Multi-Objective Optimization of Steam Power System in Iron and Steel Enterprises Based on Genetic Algorithm

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Abstract. In the fields of engineering technology, economy and systems engineering etc. there are many multi-objective optimization problems. The multi-objective optimization problem is a kind of complex optimization problem that are difficult to solve. Therefore, the thesis proposes the multi-objective optimization genetic algorithm based on Pareto optimal solution database. This algorithm improves the selection operator with a preservation mechanism--data base that can reserve the optimal solution of each generation of Pareto. As for the Pareto optimal individual in data base, the optimal solution of Pareto operation and the Euclidean distance operation are carried out. Experimental verification verifies that this algorithm not only effectively avoids the damage caused by selection, cross and mutation operation to Pareto, but has high evolution speed and stable algorithm.

Keywords: Multi-Objective Optimization, Genetic Algorithm, Data Base, Pareto Optimal Solution

1. Introduction
In recent years, multi-objective optimization is a new booming branch of science. It focuses on simultaneous optimization problem of many numerical targets in some sense [1]. In 1896, French economist V. Pareto formally put forward multi-objective optimization; in 1951, T.C.Koopmans proposed multi-objective optimization problem from the activity analysis of production and distribution and firstly proposed the concept of Pareto optimal solution [2]. Genetic algorithm uses the natural selection and genetic mechanism of biology and is a kind of overall optimization self-adaption probability search algorithm [3]. Genetic algorithm has simple thought and robust algorithm, and is easy to be realized. And it is utilized in many kinds of complex optimization problems. Genetic algorithm is a very effective method to solve the multi-objective optimization problem [4, 5]. At present, representative genetic algorithms are vector quantity assessment multi-objective optimization genetic algorithm of Schaffer, multi-objective optimization genetic algorithm of Fonseca and Fleming [6-7]. However, in the practical application they have merit and demerit.

Based on the summary and conclusion of other people’s research result, the thesis pays attention to research on optimal save strategy and population diversity aiming at the damage of Pareto optimal solution caused by selection operation, interlaces operation and mutation operation in the evolutionary process of genetic algorithm, and proposes the multi-objective optimization genetic algorithm based
on Pareto optimal solution data base. The basic thought is that to establish a data base in order to solve the Pareto optimal solution of multi-objective optimization genetic algorithm, each generation Pareto optimal solution during the evolution is put into the data base [8-10]. All individual of each generation will be operated by Pareto optimal solution algorithm and the inferior solution will be weed out. Then the Euclidean distance operation among individual will be carried out and one of which are less than the designated value will be treated as the inferior solution.

2. Analysis of Algorithm

2.1 Mathematic Model of Multi-Objective Optimization Problem

Multi-objective optimization refers to the optimization in a given area that has more than one numerical value objective. In the practical application, people often encounter the problems of design and decision-making with multi-criteria or multi-objective. In order to solve the multi-objective optimization problem, a universal mathematic model need be established. Firstly, it is necessary to determine its decision variable. Generally, the decision variable can be considered as a point in n dimension Euclidean space \( E^n \), that is:

\[
x = (x_1, x_2, \cdots, x_n) \in E^n
\]

(1)

Second is the objective function. Generally, p objective functions are not the function related to decision variable, it will be

\[
f(x) = [f_1(x), f_2(x), \cdots, f_p(x)]^T
\]

(2)

The last one is constraint condition, from the mathematical point of view, the constraint conditions are: inequality constraints and equality constraint. The constraint conditions are defined as \( m \) inequality constraints and \( k \) equality constraint:

\[
g_i(x) \leq 0, i = 1, 2, \cdots, m
\]

(3)

\[
h_j(x) = 0, j = 1, 2, \cdots, k
\]

(4)

If all objective functions seek for the minimum, multi-objective optimization problem can be described as the following mathematic model:

\[
\min f(x) = [f_1(x), f_2(x), \cdots, f_p(x)]^T
\]

(5)

subject to

\[
h_i(x) = 0, \quad i = 1, 2, \cdots, k
\]

(6)

\[
g_j(x) \leq 0, \quad j = 1, 2, \cdots, m
\]

(7)

\[
x = (x_1, x_2, \cdots, x_n) \in X \subseteq E^n
\]

(8)

\[
x_i^u \leq x_i \leq x_i^l
\]

(9)

Here, \( x \) is the decision variable, and \( f(x) \) is the objective function, \( X \) refers to the decision space of decision variable \( x \). Constraint conditions \( g_j(x) \) and \( h_i(x) \) determines the feasible data range of decision variable \( x \). \( \min \) shows the vector minimization, which means that each sub objective vector of vector quantity \( f(x) = [f_1(x), f_2(x), \cdots, f_p(x)]^T \) will minimal as much as possible under some
constraint condition. We can find that when \( p = 1 \), the mathematic model is the single object optimization mathematic model. The real world is complex, if all objective function seek for the maximum value, or some seek for the maximum value and other for the minimum value, the model can be changed:

\[
\min f(x) = [-f_1(x), -f_2(x), \ldots, -f_s(x), -f_{s+1}(x), \ldots, f_p(x)]^T
\]

subject to

\[
h_i(x) = 0, \quad i = 1, 2, \ldots, k
\]

\[
g_j(x) \leq 0, \quad j = 1, 2, \ldots, m
\]

\[
x = (x_1, x_2, \ldots, x_n) \in X \subseteq E^n
\]

\[
x_i^a \leq x_i \leq x_i^p
\]

Here, \( 1 \sim s \) seeks for the maximum value and \( s + 1 \sim p \) for the minimum value.

