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Improved Genetic Algorithm and Analytic Hierarchy Process for Electric Power Equipment Maintenance Schedule Optimization

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Abstract: Electric power equipment maintenance schedule optimization is a large-scale combinatorial optimization problem; Overall, the maintenance schedule optimization problem is focused on two aspects: model and algorithm. In modeling, weight coefficient of different optimization goal is hard to quantitative analysis and defined, this paper use Analytic Hierarchy Process(AHP) to establish a hierarchy structure and decompose the goals, use a comparison judgment matrix to determine the weight coefficient, thus accurately reflect the importance of each objective. In algorithm, this paper make many improvements for Genetic Algorithm (GA), including a special set of initial population, SUS to generate parent population, adaptive crossover and mutation coefficient. The improved GA can effectively reduce iteration times, overcome premature and stagnation in search process, and stabilize the optimization results. Simulation results show the reasonability of the new model, and the effectivity of the algorithm.

Keywords: Electric Power Equipment; Maintenance Schedule; Optimization; Genetic Algorithm; Analytic Hierarchy Process; Stochastic Universal Sampling; Adaptive

1. Preface

Maintenance of electric power equipment is an important part of power system; the maintenance plan arrangement is bound to affect the network's security and stability. On the other hand, the electric power enterprise hope the maintenance schedule can meet its own economic interests. Therefore how to ensure the reliability of power system, and maximum the economic benefit of power companies are our main problems.

Therefore, in the electric power equipment maintenance schedule optimization model, the optimization objective is divided into two categories: reliability objective and economic objective. In the construction of objective function, this paper presents the application of AHP to quantify the weight coefficient of each objective based on strict mathematical method, reunification and analysis the qualitative maintenance schedule optimization, thus making the model more reasonable and effective.

For the algorithm aspect, several optimization algorithms have been proposed, such as GA in documentary [2 5 6], Particle Swarm Optimization (PSO) in documentary [1], Ant Colony Algorithm (ACO) in documentary [3 4], Benders decomposition method in documentary [7], etc. In recent years, GA has been becoming widely used in solving optimization problems, compare with the traditional optimization methods, biological evolution prototype, wide application scope, and wide search range, all this making GA has a broad application prospect in the field of power system research. But when using the standard GA in electric power equipment maintenance schedule optimization, we meet the drawbacks of much iteration times, premature and stagnation in search process and unable to achieve global optimum, and the instability of optimization results. Therefore we make many improvements for the standard GA, including using SUS to generate parent population to reduce iteration times; making a special set of initial population, setting adaptive crossover and mutation coefficient to overcome the premature in search process; in the meantime making a special set of initial population can also stable the optimization results.

Instance in this article is referring to instance in document [8].

2. Model of Equipment Maintenance Schedule Optimization

2.1. Overview

Equipment maintenance schedule optimization is a multi-objective optimization; the objective has two categories: reliability objective and economic objective. And the reliability objective can be further divided into deterministic maintenance objective, simultaneous maintenance objective, mutex maintenance objective, and least adjust-date objective; the economic objective is include least manpower objective and least loss of electricity sale objective. As shown in figure 1.

By setting reasonable weight coefficients, the multi-objective optimization problem can be converted into single-objective optimization problem:

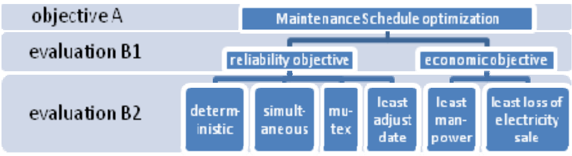

Figure 1 evaluation system of electric power equipment maintenance schedule optimization.

$$f = \min \sum_{i=1}^{N_f} \lambda_i f_i \qquad (1)$$

Note: N_f is the number of optimization objective; f_i is the objective function i, λ_i is the weight coefficient of objective function i.

