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Research Article

An Optimization Model Based on Electric Power Generation in Steel Industry

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Electric power is an important energy in steel industry. Electricity accounts for roughly 20% to 30% of the gross energy consumption and costs about 10% of the gross cost of energy. In this paper, under the premise of ensuring the stability of energy supply and the normal production safety, the mathematical programming method and the dynamic mathematical optimization model were used to set up the surplus gas in the optimal allocation among the buffer users and steam production dispatching for the production equipment. The application of this optimization model can effectively improve the energy efficiency and the accuracy of power generation, making full use of secondary energy and residual heat. It also can realize the rationalization of the electricity production structure optimization which can effectively reduce the flare of the gas and steam on one hand, and save energy and decrease production cost on the other.

1. Introduction

From the viewpoint of socioeconomic role of steel enterprises in the future, the manufacturing process of steel plants should fulfill three principal functions: (1) the function of steel product manufacturing; (2) the function of energy conversion; (3) the function of waste treatment and recycling [1, 2]. Integrated iron and steel enterprises (IISEs) need large amount of electricity power which causes higher cost. IISEs have a lot of residual heat and energy used for power generation. Carrying out scientific and reasonable electricity production and outsourcing strategy has a very important significance for steel enterprises to implement the mission of saving energy and emission reduction, minimizing the cost and improving the efficiency. Many researchers and scholars have studied the electric power system (EPS) network of the IISEs. They have achieved many fruits but mostly focusing on technology of electrical power generation [3–6] and electrical power dispatching [7–9] of IISEs. Ding et al. [3], based on the statement of the running situation of different types power plants and the analyzing of economy, bring forward the influence actors and suggestions which should be considered during a new developing thermal power plant. Zhou [4] presented the low-pressure saturated steam generation engineering of Shougang Qian'an Iron&Steel Co., Ltd, discussed effective modes of utilizing residual steam of metallurgic enterprises and better economic benefit. Fan [5] presented a few relatively mature technical schemes in electric power generation with residual heat as well as technical and economic analyses and cases. Li et al. [6] stated that by building the distributed power generation, the residual heat and energy can be recovered, transported, and reused as close as possible, and so, as to make the electric power self-support. It can be concluded that the electric power self-support or even outer supply can be completely realized through residual heat and energy recovered by distributed power generation. Yang et al. [7] provided the optimal economic management models of autonomous power plant (APP) and large consumer holding APP, respectively, offered the optimal production and distribution plan of APP and the optimal power purchasing scheme of large consumer after administering peak-valley power price by solving profit maximum function of APP and power purchasing cost minimum function of large consumer. The optimal schemes and results offered not only assure APP and large consumer to produce and manage optimally, but also reduce the sell loss of grid to some extent. Huang and Sun [8] carried out to build the simulation models to analyse electrical power system in steel enterprise. The models included consumption model, recycling model, and conversion transmission model, which were built upon the principles of material balance, energy balance, and logical relations held in steel production processes. The simulation has shown that the modeling work has achieved satisfactory result and hence can be expected to become a competent tool serving for energy saving purpose. Zhang et al. [9] proposed a rolling optimal scheduling algorithm, further, to deal with random error of real-time load forecast model, suggesting a compensated rolling optimal scheduling algorithm, and the algorithms were tested on real data; prospective results were obtained. To sum up, for the consideration of coupling relation and optimizing allocation among surplus, steam and electricity had not been reported.

The key problem of self-generating was to maximize recovery of secondary energy to generate electricity in iron and steel works, so coordinated optimizing among gases, steam, and electricity was very important. Instead, taking power as an energy medium, study electricity production dispatching optimization using the optimization theory and system energy saving. Under the background of energy management and energy conservation, this paper was undertook through the analysis of the power production side network and purchased status of IISEs, aimed at minimizing cost and optimal benefit of cost-effectiveness, the power production dynamic coupling model of surplus byproduct gas, steam was established on the basis of the principle and characteristics of self-generating equipment of iron and steel enterprise [10, 11]. It has been put into practice. Its application realizes the reasonable and efficient utilization of original energy, secondary energy, and residual heat and energy resources, thereby enhancing power conversion efficiency.

2. Mathematical Optimization Model of Power Production

2.1. Problem Description. Iron and steel enterprise power system was divided into electric power production side and power consumption side. The power production side included two modes of power production, namely, self-power plant generation and residual heat and energy generation. The corresponding power link and power users' situation of electric power production side and consumption side is shown in Figure 1. The power system of iron and steel enterprise was huge and complex. The sources of power, conversion, transmission, distribution link, and terminal users were numerous, and they almost involved all aspects of the iron and steel production. Therefore, how to make reasonable power production plan and purchase electricity strategy and find out the best proportion of self-generation and outsourcing electricity was particularly important to ensure the normal production and safety of power supply. To simplify the problem, under the circumstance of meeting the demand of power, steam and gas for the normal production, with power production side as the research object, case of gas optimal allocation between buffer users, rigid users, and steam production scheduling between production equipment, were discussed in this paper, researching on electric power reasonable production and optimization problem and exploring the optimal power production and outsourcing strategies. The connotation of the power system optimization has given priority to rigid user's gas and steam demand, and then has dealt with the optimal allocation among the rest of gas, steam, and electricity. Power generation efficiency and energy balance were all needed to be solved. It was maximum recovery residual heat and energy to power generation as far as possible, self-generation increased and outsourcing reduced, and thus saved cost of outsourcing electricity.

