Research and system design of energy dynamic balance and optimal scheduling of iron and steel enterprises

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Abstract. The steel industry is an important part of the secondary industry, and it has a strong role in promoting economic development. However, the steel industry is a high-energy-consuming industry, which has large energy consumption and waste of resources. Therefore, it is very important to do a good job of energy conservation and emission reduction in iron and steel enterprises. Therefore, this paper studies the dynamic energy balance and optimization model of iron and steel enterprises firstly, and further designs and operates the system based on this. It is show that the model has good practicability, which can balance the pipe network and reduce emission.

1. Research background

1.1. Literature review

The optimal scheduling problem of steel enterprises mainly includes two aspects. Firstly, the balance and stability of the energy system is controlled by Manual operation. Secondly, the difference in unit efficiency and the difference between peak and valley electricity prices and valley electricity prices are used to adjust generator energy in different periods to maximize power generation efficiency [1]. He Dongfeng et al. obtained the optimal solution of the model by LINGO, and the production scheduling plan of the rolling unit was obtained under the optimal scheduling conditions under the optimal utilization of electricity, steam and gas, thereby guiding the actual production. In addition, through example analysis, the scheduling scheme can achieve the optimal distribution of gas, electricity, and steam, verifying the effectiveness of the model [2]. Ren Na and others took an office building in Xi’an as an example, and used models and algorithms to obtain the optimal matching and scheduling strategy under the minimum energy cost of the integrated energy system. The results show that by optimizing the system capacity allocation, the unit price of electricity and gas can be reduced, the multi-stage heat storage can be reduced, the solar cell utilization rate can be improved, and the economic effect of the plant can be effectively improved [3]. India has also made some progress in establishing an energy centre for Steel Industry, Ramani B. researched that BHILAI steel of India integrates energy monitoring and energy modelling into a unified energy management system [4]. In 2013, Li Hongjuan etc. researched that the frequent fluctuation of residual by-product gas in iron and steel complexes had a serious impact on the energy consumption and gas balance of self-provided power plants, and the established mechanism model was difficult to forecast [5]. Liang Qingyan and
others carried out simulation verification on 4 types of agents in the steel industry, and proposed task allocation mechanisms and upstream and downstream collaboration mechanisms between agents. The results show that the constructed model can effectively solve the coordination problem between steelmaking and casting in actual scheduling, and can improve production efficiency [6]. Xiao Li et al. researched that according to the characteristics of gas energy flow system, an energy flow view description model is established and the linear optimization model of gas energy flow density is given; then, the feasibility of the optimized method is verified by simulation with actual data of a steel plant [7].

1.2. Purpose of research
As a big energy consumer, China is at the forefront of energy consumption. In recent years, with the rapid economic growth, domestic energy consumption has continued to increase, which has led to rising energy prices and a situation of energy shortage. In order to meet social production needs, it is difficult for power companies to produce electricity, and non-renewable resources such as coal are disappeared in long term. At the same time, according to statistics, domestic industrial energy consumption accounts for more than 70%, which is higher than the world average [8]. The major causes of energy consumption in iron and steel enterprises mainly include factors such as backward production technology and untimely update of production plans. Therefore, it is of great practical significance to study the energy balance and optimization of iron and steel enterprises.

2. Optimal scheduling model
2.1. Model building
The dynamic energy balance and optimal scheduling model for iron and steel enterprises is composed of a multiple objective function and a constraint of equality or inequality. The specific solution is the process of finding the extreme value of the objective function [9]. Therefore, this paper transforms the optimized scheduling model into a non-linear function. Specifically, due to the current heat storage capacity or buffer capacity of the pipe network, the pipe network will only be released when the upper limit is reached. Therefore, the relationship between the spread of the pipe network and the imbalance in the production and consumption of the pipe network is expressed:

\[ \max J_3 = \sum_{k=1}^{N_k} \sum_{i=1}^{N_i} \left( \varphi_{sk} E_{sk}(t_i) - \varphi_{sk} E_{sk}(t_i) - \varphi_{sk} \rho_{mk} E_{mk}(t_i) \right) \]