In order to show the mathematic model of multi-objective optimization problem easily, the common model can be shortened:

\[
\min_{x \in X} f(x) \quad R = \{x \in E^n | h_i(x) = 0, g_j(x) \leq 0 \}
\]

2.2 Genetic Algorithm

Genetic Algorithm is firstly proposed by American J.H. Holland. It mainly simulates the natural selection and natural genetic mechanism of evolution and solves the random search algorithm of complex problem (or the problem solving method). \{0, 1\} shows the set of binary digit with extent. In order to optimize the function \( f_i(\{x_1, x_2, \ldots, x_n\}, \{u_j, v_j\}, i = 1, 2, \ldots, n) \rightarrow R \), generally the binary string will be divided into \( n \) segment whose length is \( n \). Each segment refers to the binary code of component \( x_j \) of optimization variable \( \{x_1, x_2, \ldots, x_n\} \). There are mapping relations between binary string \( \beta_i \) (individual) with \( \beta_i \rightarrow \beta_i' \) length and optimization variable \( \{x_1, x_2, \ldots, x_n\} \):

\[
\beta_i \rightarrow \beta_i' = \phi(\beta_i) = \delta(g(f(\beta_i))) \quad \text{(and } \delta \text{ is the scaling transformation function)}
\]

The fitness of individual is

\[
\beta_i \rightarrow \phi(\beta) = \delta(\{g(f(\beta_i))\})
\]

Genetic algorithm is a group operation treating all individual in the group as the object. If the size of group is that the group of the generation \( i \) is \( \{\beta_i^1, \beta_i^2, \ldots, \beta_i^n\} \). Through the genetic manipulation \( \{0, 1\} \rightarrow \{0, 1\} \), group \( i \) can be gotten from group \( i \). After several generations’ inheritance, the search for individual with high fitness can be carried out so that the solving of optimization can be completed.

The basic genetic operation \( \wedge \) has following three operators:
1) **Reproduction (selection operator)** The operation of selecting the winning individual from the group and weeding out the inferior individual is called the selection operator. The fitness proportion method calculates the selective probability according to the fitness of individuals. If the present group is \((\beta_1, \beta_2, \cdots, \beta_n)\) and the fitness of individual is \(\varphi(\beta_i)\), according to the probability \(P(\beta_i) = \varphi(\beta_i) / \sum_{j=1}^{n} \varphi(\beta_j), i = 1, 2, \cdots, n\), the individual will be selected and copied to the next generation. So the bigger the fitness of individual is, the more the possibility of selection is.

2) **Crossover Operator.** Randomly two individuals that have already been reproduced are selected as matrix and then two crossover location are selected. And the partial structure of two individual will be replaced and regrouped so that two new individual are formed. For example, individual \(\beta_i = A_1A_2\cdots A_l\) and individual \(\beta_j = B_1B_2\cdots B_l\) are randomly selected from group and crossed, and the crossover locations are \(s\) and \(t\) (\(s \in \{1, 2, \cdots, l-1\}\), \(t \in \{s + 1, s + 2, \cdots, l\}\)). And the new individuals are \(\beta_i^* = A_1\cdots A_{s-1}B_{s+1}B_{s+2}\cdots B_{t-1}A_t\cdots A_l\), \(\beta_j^* = B_1\cdots B_{s-1}A_{s+1}A_{s+2}\cdots A_{t-1}B_t\cdots B_l\).

The crossover operation of chromosome depends on the crossing-over rate \(P_c\).

3) **Mutation Operator.** According to the less probability \(P_m\) (aberration rate), each bit of individual string are changed randomly. For example, after variation individual \(\beta_i = A_1A_2\cdots A_l\) is changed into \(\beta_i^* = A_1^*A_2^*\cdots A_l^*\), \(A_i^* = \begin{cases} \theta_i & \theta_i > P_m \quad (i = 1, \cdots, l) \\ 1-\theta_i & \theta_i \leq P_m \quad (i = 1, \cdots, l) \end{cases}\), here \(\theta_i\) is random number from 0 to 1.

2.3. **Multi-objective Optimization genetic Algorithm based on Pareto Optimal Solution Data Base**

The thesis adopts the data base to deal with the problem. The damage of crossover and mutation operations on the Pareto optimal individual can be avoided by the data base and the operation. And the operations in detail are the following:

2.3.1. In order to solve the Pareto optimal solution, a data base is established and it exists side by side with algorithm.

