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Research on improved artificial bee colony algorithm based on large-scale multi-objective group combination optimization

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Abstract: *Large power system contains many generating units, and many factors need to be considered during operation. The unit combination optimization is a nonlinear large-scale optimization problem with multi-objective and multi-constraints, and the existing methods have many shortcomings. Artificial bee colony algorithm has good performance in solving nonlinear optimization problems, but it has some disadvantages such as low optimization efficiency and local extremum. To solve these problems, an improved artificial bee colony algorithm is proposed. The algorithm introduces variable field of vision, adjusts the initial solution and selection strategy, and combines with mutation operation in genetic algorithm. A multi - objective optimization model considering economy and environmental protection is constructed. In order to solve the problem that the calculation time is too long due to the expansion of the unit scale, a phased optimization method is adopted, and the improved algorithm is applied to the start-stop scheduling stage. After determining the start-stop state of the unit, the mixed integer programming method is used for load distribution. For unit contains up to 1000 units of large power grid optimization examples are simulated experiment, the experimental results show that the improved optimization algorithm convergence and global search ability is improved, greatly reduces the computation time of the mass unit combination, multiple objective conditions have also made the ideal results, verify the effectiveness of the proposed method.*

Keywords: *Unit combination; Economic dispatch; Artificial bee colony algorithm; On a large scale; A multi-objective*

1. Introduction

Unit combination optimization refers to the development of the start-stop and output plan of each unit within a period of dispatching period under the premise of meeting the load demand and unit parameter requirements of the power system and aiming at minimizing the total power generation cost of the system [1]. As the basis of power system economic dispatching, unit combination optimization can create significant economic benefits, so it has been widely concerned by scholars at home and abroad.

In essence, unit combination optimization is a large-scale mixed integer nonlinear programming problem [2], and the solving ideas can be roughly divided into two categories: Priority List [3] (PL), Dynamic Programming [4] (DP), Lagrangian Relaxation [5], LR), Mixed Integer Linear Programming [6] (MILP) and second-order Cone Planning [7] (SOCP). And including Genetic Algorithm [8] (Genetic Algorithm, GA), Particle Swarm Optimization Algorithm [9] (PSO), Ant Colony Optimization Algorithm [10] (Ant Colony Optimization, ACO), Artificial Fish Swarm Algorithm [11] (AFSA) and other intelligent optimization algorithms. In traditional mathematical methods, PL is simple in principle and easy to implement, but its solving quality is often poor because it is difficult to select appropriate ranking index and deal with improper order of constraints [12]. DP has a good effect on the combination optimization of small-scale units. However, when the unit scale gradually expands, "dimension disaster" will occur, which is difficult to be applied in practice [13]. Although LR overcomes the dimension barrier, it has dual gaps and other problems [14]. MILP belongs to linear programming, and the objective function needs to be linearized when dealing with nonlinear programming problems. Symmetry problems will occur when solving combinatorial optimization of a large number of units, resulting in greatly prolonged calculation time [15]. Intelligent optimization algorithm has significant advantages in dealing with complex nonlinear optimization problems due to its wide adaptability, parallelism and strong stability. AFSA is a bionic algorithm proposed by Dr. Li Xiaolei in China, which is simple to implement, insensitive to initial values and has strong robustness. Compared with GA, AFSA avoids the complicated

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codec process, and the population generated by each iteration is more directional. Compared with PSO, the algorithm can prevent premature phenomenon to some extent and has more relaxed requirements on parameters. However, AFSA also has some disadvantages such as slow convergence and local extremum.

At present, most of the research on unit combination optimization is based on the power system with a scale of less than 100 units, and the few literatures on solving the problem of unit combination with a scale of more than 100 units] only aim at minimizing the total power generation cost of the system. As a matter of fact, with the rapid increase of total power generation capacity in China since the 20th century, more attention has been paid to the study of large-scale unit combination optimization. Moreover, in recent years, the national and social environmental protection efforts have been driven by low-carbon operation, reducing pollution and other targets have also been taken into consideration in unit combination optimization.

