ARCHITECTURE AND APPLICATION OF INTELLIGENT HEATING NETWORK SYSTEM BASED ON CLOUD COMPUTING PLATFORM

by

Min CAO *

Zhengzhou University of Technology, Zhengzhou, China

Original scientific paper
https://doi.org/10.2298/TSCI2104889C

The vigorous development of Internet-related technologies such as big data, the IoT, and cloud computing has brought intelligent central heating networks' intelligent upgrade opportunities. The article discusses the current situation of the urban central heating system and its intelligence and analyzes the new characteristics of the intelligent central heating network under the new situation. Because of the existing central heating system's existing problems, we have designed a complete set of system architecture and heating networks' application plans.

Key words*: IoT, intelligent heating network, central heating, system architecture*

Introduction

The intelligent central heating network has not yet formed a consistent definition. If you want to define its concept more comprehensively, you need to fully consider the development and changes of technology and describe the intelligent central heating network's new characteristics from both connotation and extension. The connotation of the intelligent central heating network includes the following aspects:

Firstly, the intelligent central heating network has advanced and flexible heating system transmission and distribution technology. The standard heating transmission and distribution system are difficult to adapt to the rapidly expanding heating area. Under the new situation that new energy is prioritized for power generation and grid connection, heating units' power generation is subject to grid dispatching. The heating fixed power mode is about to be broken, requiring the heating network. It has strong adaptability to the fluctuation of heat source load. Driven by a new heating and energy-saving technologies such as waste heat utilization, geothermal utilization, and solar energy, the current central heating transmission and distribution system are also required to have greater flexibility. Maintaining the central heating system's advanced and flexible structure is an essential cornerstone for realizing an intelligent central heating network. Secondly, the intelligent central heating network has an automated basis for heat transmission and distribution [1]. Heating power transmission and distribution automation is a necessary condition for an intelligent centralized heating network. This is because the heating power transmission and distribution automation integrate the real-time operation of the heating network, heating network structure, equipment, users, and geographic graphics to form a complete heating power transmission and distribution automation system. Thirdly, the intelligent central heating network, is integrated into the communication system of the Internet. For heat transmission and distribution network, the system architecture must be facing the Inter-

* Author's e-mail: caomin54213@163.com

net. With the development of Internet technology, especially the rapid development of mobile Internet technology, the technology ecology of terminal interconnection has been completely changed. The integration of heat transmission and distribution automation terminals into the Internet system is the only way. Fourthly, the ubiquitous sensors and measuring devices of the intelligent central heating network. A large number of sensors and intelligent measurements are sufficient to ensure the acquisition of system operating parameters, equipment operating status, wide-area measurement network, flexible protection system*, etc.*, and provide trustworthy and reliable static, and dynamic data of the heat transmission and distribution network, which is suitable for various intelligent applications provide necessary information. Fifthly, the intelligent dispatch and regulation behavior of the intelligent central heating network. Intelligent behavior is one of the core characteristics of the intelligent central heating network [2]. Due to the emergence of cloud storage and big data processing, the heat load forecast is more accurate, and it becomes possible to analyze and obtain a precise adjustment model, which makes heating control and adjustment more intelligent. Sixthly, the unified heating network system data model of the intelligent central heating network. Including the hydraulic model and thermal model of the heating network and mapping the heating network's physical model to a standard data model so that relevant data sources are related in a practical, structured and transparent way. Seventhly, smart heating network equipment management. The visibility of the primary and secondary heating network is maximized through graphical and geographic information technology so that the operation and operation of the heating network system can be visualized. Simultaneously, it is supplemented by smarter and more comprehensive analysis applications to achieve high efficiency for the central heating network. Orderly management reduces management difficulty.

Design of fuzzy controller for heating network

The extension of the intelligent central heating network includes the following four aspects:

- Integrated regulation of heat source, heating network and users, heating network and heat source, heating network and heat users to achieve a certain degree of information through intelligent terminals, networks and unified data interfaces. Interactive, and according to the integration of the three-terminal data of heat source, heating network, and user, finally, realize integrated adjustment.
- The heat network transmission and distribution network is equipped with heat storage devices. The cogeneration heat source unit as the primary heat source, it can be connected to new heat sources such as waste heat, solar energy, and geothermal energy and can realize intelligent control and control centered on the heat network.
- Scheduling, heating on demand, providing good thermal energy quality, and heating reliability. Monitor, diagnose, and respond to thermal energy quality, analyze and calculate the heat used by different users and heat transfer characteristics of different buildings, to meet different users' needs for thermal energy quality and high reliability standards.
- Construction of refined production control system. Establish a risk management and control system for the central heating network to predict the risks in operation in advance, improve the heating network's asset utilization rate, and reduce operating costs. Establish an effective and linked optimization design system to form online analysis and statistics for production command, asset management, workflow management, operation, maintenance management, and operation status monitoring [3].

