Application of statistical process control technology in operation optimization of thermal power units

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Abstract. The reliability of power plant data becomes more and more important with the development of smart power plant based on big data and artificial intelligence technology. Statistical process control technology is widely used in product production process management, but it has never been involved in thermal power. In this paper, the statistical process control technology is applied to the thermal power industry. The application results show that the statistical process control technology can not only take the calculation results as the quantitative criteria for the operation conditions of the unit, but also help to select the comprehensive optimal conditions of the unit under the specific conditions, and implement the goal of improving the management level and economic benefits of the power plant.

1. Introduction

A new round of scientific and technological revolution and industrial transformation are booming in the world. All electric power enterprises have promoted the deep integration of advanced technology and industry to enhance the management level, operation ability of operators and the core competitiveness of enterprises. The core of building smart power plant is to ensure the reliability of data and the safe and stable operation of the unit.

Reference [1] verified the practicability of SPC (statistical process control) method through the quality control of crankshaft outer diameter and engine shell defects. In reference [2], SPC idea is introduced into the intelligent monitoring of workshop status information to analyze the stability of equipment status in the production process. Literature [3] from the point of view of several cases that affect the stability of the auxiliary power system, this paper analyzes the causes and effects of 1000MW units in a power plant from construction to operation, and puts forward corresponding countermeasures. In reference [4], a kind of boiler feed water control system based on fuzzy neural network technology applied in the whole process control system of large-scale thermal power unit is studied. Literature [5] analyzes the characteristics of the flexible retrofitting technologies such as boiler oxygen enriched combustion, high-pressure electric boiler, turbine extraction steam temperature and pressure reduction and heat storage tank, and puts forward the overall solution for the flexible retrofitting of heating unit and pure condensing unit. In reference [10], the powerful data analysis ability of data mining technology is used to improve the association rule mining algorithm. The adjusted parameters are in line with the combustion adjustment test conclusion. The optimization results effectively reduce the NOx concentration at the inlet of SCR device on the premise of ensuring the boiler thermal efficiency.
In this paper, a new method to maintain stable and economic operation of thermal power plant is put forward. Statistical process control technology is applied to the operation of thermal power plant to introduce the real-time stability criterion for the optimal operation state of the unit, and the results before and after application are compared and analyzed to verify the good effect of the technology in the application of thermal power industry.

2. Overview of SPC technology
Statistical process control is a kind of technology which monitors the production process by using statistical method. The abnormal fluctuation in the process can be observed intuitively through the analysis tool [6] and measures can be taken to eliminate the abnormality to ensure the production quality.

2.1. Introduction to SPC technology
Motorola has established six sigma management standard based on statistical process control technology. When the processing capacity reaches Six Sigma, the corresponding unqualified rate is 3.4PPM (defects per million) [7]. The control technology applied in thermal power plant is 6 σ management standard.

![Figure 1. Process capability.](image)

2.2. Research status of process capability index
When there is only deviation caused by common reasons in the process, the process capability index CP is the short-term potential process capability index. The larger the CP is, the greater the degree to which the product meets the index requirements [1]. Assuming that the requirement range of the specification is \(\pm 3\sigma\) and CP = 1, the probability of meeting the standard is 99.73%.

\[
CP = \frac{USL - LSL}{6\sigma}
\]

(1)

In the actual production process, there will be a certain degree of deviation between the two centers. The relative offset K is introduced and the actual process capability index CPK is used. The greater CPK is, the greater the degree to which the product meets the index requirements [1].

\[
CP_k = \min\left\{\frac{\mu - LSL}{3\sigma}, \frac{USL - \mu}{3\sigma}\right\} = (1 - k)CP
\]

(2)

The image of CPK is as follows:
When the data is non-normal, it needs to transform the data, usually using box Cox power transformation [8] or Johnson transformation [9] to become normal parameters and analyze.

The calculation formula of CP and CPK for power plant parameters after transformation is as follows:

$$C_P = \frac{U_{UL} - L_{LL}}{x_{0.005} - x_{0.995}}.$$

$$C_{PK} = \min \left\{ \frac{U_{UL} - x_{0.5}}{x_{0.005} - x_{0.5}}, \frac{x_{0.5} - L_{LL}}{x_{0.995} - x_{0.5}} \right\}.$$

3. Application of SPC technology in thermal power industry

3.1. Filtering unsteady process data

Data mining can help the unit get the favorable information which is hard to see from the historical real operation data, and help to accumulate and inherit the experience. In the real-time dynamic process of the unit, a large number of unsteady process data are generated, which greatly interferes with the data mining, making the unit lack of reliable guidance in the real-time operation and adjustment process. In view of the above problems, the statistical process control technology based on the study of process capability in the dynamic operation process of thermal power plant is proposed to obtain the comprehensive optimal operating condition of the unit, which is suitable for different capacity units and different operating conditions.

