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MATHEMATICAL MODELING AND INTELLIGENT OPTIMIZATION SOLUTION OF GAS ALLOCATION PROBLEM IN IRON AND STEEL PRODUCTION

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This paper studies gas allocation problem in the iron and steel production. Gas allocation problem is a multi-objective optimization problem with complex constraints. A gas allocation problem is mathematically modeled with high dimension, non-linear and complex constraint features. The intelligent optimization algorithms have certain advantages in solving such model. An improved Differential Evolution algorithm based on individual quality evaluation is proposed to solve the above model. The results show multiple gas allocation schemes are provided when all constraints are met, and all optimization objectives of some schemes are better than then manual gas allocation scheme.

Key words: iron and steel, gas allocation, coke,mathematical modeling, intelligent optimization.

INTRODUCTION

Iron and steel production consumes a lot of energy. Optimization of energy allocation is a key issue in production. Gas is the main by-product of production as a secondary energy. Unreasonable gas allocation schemes will cause problems such as increased costs, waste of resources, environmental pollution and production safety. Gas allocation problem can be modeled as multi-objective optimization problem with complex constraints, and can be solved by intelligence optimization algorithms such as differential evolution.

A fuzzy optimal scheduling model for byproduct gas system is presented[1]. A real-time by-product gas scheduling with uncertainty in by-product gas flows is addressed[2].Combine back-propagation neural network and least squares support vector machine, A model is proposed to forecast the surplus gases and allocate them optimally[3]. A gas scheduling optimization model under fuzzy and interval uncertainties is developed[4]. A method with the reverse decomposition of mixed gas is proposed to determine the gas ratio of mixed gas for every equipment and making gas production balance[5]. A three layer causal network based approach for Linz-Donawitz Gas(LDG) process system is proposed[6]. A knowledge acquisition and modeling algorithm based on hierarchical granular contrastive network is proposed[7]. A multi-working condition optimization scheduling model based on multi-energy flow network is proposed[8]. A granular prediction and dynamic scheduling process based on adaptive dynamic programming is proposed[9]. Differential Evolution is a swarm intelligence optimization algorithm to solve polynomial fitting problems[10].

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MATHEMATICAL MODELING OF GAS ALLOCATION PROBLEM

Taking the gas distribution problem of a domestic iron and steel enterprise as an example, mathematical modeling is carried out. The model has two optimization goals, one is to minimize the cost of gas consumption and the other is to maximize the benefits of gas power generation. In order to facilitate modeling, the benefits of gas power generation is taken as a negative cost, and the maximization optimization problem of the benefits of gas power generation is converted into the minimization optimization problem of negative cost shown as (1). The model has multiple constrains which is respectively material balance constraint, working calorific constraint,gas consumption constraint of one process, position level constraint and fluctuation level constraint of one gas cabinet shown as (2)-(7).

$$\min F = (\sum_{i=1}^{I}\sum_{j=1}^{J} C_{ij} X_{ij}, -\sum_{i=1}^{I} \varphi_i W_i)^T \tag{1}$$

subject to

$$Q_j^l \le q_i \sum_{j=1}^{J} X_{ij} \le Q_j^u \tag{2}$$

$$V_i \le \sum_{j=1}^{J} O_{ij} - \sum_{j=1}^{J} X_{ij} - W_i \tag{3}$$

$$O_{ij} \le \tau_{ij} \sum_{i=1}^{I} X_{ij} \tag{4}$$

$$\gamma_{ij}^l \le X_{ij} \le \gamma_{ij}^u \tag{5}$$

$$h_i^l \le h_i^0 + \frac{V_i}{\varepsilon_i} \le h_i^u \tag{6}$$

$$\frac{V_i}{\varepsilon_i} \le \Delta h_i^u \tag{7}$$

$$i \in I, j \in J \tag{8}$$

where

C_{ij}: the unit consumption cost of gas i on equipment j.

X_{ij}: the decision variables, the allocated amount of gas i on equipment j.

φ_i: the unit power generation benefit of gas i.

W_i: the amount of gas i used for power generation.

