Analysis of blockage reasons of air preheater based on big data

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Abstract. With the rapid development of Internet and computer technology, the era of big data has arrived. With the increasingly high degree of automation in the power industry, data mining technology and cloud computing technology are continuously developing in the power industry to deal with massive operational data. Supervisory Information System (SIS) and Distributed Control System (DCS) have been widely used in power plants, which enables massive operation data of power plants to be saved. As data mining technology rises rapidly in the power industry, many scholars begin to use data mining technology to study and solve problems encountered in power plants. Air preheater is a kind of heat exchange equipment which uses the waste heat of flue gas to heat the air needed for boiler combustion. The air preheater can recover the heat of flue gas, reduce the temperature of smoke exhaust and improve the efficiency of boiler. In recent years, the phenomenon of air-preheater clogging is increasing. Based on big data theory, this paper investigated 26 thermal power generating units - a total of 52 air preheaters with a capacity of 300~600MW, and applied the neural network Modeling method to the air preheater clogging reasons identification system. So we can find out the clogging reasons of air preheaters timely and accurately, slow down and avoid the clogging of air preheater.

1. Introduction

Information has become one of the most valuable resources in today's world because of its unique share ability, reusability, and wide spread without space and time restrictions. With the rapid development of Internet and computer technology, the era of big data has arrived. In order to deal with massive historical records, data mining technology and cloud computing technology emerge as The Times require, and become indispensable tools for big data processing. With the rapid development of the electric power industry, the design data and operation data of various engineering boilers are increasing [1]. However, it is difficult to extract, synthesize, analyze and use these data, extract useful information from the data, and discover and enhance the value of the data. Therefore, it is necessary to adopt new means and methods to analyze and mine the existing data. Supervisory Information System (SIS) and Distributed Control System (DCS) have been widely used in power plants, which enables massive operation data of power plants to be saved. As data mining technology rises rapidly in the power industry, many scholars begin to use data mining technology to study and solve problems encountered in power plants [2,3].

Air preheater is a kind of heat exchange equipment which uses the waste heat of flue gas to heat the air needed for boiler combustion [4]. The air preheater can recover the heat of flue gas, reduce the temperature of exhaust smoke and improve the efficiency of boiler. Air preheater according to the heat transfer mode can be divided into two, one is rotary, and one is the pipe type [5,6]. At present, rotary
air preheater is generally used in units with a capacity of over 300MW, so this paper mainly studies rotary air preheater.

2. Reasons for classification

2.1. Insufficient integrated temperature at cold end of air preheater
The lowest cold end comprehensive temperature of air preheater (MCCET) refers to the minimum temperature value of sulfate plugging in the cold end of air preheater, which is related to ash, sulfur, ash to sulfur ratio, excess air coefficient and whether the boiler has denitration or not [7]. The calculation formula stipulated in the standard is:

\[
CCET = \text{flue gas outlet temperature of air preheater} + \text{air inlet temperature of air preheater}
\]  

(1)

In the combustion process, sulfur content in the fuel will form \( \text{SO}_2 \) and \( \text{SO}_3 \). As long as there is a small amount of \( \text{SO}_3 \) in the flue gas, the dew point of the flue gas will increase a lot. When the dew point of the flue gas is higher than the temperature of the metal wall of the heating surface in the low temperature section of the air preheater, ash accumulation and corrosion will be caused. The acid dew point of flue gas can be calculated accurately according to the composition of coal and excess air coefficient, etc. Boiler design manufacturers usually specify the integrated temperature of cold end of air preheater in the boiler specification.

2.2. External water
Compound itself doesn't make the heat transfer of flue gas components congestion, however, when the water to join, the large amount of water and flue gas generated by CaO hard and sticky "cement" adhesion on the surface of heat exchange, and with the increase of operation time and temperature and become more and more hard, all kinds of fly ash deposits and easily at the same time in the above offer is becoming more and more thick and not easy to remove, thus serious plugging ash and high resistance, and also results in the decrease of heat transfer efficiency. And for the external moisture caused by the accumulation of ash, even if the use of changing the wall temperature of the cold end heat exchange elements cannot be eliminated.

2.3. Improper out-of-stock control
Selective catalytic reduction (SCR), as a mature and effective denitration process, has been widely used in coal-fired power plants. In the operation of the boiler, part of \( \text{SO}_2 \) in the flue gas is converted to \( \text{SO}_3 \) under the action of catalyst. At the same time, due to a certain amount of ammonia escaping in the denitration process, \( \text{SO}_2 \) and ammonia react to form \( (\text{NH}_3)_2\text{SO}_3 \) and \( \text{NH}_4\text{HSO}_4 \), and the yield depends on the content of \( \text{NH}_3 \) and \( \text{SO}_3 \) in the flue gas. \( \text{NH}_4\text{HSO}_4 \) tends to present liquid phase in the middle temperature and low temperature segments of the air preheater. In the liquid phase, \( \text{NH}_4\text{HSO}_4 \) is highly corrosive and viscous, which will form strong corrosion on the middle temperature and cold segments of the air preheater, quickly stick to the surface of the heat transfer element, and then absorb a large amount of fly ash, causing blockage of the air preheater.

