MATEC Web of Conferences **100**, 05013 (2017) DOI: 10.1051/matecconf/201710005013
GCMM 2016

A Gas Scheduling Optimization Model for Steel Enterprises

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Abstract. Regarding the scheduling problems of steel enterprises, this research designs the gas scheduling optimization model according to the rules and priorities. Considering different features and the process changes of the gas unit in the process of actual production, the calculation model of process state and gas consumption soft measurement together with the rules of scheduling optimization is proposed to provide the dispatchers with real-time gas using status of each process, then help them to timely schedule and reduce the gas volume fluctuations. In the meantime, operation forewarning and alarm functions are provided to avoid the abnormal situation in the scheduling, which has brought about very good application effect in the actual scheduling and ensures the safety of the gas pipe network system and the production stability.

Keywords. Steel enterprises, gas scheduling optimization, process state calculation, soft measurement, operation forewarning.

1 Introduction

Steel industry is one of the energy-intensive industries which shares 10% total energy consumption of the national economy and the energy cost of steel enterprises takes about a third of the production cost [1]. High energy consumption not only increases the cost of steel products but brings about much pollution and emission. In practice, due to the changes of factors such as the production and maintenance schedule, gas production and consumption keep changing. Gas system exhibits imbalance in a short time which results in low gas utilization rate. The aforementioned problems need to be solved by optimizing the gas system scheduling.

Recently, researches about the energy optimization model of steel enterprises have been carried out extensively. Ref. [2] described the relationship between the various units of gas pipeline network as the form of matrix then modeled and solved the problem with partial least squares regression method. Ref. [3-5] proposed the gas supply and demand forecast model of steel enterprises and realized the gas tank safety control and integrated power generation benefit maximization.

Although the above algorithm is theoretically reasonable and the simulation results are satisfactory, the instantaneity and effectiveness of are not enough for the gas scheduling. In this research, according to the characteristics of gas pipeline network system and the actual scheduling process in steel enterprises, the generation and consumption of gas are scientifically and effectively estimated and the by-product gas system is modeled and analyzed. Then the gas scheduling optimization model is proposed according to the rules and priorities. The proposed model is of great significant in reducing the gas loss and balance of the whole gas system.

2 Problem description

The by-product gas system of steel enterprises is mainly composed of blast furnace gas and converter gas system. The gas system is illustrated in Figure 1:

The basic data of energy control system of steel enterprises is relatively consummate, telephone scheduling has been replaced by centralized scheduling. However, balance scheduling operation is still dependent on the experience of scheduling staff. Gas scheduling is based on the expertise of scheduling staff which is highly influenced by human intervention besides the following problems:

(1) When the process system state changes, the gas consumption variation is very larger. The gas will exhibit large fluctuation and loss if the scheduling center is not informed timely.

(2) At present, the measured value of some gas meter different from the actual value. For examples: the gas consumption power plant boiler is not accurate, the gas generation meter of blast furnace is not accurate in small scale range.

(3) When there is a large fluctuation of gas, the extra blast furnace gas is usually released to maintain the pipe network pressure. For examples: re-blowing of blast furnace after maintenance will cause large amount of gas, maintenance of rolling accident will decrease the gas consumption sharply.

(4) There are no operation forewarning and alarm functions in existing gas scheduling. For example: when there is gas release while the power plant boilers capable to consume the gas and the boiler is running normally, the boiler load should be raised to reduce gas release.