2.3.2. Each individual in the initial group are set with a tag \(\text{flag}\) , \(\text{flag} = 0\) means that this individual is an inferior solution and \(\text{flag} = 1\) refers to the Pareto optimal solution. And the initialization is \(\text{flag} = 1\).

2.3.3. The Pareto optimal solutions of each generation generated from the evolutionary process are put into the data base. And meanwhile, each generation carry out the Pareto optimal solution algorithm individual in data base. The inferior individual is set as \(\text{flag} = 0\) . And the Euclidean distance algorithm is carrying out on individual and one individual that is less than designated value is considered as the inferior individual with \(\text{flag} = 0\).

2.3.4. Individual with \(\text{flag} = 0\) in data base are cleared away.

The thesis improves the selection operator so that can meet the following principles:

1) Priority selection principle of non-inferior solution individual rather than inferior solution individual.

2) Proportionalselection principle of inner probability of non-inferior solution set and inferior solution set.
The design plan is: according to the concept of Pareto optimal individual, group of each generation are divided into non-inferior solution set and inferior solution set. During the selection operation, selective probability of non-inferior solution individual is far bigger than the inferior solution individual. However, the individual are selected in non-inferior solution set and inferior solution set by the probability proportion.

If the size of group is $\text{PopSize}$, $k$ is the number of the non-inferior solution individual, $\text{rand}1$ and $\text{rand}2$ are random proportion and $0 \leq \text{rand}1, \text{rand}2 \leq 1$, the selection probability of individual of non-inferior solution set $A$ will be:

$$a_i = \frac{\text{PopSize} - k}{\text{PopSize}} + \text{rand}1,$$

and the selection probability of individual of non-inferior solution set $A$ will be:

$$b_i = \text{rand}2.$$

In the preliminary stage of operation of algorithm, there are less Pareto optimal individual and smaller $k$ and generally $a_i > b_i$. So the individual in non-inferior solution set has priority selection than one in inferior solution set. In the middle and later stages, there are more Pareto optimal individual and bigger $k$ or $k$ is close to $\text{PopSize}$ and there are less differences between $a_i$ and $b_i$. The selection chances of non-inferior solution individual and inferior solution individual are close. In this way, it is effective to avoid the quick algorithm convergence and the keep it away from the premature phenomenon. The basic program is shown as Figure 1.

![Figure 1](image-url)  
**Figure 1** Program of multi-objective optimization genetic algorithm based on Pareto optimal solution data base

3. Experimental Analysis  
With the help of Matlab, a group of multi-objective optimization problem is calculated to verify the function of this algorithm. And the specified parameters are: $\text{PopSize} = 100$, genetic length
Maximum Generation $\text{MaxGeneration} = 50$, crossover probability $P_c = 0.7$, mutation probability $P_m = 0.2$, Euclidean distance $\text{Distance} = 1e^{-4}$.

Problem 1:

$$\min f_1(x) = \sin(x^2 + y^2 + 1)$$  \hspace{1cm} (17)

$$\min f_2(x) = \sin(x^2 + y^2 - 1)$$  \hspace{1cm} (18)

$$0 \leq x, y \leq \frac{3}{4}\pi$$  \hspace{1cm} (19)

![Figure 2 Optimal front end of problem 1](image1.png)

![Figure 3 Optimal solution set of problem 1](image2.png)

From Figure 2 to Figure 3, we can find that with the algorithm in the thesis, the number of Pareto optimal solution is very big that are distributed widely and well. The curve of optimal front end is smooth and well-balanced. Besides the evolutionary in this thesis is so quick that problem 1 just evolves 20 generations and gets a very good optimization. If a common multi-objective optimization genetic algorithm is adopted, a comparatively complex problem likes problem 1 will need hundreds time evolution and the results cannot be satisfied.

4. Discussion

The algorithm improves the selection operator, and adopts a preservation mechanism—data base that can overcome the traditional problems. And its basic concept is that: in order to seek for the multi-objective optimization genetic algorithm of Pareto optimal solution, a data base is established. Pareto optimal solution of each generation during the evolution is put into data base, and firstly each generation carries out the Pareto optimal solution calculation to all individual in data base and the inferior one are clear away. And then the Euclidean distance operation will be carried out among
individual and one of the individual that are less than the certain value will be treated as the inferior solution. The data base and the operations above can effectively avoid the damage of crossover and mutation operations on the Pareto optimal individual. And the biggest advantage of the design is that it can keep away the human factors on the algorithm that the algorithm has high adaptive ability self-adapted ability.

**Conclusion**

The thesis analyses the significance and necessity of saving the Pareto optimal solution during seeking for multi-objective optimization genetic algorithm of Pareto optimal solution. It proposes a multi-objective optimization genetic algorithm based on Pareto optimal solution data base. This new algorithm enhances the algorithm performance to a large extent and improves the quality of algorithm. Abundant computer simulation calculations show that new algorithm can not only get well-distributed Pareto optimal solution and its algorithm is stable that is hardly influenced by its own randomness. This algorithm has high speed evolution and only 20-40 generation can get nice optimization.

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