

Transmission Line Maintenance Scheduling Based on Graph Coloring

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Abstract—In order to improve the efficiency of transmission line maintenance scheduling, a multi-objective and multi-scale mathematical model is proposed. The coloring problem of graph theory and analytic hierarchy process are combined, and various constraints are considered in the model. In order to deal with discrete variables problems, a new method based on harmony search algorithm combined with ant colony algorithm is proposed. The harmony search algorithm is developed based on an analogy with music improvisation process. Musical performers seek to find pleasing harmony as determined by aesthetic standard, just as the optimization process seeks to find global optimization solution. Harmony search algorithm is suitable for solving the problem of continuous variable problem, so it is improved in this paper. The number of color got by using ant colony algorithm is the first stage, and the coloring order obtained by using improved harmony search algorithm is the second stage. Furthermore we discuss the application of our models to a case, and simulation results show that the proposed model and algorithm are effective.

Keywords—transmission line; maintenance scheduling; graph coloring; harmony search algorithm; multi-objective optimization

I. INTRODUCTION

With the rapid development of industry and science and technology, the structure and scale of the transmission line become more and more complex. Increasing the size of the grid increase the transmission capacity, factors that affect the reliable operation of the power system also increase. Regular maintenance of the transmission lines is to ensure safe and reliable operation of power system. Maintenance activities are often under conditions of transmission line outage, line outage may cause the system to reduce the power supply reliability and transmission capacity. At present, most of the regional transmission line maintenance planners rely on the original manual method or simple computer program, which is difficult to make a

reasonable maintenance plan. Reasonable arrangement for transmission line maintenance has become an important subject line administration.

Maintenance scheduling has become a hot research. Yare[1,2] applied respectively discrete multi PSO and PSO to make generator maintenance plan. Geetha[3] studied coordinated preventive maintenance planning problem under competitive mechanism. None of the above document solved transmission line maintenance. Jiang and Zhao[4] used traditional methods to make transmission line maintenance plan, which need to spend a lot of time for large-scale maintenance tasks. Gao[5], and Liu[6,7] proposed optimization model based on characteristic of line maintenance, and the application of intelligent algorithm was carried out for solving the model. Unfortunately, they did not consider multiple sets of maintenance. Graph coloring will be made use of in this paper to build transmission line maintenance model. What's more, line maintenance plan is NP-hard problem, which is difficult to solve. This paper presents an improved harmony search algorithm to solve the problem.

II. PROBLEM FORMULATION

Firstly, each bureau provides maintenance tasks when staff scheduling makes the transmission line maintenance plan. Secondly, staff scheduling analyzes the maintenance tasks. Finally, staff scheduling makes a reasonable maintenance plan based on maintenance tasks characteristic. The parameters and decision factors of the model are as follows.

- a) The same power administration can not repair two parallel lines at the same time
- b) The same substation can not be two parallel lines at the same time
- c) The urgent degree of the mission

III. THE MODEL FOR TRANSMISSION LINE MAINTENANCE SCHEDULING

When transmission line maintenance plan is made, the parallel lines can't overhaul in the same time. Correspondingly, when color a graph, the adjacent vertex can't color the same color. So the parallel lines can be taken regard as the adjacent vertex of coloring problem. As a result, the problem of electric power line overhaul plan be described by coloring problem.

Suppose the transmission line maintenance task is $A = \{a_1, a_2, \dots, a_n\}$, A is looked on as the set of the vertex in coloring problem. If two lines are parallel, the two lines are called conflicting lines. The conflicting lines are represented by disorder couple gather E , E is taken regard as the set of the edge in coloring problem, if a_i and a_j conflict each other, then $(a_i, a_j) \in E$. Suppose time quantum is $T = \{t_1, t_2, \dots, t_i \dots\}$, T represents the number of time quantum when overhaul lines satisfy the requests that the conflicting lines can't overhaul in the same time. Therefore, the undirected graph $G = (A, E)$ can show the problem of electric power line overhaul, and the aim T is that the minimum amount of color is obtained by coloring.

Three objective functions are considered are considered in this paper, which can be stated as follows.

The first objective function is the minimization of the time quantum. The total overhaul time is certain for ransmission line maintenance, so the minimum time quantum can make each maintenance task have enough overhaul time. The time quantum can be got based on the model of vertex coloring, which is discribed as follows:

$$f_1^* = \min f_1 = \min t_{\max} \quad (1)$$

Where t_{\max} is the minimum color of vertex coloring, that is to say, t_{\max} is the time quantum of ransmission line maintenance.