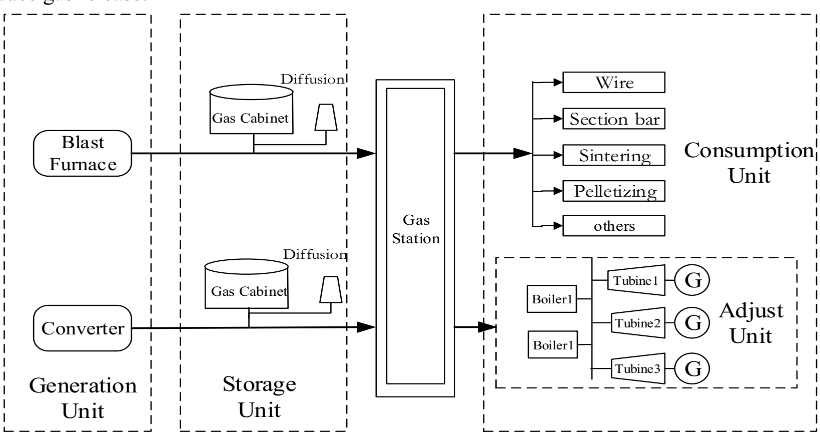

Fig. 1. The gas system diagram.

3 Gas scheduling optimization design

According to the features of steel enterprises' gas pipe network, the gas scheduling optimization is proposed based on the energy control system, including:

(1) Process state calculation

By the calculation of process states including blast furnace, cowper stove, steel rolling furnace, sintering, thermal power plant, etc., the switching state of the main gas units are judged so that the scheduling staff can see each process state in real time.

(2) Gas soft measurement

When the process states change, the gas consumption of the current states can be estimated according to the features of the gas system. Then the fluctuation quantity of gas consumption caused by process states change can be calculated.

(3) Building up the gas scheduling optimization model based on the rules

According to the effective scheduling rules, the fluctuating range and the consumption amount of gas are determined. Then the gas can be scheduled according to the priorities.

(4) Forewarning and alarm of scheduling rules

According to the scheduling guidelines, forewarning and alarm will be given against violation of scheduling rules to correct the unreasonable operation of scheduling staff.

The optimized scheduling process is illustrated in Figure 2:

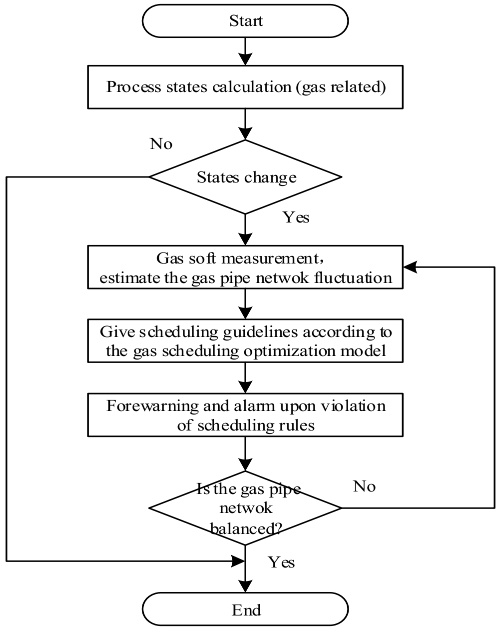

Fig. 2. The gas scheduling optimization diagram.

3.1 Process states calculation

The processes related to the gas production and consumption, including sintering, blast furnace, converter, steel rolling furnace, etc., are calculated. When the states change, the scheduling staff will be informed by warning so that the real-time process states can be taken into account for gas scheduling optimization. Take the sintering process as an example, the state logic is shown in Figure 3:

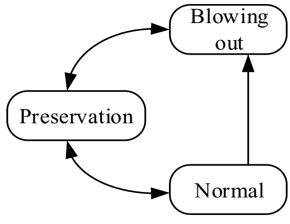

Fig. 3. Sintering state logic.

The sintering ignition furnace have three operation states including ignition, preservation, and blowing out. The dynamic model of gas consumption is shown below:

$$g(t)=\begin{cases} Q_n, & t\in \text{normal production} \\ Q_p, & t\in \text{preservation} \\ 0, & t\in \text{blowing out} \end{cases} \tag{1}$$

where: Q_n is the gas consumption of the sintering furnace in normal state, Nm^3/h; Q_p is the gas consumption of the sintering furnace in preservation state, Nm^3/h.

The state calculation logic of the sintering ignition furnace is described below:

(1) Blowing out: the gas consumption of sintering furnace is below the setting value (such as 100 m3/h) or the average firing temperature of sintering furnace is below the setting value (such as 400 ˚C), and the temperature rate is 0 m/min.