I: the type number of gas, the value is 3.

i: the index of gas, the value 1,2 and 3 denotes coke oven gas, blast furnace gas and converter gas, respectively.

J: the total number of device.

j: the index of device.

O_{ij}: the recovered amount of gas i on device j.

Q_j^l, Q_j^u: the lower and upper limit of the operating calorific value of the equipment j.

q_i: the unit calorific value of gas i.

V_i: the changed volume of the gas i cabinet.

τ_i: the recovery factor of gas i on device j.

$\gamma_{ij}^l, \gamma_{ij}^u$: the lower and upper limit of gas i demand on equipment j.

h_i^l, h_i^u: the lower and upper amount limit of gas i cabinet;

h_i^0: the last amount of gas i cabinet.

ε_i: the volume conversion coefficient of gas i cabinet.

Δh_i^u: the upper limit of changed amount of gas i cabinet,

IMPROVED DIFFERENTIAL EVOLUTION ALGORITHM BASED ON INDIVIDUAL QUALITY EVALUATION

Differential evolution

The classic Differential Evolution(DE) starts from an initial population that includes a certain number of individuals generated randomly from solution space. In every generation of evolution, some individuals are selected as parents to mutate and crossover to generate offspring. There are only three control parameters, population size *NP*, scale factor *F*, and crossover rate *CR*.

Improved DE based on individual quality evaluation

The information of individual quality includes fitness value, constraint violation count and constraint violation amount, which can considered to adjust the control parameter, mutation and crossover strategy. In one population, the individual who has smaller fitness or constraint violation degree is superior, the opposite is inferior. The superior individual control search direction. The inferior individual control the population diversity. In general, a better individual is more probable to be near the superior individuals or be far from the inferior individuals. The individuals are evaluated and sorted according to the individual quality information. Select some individuals at one proportion as superior ones from sorted population. the initial value of the proportion is relatively small and gradually increases with evolution. To set the control parameters of the i^{th} individual in sorted population, the control parameter F is redefined as F_i and CR as $CR_{i.}$ The i^{th} individual is selected as the search centre. If the individual is superior one, the F_i and CR_i are both set to a smaller value for the exploitation search in a smaller area, and more genes of the superior one are retained in the crossover process, and vice versa, the F_i and CR_i are set to a larger value for the exploration search in a larger area and more genes of the mutated individual are retained in the crossover process.

Create and sort the element of the F' and CR' queue in ascending order as follows:

$$F_i^{'} = N\left(\frac{i}{NP}, 0,1\right), i = 1, \cdots NP,$$

$$F_i^{'} \in [0,1,0,9] \tag{9}$$

$$CR_i^{'} = N\left(\frac{i}{NP}, 0,1\right), i = 1, \cdots NP,$$

$$CR_i^{'} \in [0,1,0,9] \tag{10}$$

where

F_i, $CR_i^{'}$: the i^{th} element of F' and CR' queue.

N: the Normal distribution.

The i^{th} element of the sorted F' and CR' queue are respectively F_i and CR_i.

In the first half of evolution, individual quality is generally worse, but population diversity is better. The mutation strategy should be that superior individual itself should be as basic individual and mutate in a random direction, and inferior individual itself should be also as basic individual,but mutate in the direction towards superior individual, shown as (11)-(12).

if X_i is a superior individual then

$$v_i = X_i + F_i * (X_{r1} - X_i) + F_i * (X_{r2} - X_{r3}) \tag{11}$$

else

$$v_i = X_i + F_i * (X_{rs} - X_i) + F_i * (X_{r1} - X_{r2}) \tag{12}$$

where

v_i: the i^{th} mutation individual,

X_i: the i^{th} basic individual,

$r1, r2, r3$: the indexes of three selected individuals at random, $r1 \neq r2 \neq r3 \neq i$,

rs: the index of the selected superior individual at random, $rs \neq r1 \neq r2 \neq i$.