1) *Reliability objective*

a) *Deterministic maintenance:*

If a task is from superior departments' order, or is an important task in the last maintenance period, or is a task coordinate with infrastructure project, the date of maintenance cannot be adjusted.

$$f_{determ} = \min \sum |x_i - x_{i0}| \qquad (2)$$

Note: f_{determ} present the deterministic maintenance objective function value; x_i is the date for equipment i to begin maintenance; x_{i0} is equipment i's deterministic maintenance start date.

b) *Simultaneous maintenance:*

For the equipments in the same line, different maintenance dates will cause repeated power failures, so the maintenance date should be simultaneous.

$$f_{simul} = \min \sum |x_i - x_j| \qquad (3)$$

Note: f_{simul} present the simultaneous maintenance objective function value; x_i x_j are the date for equipment i and j to begin maintenance.

c) *Mutex maintenance:*

For mutual backup equipments, or equipments which maintained in the same time will cause overload, cannot be maintained in the same time.

$$f_{mutex} = \min \sum \max(d_i,\ d_j) - |x_i - x_j|) \quad (d_i,\ d_j) > |x_i - x_j|) \qquad (4)$$

Note: f_{mutex} present the mutex maintenance objective function value; x_i x_j are the date for equipment i and j to begin maintenance; d_i, d_j are the duration of equipment i and j's maintenance.

d) *Least adjust-date:*

Maintenance system requires equipment to maintain in time, does not allow ultra-period operation; on the other hand, under resource constraints, equipment maintained before expiration date is not economy, and is unrealistic.

$$f_{adjustdate} = \min \sum_{i=1}^{N_d} |x_i - x_{i0}| \qquad (5)$$

Note: $f_{adjustdate}$ is the least adjust-date maintenance objective value; x_i is equipment i maintenance start data; x_{i0} is the expiration date for equipment i to maintained.

2) *Economic objective*

a) *Least manpower:*

Under the maintenance resources constraints, in one day the maximum number of equipment to be maintained can be set as N_{max}, so the actual number of equipment to be maintained should less than the value.

$$f_{mainpower} = \min \sum N_i - N_{max} \ (N_i > N_{max}) \qquad (6)$$

Note: $f_{mainpower}$ present the least manpower objective function value; N_i is the actual number of equipment to be maintained.

b) *Least loss of electricity sale*

$$f_{loss} = \min \sum power(x_i) - power_i \qquad (7)$$

Note: f_{loss} present the least loss of electricity sale objective function value; $power(x_i)$ is the actual loss when equipment i is maintained, $power_i$ is the minimum loss when equipment i is maintained.

2.2. AHP to determine the weight coefficient of different objectives

As show in above, these six optimization objectives have different degree of importance, and vary while the regions or time change as the requirement of the power company. All these will eventually reflect to the weight coefficients of the optimization objective. This paper proposed the application of AHP to evaluate the relative importance of each objective, and determine weight coefficients. AHP is a comprehensive qualitative and quantitative analysis, a decision-making method which modeling the human brain thinking, unify the quantitative and qualitative mixed problem. The specific process of the Application of AHP is as follows:

1) As shown in Figure 1, determine the index system.

2) Compare attributes, Set deterministic maintenance as the most important goal, followed by simultaneous maintenance and mutex maintenance, then is least manpower and least adjust-date; the last is least loss of electricity sale. Thus get comparison judgment matrix R.

Table 1 AHP Comparison judgment matrix R

Attribute	R1	R2	R3	R4	R5	R6
R1	1	3	3	7	4	9
R2	1/3	1	1	6	3	9
R3	1/3	1	1	6	3	9
R4	1/7	1/6	1/6	1	1/3	5
R5	1/4	1/3	1/3	3	1	7
R6	1/9	1/9	1/9	1/5	1/7	1

3) According to comparison judgment matrix R, the weight coefficient vector λ is found, λ= [40.759 21.049 21.049 4.9765 10.017 2.1498];

A. *AHP compared with fixed value method to* *determine the weight coefficient*

In the instance, we used AHP and fixed value method respectively, calculated 5 times for each method, set the iteration time 200. The results are as follows:

Table 2 Results of method using fixed-value and AHP

f		Reliability objective				Financial objective	
		$f_{constant}$	f_{simul}	f_{mutex}	$f_{adjustday}$	f_{force}	f_{load}
Fixed value	608.3	0.0	9.2	0.6	20.2	0.2	1.469
AHP	231.7	0.0	0.0	0.0	45.4	0.2	1.731

As Show in table 2, when using fixed value method, there will occur contraries with simultaneous maintenance, mutex maintenance and least manpower. On the contrary, when using AHP, the maintenance schedule will always meet the simultaneous maintenance, mutex maintenance request. Compare the fitness values, the average value when using AHP is 231.7 that is 38.1% of the fixed-value method value, Jump out of local optimum situation which is caused by fuzzy judgments of weight coefficients. From the comparison in Figure 2, obviously after the use of AHP, the convergence speed has been accelerated, the fitness value of iteration after 300 times seem not change, so reduce the number of iteration from 500 to 300. In sum, using AHP can not only enhance the capacity of convergence to the global optimum, but also speed up the convergence rate of species evolution.