The above formula mainly includes three objective functions: minimizing the amount of pipe network release, minimizing the amount of external energy and minimizing the amount of energy purchased. In order to clearly express the objective function that minimizes the release of the pipe network, the objective function is piecewise linearly expressed. At the same time, with economic maximization as the research goal, the final objective function is obtained:

\[ \max J_3 = \sum_{k=1}^{N_k} \sum_{i=1}^{N_i} \left[ \varphi_{sk} E_{sk}(t_i) - \varphi_{sk} E_{sk}(t_i) + \varphi_{sk} \rho_{mk} V_i(t_i) \right] \]

In the formula, \( \varphi_{sk} \) is the weight coefficient of network balancing, can not only reflect the price factor, but also make the process of solving the piecewise linear function of the energy release in the original problem automatically satisfied. Therefore, after excluding this formula, a linear programming model related to the scheduling problem can be obtained.
In summary, the mathematical programming problem after transformation is expressed by the objective function:

$$\max J_3 = \sum_{i=1}^{T_N} \sum_{k=1}^{N_J} \left[ \lambda_n \hat{E}_n^d(t_i) - \lambda_n \hat{E}_n^b(t_i) + \frac{\theta_n}{K_i} \psi(t_i) \right].$$

Among them, the constraint condition is that for the unit model $D$, it is set to correspond to the energy pipeline network as $I$, $1 \leq I \leq N_p$, and the corresponding energy pipeline network for each period $t_i$. And $1 \leq i \leq T_N$ has the following constraints:

The energy ratio in the unit model is binding:

$$\lambda_{D(i)}^{(min)} \leq \lambda_{D(i)}(t_i) \leq \lambda_{D(i)}^{(max)}.$$  

Constraint of energy consumption of unit model:  

$$x_{D(i)}^{(min)} \leq x_{D(i)}(t_i) \leq x_{D(i)}^{(max)}.$$  

2.2. Solve

The set of all feasible solutions for a linear programming problem has a limited number of vertices. This indicates that the optimal solution of the linear programming problem must be obtained at the apex. Methods for obtaining linear mathematical programming problems usually include the simplex method, the interior point method, and the exterior point method [10]. Among them, in the actual solution process, the main method is the simplex method. In the course of a specific solution, it is necessary to start with one feasible solution in the feasible region, and then move to another feasible solution according to the relevant criteria of the problem until the objective function reaches the maximum value. However, after adding variables in the actual solution process, the simplex method cannot solve the optimal solution. In the actual calculation process of the dynamic imbalance optimal scheduling model for iron and steel enterprises, hundreds of scheduling units are involved, which are subdivided into more than a dozen fields, which have more constraints and higher time requirements, and the simple solution method cannot meet this requirement. Yes, so a more effective solution is needed. Primal dual interior point method is a linear programming algorithm, which can gradually approach the optimal solution from the feasible region, and can solve large-scale linear programming problems. Therefore, the double interior point method is used to solve. The specific calculation process is as follows:

Optimization problem handling: $\min f^T x$.

Constraints are $Ax = b$  

$0 \leq x \leq u$.

Among them, $f$ is the objective function, $x$ is the decision variable, $A$ is the constraint matrix, and $b$ is the constraint constant. In order to obtain the optimal solution, increase the relaxation variable, the equation is as follows: $\min f^T x$. Constraints are $A_{x+u} = b$. On this basis, the dual problem is further established in the following form: $\max b^T y - u^T w$. Constraints are $A_{v+u}^T \cdot y - w + z = f$.  

Where $y$ and $w$ are dual problem variables, and $z$ is a dual relaxation variable. The optimal conditions for obtaining a linear problem are:

$$F(x, y, z, s, w) = \begin{bmatrix}
A_{x-b} \\
x+s-u \\
x_i z_j \\
_s w_j
\end{bmatrix} = 0.$$
In the above formula \( x \geq 0, \ z \geq 0, \ s \geq 0, \ w \geq 0 \), \( x_i^z, x_i^s, x_i^w \) are combined product factors, and \( x_i^z = 0 \) and \( x_i^s = 0 \) are additional conditions for linear problems. \( x^T z + s^T w \) is duality, which is mainly used to measure the residual amount when the remainder of all combination products.