The heating network system in the heating network remote control system is a relatively complex controlled object, which can be described by the second-order pure lag model:

$$G(s)=\frac{K\mathrm{e}^{-\tau d^s}}{H_1 s^2+H_2 s+1} \tag{1}$$

where K is the amplification factor, τd – the pure lag time, and H_1 and H_2 – are time constant. Through the empirical method, the coefficients in the model are tuned, and the mathematical model representative of the heating network system is obtained:

$$G(s)=\frac{10.1}{0.196s^2+0.274s+1} \tag{2}$$

The fuzzy controller used in this design is a multi-variable 2-D fuzzy controller with dual input and a single output, as shown in fig. 1. The two input variables of the controller are the temperature difference, W_D, of the secondary supply and return water and the temperature deviation change rate, W_P, the output variable is the opening V of the proportional solenoid valve [4].

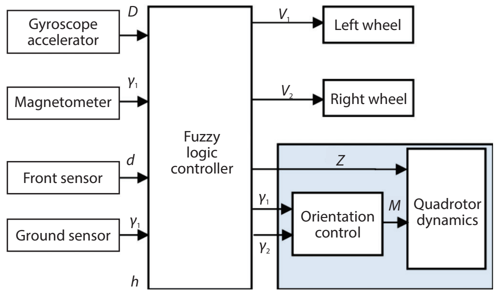

Figure 1. Block diagram of 2-D fuzzy controller structure

We divide the temperature difference, W_D, into seven fuzzy sets, namely {FD, FZ, FX, L0, ZX, ZZ, ZD}, and the corresponding physical states of the temperature sampling values are, respectively {beyond the lower limit of the set range, far lower at the lower limit of the setting range, slightly lower than the lower limit of the setting range, within the setting range, slightly higher than the upper limit of the setting range, much higher than the upper limit of the setting range, and exceeding the upper limit of the setting range}. The domain of W_D is defined as {–3, –2, –1, 0, 1, 2, 3}. The membership degree of the temperature difference W_D obtained is shown in tab. 1.

Table 1. Degree of membership of temperature difference W_D

Fuzzy set	Domain						
	–3	–2	–1	0	1	2	3
FD	0.0	0.0	0.0	0.0	0.0	0.5	1.0
FZ	0.0	0.0	0.0	0.0	0.5	1.0	0.5
FX	0.0	0.0	0.0	0.5	1.0	0.5	0.0
L0	0.0	0.0	0.5	1.0	0.5	0.0	0.0
ZX	0.0	0.5	1.0	0.5	0.0	0.0	0.0
ZZ	0.5	1.0	0.5	0.0	0.0	0.0	0.0
ZD	1.0	0.5	0.0	0.0	0.0	0.0	0.0

Similarly, the paper divides the temperature deviation change rate W_P into even fuzzy sets, namely {FD, FZ, FX, L0, ZX, ZZ, ZD}. The corresponding physical state of the temperature deviation sampling value is {beyond the lower limit of the setting range, far lower than the lower limit of the setting range, slightly lower than the lower limit of the setting range, within the setting range, slightly higher than the upper limit of the setting range, far above the upper limit of the setting range, and exceeding the upper limit of the setting range}. The domain of W_P is

{–3, –2, –1, 0,1, 2, 3}. The membership degree of temperature deviation change rate WP obtained is shown in tab. 2.

Table 2. The W_P membership degree of temperature deviation change rate

Fuzzy set	Domain						
	–3	–2	–1	0	1	2	3
FD	0.0	0.0	0.0	0.0	0.0	0.5	1.0
FZ	0.0	0.0	0.0	0.0	0.5	1.0	0.5
FX	0.0	0.0	0.0	0.5	1.0	0.5	0.0
L0	0.0	0.0	0.5	1.0	0.5	0.0	0.0
ZX	0.0	0.5	1.0	0.5	0.0	0.0	0.0
ZZ	0.5	1.0	0.5	0.0	0.0	0.0	0.0
ZD	1.0	0.5	0.0	0.0	0.0	0.0	0.0

The article divides the opening degree, V, of the proportional solenoid valve into 5 fuzzy sets, namely {OF, OB, OM, OS, CL}, and the proportional solenoid's corresponding physical states valve are {full open, wide open, half-open, slightly open, and shut down}. The domain of V is {0. 0, 0.5, 1.0, 1.5, 2.0}. The membership degree of opening V of the proportional solenoid valve is shown in tab. 3.