On the basis of the above analysis, this paper first builds a multi-objective combinational optimization model that takes both economy and environmental protection into account. Since different objective functions cannot reach the optimal at the same time, a multi-objective processing strategy based on linear weighting method is adopted for efficient solution. Considering that the expansion of unit size will lead to a significant increase in the complexity of the problem and seriously affect the efficiency of the solution, the optimization process is divided into two stages: start-stop arrangement and load distribution, so as to shorten the solution time. Then, an improved artificial bee colony algorithm is proposed:. The improved algorithm was applied to solve the start-stop scheduling stage to obtain the start-stop status of each unit, and then Mixed Integer Programming (MIP) was used to calculate the optimal output of each unit to achieve load distribution. Finally, to verify the effectiveness of the proposed method, a large-scale simulation experiment of unit combination optimization is carried out.

2. Mathematical model of multi-objective unit combination problem

2.1. Objective function

Economic objective: lowest total cost of power generation

$$\min F=\sum_{t=1}^{T}\sum_{i=1}^{N}[f(p_{it})u_{it}+S_i u_{it}(1-u_{i(t-1)})] \tag{1}$$

$$f(p_{it})=\alpha_i p_{it}^2+\beta_i p_{it}+\gamma_i \tag{2}$$

$$S_i=\begin{cases} S_i^{hot} & T_{i,\min}^{off}\leqslant T_i^{off}\leqslant T_{i,\min}^{off}+T_i^{cold} \\ S_i^{cold} & T_i^{off}>T_{i,\min}^{off}+T_i^{cold} \end{cases} \tag{3}$$

Where, F is the total cost of system power generation; N is the number of thermal power units; T is the number of scheduling periods, and each period is 1h. Pit is the active power output of unit I in time period T; Uit refers to the start-stop state of unit I at time period T. 0 represents shutdown and 1 represents operation. F (pit) is the fuel cost of unit I in time period T; I, I and I are fuel cost coefficients of unit I; Si is the start-up cost of unit I; Shot I and Scold I are the hot and cold start-up costs of unit I respectively; Toff I, Toff I,min are the continuous and minimum downtime of unit I respectively; Tcold I is the cold startup time of unit I.

Environmental targets: CO_2, SO_2 emissions minimum

$$\min E_c=\sum_{t=1}^{T}\sum_{i=1}^{N}\left[(a_{ci}p^2{}_{it}+b_{ci}p_{it}+c_{ci})u_{it}\right] \tag{4}$$

$$\min E_s=\sum_{t=1}^{T}\sum_{i=1}^{N}\left[(a_{si}p^2{}_{it}+b_{si}p_{it}+c_{si})u_{it}\right] \tag{5}$$

Where, Ec is the CO_2 emission of the system; Es is system SO_2 emission; α CI, BCI, and CCI are CO_2 emission coefficients of unit I; α SI, BSI and CSI are SO_2 emission coefficients of unit I.

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2.2. Constraints

Constraints on upper and lower limits of power

$$p_{i,\min} \leqslant p_{it} \leqslant p_{i,\max} \tag{6}$$

Where, PI, min, PI and Max are the minimum and maximum active output of unit I respectively.

Power balance constraint

$$\sum_{i=1}^{N} u_{it} p_{it} = L_t \tag{7}$$

Where, Lt is the load demand of the system in time period T.

Rotating reserve constraint

In order to ensure the reliability of power supply, the system usually reserves part of the power generation capacity. In this paper, 10% of the load demand in each time period is used as the rotation reserve in this time period.

$$\sum_{i=1}^{N} u_{it} p_{i,\max} \geqslant L_t + R_t \tag{8}$$

Where, Rt is the rotation reserve of the system at time period T.

Minimum start and stop time constraint

$$\begin{cases} T_i^{on} \geqslant T_{i,\min}^{on} \\ T_i^{off} \geqslant T_{i,\min}^{off} \end{cases} \tag{9}$$

Where Ton I and Toff I are the continuous start and stop time of unit I respectively; Ton I,min, Toff I,min are the minimum start and stop time of unit I respectively.