### 2.3. Optimization strategy

The internal systems of iron and steel enterprises are relatively complicated, and abnormal situations often occur during operation. Therefore, to prove that the enterprise is operating normally, the enterprise must add random emergencies to cause errors in the energy optimization strategy, adopt a moving window event-driven rolling optimization strategy, and improve the scheduling optimization model to prevent emergencies.

When the energy equipment of a steel enterprise has problems, it should be determined the type of the corresponding unit firstly, then modified the constraint conditions, and further deleted the decision variables which related to the damaged equipment in the objective function. When meet temporary task in a steel enterprise, it should be changed the period, constraints and the objective function of the corresponding unit. The steps as follows:

1. The first step is to determine the length \( A \) of the scheduling window.
2. The second step is to obtain the initial value \( A \) of the initial energy buffered pipe network. In this process, if there is damage to the equipment, the corresponding constraints and objective functions should also be modified during production. Among them, the objective function weight is formulated according to the energy purchase price and external sales price.
3. The third step is to generate the objective function. This model mainly refers to the energy optimization and scheduling model during the time of the accident and the window length to obtain the scheduling decision model.
4. The fourth step is to execute scheduling decisions.
5. The fifth step is to determine whether a damage event has occurred during the execution of the window scheduling decision process. If there is a damaging event, go to the first step, if there is no damaging event, continue to execute.
6. The sixth step is to execute the scheduling decision within the window to determine whether the entire scheduling termination time is reached. If the termination time is reached, the optimization adjustment is terminated. If the entire scheduling termination time has not been reached, go to the first step.

This optimization method based on moving window time maintains the principle of optimization, but during the entire event process, instead of performing global optimization, it optimizes the production time of iron and steel enterprises over time. It can be seen that rolling optimization can well adapt to the window range when adapting to the scheduling optimization strategy, and has good adaptability to accidents. The most important thing is that the equipment can be adjusted because of modeling errors.

### 2.4. Strategic evaluation

After optimizing the objective function for scheduling, you can evaluate the objective function and other objective functions as the final evaluation function, provide corresponding decision support, or modify the optimization scheme. Among them, the evaluation of the optimization plan mainly includes predictive evaluation and post evaluation. Predictive evaluation is mainly measured when no scheduling is performed. By studying different pre-scheduling models, the final scheduling strategy can be determined. Moreover, we need to study each model at different time periods and then determine the optimal scheduling scheme. The reference standards for future evaluations mainly include the energy consumption of steel, gas emissions, and loss statistics of energy equipment and related production equipment.
3. System design and implementation

At present, this article theoretically studies the energy balance and optimization of iron and steel enterprises. Based on this, the energy balance and optimization system of iron and steel enterprises is further designed and implemented.

3.1. System structure

The main purpose is to improve the comprehensive utilization efficiency of energy while ensuring the safe operation of iron and steel enterprises. Specifically, the system structure mainly includes a production database, external parameters, a model library, an energy network structure, an energy information prediction module, a balance optimization scheduling module, and a result evaluation correction model.

After determining the framework structure, you need to design the internal modules of the system. These modules are mainly divided into four modules: energy prediction, balanced scheduling, and auxiliary functions and system settings. Among them, energy forecasting mainly includes energy production and sales forecasting modules, balanced scheduling mainly includes temporary parameter input processing modules, optimization and post-processing modules; auxiliary modules are mainly decision result output modules. The system module mainly includes a parameter input module.

3.2. Database design

The database is the core and foundation of the dynamic balance optimization scheduling system for iron and steel enterprises. It mainly stores data such as unit model parameters and scheduling results. There are two main methods for storing procedures in the database. The first method is to write and query, modify, and add directly to the application, and then send commands and process results to the database. The other is to create stored procedures in the database, using the application stored procedures to access the database. The advantages of using stored procedures are:

First, you only need to store the data once during the creation process, and you can use it unlimited times later.

Second, it has faster execution speed. Program execution for a large amount of data is faster than writing database access code directly in the program.

Third, reduce network traffic. For a large number of SQL statements, the program execution can be implemented separately without sending multiple times in the network.

