Analysis and research on the heat load forecasting of solar central heating

Chao Zuo¹, Xiaojuan lu²

¹Electrical engineering and automation, Lanzhou Jiaotong University, Lanzhou, Gansu, 730050, China
²Electrical engineering and automation, Lanzhou Jiaotong University, Lanzhou, Gansu, 730050, China
*2618041@stu.lzjtu.edu.cn
*Chao zuo’s e-mail:361849133@qq.com

Abstract. With the decrease of traditional energy reserves and the improvement of environmental protection requirements, people pay more and more attention to the efficient and clean application of new energy[1]. In this paper, through the analysis of the historical data of a heat exchange station in a small district in Lanzhou, two prediction algorithms of BP neural network and SVM support vector product are used to predict the heat load. The two prediction algorithms are used to predict the heat load, and the optimal prediction algorithm is found out based on the analysis results. On this basis, the optimal prediction algorithm is used to make long-term and short-term prediction of heat load. Accurate prediction of solar energy central heating system can provide reference for the operation of solar thermal storage system, make great use of the utilization rate of solar energy in the heating system, reduce the waste of clean energy in the solar central heating system, reduce the use cycle of traditional energy and reduce carbon emissions. At the same time, forecasting the heating load in advance can reduce the waste caused by the lag of hot water, reduce the energy consumption of the heating system, and enable the thermal company to provide heat according to the needs of users, reduce costs and improve customer satisfaction.

1. Introduction

At present, heat sources are mainly provided by thermal power plants, regional boilers and heat exchange stations in China. The characteristics of such heat sources are that the heating cycle and heating time are relatively fixed each year[2]. Although the heat source of the traditional heating method is stable, the traditional energy is harmful to the environment. The environment of the heating area becomes worse every year. The development and research of new energy heating has attracted a lot of scientists' attention. Seasonal heat storage central heating is a kind of new energy heating. The solar irradiance is seasonal uneven, that is, surplus in summer and insufficient in winter. Due to the weak radiation in winter, the standard rate of direct heating with solar energy is very low. In order to overcome this contradiction, people pay more and more attention to the solar energy storage heating technology with the characteristics of "storing in summer and using in winter". The system can store the solar energy heat of spring, summer and autumn in the underground pool or soil for winter heating, and realize low energy consumption and coal-free clean heating[3]. China is a big country of solar energy heat utilization, and its industry and market scale rank first in the world[4]. But at present,
China's seasonal heat storage solar central heating technology is still in the initial stage, there are many problems in the scheme demonstration, design optimization, operation control and other aspects, as a result, the imbalance of heat supply and demand often occurs in the operation of solar central heating system, resulting in energy waste or substandard phenomenon[5]. During the operation of the solar heating system, in order to ensure that the indoor temperature of the thermal users reaches the comfortable temperature, it is necessary to make accurate thermal load regulation. If the heating enterprise can make an accurate choice between solar energy and traditional energy, it can make the maximum use of solar energy, and at the same time, it can avoid that the energy value of solar energy is not up to the standard and the indoor temperature is not up to standard. The heat load forecast provides an important reference for the operation and regulation of heat exchange station, so that the relevant operators of heat supply enterprises can adjust and control the heat exchange station according to the change trend of heat load in a short period of time in the future[6]. Heating companies make an accurate choice between solar energy and traditional energy, so as to meet the demand of heat load of thermal users, provide heat on demand, make great use of solar energy, reduce the use of traditional energy, so as to reduce emissions and further reduce environmental pollution.

In order to optimize the heat load forecasting, two kinds of forecasting methods are adopted in this paper, which include the water supply temperature of the secondary side, the return water temperature of the secondary side, the flow rate of the secondary side, the pressure and the outdoor temperature as the influencing factors. BP neural network prediction and SVM support vector product are used to train and analyze the historical data provided by Lanzhou thermal power company. Find out the optimal prediction algorithm, improve the accuracy of prediction, improve the traditional regulation method of thermal enterprises, and maximize the use of solar energy. It also improves the experience of thermal users, increases customer satisfaction, improves the work efficiency of thermal enterprises, and reduces operating costs.

2. Structure of solar central heating system
The solar central heating system is shown in Figure 1, and its main equipment is composed of solar collector plate, hot water storage pool, heat exchange station and long heat source[7]. The operation mode and working principle of solar central heating are as follows: in non-heating season, the solar collector plate and hot water heat storage pool complete the heating and storage of thermal medium. In the early stage of the heating season, the solar collector plate continues to work. The thermal medium in the heat storage pool and the heat medium heated by the solar panel provide heat energy for the heat users, so as to ensure the utilization efficiency of solar energy during the heating period. When the energy value of solar energy fails to meet the heating standard in the middle of heating or in bad weather, the heat storage medium is heated by the boiler of heat source plant or the waste heat generated by cogeneration is connected to provide heat for heat users.