The second objective function is the economic lost. A certain overhaul time will be expected for some maintenance tasks. If the actual time is later than the expected time, it will result in economic lost at a certain degree. The second objective function can be stated as follows:

$$f_2^* = \min f_2 = \min k \sum_{i=1}^n \max(\eta_{\text{expect}} - \eta_{\text{fact}}, 0) \quad (2)$$

Where $\eta_{\text{expect}} = \{\eta_1, \eta_2, \dots, \eta_n\}$ is the expected overhaul time, $\eta_{\text{fact}} = \{\eta_1, \eta_2, \dots, \eta_n\}$ is the actual overhaul time, k is a parameter of economic lost that can be got by historical data

The third objective function is the average degree of maintenance tasks. There is too much or too little maintenance tasks at the same time quantum, which is not expected for maintenance staff, so the work balance degree is considered, which can be defined as:

$$f_3^* = \min f_3 = \min \frac{1}{t_{\max} - 1} \sum_{i=1}^{t_{\max}} (s_i - \bar{s})^2 \quad (3)$$

where s_i is the number of jobs in each time quantum.

Because the three objectives are conflicting, a new objective is defined:

$$f = \min \sum_{i=1}^3 \omega_i f_i \quad (4)$$

where ω_i is got according to analytic hierarchy process.

$$A = \begin{pmatrix} 1 & \frac{1}{4} & 1 \\ 4 & 1 & 3 \\ 1 & \frac{1}{3} & 1 \end{pmatrix}$$

A is the judgment matrix that is given by expert in electric line overhaul. Then the ω_i is got, which is $\omega_1 = 0.174$, $\omega_2 = 0.634$, $\omega_3 = 0.192$, and $CI = 0.0048$, $CR = 0.0083 < 0.10$. So matrix A has satisfactory consistency.

IV. THE SOLUTION ALGORITHM

Ant colony algorithm(ACO)[8] is proposed by Dorigo M and some other Italian scholars, which simulates the ant finding path behavior in nature. The ant colony algorithm solves the question according to the method of ant finding food and goes back to the nest. Because ACO is suitable for solving the problem of discrete variable, the number of color for graph coloring is got by it.

The harmony search (HS) algorithm[9,10] is originally developed by Geem et al, which is used mainly to solve continuous variables problem. It is difficult to deal with integer programming problem. What's more, it is easy to fall into local optimization, so an improved HS(IHS) is proposed to optimize maintenance constraints in this paper.

The IHS in this paper can be described as follow, and the procedure is given in Fig. 1.

Step 1: initialize the problem and algorithm parameters

In this step, the optimization problem is specified as follows:

$$\text{Minimize } f(x) \quad (5)$$

$$\text{Subject to } x_i \in X_i, i = 1, 2, \dots, N \quad (6)$$

where $f(x)$ is an objective function; x is a solution vector composed of decision variable x_i ; N is the number of decision variables; X_i is the set of the possible range of values for each decision variable, that is, $X_i = \{x_i(1), x_i(2), \dots, x_i(K)\}$; and K is the number of possible values for the decision variables. In addition, the harmony memory size (HMS), harmony memory considering rate (HMCR), pitch adjusting rate (PAR) and the number of improvisations (NI) are given in this step.

For distribution network reconfiguration problem, the objective function is loss minimization, switches that can be opened or closed is the decision variable; the number of decision variables N is the number of branches in the network.

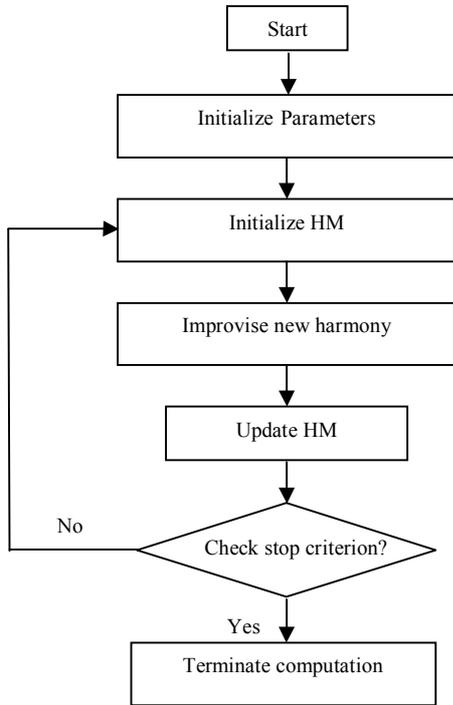


Figure 1. Optimization procedure of harmony search algorithm

Step 2: initialize the harmony memory

In this step, the harmony memory(HM) matrix is filled with as many randomly generated solution vectors as the HMS.

For transmission line maintenance scheduling problem, x_i of HM is order variable. The same number represents that transmission line is overhauled at the same time quantum. If solution vector is not infeasible, the number of x_i can be changed.

Step 3: improvise a new harmony

In this step, a new harmony is improvised, which bases on three rules:

a) random selection

In the random selection process, the new harmony improvisation process bases on random operation, that is to say, the new harmony vector is generated randomly.

b) memory consideration

In the memory consideration process, a harmony vector in HMS is selected by roulette methods, and then the new harmony vector bases on cross operation for the selected vector.

c) pitch adjustment

In the pitch adjustment process, a harmony vector in HMS is selected by roulette methods, and then the new harmony vector bases on insert operation for the selected vector.