3.3. Software implementation

As the decision support of the internal energy management system, the energy balance and optimized scheduling system of the iron and steel enterprise can realize the data exchange between the program and the data server, and provide users with more efficient services. Therefore, this paper designs a system based on the B/S model framework. At the same time, the system in this article was developed using Microsoft .net technology. For the B/S structure of web browsing, the description of each module is shown below.

Web layer. This article relates to the Web layer as a presentation layer, which can provide clients with access to corresponding programs. Specifically, the business layer is mainly used to complete business processing. The Web is mainly composed of ASP.NET Web forms and code, using HTML to provide user operation pages. In the web-based application system, security authentication is more important, so in order to ensure the normal operation of the system, on the basis of EMS, ePass authorization authentication is performed on the web in the energy management system.

Business Layer. The business layer is the core of the entire EMS basic energy management system. It mainly processes the calling model through data access, finally returns the results, and displays it in the web layer.

Data access layer. The system mainly uses stored procedures to implement data operations, and accesses between different databases through packaging technology, and optimizes specific data to ensure that the database can run efficiently.
3.4. Functional model
According to the planned tasks and equipment functions of various processes in the production process of iron and steel enterprises, dynamic energy balance and energy saving are the ultimate goals. Among them, the optimized scheduling model mainly includes the following functional models:

System configuration is based on the entire software function, and based on the existing model in the specific production situation of the enterprise as the basic component unit, the process of establishing the equipment connection and energy distribution network topology structure. This system configuration mainly includes two parts: pipe network configuration and unit modeling. Among them, the pipe network configuration is mainly divided into energy type settings, and outsourced and outsourced energy information settings. Unit modeling is mainly to determine the expression of energy supply and demand balance of different units based on the established database.

Energy supply and demand forecast. According to the production tasks assigned to the dispatching units at all levels, energy demand can be forecasted within a specified time. Different supply and demand curves or energy production curves can be drawn according to user needs. It mainly includes predicting the compliance of combined equipment, predicting the classification of energy sources, and predicting the location of gas storage tanks.

Dynamic energy balance optimization. Based on the determination of production tasks and safe production, according to the scheduling goals, the optimal energy scheduling and distribution plan for gas, electricity, and steam is given. Based on the optimal scheduling, users can make corresponding amendments to the scheduling results based on the scheduling goals, and readjust the scheduling scheme in conjunction with constraints.

3.5. Result analysis
Combined with the previous chapter to build an optimal scheduling model, this chapter designed the system to execute the system.

![Figure 1. Scheduling results.](image)

Figure 1 shows under the premise of maintaining normal operation, the power pipeline network can effectively control the stability of the load. Under this premise, takeaway can be realized. It can be seen that the scheduling scheme can meet the two objective functions of pipe network balance and minimum release. Similarly, steam and natural gas as well as gas storage tanks are within normal limits.
4. Conclusions
This paper introduces the energy balance and optimal scheduling problems and system design of steel enterprises in detail, gives the optimal scheduling model, system design and software implementation. Through step-by-step, layered, and rational design of the interface design, meticulous work on the entire system was achieved by designing the system, and the process from system design to implementation was finally completed. It provides theoretical support for iron and steel enterprises of dynamic energy balance.

Acknowledgement
The research is supported by Humanities and Social Sciences Foundation of Chongqing Education Commission (No. 20SKGH352).

References
[1] Xu H Y and Yang T 2019 Metallurgical Automation 44 35
[2] He D F, Liu P Z and Feng K 2019 China Metallurgy 29 75
[3] Ren N, Wang Y Q and Xu Z L 2018 Power System Technology 44 3504
[4] Li H J, Wang J J and Wang H 2013 Journal of Process Engineering 13 451
[5] Li H J, Wang J J and Wang H 2013 Journal of Iron and Steel Research 257 11
[6] Liang Q Y and Sun Y G 2019 Computer Applications and Software 36 255
[7] Xiao L, Gang Z and Qi Z 2021 Sustainable Design and Manufacturing 2020 (KES-SDM 2020) 475 84
[8] Ji C M, Ma H Y and Wu J J 2019 Journal of Hydraulic Engineering 50 535
[9] Wang X L 2019 Computer and Digital Engineering 47 1678
[10] Nie L, Zhang G H and Wang X G 2019 China Mechanical Engineering 30 1492