3. The Improved Ga Optimization Design

A. A special set of initial population

In General the initial population is always create randomly within the problem space. but in the equipment maintenance schedule, as statements (2), (5) shows, the deterministic maintenance value is related to deterministic maintenance start date, and the least adjust-date value is related to the expiration date for equipment to maintain. Thus can grasp the space distribution of optimal solution in the problem space, by using these certain value to compose an initial individual, could jump out of the local optimum during evolution, speed up the convergence rate to global optimal solution. This is named improvement 1.

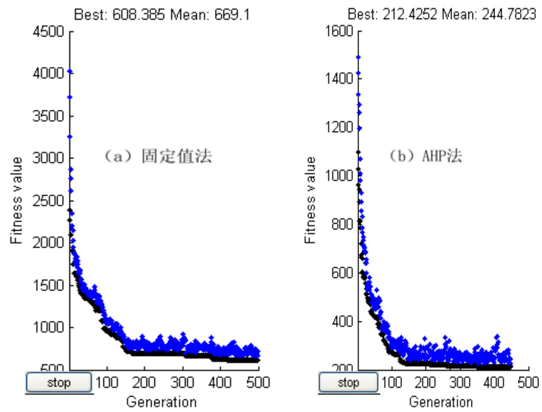

Figure 2 Fitness value of method using fixed-value and AHP.

Table 3 Optimization results of different improvement

algorithm	Iteration times	1	2	3	4	5	6	7	8	9	10	ave	min	max	var
Standard GA	300	257	269	188	193	279	238	248	253	248	228	240	188	279	888
Improve 1 GA	300	158	168	158	183	178	168	184	143	173	153	167	143	184	181
Improve 1~2 GA	300	153	148	148	148	163	138	148	143	138	148	147	138	163	53
Improve 1~3 GA	300	138	148	143	163	143	158	138	143	157	163	149	138	163	101
	200	138	168	158	169	138	143	138	148	148	143	149	138	169	139

In the instance, algorithm use standard GA and improvement 1 GA, calculated 10 times for each, and set the iteration time 300. The results are show in table 3 line 2~3, the average of fitness value is 166.5, decreased by 30.4% compare with standard GA. So using the dependence on initial population; a special set of initial population is introduced to the algorithm, improve the quality of the initial population, and thus overcome the premature phenomena in search process effectively.

B. Using SUS generate parent population

Generally GA use roulette wheel selection method, but roulette wheel selection method is lack of inter-group competition, so decelerate the convergence rate. In this paper, Stochastic Universal Sampling (SUS) selection is used, this method provide more protection for high-fitness individuals, thus accelerate the evolution process, speed up the convergence rate. This is improvement 2.

Using SUS to select individuals: generate population wheel according to exception value, using a random number γ which is in random of [0.1/parent], While γ is in the context of individual i, copy the individual to the parent populations; $\gamma = \gamma + 1/parent$, repeat the above steps and generate parent population, shown in Figure 4.

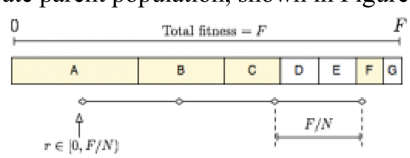

Figure 3 Using SUS generate parent population.

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In the instance, algorithm use improvement 1~2 GA, calculated 10, and set the iteration time 300. as show in table 3 line 4, the average of fitness value is 147.4 with a variance of 52.9.compare with improvement 1GA, the stability of the fitness value is enhanced; and the value is reduced by 12%, that is using SUS to generate parent population could speed up the convergence rate, but due to its excellent individual protection, SUS will reduce the diversity of populations, and is prone to fall into local optimum, so the algorithm needs further improvement.