At the same time, the SCR denitration system arrangement on the outside of the above or boiler air preheater and flue section and air preheater and economizer flue section is different, so the flue flow field is also changed by the limited space, between SCR system and air preheater also does not have enough steady flow range, flue gas distribution, the distribution of ammonia is uneven, exacerbated by the possibility of air preheater was blocked.

2.4. Improper selection of waveform of air preheater heat exchanger
The component for heat exchange in the air preheater is called the heat exchange element, and the heat exchange element has a variety of plate types. Different plate type corresponds to different heat transfer efficiency and resistance characteristics, boiler manufacturers according to the design parameters to select the appropriate plate type. For FNC plate type with high heat transfer efficiency,
its complicated corrugated structure shape is likely to cause the air preheater to block ash. For air preheater with SCR equipment, double corrugated type (DU) with high heat transfer efficiency and not easy to block ash should be adopted. Is also a double corrugated, different specifications of its anti-blocking gray performance will be different. Therefore, in the high and low temperature section of the air preheater, to choose different specifications of double corrugated heat exchanger, low temperature section of the preheater to use the better performance of anti-blocking gray specifications.

2.5. The actual coal quality deviation of the boiler is large
In addition to the above factors, other characteristics of boiler fuel will also affect the formation of NH₃, SO₃ and ABS. The most influential factors are: (1) nitrogen, oxygen and volatiles (affecting the generation of NOₓ); (2) chlorine, which increases the corrosion of the air preheater; (3) calcium oxide and magnesium oxide in fly ash will affect the concentration of SO₃; (4) vanadium, mainly found in fuel equipment, will increase the oxidation of SO₂. Due to the different content of these substances in coal, the content of NOₓ in the flue gas will be affected, so the SCR system needs to be adjusted accordingly. If the operation is improper, ammonia escape will be increased.

3. Analysis of air preheater blockage
The resistance characteristic of air preheater is a comprehensive embodiment, which is mainly determined by the above-mentioned smoke temperature, wind temperature and smoke composition. It is a multivariable control object. When one of the conditions is changed, the air preheater resistance changes accordingly. The resistance value of the air preheater is an important basis for measuring whether the air preheater is blocked. Generally speaking, when the resistance value of the air preheater is greater than 1.2 times of the design resistance of the air preheater (under the same load condition), the air preheater is blocked [8].

It is a critical period for prevention and control of air preheater blockage in the initial period of air preheater resistance increase. After the local blockage of the air preheater, the heating surface is adhered to the fly ash in the flue gas, and it is easy to absorb the fly ash flowing through here, which further aggravates the adhesion of the fly ash and aggravates the blockage. At this time, if the main cause of air preheater blockage can be accurately determined, countermeasures can be formulated to slow down or avoid further increase of resistance and remove the blockage risk [9].

Therefore, the neural network modelling method is applied to the air conditioner clogging because identification system based on the background of big data to timely and accurately determine the clogging cause of air conditioner [10].

Smoothing removes most of the "noise" from the data. Traditional data Smoothing method to achieve the overall smooth, data set on the local details should not be too sensitive, and nonparametric Smoothing method is not dependent on the population distribution and its parameter, more flexible, Locally Weighted Scatterplot Smoothing (LOESS) is one of them. It uses a lower order polynomial to locally approximate the data, and finally gets LOESS smoothing result [11].

System Modeling of the input and output model expression should be a system in equilibrium points of the increment of transitive relation, which requires the statistical characteristic of data has nothing to do with statistical time starting point, and the measured data are random time sequence, the "zero" is arbitrary, so you need to type (2) was carried out on the data from the field of zero initial processing.

\[
\begin{align*}
  u^*(k) &= u(k) - \frac{1}{N} \sum_{i=1}^{N} u(i) \\
  y^*(k) &= y(k) - \frac{1}{N} \sum_{i=1}^{N} y(i)
\end{align*}
\] (2)

Where: \(N\) represents total number of data, \(u\) represents input sequence, \(y\) represents output sequence.