2.2. Model Simplification and Assumption. In Figure 1, CCPP is rigid user; CHP, CDQ, sintering residual heat, BOF saturated steam, rolling mill furnace residual heat generation are all buffer users. The steam system is not only sourced from residual heat boiler, but also from the boiler-steam turbine. Boiler-steam turbine produces high pressure steam; CCPP residual heat boiler produces high pressure steam and medium pressure steam; CHP residual heat boiler produces medium pressure steam and low pressure steam; CDQ residual heat boiler produces high pressure steam and medium pressure steam; Sintering residual heat boiler produces medium pressure steam; BOF saturated steam residual heat boiler produces medium and low pressure steam; Rolling mill furnace residual heat boiler produces medium and low pressure steam. In order to increase capacity of self-generating, the medium saturated steam of BOF and the medium steam rolling mill furnace generated electricity.

BFG: blast furnace gas, COG: coke oven gas, LDG: Linz Donawitz gas, CCPP: gas-steam combined cycle power plant, CHP: combined heat and power, TRT: blast furnace top gas recovery turbine unit, CDQ: coke dry quenching, S1: high pressure steam, S2: medium pressure steam, S3: low pressure steam, BOF: basic oxygen furnace, SPPG: self-power plant generation, and RHEG: residual heat and energy generating.

Electric power production side of iron and steel enterprises included a variety of power generation and steam production equipment, and its characteristic parameters were different with each other and were both interrelated and influenced by the gas system and steam system causing the complexity of the actual operation, which brings certain difficulties on optimization modeling. Therefore, in this paper, the following assumptions were put forward for the optimization model.

(1) In the given production conditions, gas rigid user consumption was constant; thus, the model only considered the optimization and allocation of distribution between the gas in a buffer users (gas power generating equipment, steam boiler) and did not consider optimal assignment problem of the gas in rigid users of steel production process.

(2) In the given production conditions, the steam demand was considered as a constant. Thus only optimal scheduling problems of steam in relative generation and power items were studied in this paper.