![Structure diagram of solar central heating system](image-url)
3. mathematical model

3.1. Mathematical model of solar thermal storage system

\[
\left( mc_w \right) \frac{dT_p}{dt} = G_0 C_w \left(T_{g0} - T_p \right) - Q_{gr} - US(T_p - T_{sol})
\]  

(1)

In the formula, \( m \) — Water quantity of heat storage tank; \( c_w \) — Specific heat capacity of water; \( G_0 \) — Hot water flow in collector; \( U \) — Heat loss coefficient; \( S \) — Surface area of heat storage tank; \( T_{g0} \) — Inlet temperature of heat storage tank; \( T_p \) — Inlet temperature of heat storage tank; \( T_{sol} \) — soil temperature; \( t \) — time;

3.2. Heating load of buildings

\[
Q_{gr} = q_v V (T_v - T_w) 
\]  

(2)

In the formula \( Q_{gr} \) — Heating design heat load; \( q_v \) — Volume heat index of building heating; \( V \) — Building volume; \( T_v \) — indoor temperature; \( T_w \) — Outdoor temperature;

3.3. Mathematical model of heating system

\[
C_{h1} \frac{dT_{h1}}{dt} = c_w G_1 \left(T_{g1} - T_{h1} \right) - Q_{hr1}
\]  

(3)

\[
C_{h2} \frac{dT_{h2}}{dt} = Q_{hr} - Q_g
\]  

(4)

\[
Q_g = c_w G_1 \left(T_{g1} - T_{h2} \right)
\]  

(5)

\[
\Delta T_{pj} = \frac{(T_{g1} - T_{g2}) - (T_{h1} - T_{h2})}{\ln \frac{T_{g1} - T_{g2}}{T_{h1} - T_{h2}}}
\]  

(6)

\[
Q_{hr} = S_k KB \Delta T_{pj}
\]  

(7)

\[
G_1 = \frac{Q_{gr}}{c_w (T_{g1} - T_{h1})}
\]  

(8)

\[
G_2 = \frac{Q_{hr}}{c_w (T_{g2} - T_{h2})}
\]  

(9)

\[
C_n \frac{dT_n}{dt} = AQ_x - U_r(T_n - T_w)
\]  

(10)

In the formula (3) to (10) \( C_{h1} \) — Heat capacity of hot medium in primary side of plate heat exchanger; \( T_{h1} \) — Return water temperature of primary network; \( T_{g1} \) — Water supply temperature of primary
network; \( Q_{hr} \) ——Heat exchange capacity of heat exchange station; \( C_{hr2} \) ——Heat capacity of hot medium in secondary side of layout heat exchanger; \( T_{g2} \) ——Water supply temperature of secondary network; \( Q_g \) ——Heat supply capacity of heat exchange station; \( T_{h2} \) ——Return water temperature of secondary network; \( \Delta T_{pj} \) ——Heat exchange temperature difference between primary and secondary network side of heat exchanger; \( G_2 \) ——Design flow rate of secondary side fluid in heat exchanger; \( C_n \) ——Indoor air heat capacity; \( A \) ——Heating area; \( Q_s \) ——Indoor heat dissipation; \( U_r \) ——Heat transfer coefficient between indoor and outdoor; \( S_h \) ——Heat exchange area of heat exchanger; \( B \) ——scale factor; \( K \) ——Heat transfer coefficient of heat exchanger;

4. Simulation experiment and analysis

In order to verify the feasibility of solar heating and the lag of hot water in heating system, the following simulation is carried out. In this paper, a district in Lanzhou city is selected as the research object, and the heating model is established by using the Simulink toolbox in MATLAB.

As shown in Figure 3, when the simulation time is 5500 seconds and the temperature reaches stable state, the water supply \( T_{g2} \) of the heat exchange station is 50 °C, and the return water temperature \( T_{h2} \) is 40 °C, the indoor temperature is 18 °C. After 5500 seconds, the outdoor temperature step from -11 °C to -5 °C, and the system tends to be stable for about two hours, which further explains the hysteresis of hot water. The reference of solar heating is given, and it is proved that the prediction of heat load is conducive to energy saving and improving the utilization rate of solar energy.
Figure 4 is the simulation diagram of the solar thermal storage pool. Through this figure, we can see the temperature change of the hot medium in the heat storage pool during the heating period, which can provide reference for the heating work.

5. heat load forecast

Heat load forecasting plays an important role in heating work. Heat load forecasting is to find out the influencing factors of heating load change by analyzing the change of heat load. On this basis, the heating load is estimated and speculated in advance, so as to directly improve the utilization efficiency of heating energy[8]. At the same time, the efficient use of solar energy to guide.