Step 4: update the harmony memory

The new harmony vector replaces the worst harmony in the HM, if its objective function value is better than that of the worst harmony.

Step 5: check stopping criterion

Steps 3 and 4 are repeated until the termination criterion (NI) is satisfied.

V. EXPERIMENTAL RESULTS

In this section, we present some numerical examples to consider the model behavior and the near-optimal solutions. Parameters of algorithm is as in [8] and [9]. The maintenance tasks are shown in TABLE I, and maintenance constraints are given in TABLE II.

TABLE I . THE GIVEN MAINTENANCE TASKS

Maintenance line	Start time	End time	Urgent degree
1	1	5	5.4
2			5.4
3			3.7
4			4.1
5	7	12	0.2
6			0.7
7			2.5
8			2.2
9			1.8
10			0.4
11			1.3
12			1.8
13			2.4
14			2.5
15			4.4
16			4.1
17			4.5
18			5.8
19			6.2
20			8.2
21			9.1
22			8.3
23			7.1
24			6.4
25			6.8
26			8.3
27			8.7
28			7.4
29			7.1
30	6	10	5.8

TABLE II. RESTRICTIONS OF MAINTENANCE RELATIONSHIP

Maintenance line	Same time quantum overhaul
2, 10	no
6, 18	no
9,19	no
20, 22	no

TABLE III. compares the proposed algorithm with the results of ACO, PSO and GA algorithm. According to TABLE III., we have found that the different results are obtained by different algorithms. The optimal result is got by the proposed algorithm.

TABLE III.. EXPERIMENT RESULTS FOR 30 SETS OF DATA

Number of colors	Algorithm	Mean	Best	Worst
2	ACO	91.5339	89.5461	92.9054
	PSO	91.8231	90.0125	93.2145
	GA	91.6120	89.7125	92.9521
	IHS	90.5382	89.3703	91.4542

TABLE IV. shows the optimal maintenance strategy. The set {27, 1, 22, 26, 16, 30, 10, 6, 5, 12, 11, 9, 13, 4, 7} and {2, 28, 29, 19, 25, 17, 21, 3, 8, 15, 20, 18, 23, 24, 14} can overhaul at the same time. What's more, if the number of tasks is too big to overhaul simultaneously, the maintenance order can be got by TABLE IV. too. Fig. 2 shows the stem graph of maintenance order.

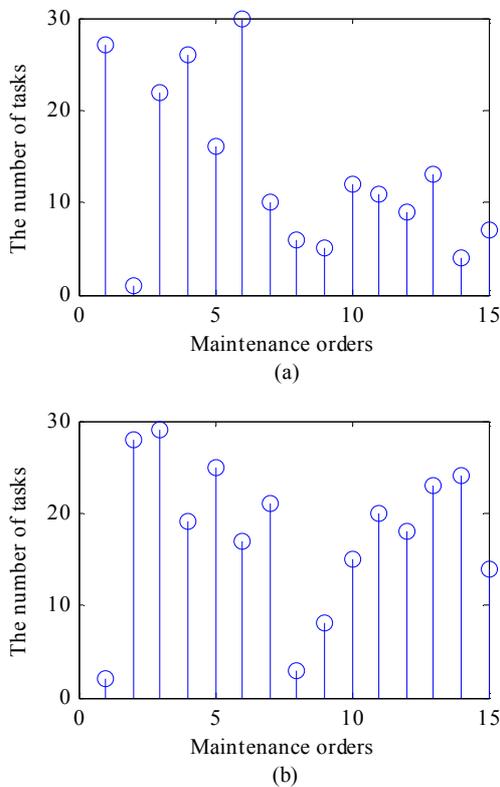


Figure 2. Maintenance orders for two sets

TABLE IV. MAINTENANCE ORDERS FOR 30 SETS OF DATA

Number of colors	Optimal maintenance order
2	27, 1, 22, 26, 16, 30, 10, 6, 5, 12, 11, 9, 13, 4, 7
	2, 28, 29, 19, 25, 17, 21, 3, 8, 15, 20, 18, 23, 24, 14

When we use this model to make transmission line maintenance schedule, not only the time quantum but also the overhaul order of each maintenance task are can be got according to the results, that is to say, which job is in which time quantum is can be got by the simulation results.

VI. CONCLUSIONS

A multi-objective and multi-scale mode is presented based on the analysis of transmission line maintenance scheduling problem, and various constrains are taken into account. The coloring problem of graph theory and analytic hierarchy process are combined to make scheduling by using ACO and IHS. Simulation results show that we can make transmission line maintenance plan based on the proposed model quickly, and the IHS is superior to ACO, PSO and GA in quality.

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