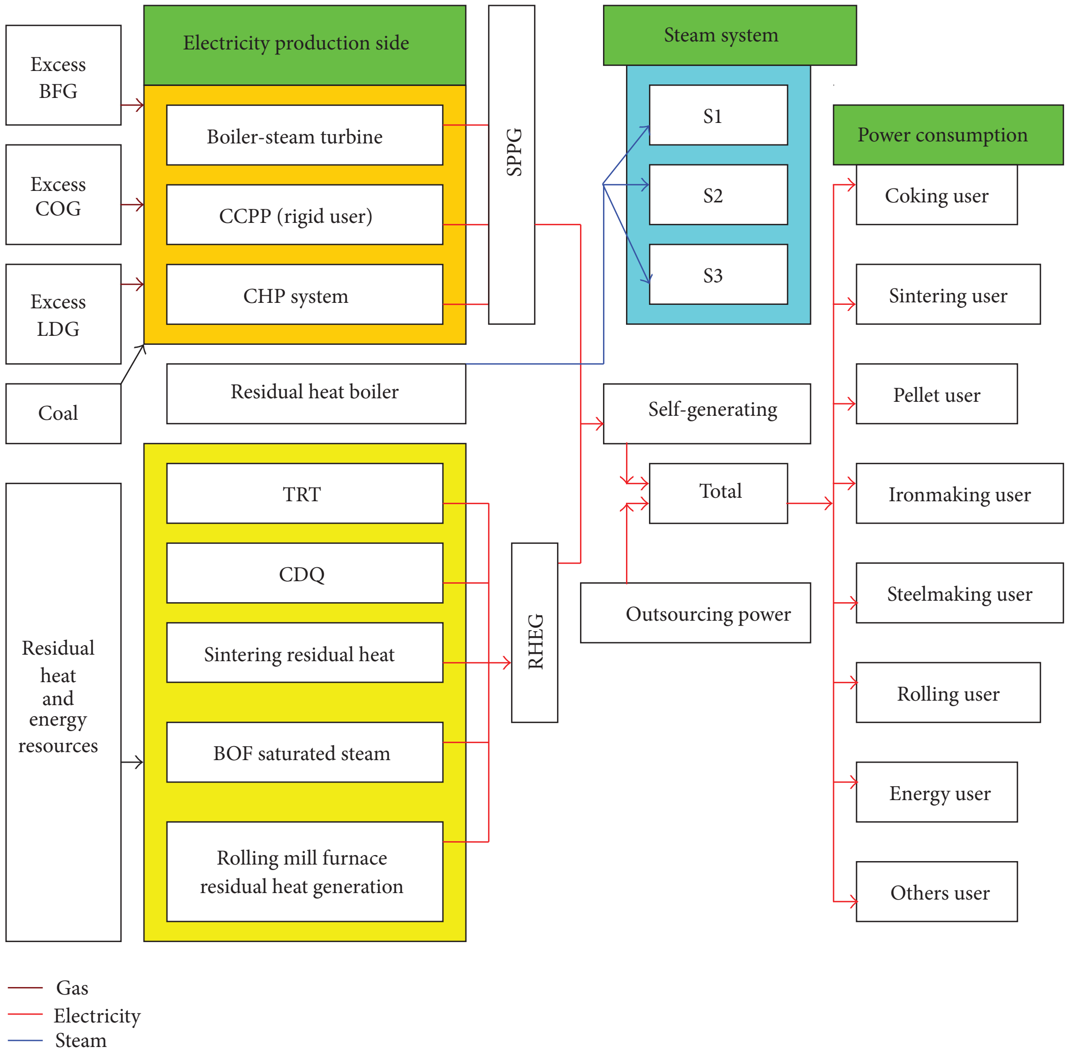

FIGURE 1: The schematic illustration of electrical energy system in iron and steel enterprise.

(3) Actual steel production process, boiler efficiency with boiler load changing (if this efficiency changes can be ignored, the more byproduct gas, the more power generation), but the influence of boiler load on the model optimization result was very small, so it was assumed that boiler thermal efficiency of the model was constant in different time, as well as equipment generating efficiency, residual heat recovery efficiency, and steam turbine efficiency was constant; thus, unit system generating (thermal) efficiency also remained unchanging, steam turbine power generation and extraction quantity also thought to be approximate was of linear relationship.

2.3. Objective Function. Owing to modeling, different time value would cause different mathematical models; thus, we need to control time interval. The model time interval was determined in a unit of time of 3 minutes.

Due to the output regulation limitations of the generating set, unit output value was presented in the form of every 3 minutes instantaneous value in power generation plan; thus, we chose 3 minutes in this paper, and in order to reflect the power network dynamical change continuously and compactly (the time did not include power turn-on time and turn-off time, and in a day work shift. The reason was that the data was more suitable for statistics.) The mathematical expression of this model was reduced a lot of form of juxtaposed, helpful to control model scale.

The model was established considering power reasonable production and outsourcing, with related multicycle mixed integer linear programming (MILP) model of gas and steam. Lee et al. [12] established the MILP model of best decision outsourcing power by the method of mathematical programming in iron and steel enterprise, the results of model application verified its correctness and effectiveness in a few cases and obtained satisfactory energy-saving effect. According to the actual demand, the objective function included outsourcing electric cost, self-generating cost, outsourcing power coal cost, consumption gas cost, and comprehensive cost of steam production and gas diffusion punishment cost system integrated operation cost minimum. The objective function expression was as follows:

$$\begin{aligned}\operatorname{Min} S = &\sum_t C^{\text{ele}}_{\text{buy},t} \cdot E^{\text{buy}}_t + \sum_t \sum_m C^{\text{ele}}_{\text{gen},m} \cdot E^{\text{gen}}_{m,t} \\ &+ \sum_t \sum_m C^{\text{coal}} \cdot f_{m,t} + \int_0^{480} \sum_i \sum_m C^{\text{gas}}_i \cdot F_{m,i,t}\, dt \\ &+ \int_0^{480} \sum_k \sum_m C^{ste}_{m,k} \cdot Q_{m,k,t}\, dt + \int_0^{480} \sum_i C^{\text{Gas}}_i \cdot F^{\text{Gas}}_{i,t}\, dt.\end{aligned} \tag{1}$$

The meanings and units of every parameter in the objective function and constraint conditions were listed in Table 1.

In the condition, the above objective function meets the related constraint. The minimum value of the system comprehensive operation cost was obtained as the optimum value of the function. In the formula, the first item is outsourcing electricity cost, when the self-generating electricity could not satisfy production requirements or when generation set malfunction existence from the external power grid electricity outsourcing cost; the second item is self-generating cost; the third item is purchased power coal cost, ensuring coal-fired boilers or mixed burning gas boiler fuel demand in order to maintain stable heat load; the fourth item is equipment consumption gas cost; the fifth item is comprehensive cost of steam production; the last item is the cost of gas radiation punishment. This paper was argued that gas diffusion cost should be higher than normal use, so the gas punishment cost is larger (the gas diffusion refers to the gas that injection into the atmosphere polluting environment, but power generation with gas was not taken into account, because power generation was beneficial).

2.4. Constraint Conditions. Constraint conditions could reflect the actual operation conditions on the system requirements and system internal relationship between various physical quantities. Combined with actual production situation of iron and steel enterprise, the constraints in the model were energy demand constraints, equipment capacity constraints, and thermal balance constraints.

2.4.1. Energy Demand Constraints. To meet these energy demands and to guarantee normal operation of various processes, each production process in different period on electric power, steam, gas, and other secondary energy demand was different in IISEs. Consider the following.

(1) For power demand constraints, consider

$$\forall t, \quad \sum_m E^{\text{gen}}_{m,t} + E^{\text{buy}}_t \ge D^{\text{ele}}_t. \tag{2}$$

(2) For steam demand constraints, consider

$$\forall k, t, \quad \int_0^{480} \sum_m Q_{m,k,t}\, dt \ge D^{\text{ste}}_{k,t}. \tag{3}$$

Table 1: Meanings and units of variables in the model.