3.2. Maintain stable operation of the unit

There are two ways to maintain the stability of the unit. One is to strengthen control, that is to say, to add controller. However, it requires high precision, which is based on a more rigorous control theory. When there are more control links, the more difficult it is to adjust, the worse the stability of the control will be, and the controller will lose stability when the control function becomes a shock wave; in addition, when the boundary conditions of the power generation, i.e. the temperature, load and environment change, the adaptability of the original parameters will become poor, and need to be adjusted again, otherwise the controller will lose stability. The second is to eliminate the noise, that is, to eliminate the input side disturbance, that is to achieve the thermodynamic stability. The steady state of thermodynamics includes load stability and combustion stability. The influence factor of combustion stability is that the change of coal quality leads to the lag of system adjustment, which makes the equipment generate energy storage and heat release, and the state of transient stability is easy to be destroyed. It is necessary to improve the structural stability and anti-interference ability of the system, so that the system can return to balance in time, at this time, the boiler evaporation capacity and steam turbine inlet capacity reach the best matching degree. Using statistical process control technology can achieve the effect of "eliminating noise".
3.3. Strictly control the parameters representing the stable operation of the unit

According to the statistics and analysis of the operation parameters under the specific conditions of the thermal power plant, the fluctuation of the main steam pressure, the main control output of the furnace, the temperature of the main reheat steam, the temperature distribution of the furnace, the oxygen content, the negative pressure of the furnace and other parameters can represent the stability of the working condition. The key parameters that can represent the stability of the working condition are selected to evaluate the stability of the working condition. For example, the specific stability parameters of the boiler combustion system are the main steam pressure. The continuous time period of the specific key parameters under the same condition is taken as a sample, and the statistical samples are transformed by box Cox or Johnson transformation to meet the normal distribution, and the fluctuation of the key parameters is unified. Based on the study of accounting and process capability analysis, the six standard deviations (6σ) of the sample are calculated, the Cₚ and CₚK values are analyzed, and the CP and CPK are used to measure the process capability, which reflects the steady-state characteristics of key parameters, judges the operation stability of the unit, and then establishes the non normal data sample process capability (Cₚ / CₚK) as the quantitative criterion for the operation condition of the unit. Through the ranking of the criteria, the process capability (Cₚ / CₚK) is selected. According to the optimal operating conditions of the unit, the adjustment of operating parameters of the unit is guided.

The performance feature of this condition is that when the unit has local disturbance, its main operation parameters fluctuate the least, that is, the system has the strongest anti-interference ability, the unit's long-term variable condition operation adjustment amount is the smallest, and the comprehensive energy consumption is the best. "Optimal" condition is the actual existence of the unit, rather than the design work condition or unstable economic condition. Take a piece of continuous and stable data, and transform the data type of normal distribution to meet the CP and CPK calculation conditions.

4. Analysis of application effect of SPC technology in a power plant in Hubei Province

According to the Six Sigma quality control standard based on the statistical process control technology, the criteria are sorted, and the comprehensive optimal condition of the unit under this condition is selected, and the operation parameters at this time are taken as the key parameters in the actual operation adjustment. According to the main steam pressure data of a power plant in Hubei Province in different periods under the same boundary conditions (before and after the guidance of six sigma control standard), the 0.995 quantile x0.995, the median x0.5 and the 0.005 quantile x0.005 are calculated, and the CP and CPK values are calculated, as shown in the following table. It is shown that:

| Time Parameter         | stable condition | unstable condition |
|------------------------|------------------|--------------------|
| X0.995                 | 22.554474        | 22.806242          |
| X0.5                   | 22.311861        | 22.229462          |
| X0.005                 | 22.0207214       | 21.572573          |
| Set main steam pressure| 22.199574        | 22.199574          |
| Range of fluctuation   | 0.5              | 0.5                |
| USL                    | 22.699574        | 22.699574          |
| LSL                    | 21.699574        | 21.699574          |
| CPU                    | 1.598071826      | 0.815062936        |
| CPL                    | 2.103070142      | 0.806662922        |
| Cpk                    | 1.598071826      | 0.806662922        |
| Cp                     | 1.873527173      | 0.810590199        |
From the two groups of curves and the calculated CP and CPK values, we find that the larger the CP and CPK values are, the smaller the main steam pressure fluctuation of the unit is, and the more stable it is. Based on this discrimination condition, the boundary judgment and economic judgment are carried out for the selected stable conditions, and the optimal guidance adjustment scheme is selected for the economic conditions according to the boundary conditions.

In this paper, the statistical process control technology based on the study of dynamic process capability of thermal power plant operation is applied to distinguish and guide the operation of thermal power unit. The performance characteristics of the working condition after use are that the fluctuation of the main operating parameters is the smallest when the unit has local disturbance, that is, the anti-interference ability of the system is the strongest, the adjustment amount of the long-term variable working condition operation of the unit is the smallest, and the comprehensive energy consumption is the best.

5. Conclusion
In this paper, the mark of judging the production quality of thermal power plant by Motorola quality control standard six sigma process capability is put forward and the practical application effect is achieved.
In the traditional three-level small index evaluation system, the coal consumption at a certain time is the lowest, because the lowest coal consumption at that time does not necessarily make the system in the optimal operation state for a long time, it cannot avoid the over temperature or over pressure at the next time, which is not conducive to the stable operation of the unit group.

Under the existing equipment conditions of thermal power plants, based on the idea of 6 σ statistics, the statistical process control technology is applied to the operation of thermal power units, which improves the anti-interference ability of the whole system, realizes the control concept from target process control to factor control, comprehensively considers the boundary factors such as safety, economy and environmental protection, realizes stability and sustainability, and finally Reach the best in a long time. It has carried out the cultural concept of "providing inexhaustible power for the sustainable and healthy development of the enterprise with efficient operation and management".

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