Table 3. Degree of membership of proportional solenoid valve opening V

Fuzzy set	Domain				
	0.0	0.5	1.0	1.5	2.0
OF	0.0	0.0	0.0	0.5	1.0
OB	0.0	0.0	0.5	1.0	0.5
OM	0.0	0.5	1.0	0.5	0.0
OS	0.5	1.0	0.5	0.0	0.0
CL	1.0	0.5	0.0	0.0	0.0

This design uses the triangle membership function commonly used in engineering as the fuzzy control system subset's membership function. It has the advantages of simple calculation and small memory usage:

$$\mu(x)=\begin{cases} 0, & x<a \\ \dfrac{x-a}{b-a}, & a\le x<b \\ \dfrac{c-x}{c-b}, & b\le x<c \\ 0, & x\ge c \end{cases} \tag{3}$$

The fuzzy control rules formulated according to the actual operating experience onsite are shown in tab. 4, a total of 49 items. If the temperature sampling value is far below the setting range's lower limit, and the temperature deviation sampling value is far lower than the setting range lower limit, the proportional solenoid valve is fully opened. The temperature sampling value is slightly lower than the lower limit of the setting range, the temperature deviation sampling value is slightly lower than the lower limit of the setting range, and the proportional solenoid valve is half-open [5]. We can use the maximum membership method to de-fuzzify the fuzzy set obtained by fuzzy inference.

Table 4. Fuzzy control rules

W_D	W_p						
	FD	FZ	FX	L0	ZX	ZZ	ZD
FD	OF	OF	OF	OF	OF	OF	OF
FX	OS	OS	OS	OS	OS	OS	OS
L0	OS	OS	OS	CL	OS	OS	OS
ZX	OS	OS	OS	OS	OS	OS	OS
ZZ	OB	OB	OB	OB	OB	OF	OF
ZD	OF	OF	OB	OM	OB	OB	OF

Architecture design of intelligent central heating network based on the cloud computing platform

The intelligent central heating network adopts a four-layer structure: the processing system and equipment layer, information layer, management, control layer, and decision-making layer [6]. Mainly include the following:

Process system and equipment layer

The processing system and equipment layer's design is based on the traditional central heating network with a heat storage system, making the heating network more flexible, more adaptable, and accepting more diversified heat sources. As shown in fig. 2.

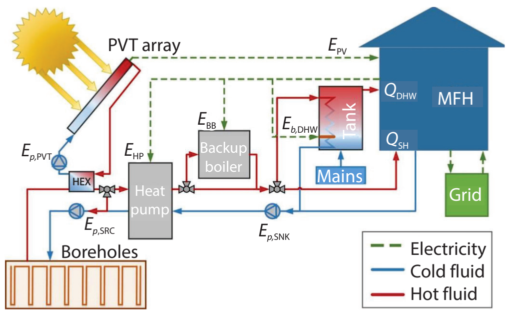

Figure 2. Multi-heat source complementary mode heating system

The bottom layer also needs to include smart sensors and various smart devices [7]. The equipment is distributed in the heat storage system, heat source station, primary and secondary network, remote heat station, thermal users, and the external environment, as shown in fig. 3.

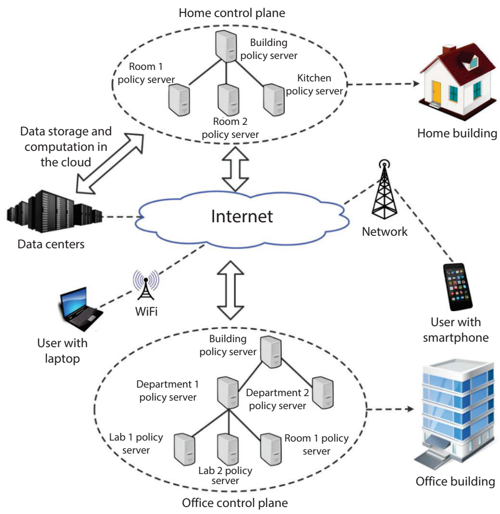

Figure 3. Equipment layer structure diagram of the smart central heating network

Information layer

The information layer includes the data collected by the sensor network and the models and calculation results generated by each control management system, including various forms of structured and unstructured real-time data and historical data. As shown in fig. 4.