Nomenclature	
Subscripts	
t	Unit of time, h
m	Power generation and steam production equipment
i	Kinds of gas (BFG, COG, and LDG)
k	Kinds of steam (S1, S2, and S3)
Variables	
$C^{\text{ele}}_{\text{buy},t}$	Price of outsourcing electricity in t time point, RMB/kW·h
$C^{\text{ele}}_{\text{gen},m}$	Price of self-generation of device m, RMB/kW·h
C^{coal}	Price of outsourcing coal, RMB/t
C^{gas}_i	Price of i gas, RMB/m^3
$C^{\text{ste}}_{m,k}$	Cost of k steam production device m, RMB/t
C^{Gas}_i	Punishment price of i gas, RMB/m^3
$f_{m,t}$	Consumption of equipment m in t time point, t/h
$F_{m,i,t}$	Consumption of i gas equipment m in t time point, m^3/h
$Q_{m,k,t}$	Production quantity of k steam equipment m in t time, t/h
$F^{\text{Gas}}_{i,t}$	Emission capacity of i gas in t time point, m^3/h
E^{buy}_t	Outsourcing electricity of t time point, kW
$E^{\text{gen}}_{m,t}$	Generation capacity of equipment m in t time point, kW

(3) For gas balance constraints, consider

$$\forall i, t, \quad \int_0^{480} \sum_m F_{m,i,t}\, dt + \int_0^{480} F^{\text{Gas}}_{i,t} dt = B_{i,t}. \tag{4}$$

2.4.2. Equipment Capacity Constraints. All kinds of energy conversion, storage, and consumption equipment had its rated working range, and for each power generation and steam production equipment working range, its upper and lower limit can be set according to the actual situation. Consider the following.

(1) For equipment rated generating capacity constraints, consider

$$\forall m, \quad E^{\text{gen}}_{m,t} \le E_m. \tag{5}$$

(2) For equipment steam production capacity constraints, consider the following.

Equipment Extraction Volume Constraints. They are suitable for the power equipment from steam turbine extraction, such as self-power station boiler and CDQ. Consider

$$\forall m, \quad \int_0^{480} Q_{m,k,t} \le A_{m,k} \tag{6}$$

Equipment Production Volume Constraint. In allusion to the steam boilers, waste heat resource steam production equipment; consider

$$\forall m, \quad \int_0^{480} \sum_k Q_{m,k,t} \le A_m. \tag{7}$$

2.4.3. Thermal Balance Constraints. Electric power production was greatly influenced by gas, steam, steam coal, and residual heat resource in iron and steel enterprise, and they were interrelated with and influenced by each other, so through establishing approximate thermal balance relation of equipment to optimal dispatching relationships were obtained. The electric power production system consisted of self-generating station power generation equipment and residual heat power generation equipment. Consider the following.

(1) For thermal balance constraint of self-generating link, consider

$$\forall m, \quad \sum_t E_{m,t}^{\text{gen}} \cdot h^{\text{ele}} + \int_0^{480} \sum_k Q_{m,k,t}\, dt \cdot h_k^{\text{ste}} = \eta_m \left(\int_0^{480} \sum_i F_{m,i,t} \cdot h_i^{\text{gas}}\, dt + f_{m,t} \cdot h^{\text{coal}} \right). \tag{8}$$

(2) For thermal balance constraint of waste heat and energy recovery generation link, consider

$$\forall m, \quad \sum_t E_{m,t}^{\text{gen}} \cdot h^{\text{ele}} + \int_0^{480} \sum_k Q_{m,k,t} \cdot h_k^{\text{ste}}\, dt = \eta_m \cdot R_{m,t}. \tag{9}$$

(3) For thermal balance constraint of steam boiler, consider

$$\forall m, \quad \int_0^{480} \sum_k Q_{m,k,t}\, dt \cdot h_k^{\text{ste}} = \eta_m \cdot \int_0^{480} \sum_i F_{m,i,t}\, dt \cdot h_i^{\text{gas}}. \tag{10}$$

In the above formulas η_m is system power generation efficiency for power generation equipment and is system thermal efficiency for steam production equipment; $R_{m,t}$ represents different meanings in recycling links of residual heat and energy resource; for example, in CDQ, sintering, converter, and heating furnace, respectively, it represents the red coke sensible heat, sinter flue gas sensible heat, converter flue gas sensible heat, and heat furnace flue gas sensible heat.

2.4.4. Relation Constraint between Steam Turbine Unit Power Generation and Extraction Quantity. Steam turbine is an important means to adjust steam and power balance in the system. The front of assumptions was a linear relationship between steam turbine power generation and extraction quantity. Consider

$$\forall m, t, \quad \sum_t E_{m,t}^{\text{gen}} + \int_0^{480} \sum_k q_k \cdot Q_{m,k,t}\, dt = E_m^{\text{gen}} \cdot a. \tag{11}$$

Among them, q_k is steam discount coefficient of power; $0 \le a \le 1$ is used to determine the load of steam turbine.