According to the statistics of the individual quality improvement in some continuous generations, when less than a defined threshold, the evolution is into the second stage. In this stage, in general individual quality is better, while population diversity is worse. The mutation strategy should be that superior individual selects an individual except itself at random as basic individual and mutate in a random direction, and inferior individual should select also an individual except itself at random as basic individual and mutate in the direction towards superior individual, shown as (13)-(14).

if X_i is a superior individual then

$$v_i = X_{r1} + F_i * (X_{r2} - X_{r1}) + F_i * (X_{r3} - X_{r4}) \tag{13}$$

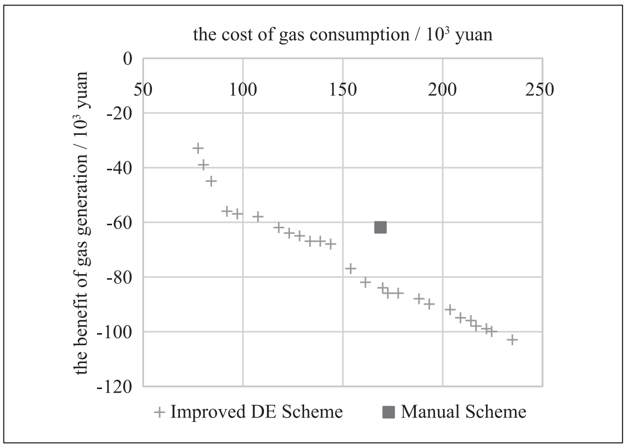

Figure 1 The gas allocation results under coke oven gas surplus condition

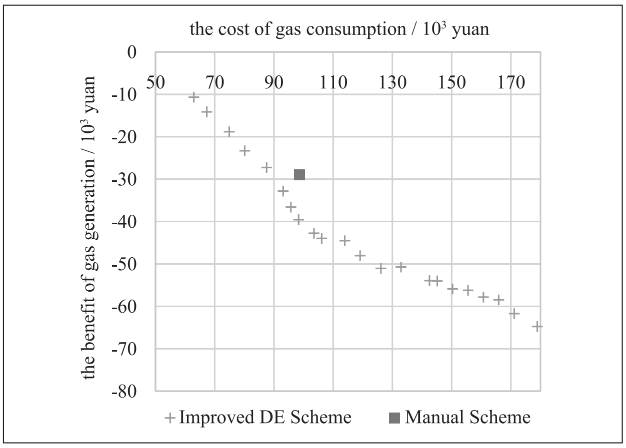

Figure 2 The gas allocation results under coke oven gas shortage condition

else

$$v_i = X_{r1} + F_i * \left(X_{rs} - X_{r1} \right) + F_i * \left(X_{r2} - X_{r3} \right) \quad (14)$$

where

r4: the index of the selected individuals at random, $r1 \neq r2 \neq r3 \neq r4 \neq i$.

INTELLIGENT OPTIMIZATION SOLUTION OF GAS ALLOCATION PROBLEM

Compare the problem solution under the two working conditions that coke oven gas is surplus and deficiency, other gas is basically balanced. The results of manual allocation and improved DE allocation under two working conditions are shown as Figure 1 and 2. When the coke oven gas is surplus, in order to ensure the stability of the gas cabinet and the balance of the energy pipeline network, consume some surplus coke oven gas to increase the calorific value of production process and generate power. So, the energy consumption cost and power generation benefit are both high. On the contrary, when coke oven gas is insufficient, gas is mainly used to ensure production, and the power generation benefit is reduced. The multiple gas allocation schemes are provided when all constraints are met, and all optimization objectives of some schemes are better than then manual gas allocation scheme, ones of other schemes do not dominate each other.

CONCLUSIONS

In this paper, gas allocation problem in iron and steel production is mathematically modeled. The two optimization objectives and multiple production constraints are defined. Based on the idea of individual quality evaluation, the control parameters setting and mutation strategy of classical differential evolution are improved. Use the improved differential evolution algorithm to solve the gas allocation model. The results show that improved DE can get more gas allocation schemes when all the constraints are met. Some schemes dominate the manual scheme, whose two objectives are both better than manual schemes, other schemes are non-dominated each other.

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Note: The responsible translators for English language is J. Wang - University of Science and Technology Liaoning, China