circulating pumps meeting such formula is the optimal solution in the dynamic distributed heating systems (including mix water pumps). Comparative analysis has been made that aims at the common forms of mix water systems and several conclusions are as followed.

1) When the design project of dynamic distributed heating systems with variable frequency pumps is applied, the optimal solution for thermal stations (including thermal entrance) should adopt two pump systems: circulating pumps are installed in the return pipes in the primary heating systems and the circulating mix pumps should be installed on the supply pipes in the secondary heating systems.

2) In the reconstruction project, the variable frequency mixing pumps should be installed in the by-pass pipes because the pressure of supply flow is greater than that of the return flow.

3) The backward ideas of regulator adjusting flow in the heating systems should be replaced with variable frequency control as the change of cooling load during the whole operation.

Control strategy and adjustment

At present two control strategies in the heating systems are mainly applied. Artificial inspection local control heat users and pipe operation; the other kind is to apply the technology of remote control in the heating pipe network, including the control strategy of the whole heating system with thermal stations and the networks. In recent years, control strategy with computer has been applies to heating system network. But most in the local control of the thermal station level can't achieve the result of the central heating system whole optimization.

Lianzhong Li [12] points out the pros and cons with three kinds of control strategy in the mixed water heating system: the weather compensator control, based on fuzzy reasoning, the interior temperature controller, the control strategy of interaction with weather compensator and interior temperature controller. He thinks that the fluctuation of indoor temperature is greater as the regular coaster will not compensate the heat gain when the heat gain is greater. The weather compensator can effectively adjust the set point of water supply temperature and reduce the fluctuation of indoor temperature. So the energy saving effect is great. The change of heat load can be tracked effectively combining with adjustment of water temperature and water mixing ratio by weather compensator based on fuzzy inference and the control strategy with indoor air temperature compensator. The thermal comfort of users and the economic operation will be improved.

Ya-nan Liu [20] put forward some control strategies based on the studies in distributed network systems through the study on the regulating characteristics in the system. The variable flow regulation mode should be adopted in the
mixed water heating systems with distributed powers. The mixed water ratio is proportional to and lags behind the trend of the outdoor air temperature. The mixed water flow and water supply flow respectively increases and the increasing extent is different based on the length of pipes in the system. The adjustment of the heating system should be made in advance because of the great thermal inertia in the heating system and buildings.

Recently the most effective control strategy is to monitor the whole heating system by adopting the technology with computer monitoring. Therefore the various states of the heating systems and the parameters of each running thermal station can be timely collected to the computers. It can be useful for improving energy efficiency, decrease heat loss and so on for the heating system.

Conclusions

At present there have been many progresses in aspects of mathematical model, structures of pipe networks, hydraulic stability and regulation and control strategy in the dynamic distributed heating system. In the construction the energy saving effect is greatly improves and produces substantial economic benefit with frequency conversion technology in the dynamic distributed heating system. But there are still some problems we should continue to work for. Due to the set of the pumps in the dynamic distributed heating system, the position and the pattern of the constant pressure need to be renewably studied in the innovatively system, otherwise the pressure somewhere in the system will be too high or too low under different operations, which affects the efficiency of the system.

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