2.4.5. Adjustment Range Constraint of Gas Buffer User. Boiler is one of the gas buffer users in iron and steel enterprises and its kinds are various. Among them, pure burning gas boiler and coal powder boiler of mixed burning gas are the most typical. Gas stove has the lowest and maximum load limitation, and gas could be only adjusted in this range. Instead, for the coal powder boiler, pulverized coal practical quantity could be adjusted according to gas surplus condition coal utility. Therefore, gas buffer user should meet the following constraint condition. Generally speaking, CCPP is one of the rigid users for the efficiency changed a lot with the load change, and its regulating range is not large. So it was ruled out. Consider

$$\forall m, i, \quad F_{m,i}^{\min} \le F_{m,i,t} \le F_{m,i}^{\max}. \tag{12}$$

2.4.6. Variable Nonnegative Constraints. Ensuring that all continuous variables were not less than zero, we can consider

$$E_{m,t}^{\text{buy}} \ge 0, \quad E_t^{\text{buy}} \ge 0, \quad f_{m,t} \ge 0, \quad F_{m,i,t} \ge 0, \quad Q_{m,k,t} \ge 0, \quad F_{i,t}^{\text{Gas}} \ge 0. \tag{13}$$

These constraint conditions were all related to each other.

2.4.7. Parameter Definition. The meanings and units of every parameter in the objective function and constraint conditions were listed in Table 2.

3. Illustrative Example

According to the power mathematical optimization model in the above section, taking an integrated iron and steel enterprise in Northern China, for example, the electric power production optimization model was established on the basis of the actual power equipment situation, as shown in Figure 2.

To meet the demand of iron and steel enterprise under the premise of electric power production, combined with production side optimization model diagram, the objective function was got as follows:

$$\begin{aligned}
\text{Min } S = {} & \sum_t C_{\text{buy},t}^{\text{ele}} \cdot E_t^{\text{buy}} + \sum_t \sum_m C_{\text{gen},m}^{\text{ele}} \cdot E_{m,t}^{\text{gen}} + \sum_t C^{\text{coal}} \cdot f_{1,t} \\
& + \left(\int_{t=0}^{480} \sum_{g1} C_1^{\text{gas}} \cdot F_{1,g1,t}\, dt + \int_{t=0}^{480} \sum_{g2} C_2^{\text{gas}} \cdot F_{2,g2,t}\, dt + \int_{t=0}^{480} \sum_{g3} C_3^{\text{gas}} \cdot F_{3,g3,t}\, dt \right) \\
& + \left(\int_{t=0}^{480} \sum_{s1} C_{1,s1}^{\text{ste}} \cdot Q_{1,s1,t}\, dt + \int_{t=0}^{480} \sum_{s2} C_{2,s2}^{\text{ste}} \cdot Q_{2,s2,t}\, dt + \int_{t=0}^{480} \sum_{s3} C_{3,s3}^{\text{ste}} \cdot Q_{3,s3,t}\, dt \right) \\
& + \int_{t=0}^{480} \sum_i C_i^{\text{Gas}} \cdot F_{i,t}^{\text{Gas}}\, dt.
\end{aligned} \tag{14}$$

In the formula, they are, respectively, outsourcing electricity cost, self-generating cost, gas radiation punishment