Control layer

The management and control layer is established to include the heating network production and operation monitoring system,

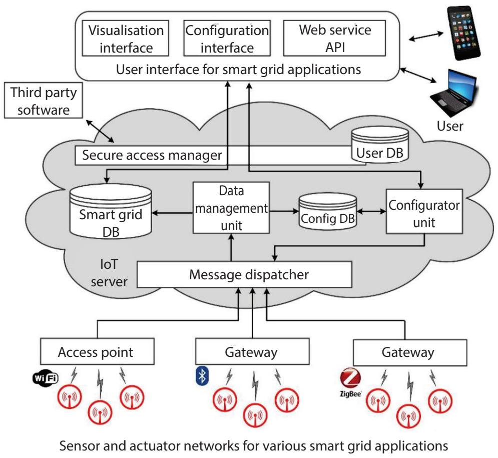

Figure 4. Schematic diagram of the information layer

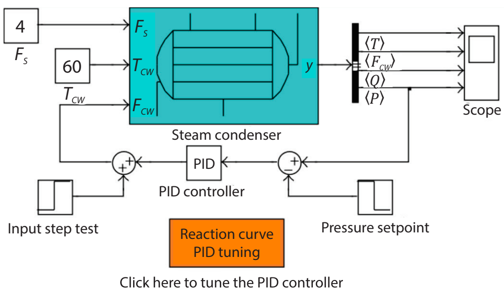

Figure 5. Schematic diagram of intelligent curve adjustment system based on heat exchange station

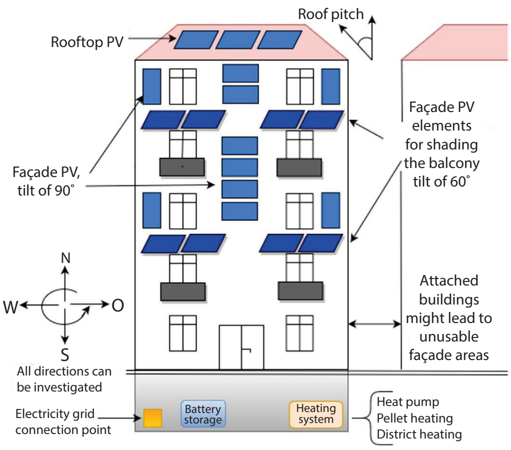

Figure 6. Schematic diagram of building-level intelligent regulation system

heating network energy consumption analysis system, heating customer service system, heating network charging management system, heating network GIS system, heating network integrated management system, heating network hydraulic balance analysis system, and equipment maintenance. System and other integrated management and control systems, and the core functions of the control layers are shown in fig. 5.

Integrated intelligent adjustment of network sources

The management and control layer builds a heat storage system to automatically track the heat exchange station's adjustment changes, maintain the stability of the first network, and ensure the heating quality and heating safety. The heat source side can automatically adjust the heat supply according to the actual heat load on the user side to achieve precise heat supply adjustment. On the heat source side, build a multi-heat source system, including solar heating, distributed energy station heating, *etc.* The established heat storage system co-operates with the cogeneration unit's heat source to adjust the heat load to avoid excessive heating and realize energy saving [8].

Primary network hydraulic intelligence analysis

The management and control layer establishes a hydraulic analysis system and carries out the technical transformation of the primary network pipe-line to co-ordinate with the pipe-line network's hydraulic adjustment.

Intelligent adjustment system of heat exchange station

The management and control layer adds a station-one optimized intelligent adjustment system to provide heat on demand according to the ambient temperature.

Unconventional thermal user intelligent control

The control layer adds balance valves and intelligent regulating valves. The intelligent adjustment system for conventional heat users adds an intelligent adjustment valve with adjustable flow, adds a balance valve*, etc.* It carries out energy-saving transformations for hot users and solves uneven heating and cooling between hot users, thereby reducing the overall excessive heating. As shown in fig. 6.

Intelligent temperature control system for thermal users

Users install smart indoor thermometers, and most of them realize household heat metering, as shown in fig. 7.

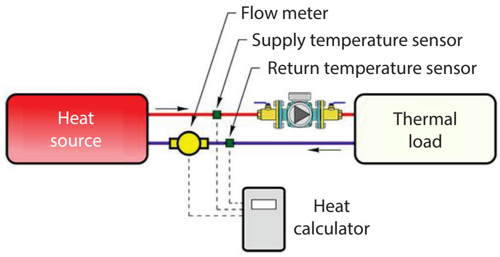

Figure 7. Household heat metering system

Decision-making layer

The decision-making layer contains various data mining algorithms based on decision trees and association analysis as the top-level design of the intelligent central heating network to provide decision support for the lower-level management and control system and enterprise decision-makers. The primary data mining tasks that need to be implemented at this stage include analysis of the heat transfer characteristics of buildings in different regions based on thermal user room temperature detection and meteorological mass data mining; based on thermal user necessary information, massive operating history data, user room temperature data and meteorological data precise prediction of heat load by analysis; establishment of heating quality analysis and audit model based on user payment, room temperature feedback information and pipe network operation data; find the best based on real-time historical data of hydroelectric heating energy consumption, real-time historical data of pipe heating operation and meteorological data and optimal economic operation strategy [9].