Unit climbing constraints

$$\begin{cases} p_{it} - p_{i,t-1} \leqslant R_{\mathrm{U},i} \\ p_{i,t-1} - p_{it} \geqslant R_{\mathrm{D},i} \end{cases} \tag{10}$$

Where RU, I, RD and I are the maximum climbing rate and maximum landslide rate of unit I respectively.

2.3. Multi-objective processing and phased optimization

2.3.1. Multi-objective processing

The model adopts multi-objective processing strategy based on linear weighting method, which is easy to use and effective. The specific steps are as follows.

Step 1 Normalize each objective function according to Formula (11) to unify dimensions.

$$\varphi(x) = \frac{f(x) - f_{\min}}{f_{\max} - f_{\min}} \tag{11}$$

Where :(x) is the objective function after normalized processing; F (x) is the original objective function; Fmax and fmin are the maximum and minimum values of the original objective function respectively.

Step 2 Set wi for each objective function I (x) based on the importance of each objective. Set WI > 0 and ∑ WI = 1(I = 1, 2..., n, n is the number of objective functions).

Step 3 Convert the original problem into a single-goal problem according to Equation (12).

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$$\begin{cases} \min Y = \sum [w_i \varphi_i(x)] \\ \text{s.t. } x \in X \end{cases} \tag{12}$$

Where, X is the feasible region of the objective function.

According to the above steps, a multi-objective optimization function with consideration of economy and environmental protection can be obtained:

$$\begin{cases} \min Y = w_1 F' + w_2 E_c' + w_3 E_s' \\ F' = \dfrac{F - F_{\min}}{F_{\max} - F_{\min}} \\ E_c' = \dfrac{E_c - E_{c,\min}}{E_{c,\max} - E_{c,\min}}, E_s' = \dfrac{E_s - E_{s,\min}}{E_{s,\max} - E_{s,\min}} \\ \text{s.t. } (6)\sim(10) \end{cases} \tag{13}$$

2.3.2. Phased optimization

The traditional method of intelligent algorithm to solve the unit combination problem is to calculate the objective function value after the start-stop and output conditions of the unit are determined, and then perform the next operation according to the value of the objective function. However, with the increase of the number of units, the complexity of the problem will increase proportionally. If we still use this method, the solution time will be greatly prolonged, and the practical value of the whole optimized Y scheme will be significantly reduced. Based on the above analysis, this paper decided to adopt a phased optimization method, which divided the optimization process into two stages: start-stop arrangement and load distribution.

Among them, the start-stop arrangement stage is responsible for optimizing the start-stop state of each unit. Referring to the weighted sum of start-stop cost, medium-load average fuel cost and rotating reserve remaining in other studies as the optimization objective at this stage [20], this paper extends the maximum objective. Medium Load Average Function Value (MLAFV) is used to replace Medium Load Average fuel cost, and the calculation method of the Average objective Function Value of each unit is as follows:

$$y_a(p_i) = \frac{w_1 f(p_i) + w_2 e_c(p_i) + w_3 e_s(p_i)}{p_i} \tag{14}$$

$$e_c(p_i) = a_{ci} p^2{}_i + b_{ci} p_i + c_{ci} \tag{15}$$

$$e_s(p_i) = a_{si} p^2{}_i + b_{si} p_i + c_{si} \tag{16}$$

Where, ya (PI) is the average objective function value of unit I; Ec (PI) is the CO2 emission of unit I; Es (PI) is the SO2 emission of unit I.

Then, the optimization objective of the start-stop arrangement stage is obtained, as shown in Equation (17).

$$\begin{cases} \min Y_1 = C_S + 1.5 \times AFV_M + 0.5 \times \sum_{t=1}^{T} R_{S,t} \\ C_S = \sum_{t=1}^{T} \sum_{i=1}^{N} S_i u_{it} (1 - u_{i(t-1)}) \\ AFV_M = \sum_{t=1}^{T} \sum_{i=1}^{N} u_{it} y_a(p_i) \Big|_{p_i = (p_{i,\min} + p_{i,\max})/2} \\ R_{S,t} = \sum_{i=1}^{N} u_{it} p_{i,\max} - L_t - R_t \\ \text{s.t. } (8),(9) \end{cases} \tag{17}$$

Where: CS stands for start-stop cost; AFVM represents the average objective function value of medium load; RS, t represents the rotational reserve surplus of time period T.