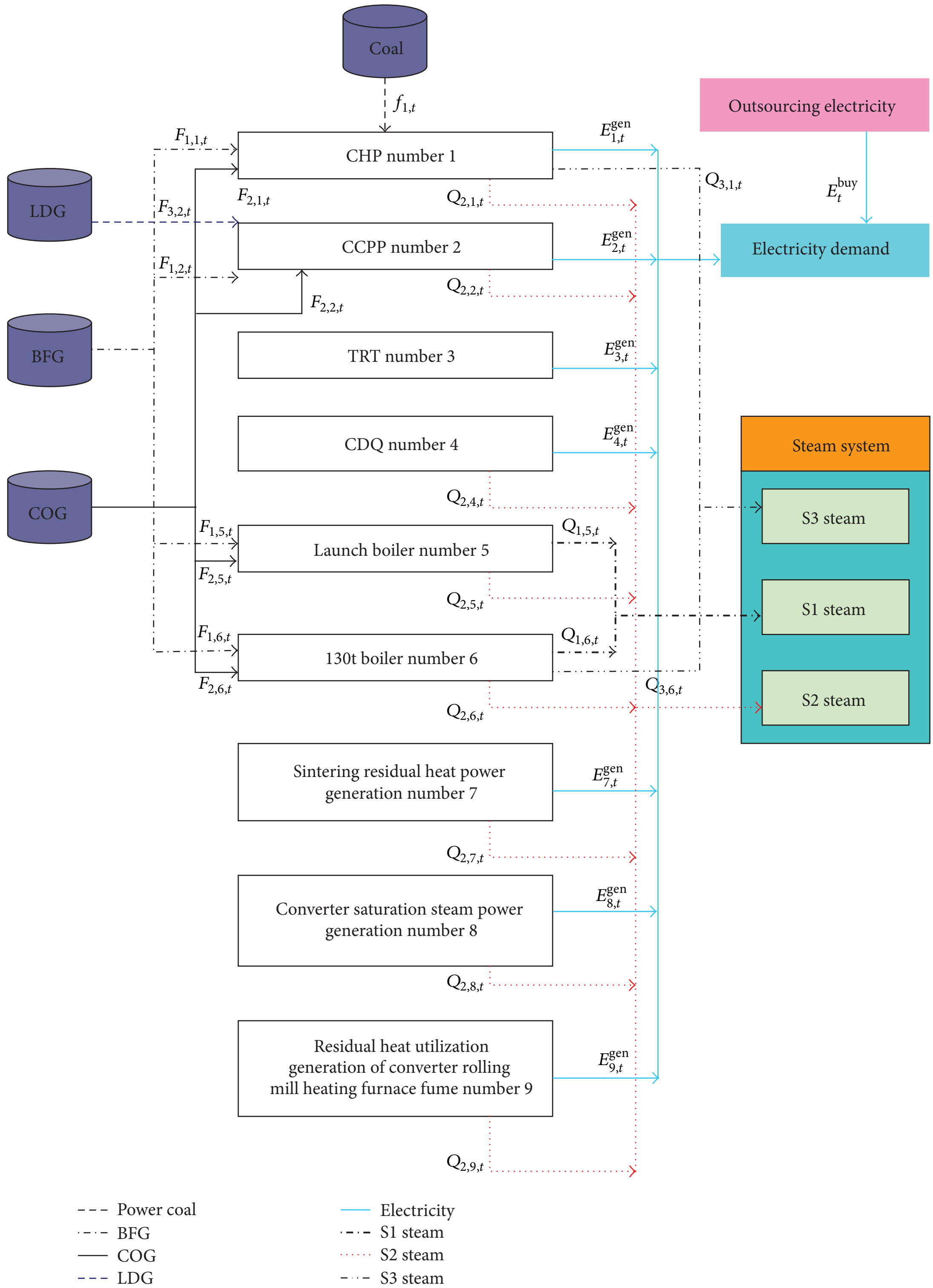

FIGURE 2: Optimization model of power production side of an integrated iron and steel enterprise.

cost, equipment consumption gas cost, comprehensive cost of steam production, and purchased power coal cost.

3.1. Parameter Definition. Each parameter meaning and unit of variable in the model was listed in Table 3.

3.2. Model Solution and Discussion. With ILOG COLEX software, the above model can be solved by taking the related parameters of company electric power, gas, steam data, and equipment into this model. The optimization results were shown in Figure 3 and Table 4.

Table 2: Meanings and units of variables in the model.

Nomenclature	
Subscripts	
t	Unit of time, h
m	Power generation and steam production equipment
i	Kinds of gas (BFG, COG, and LDG)
k	Kinds of steam (S1, S2, and S3)
Variables	
$C^{\text{ele}}_{\text{buy},t}$	Price of outsourcing electricity in t time point, RMB/kW·h
$C^{\text{ele}}_{\text{gen},m}$	Price of self-generation of device m, RMB/kW·h
C^{coal}	Price of outsourcing coal, RMB/t
C^{gas}_{i}	Price of i gas, RMB/m^3
$C^{\text{ste}}_{m,k}$	Cost of k steam production device m, RMB/t
C^{Gas}_{i}	Punishment price of i gas, RMB/m^3
D^{ele}_{t}	Power demand of t time point, kW·h
$D^{\text{ste}}_{k,t}$	k steam production demand of t time, t/h
$B_{i,t}$	i gas surplus of t time, m^3/h
E_m	Rated generating capacity of equipment m, kW
A_m	Steam production quantity of equipment m, t/h
$F^{\min}_{m,i}$	Adjust lower limit of equipment m gas-fired i, m^3/h
$F^{\max}_{m,i}$	Adjust upper limit of equipment m gas-fired i, m^3/h
h^{ele}	Calorific value of the electricity, kJ/kW·h
h^{ste}_{k}	Calorific value of k steam, kJ/kg
h^{gas}_{i}	Calorific value of i gas, kJ/m^3
h^{coal}	Calorific value of heating coal, kJ/kg
η_m	System generating (thermal) efficiency of equipment m, %
$R_{m,t}$	Caloric value of recovery of residual heat and energy resources of equipment m in t time, kJ/h
E^{buy}_{t}	Outsourcing electricity of t time point, kW
$E^{\text{gen}}_{m,t}$	Generation capacity of equipment m in t time point, kW
$f_{m,t}$	Consumption of equipment m in t time point, t/h
$F_{m,i,t}$	Consumption of i gas equipment m in t time point, m^3/h
$Q_{m,k,t}$	Production quantity of k steam equipment m in t time, t/h
$F^{\text{Gas}}_{i,t}$	Emission capacity of i gas in t time point, m^3/h
$A_{m,k}$	Extraction quantity of equipment m, t/h

(In Figure 3 abscissa is the number of time unit and each unit of time is 3 minutes, select 48 points one day).

The example of IISEs datum was shown in Table 4.