(2) Preservation: the average ignition temperature of ignition furnace is above the setting value (such as 400 ˚C), and the temperature rate is 0 m/min.

(3) Ignition: the temperature rate of sintering furnace is above the setting value and the average ignition temperature of ignition furnace is above the setting value (such as 900 ˚C).

3.2 Gas soft measurement

The measurement accuracy of gas meter is bad considering small range measurement and the impurities and soft measurement should be carried out to calculate and correct the gas production. At the same time, when the process states change, gas production and the gas consumption of power plant boiler can be calculated according to the correlations between the processes' data, so that the scheduling staff can be aware of the pipeline network fluctuating quantity. When the deviation between estimated and actual value is intolerant, warning will be given to remind the scheduling staff to optimize the scheduling of gas consumption. Take the gas consumption of power plant boiler as an example, the algorithm model of gas soft measurement is introduced as below.

Regarding the gas consumption calculation of single boiler, the boiler heat absorption is first calculated according to the main steam enthalpy rise and gas flow, then the boiler heat release can be obtained from the calorific value of gas. Finally, the gas consumption per hour can be calculated based on the heat efficiency of boiler:

$$V_G = \frac{(H_{zzq} - H_{gs}) * Q_{zzq} * 1000}{\eta H_m} \quad (2)$$

where: V_G is the gas consumption of boiler (m^3/h); H_{zzq} is the main steam enthalpy of gas boiler (KJ/kg); H_{gs} is the water feed enthalpy (KJ/kg); Q_{zzq} is the main stream flow (t/h); η is the heat efficiency of gas boiler; H_m is the calorific value of gas (KJ/m^3) which can be obtained from the calorific value analyzer.

3.3 Function description of scheduling based on rules

In this research, gas scheduling algorithm is designed based on the rules, which includes:

3.3.1 Scheduling priority division

In order to further utilize the gas resource and satisfy the needs of actual production, each unit of the gas system is simplified and the units are divided into three categories according to the applications as shown in Table 1:

Table 1. Categories of the users.

Categories	Contents
Type 1	Users must be ensured in main production.
Type 2	Users with small correlation between main production.

 DOI: 10.1051/matecconf/201710005013

Type 3	Buffer and adjust the user.

Set the scheduling priority for each type of user. According to the priority ranking, gas supply of some users are suggested to be cut off upon gas shortage. The definition of priority can be given by the user. The priorities are represented by integers, the greater value means that the user is less important and the adjustment is faster, which will be adjusted to relieve the gas pipeline pressure when the gas is not balanced.

3.3.2 Scheduling rules description

The type 3 users are first adjusted upon gas fluctuation, type 1 and 2 users will be adjusted when the adjustment range of type 3 is beyond. Specific scheduling principles depend on the fluctuation quality, unit of action, state of the consumption user, and the adjustment ability of the unit user, the purpose of adjustment is the balance between production and consumption of gas. Negative fluctuation quality means gas oversupply and the consumption of type 3 users should be increased to balance the gas supply. If the fluctuation quality is in the adjustment range of a certain type of users, the users of high priority value will be adjusted. When the fluctuation quality is beyond the adjustment range of a certain type of users the adjustment will minimum the number of adjusted users. For gas oversupply, the gas consumption of type 3 users will be adjusted to the maximum value and the extra gas will be released. For gas undersupply, the gas consumption of type 3 users will be adjusted to the minimum value and some users will be cut off according to the priorities.

3.3.3 Scheduling function process

The gas medium of the new district includes blast furnace gas (BFG) and Linz-Donawitz process gas (LDG). The specific algorithm process depends on the gas medium as illustrated in Figure 4:

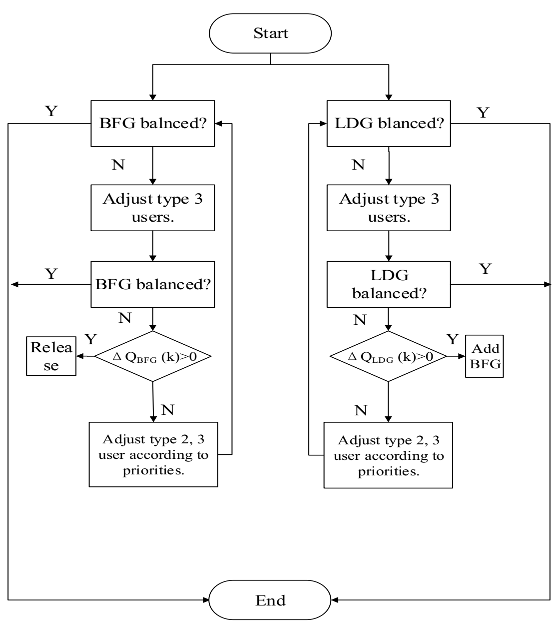

Fig. 4. Scheduling process diagram.

The residual fluctuation quality $\Delta Q_{BFG}(k)$, $\Delta Q_{LDG}(k)$ represent the residual fluctuation beyond the adjustment range of blast furnace and converter after the adjustment of three types of users.

3.4 Scheduling forewarning and alarm functions

Based on the scheduling results of model calculation in the previous section, forewarning and alarm will be given against violation of scheduling rules to correct the unreasonable operation of scheduling staff.

3.4.1 Scheduling forewarning

During the gas scheduling, the scheduling staff should timely response to the changes of pipeline network system. The forewarning functions are designed to remind about some significant operations and help the scheduling staff to make actions in advance. For examples:

When there is a blast furnace plan damping down, it is suggested to maintain every gasometer (blast furnace, converter) at a high counter, the unsatisfied counters will result in forewarnings.

(1) When the blast furnace gas production sharply decreases, or the variation rate beyond the set value, forewarning will be given.

(2) At the beginning of the converter blowing (or the blowing step 1), it is suggested to recover the converter gas and check the counters of the gasometer so that to improve the converter gas recovery rate.

3.4.2 Scheduling alarm

Violation of scheduling rules will be displayed and prompted on screen in the form of alarm, for example:

(1) Power plant boiler has the ability to consume and operates normally while there is gas release.

(2) There is gas release while the gas tank have space of absorption.

(3) The CO and O2 concentration of converter gas are in safe range while the gas is not recovered when possible.

4 Application effect

Regarding the specific gas scheduling problems of steel enterprises, the aforementioned model is applied to the following two practical production cases: case 1 represents a certain normal production case, case 2 is based on case 1 while the profile production line is shut down due to unplanned maintenance. The gas optimization results are shown in Table 2.

Table 2. Gas optimization of different production cases.

Process	Case 1			Case 2		
	Production (t/h)	Blast furnace gas (m3/h)	Converter gas (m3/h)	Production (t/h)	Blast furnace gas (m3/h)	Converter gas (m3/h)
Sintering	298	15830	0	298	15830	0
Puddling	272	405782	0	272	405782	0
Steelify	235	4255	7270	235	4255	7270
Bar	152	64865	0	152	64865	0
Profiles	65	10980	0	0	0	0
Power plant		192905	15745	0	203885	15745
Release		0	0	0	0	0

Table 2 indicates that the energy supply of each process has been timely redistributed by the scheduling optimization model when the production case changes. There is no gas release after the optimization which confirms the validity of the proposed rule-based gas scheduling optimization model. In addition, the forewarning and alarm functions improve the fault treating ability of scheduling staff.

5 Conclusions

The proposed gas scheduling optimization functions take the different characteristics and technical requirements of various gas units of steel enterprises in practical production process in account. The rule-based gas scheduling optimization model has been established. Algorithm models of Process state calculation and gas consumption soft measurement have been proposed to deal with specific scheduling problems. Based on the rules of scheduling optimization, the scheduling staff are timely informed about the gas consumption state of various processes then schedule gas in time and reduce fluctuation quality. The model can effectively avoid the abnormal situations by forewarning and improve the safety of the gas tank and the stability of production, which has obtained well application effect in practice. This model is of great theoretical and practical significance in reducing gas release and realizing the balance of the whole gas system.

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