Usually input and output data dimension is different, and often tens of times the gap between the
numerical and directly applied in neural network will lead to the role of the small scale of small data, data fluctuate in average large at the same time, rising and falling load system characteristics are different, so in order to balance all kinds of data, the data is normalized to the (-1, 1) range of processing. The most commonly used is linear function transformation, as shown in equation (3).

$$X_i = \frac{x_i - x_{\min}}{x_{\max} - x_{\min}}$$  \hspace{1cm} (3)

Considering the practice, and cannot be determined in advance of real-time acquisition of input data, so only to normalization of the training sample, on the basis of the training sample and test sample of the attributes of the normalized normalization, at the same time, the neural network output forecast range (-1, 1), need to be based on the target in the training sample data normalization attributes in the normalization, to transform into a region also consistent with the actual.

The neural network model is mainly composed of input layer, hidden layer and output layer. The network topology, learning samples and learning algorithm are the main factors affecting the learning and generalization ability of neural networks. In this paper, the classical 3-layer neural network model is selected. The input is flue gas composition, the cold end comprehensive temperature of air preheater and so on, while the output is air preheater resistance. The topology structure of the neural network is shown in figure 1.

![Neural network topology](image)

**Figure 1.** Neural network topology.

The classical BP neural network has no accurate theoretical basis for the setting of initial weight, initial learning rate, hidden layer number, hidden layer unit number, etc. and has disadvantages such as easy to fall into local optimum and slow learning speed. Bayesian algorithm is a kind of knowledge points type algorithm, based on the statistics, focusing on the probability distribution of weight throughout the right space, the original is a prior distribution, distribution of training data structure after posterior distribution, the probability model, the analysis of the traditional problem can be converted to the sense of probability are obtained by the calculation method of stochastic simulation approximate global optimal solution.

The ultimate goal of neural network training is to find the right weight vector, so that the root mean
square error $E$ can be minimized. According to Bayesian principle, the posterior probability of weight vector is shown in formula (4).

$$P(W|D) = \frac{P(D|W) \times P(W)}{P(D)}$$

(4)

Where, $P(W)$ is the prior probability distribution of weight vector $W$; $P(D|W)$ is the likelihood function; $P(D)$ is a constant independent of $W$, and is the distribution of samples.

As the object is complex and the data volume is huge, it is necessary to extract some useful information to summarize all the features by using the data mining method. The Modeling process of the improved neural network combined with Bayesian is shown in figure 2.

![Figure 2. Modeling process of Bayesian improved neural network.](image)

Due to the huge amount of data, the sampling period is very long and the data fluctuates violently, so the smoothing parameter is set as 800. After smoothing and zero initial processing, the data interference term is weakened to some extent. After pre-processing, the curve trend remains

![Figure 3. Summary diagram of the difference between target data and predicted data.](image)
unchanged and the dentate characteristics are greatly reduced.

In the training model, the learning rate is set as 0.01, the learning times as 20 000, and the classical neural network fails to converge after learning for 20 000 times, at which time the training mean square error is 0.1462. The Bayesian neural network converges after 1138 learning, and the training mean square error is 0.0159.

Take the difference between the target data and the predicted data as the error, and output the result as shown in figure 3. It can be seen from the observation that the error of the system reaching the steady-state period is basically within 0.2%. There are many weight and threshold matrix data, which are not listed separately in this paper. According to the final statistics, the change of the clogging reason of air preheater before and after denitration is shown in Table 1.

Table 1. Statistics of resistance changes of air preheater after out of stock transformation.

| The name of the                                 | Number  |
|------------------------------------------------|---------|
| Number of sample units                         | 26      |
| The number of units of air preheater resistance increased after denitration transformation | 22      |
| Resistance increases unit ratio                | 84.62%  |
| After denitration, the air preheater resistance increased to more than 1.2 times of the original resistance | 12      |
| Resistance increased by 1.2 times the unit ratio | 46.15%  |
| The ratio of the number of unplanned shutdown times to the total number of unplanned shutdown times caused by the clogging of air preheater before denitration transformation | 3.14%   |
| The ratio of the number of unplanned shutdown times caused by air preheater blockage after denitration transformation | 10.62%  |

4. Conclusions
This paper only studies the resistance of air preheater for boilers in thermal power plants, which provides a more practical reference for identifying the cause of air preheater clogging based on big data. Mining the relationship between data in more complex systems is the future direction of power plant big data development.

- Using pretreatment, zero initial processing method in data mining, the collected in the actual operation of the boiler air preheater system of flue gas composition and air preheater cold end temperature of large amounts of data, filtering, heavy mining, sifting, get sample data of the system, then using neural network identification method for air preheater resistance system modeling.
- The results show that the model has certain accuracy and rapidity, and the identification process provides a reference for offline system identification by combining big data with intelligent identification, and has important practical significance for improving the prevention and treatment of air preheater blockage in thermal power plants.
- Combining the Bayesian algorithm with the classical BP neural network, the weight optimization can be transformed into error regular function optimization. The practical results show that this method can accelerate the convergence speed and effectively avoid the neural network falling into local optimal.
- The current denitration system operation is gradually becoming the main cause of air preheater blockage.

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