Big data analysis

After completing the cloud computing platform, a large number of online application software systems will generate a considerable amount of data [10]. These data include both structured data and unstructured data. The types and types of data are involved. How to effectively use and ensure the safety of the heat network. The *intelligent heating network's* real goal is to positively impact scheduling, management, and operation [11]. Therefore, these complex and logically related data are further analyzed and mined to form a series of mathematical models to guide and dispatch the operation of heat sources, heat networks, and heat stations to achieve energy saving, downsizing, and increasing efficiency.

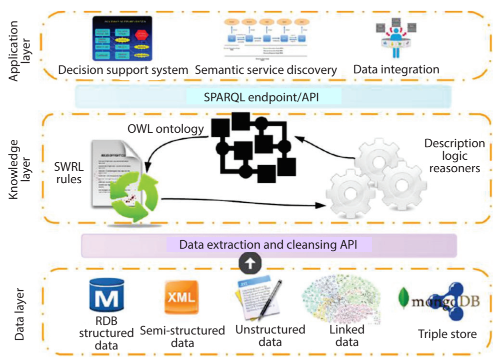

Figure 8. The structure of the supporting platform for heat supply big data analysis

See fig. 8 for the prominent data analysis support platform structure. We adopt the method of big data analysis, which can produce the correlation between multiple irrelevant data, and then effectively intervene in the heat network scheduling. For example, the curve relationship between complaint rate, weather, user room temperature, and other conditions and heating temperature can be calculated, and the output result can be changed by adjusting a particular condition arbitrarily until a satisfactory solution is obtained.

Conclusion

This article discusses the current situation of the urban central heating system and its intelligence and analyzes the new characteristics of the intelligent central heating network under the new situation. The basic process system of central heating is constructed layer by layer, and a complete set is designed. The system architecture and application scheme of the intelligent central heating network.

References

[1] Chicherin, S. V., Comparison of a District Heating System Operation Based on Actual Data-Omsk City, Russia, Case Study, *International Journal of Sustainable Energy*, *38* (2019), 6, pp. 603-614
[2] Buzoverov, E. A., Isaev, M. V., Experience with Unglazed Solar Collectors in District Heating Systems, *Applied Solar Energy*, *56* (2020), 4, pp. 248-251
[3] Wu, S., Construction of Visual 3-D Fabric Reinforced Composite Thermal Perfomance Prediction System, *Thermal Science*, *23* (2019), 5, pp. 2857-2865
[4] Mostafavi, S. A., Rezaei, A., Energy Consumption in Greenhouses and Selection of an Optimized Heating System with Minimum Energy Consumption, *Heat Transfer-Asian Research*, *48* (2019), 7, pp. 3257-3277
[5] Mijakovski, V. I., *et al.*, Techno-Economic Analysis of the Reconstruction of Central Heating System in Thermal Power Plant Bitola, *Termotehnika*, *43* (2017), 1-4, pp. 67-72
[6] Muntea, C., Some Aspects of Historical Monument Buildings Central Heating, *Revista Romana de Inginerie Civila*, *10* (2019), 3, pp. 230-233
[7] Tashevski, D., *et al.*, Environmental Benefits from Optimisation of Sustainable Heating Systems in Skopje, *Journal of Environmental Protection and Ecology*, *18* (2017), 3, pp. 1158-1168
[8] Kunith, A., *et al.*, Electrification of a City Bus Network – An Optimization Model for Cost-Effective Placing of Charging Infrastructure and Battery Sizing of Fast-Charging Electric Bus Systems, *International Journal of Sustainable Transportation*, *11* (2017), 10, pp. 707-720
[9] Parks, D., Energy Efficiency Left Behind, Policy Assemblages in Sweden's Most Climate-Smart City, *European Planning Studies*, *27* (2019), 2, pp. 318-335
[10] Wu, S., Construction of Visual 3-D Fabric Reinforced Composite Thermal Perfomance Prediction System, *Thermal Science*, *23* (2019), 5, pp. 2857-2865
[11] Johnston, D., *et al.*, Quantifying the Performance of a Passive Deaerator in a Gas-fFred Closed Loop Domestic Wet Central Heating System, *Building Services Engineering Research and Technology*, *38* (2017), 3, pp. 269-286

Paper submitted: November 2, 2020
Paper revised: December 6, 2020
Paper accepted: January 9, 2021