Through Figure 3, it was known that there was not much difference before optimization and after optimization at first, but as time went by, the datum of this enterprise power network system had larger deviation after optimization and before optimization. Then through Table 4, it can be known that the capacity of CDQ generation was increasing, 120000 kW, and the reason was that CDQ S2 extraction decrement of 70 t/h recycling was used to generate electricity. The capacity of sintering residual heat power generation

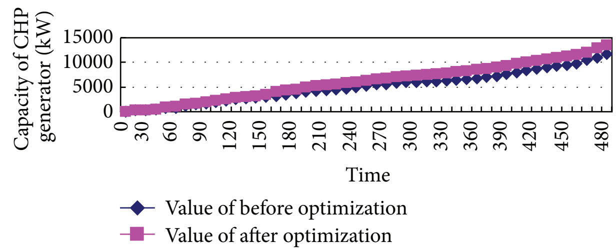

Figure 3: The CHP data of power system network of an iron and steel enterprise in one day.

was increasing, 32160 kW, and the reason was that steam S2 recovery of sintering increment of 20 t/h recycling was used to generate electricity. The capacity of converter saturation steam power generation was increasing, 1386 kW, and the reason was that steam S2 recovery of converter increment of 0.83 t/h recycling was used to generate electricity. The capacity of residual heat utilization generation of converter rolling mill heating furnace fume was increasing, 60 kW, and the reason was that steam S2 recovery of rolling mill increment of 0.04 t/h recycling was used to generate electricity. The capacity of CHP generation was increasing, 1878 kW, and the reason was that the rest of surplus gas should have been supplied to CHP in order to maintain load demand of unit power and steam production and reduced heat supply. It also can be known that the cost of every day is ¥ 1166.712 thousand after optimization, saving a cost of ¥ 335.199 thousand than before optimization. It is accounting for about 23.32% of the cost before optimization and the optimization effect was obvious. It can reduce steam and surplus gas radiation quantity and increase the capacity of power generation, thus saving energy. It had brought great economic benefits to this enterprise. Consider the following.

(1) *Electric Power Generation and Outsourcing Analysis.* The generation equipment of the model include CHP, CCPP, TRT, CDQ, sintering residual heat power generation, converter saturation steam power generation, and residual heat utilization generation of converter rolling mill heating furnace off-gas. From the optimization results of Table 4, it can be seen that this model gave the reasonable solutions of power production and the best outsourcing of company. The outsourcing price was taken for ¥ 0.5 per kW h. The optimization results have shown that self-generation increased and outsourcing reduced and thus saved cost of outsourcing electricity.

(2) *Steam Production Analysis.* The S2 steam of converter and rolling recovery were changed in a very small way after the optimization, and yet the S2 steam of sintering recovery was 1.5 times as much as that before the optimization. It adopted the mode of "using two sets of residual heat boiler with a turbine generator". The capacity of generation was 20 kW·h per ton sinter (sintering machine sets are 4 × 402 t/h). Startup boiler and 130-ton boiler were full load production after the optimization, and steam production amount kept rated quantity, but steam ratio changed. The extraction quantity of CDQ was reduced from 100 tons to 30 tons per hour to realize

Table 3: Meanings and units of variables in the model.

Sign	Meaning	Unit
t	Unit of time	h
m	Power generation and steam production equipment	—
s	Equipment of steam production	—
S1	Equipment of steam S1 production	—
S2	Equipment of steam S2 production	—
S3	Equipment of steam S3 production	—
g1	Equipment of BFG consumption	—
g2	Equipment of COG consumption	—
g3	Equipment of LDG consumption	—
i	Kinds of gas (BFG, COG, and LDG)	—
k	Kinds of steam (S1, S2,and S3)	—
E_t^{buy}	Outsourcing electricity capacity of t time point	kW
$E_{m,t}^{\text{gen}}$	Generation capacity of equipment m in t time point	kW
$f_{1,t}$	Power coal consumption of equipment 1# in t time point	t/h
$F_{1,\text{g1},t}$	BFG consumption of equipment g1 in t time point	m^3/h
$F_{2,\text{g2},t}$	COG consumption of equipment g2 in t time point	m^3/h
$F_{3,\text{g3},t}$	LDG consumption of equipment g3 in t time point	m^3/h
$Q_{1,\text{S1},t}$	S1 steam production quantity of equipment S1 in t time	t/h
$Q_{2,\text{S2},t}$	S2 steam production quantity of equipment S2 in t time	t/h
$Q_{3,\text{S3},t}$	S3 steam production quantity of equipment S3 in t time	t/h
$F_{i,t}^{\text{Gas}}$	Emission capacity of i gas in t time point	m^3/h

less extraction and more power generation. Self-generation capacity was increased and outsourcing power electricity was reduced, and then saved outsourcing electric cost of this enterprise.

(3) *Gas Distribution Analysis.* The consumption capacity of BFG and COG was increased after optimization; the consumption of power coal was decreased 11 tons; the consumption of BFG of startup boiler was reduced to 1000 m^3/h and the consumption of COG of startup boiler was reduced to 10.3 m^3/h, and consumption of BFG of 130-ton boiler was reduced to 16700 m^3/h; but the consumption of COG of 130-ton boiler was increased to 2281.7 m^3/h. In order to meet the demand of the enterprise steam, gas should have been distributed prior to rigid user CCPP, and then make two kinds boiler product steam under full load, the rest of surplus gas should be supplied for coal gas, CHP in order to maintain load demand of unit power and steam production, so as to realized reduce gas diffusion, self-generation increased and outsourcing power electricity reduced, production cost of enterprise reduced.