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The load distribution stage is carried out after the start-stop arrangement stage is completed, and the total objective function formula (13) is taken as the optimization objective to allocate the output for each unit. Different from the traditional method in which each iteration is calculated repeatedly, this stage only needs to execute once on the basis of the start-stop state determined in the previous stage, so the solution time is greatly shortened.

Accordingly, the constraint processing is divided into two parts, which are executed in different phases. Among them, constraint processing in start-stop arrangement stage consists of the following two steps:

Procedure Step 1 Check whether the rotation standby constraint is met in this period. If not, start the available unit randomly until the requirement is met.

Step 2 Check whether the sum of the minimum active power output of the current operating unit is lower than the load requirement in this period to avoid violating the power balance constraint. If the sum is higher, shut down the operating unit randomly until the condition is met.

Repeat the two steps until all conditions are met, then continue to process the next period. It should be noted that the constraint of start-stop time should be taken into account when the unit is started or shut down in the above steps. It is required that the unit should adjust the subsequent period to meet Formula (9) without changing the state of the previous period. If it cannot, the unit will be skipped.

Load distribution phase in each period constraint processing need in order to perform the following operations: first of all, all the unit output is set to its minimum active power output to meet lower bound constraint, then, on the premise of not more than upper limit, according to the objective function value slightly higher rate from low to high order for distribution unit load, until meet the restrictions of the balance of power. If the climbing constraint needs to be considered, it should also check whether the output of the current period satisfies formula (10) compared with the previous period. If not, the output should be increased or decreased accordingly.

3. Improvement of artificial bee colony algorithm

Artificial bee colony algorithm is a new kind of swarm intelligence optimization algorithm after ant colony algorithm and particle swarm optimization algorithm, which mainly simulates intelligent honey gathering behavior of bee population. Function optimization tests show that ABC algorithm has better optimization performance than genetic algorithm, differential evolution algorithm and particle swarm optimization algorithm]. In ABC algorithm, bees are divided into three roles: lead bee, follow bee and scout bee. The lead bees are responsible for searching for new food sources and collecting honey, and then transmit the information of food sources to the following bees through dancing. The following bees select the food source to collect honey by observing the information of the food source of the guide bees. When a food source is abandoned, its lead bee becomes a scout and starts looking for a new food source. Therefore, leading bees have the function of maintaining good food source, and have elite characteristics. The number of bees corresponding to better food sources was increased by following bees to accelerate the convergence of the algorithm. Scout bees randomly search for new food sources, helping the algorithm jump out of local optima. The essence of using ABC algorithm to solve the optimization problem is to regard the process of searching for the optimal food source as the process of searching for the optimal solution of the optimization problem. In ABC algorithm, the location of food source represents a feasible solution to the optimization problem. The food concentration of the food source corresponds to the quality of the solution, namely the fitness value; The process of collecting honey corresponds to the process of calculating fitness values.

3.1. Improvement of initial solution

The initial solution is the starting point for the algorithm to search. The initial solution of the basic ABC algorithm is randomly generated. If the initial solution is not reasonable, the performance of the algorithm will be greatly affected, so it is necessary to improve the generation method of the initial solution. In order to make the initial solutions diversified and evenly distributed in the search space, Ding Haijun et al. [4] proposed the initial solution of inter-cell generation method, which ensured that the initial population contained abundant solutions and enhanced the possibility of the search convergence to the global optimal advantage. 5] It is helpful to improve efficiency and quality of solutions to generate initial solutions by using reverse learning method. Luo Jun et al. 6] Based on the characteristics of chaos, such as randomness, ergodicity and sensitivity of initial conditions, the initial solution of chaos sequence is proposed to improve the diversity of knowledge and ergodicity of search. Bolaji A. In order to ensure the feasibility and diversity of all solutions in ABC algorithm when solving constrained optimization problems. L et al. 7] proposed the use of backtracking algorithm to generate a feasible initial solution.