Heat load forecasting is based on the historical data in heating work, which can forecast and judge the heat demand in a certain period in the future. Heat load forecast is divided into Medium-term Forecast and short-term forecast. Based on the analysis of the historical data of Lanzhou thermal power company, this paper takes the water supply temperature of the secondary side, the return water temperature of the secondary side, the secondary flow rate, pressure and outdoor temperature of the heat exchange station as the input data, and the user's actual heat load as the output data to predict the heat load. Two different forecasting methods are used to make short-term and medium-term heat load forecasting, and find the optimal prediction algorithm.
5.1. BP artificial neural network

BP neural network has the ability to classify arbitrary complex patterns and excellent multi-dimensional function mapping ability, which solves the problem that simple perceptron can not solve. In terms of structure, BP network has input layer, hidden layer and output layer; in essence, BP algorithm takes the square of network error as the objective function and uses gradient descent method to calculate the minimum value of the objective function[9].

The artificial neural network learns the heat load influence rules through its own training, and gets the result closest to the expected output value when the input value is given. Figure 5 shows the prediction results made by BP artificial neural network, with one month's historical data as the training set and the previous day as the test set, in hours as the unit. The results show that the accuracy is 97.03%

Fig. 5 short term heat load prediction based on BP neural network

5.2. SVM support vector product

Support vector machine (SVM) is a kind of generalized linear classification which classifies data by supervised learning. Its decision boundary is the maximum margin hyperplane to solve the learning samples[10].

SVM uses the hinge loss function to calculate the empirical risk, and adds a regularization term to the solution system to optimize the structural risk. It is a sparse and robust classifier. SVM is one of the common kernel learning methods for nonlinear classification[11].

Equations (11) and (12) are the expressions of SVM regression function \( x_i, y_i (i = 1,2,3,4,5) \) is the input and output. In this paper, \( x_i \) is the characteristic value of the sample input, which are the water supply temperature of the secondary side, the return water temperature of the secondary side, the secondary flow rate, pressure and outdoor temperature of the heat exchange station. The output \( y_i \) is the heat load.

\[
\begin{align*}
  f(x) &= w^* \cdot \Phi(x) + b^* \\
  &= \sum_{j=1}^{l} (\alpha^*_j - \alpha^*_i) \Phi(x_j) \cdot \Phi(x) + b^* \\
  &= \sum_{j=1}^{l} (\alpha^*_j - \alpha^*_i) K(x_j, x) + b^*
\end{align*}
\] (11)
\[
\min \frac{1}{2} \|w\|^2 + C \sum_i (\xi_i + \xi_i^*) \\
\left\{
\begin{array}{l}
y_i - w \cdot \Phi(x_i) - b \leq \varepsilon + \xi_i \\
- y_i + w \cdot \Phi(x_i) - b \leq \varepsilon + \xi_i^* (i = 1, 2, \ldots, 5) \\
\xi_i \geq 0, \xi_i^* \geq 0
\end{array}
\right.
\] (12)

In this paper, the historical data of two heating seasons are taken as the test set, and the previous two months as the training set. The medium-term forecast is made and the prediction results are obtained. Do the training set in one week and make short-term forecast in hours.

It can be seen from Figure 6 and Figure 7 that the accuracy of the results predicted by SVM is 99.7\% and 99.6\% respectively. In the long-term and long-term prediction, it can be seen that the more data in the training set, the more accurate the results will be.

![Fig. 6 SVM long term heat load prediction](image6)

![Fig. 7 short term heat load prediction based on SVM](image7)

6. conclusion
In order to make a systematic and comprehensive understanding of the solar central heating system,
this paper uses matlab-simulink toolbox to make the corresponding mathematical modeling and simulation. Through the real historical data and the actual working conditions, the feasibility of the simulation is obtained, and once again proves that there is a lag in the heating medium, leading to a large amount of energy consumption. The necessity of heat load forecasting is obtained through simulation adjustment. The heat load forecast can effectively guide the heating work, which is of great help to the work efficiency of the thermal power company. At the same time, it also has a certain guiding role for the solar energy central heating system. In the heating season, the staff of the thermal power company can make further use of the clean energy of solar energy through the heat load forecast, so as to make it play the most effective role, reduce the traditional energy consumption, greatly reduce the carbon emission, and actively respond to the slogan of "green water and green mountains are golden mountains and silver mountains".

In this paper, through the historical data of Lanzhou thermal power company, combined with the actual working conditions, two prediction algorithms are used to make long-term and short-term prediction of heat load. Through the comparative analysis of the prediction results, it is concluded that SVM model can more accurately predict the heat load compared with BP neural network model. It also provides accurate operation guidance for the application of solar thermal storage.

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