In allusion to a specified scale of iron and steel enterprise, when using the optimal model for electric power production and outsourcing optimization analysis, only in the accordance with the specific configuration of power production side, put each power generation equipment and steam production equipment into consideration, clear about production-consumption relationship of gas, steam coal consumption, electric power, steam production, and other energy medium, make electric power production optimization problems concretization and then specific issue in-depth analysis and study, and find out power reasonable production plan and outsourcing strategies in iron and steel enterprise.

The characteristic of the model was a coupling optimization model which includes comprehensive consideration of power, gas, and steam (three kinds of energy medium of iron and steel enterprise); it realized the power network dynamic and continuity; it improved the accuracy of the data and thus can guide iron and steel enterprise reasonable utilization of primary energy (power coal), secondary energy (by-product gas), and residual heat and energy resource to conduct electricity and steam production; it promoted energy conservation and emission reduction, improved production data accuracy of power network and saved electricity cost to reduce enterprise production cost.

4. Conclusion

(1) Through the establishment of the electric power generation dynamical optimization model in IISEs, it can be known that the EPS generation optimal dispatching was concerned with gas optimal allocation between the buffer users and steam optimal production in the conditions of production equipment. Through the optimization, the best power production and outsourcing solutions for enterprise can be found out.

(2) EPS generation dynamic optimization model was a coupling optimization model which is based on power, gas, and steam which are three common kinds of energy medium of iron and steel enterprise;

Table 4: Comparison of optimal results of the model.

Sign	Meaning	Value of before optimization	Value of after optimization	Unit
$E_{1,t}^{gen}$	Capacity of CHP generation	11646	13524	kW
$E_{2,t}^{gen}$	Capacity of CCPP generation	12542	12542	kW
$E_{3,t}^{gen}$	Capacity of TRT generation	10983	10983	kW
$E_{4,t}^{gen}$	Capacity of CDQ generation	49500	169500	kW
$E_{7,t}^{gen}$	Sintering residual heat power generation	101025	133185	kW
$E_{8,t}^{gen}$	Converter saturation steam power generation	11124	12510	kW
$E_{9,t}^{gen}$	Residual heat utilization generation of converter rolling mill heating furnace fume	950	1010	kW
E_{t}^{gen}	Total self-generating	197770	353254	kW
E_{t}^{buy}	Outsourcing electricity	199950	44466	kW
$f_{1,t}$	Outsourcing power coal of thermoelectric	79	68	t/h
$F_{1,1,t}$	Combust BFG of thermoelectric	340000	400000	m^3/h
$F_{1,5,t}$	Combust BFG of startup boiler	53000	52000	m^3/h
$F_{1,6,t}$	Combust BFG of 130-ton boiler	230000	213300	m^3/h
$F_{2,1,t}$	Combust COG of thermoelectric	28000	30309	m^3/h
$F_{2,5,t}$	Combust COG of startup boiler	2500	2489.7	m^3/h
$F_{2,6,t}$	Combust COG of 130-ton boiler	1900	4181.7	m^3/h
$F_{1,t}^{Gas}$	Emission capacity of BFG	2300	300	m^3/h
$F_{2,t}^{Gas}$	Emission capacity of COG	7480	108	m^3/h
$F_{3,t}^{Gas}$	Emission capacity of LDG	3200	350	m^3/h
$Q_{1,5,t}$	Steam S1 production of startup boiler	50	11.231	t/h
$Q_{1,6,t}$	Steam S1 production of 130-ton boiler	20	58.769	t/h
$Q_{2,1,t}$	Thermoelectric S2 extraction	0	0	t/h
$Q_{2,4,t}$	CDQ S2 extraction	100	30	t/h
$Q_{2,5,t}$	Steam S2 production of startup boiler	20	58.769	t/h
$Q_{2,6,t}$	Steam S2 production of 130-ton boiler	40–50	0	t/h
$Q_{2,7,t}$	Steam S2 recovery of sintering	40	60	t/h
$Q_{2,8,t}$	Steam S2 recovery of converter	100	100.83	t/h
$Q_{2,9,t}$	Steam S2 recovery of rolling mill	60	60.04	t/h
$Q_{3,1,t}$	Thermoelectric S3 extraction	0	18.769	t/h
$Q_{3,6,t}$	Steam S3 production of 130 ton boiler	220	201.23	t/h
S	Objective value	1501911	1166712	¥ per day

the model can realize the power network dynamic and continuity and improve the accuracy of the data, thus it can guide IISEs reasonable utilization of primary energy (power coal), secondary energy (by-product gas), and residual heat and energy resource to conduct electricity and steam production; it promoted energy conservation and emission reduction improve production data accuracy of power network and saved electricity cost to reduce IISEs production cost.

Conflict of Interests

The authors declare that they have no conflict of interests regarding the publication of this paper.

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