3.2. Improvement of selection strategy

In the basic ABC algorithm, follower bees choose solutions in roulette mode, which is easy to lead to the decline of solution diversity and premature convergence of the algorithm. In the process of searching the optimal solution, different selection pressure is required at different stages, so that the diversity of solutions can be maintained and the convergence rate of the optimal solution can be accelerated. In order to dynamically adjust the selection pressure in the process of searching the optimal solution, Ding Haijun et al. 4] introduced the Bolzmann selection strategy of simulated annealing algorithm into the artificial bee colony algorithm on the basis of analyzing the characteristics of the search mechanism of the existing bee colony algorithm. In order to avoid the problem of too large fitness span and adjust the selection pressure dynamically, Bu Denghui et al. 8] adopted the sorting selection method for exponential stretching.

3.3. Selection of solution update formula

In the updating formula of basic ABC algorithm, RIj is a random number between [-1, 1]. Alam M. S et al. [9] proposed to find an appropriate scaling factor for RIJ so that it could dynamically and adaptively change the step size to better search for the optimal solution. In order to overcome the defect of large randomness of the basic ABC algorithm, Hu Ke et al. 10] used the difference of fitness values of different solutions to guide the direction of optimization. In the later stage of search, the solution is very close to the optimal solution and even is the same within the significant number. Therefore, a perturbation factor is added after the solution updating formula to improve the convergence rate of evolution through local fine-tuning in the later stage of search. The solution update formula of the basic ABC algorithm does not use any comparison information, which may lead to poor local search ability of the algorithm. Wang Huiying [11] introduced the local optimal solution and individual extreme value information into the search mode of leading bees to further improve the local search ability of the algorithm, and added the asynchronous change learning factor to adjust the role of bees' own experience and social group experience in the whole search process.

3.4. Combination with other algorithms

Because of local convergence, ABC algorithm is difficult to obtain satisfactory solution in complex problems. To solve this problem, a hybrid algorithm can be combined with other algorithms. ABC algorithm is a single-dimensional update algorithm, which will lead to the contradiction between single-dimensional and single-dimensional update. The main reason is that each dimension of the solution is updated separately and lacks information exchange. El-abd M12] integrated the whole updating idea of particle swarm optimization into the colony algorithm, and added the influence of global information into the one-dimension updating formula of the colony algorithm. Bu Denghui et al. [9] added a trial mechanism based on overall update after single-dimension update, and dynamically adjusted the proportion of single and overall update according to the success rate of single-dimension update. Luo Jun et al. 13] Referring to the idea of combining crossover and mutation in genetic algorithm, an improved bee colony optimization algorithm based on crossover factor was proposed. By adopting crossover factor, a new solution set was generated, and the diversity of solutions was increased. The tabu strategy of tabu search algorithm is to use tabu table to store and mark the local optimal solutions, so as to avoid finding these solutions in the future search process, so as to jump out of the local optimal advantages. Luo Jun et al. 14] proposed a swarm algorithm with tabu strategy for reference. In addition, scholars also proposed to combine the simulated annealing algorithm and differential evolution algorithm with ABC algorithm to improve the performance of the algorithm.

4. Conclusion

In this paper, a combinatorial optimization model of multi-objective units based on linear weighting method is established, which considers both economy and environmental protection. In order to adapt to large-scale units, the optimization process is divided into two stages: start-stop arrangement and load distribution. An improved artificial bee colony algorithm was proposed, which introduced variable field

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of vision, adjusted selection strategy and combined with mutation operation in genetic algorithm. The improved algorithm is applied to solve the start-stop scheduling stage, and the start-stop state of the unit is obtained. MIP is used to realize load distribution. Through the large-scale combination of 100~1000 units of simulation experiments, the results show that:

1) The improved artificial bee colony algorithm makes up for the shortcomings of the original algorithm, improves the optimization efficiency and strengthens the global search ability;

2) The phased optimization method greatly shortens the calculation time and can effectively solve the large-scale unit combination problem;

3) Multi-objective optimization model can significantly reduce CO2 and SO2 emissions of power system, so as to achieve environmental protection goals.

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