C. Adaptive population crossover coefficient and population mutation coefficient

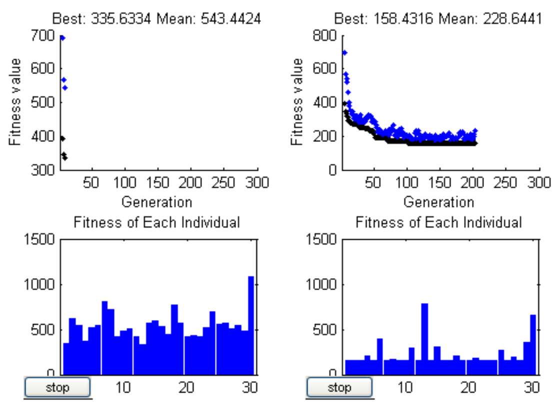

Figure 4 Fitness value of improvement 1~3GA

As shown in figure 4, the left picture shows iteration fitness value and individual fitness value in early iteration, where have an obvious species diversity and a large population fitness value. Here should have a big population crossover coefficient to makes the excellent individuals can generate more child individuals, and take a smaller population mutation coefficient. The right picture shows these values in the final iteration, when the species diversity is not obvious and population fitness is small. At this time the population should have a small population crossover coefficient and a big population mutation coefficient to maintain the diversity of population, produce new individuals and find new optimal value. This is the improvement 3.

$$xFrac = \begin{cases} \left(1-\frac{\min(f)}{\mathrm{mean}(f)}\right)^{xPara}, & \frac{\min(f)}{\mathrm{mean}(f)} < xSet \\ ySet * \left(1-\left(\left(\frac{\min(f)}{\mathrm{mean}(f)}-xSet\right)/(1-xSet)\right)^{xPara}\right) & \frac{\min(f)}{\mathrm{mean}(f)} > xSet \end{cases} \quad (13)$$

Note: $\min(f)$ is minimum of fitness value; $\mathrm{mean}(f)$ is average of fitness value; $xPara$ is the adaptive coefficient; $xSet, ySet$ is adaptive initial value, which is depend on $\frac{\min(f)}{\mathrm{mean}(f)}$ value in the middle of iteration。

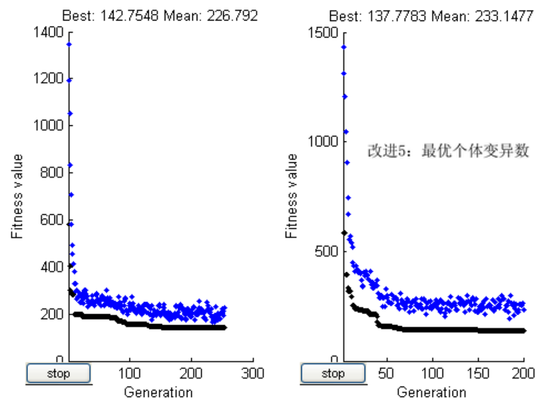

Figure 5 Fitness value of improvement 1~3GA.1~4GA

In the instance, algorithm use improvement 1~3 GA, calculated 10, and set the iteration time 300. As show in table 3 line 5, the average of value is 149.3. That is similar to the previous calculation results, observe Figure 5 carefully could find the value seems not change after 200 iterations, so set the iteration time 200 and the results is shown in table 3 line 6, the average of fitness value is 149.0, that means setting the adaptive crossover and mutation coefficient is able to maintain the diversity of population, enhance the capacity of jump out the local optimal solution and overcome the premature appears in search process, therefore making the algorithm search to the global optimal solution in fewer iteration time.

Table 4 maintenance schedule before and after optimization

No.	Original date	Optimized date	No.	Original date	Optimized date	No.	Original date	Optimized date
1	5	5	8	13	9	15	18	18
2	11	11	9	13	13	16	14	9
3	12	12	10	15	15	17	14	9
4	19	19	11	21	21	18	19	19
5	20	20	12	4	18	19	20	21
6	4	18	13	26	26	20	4	4
7	22	22	14	27	28	21	7	7

Table 5 results comparison before and after optimization

	f	Reliability objective				Financial objective	
		$f_{constant}$	f_{simul}	f_{mutex}	$f_{adjustday}$	f_{force}	f_{load}
original	582.3	0	25	2	0	1	1.847
optimized	138.0	0	0	0	27	0	1.677

4. Instance and Simulation

As shown in table 5, the original maintenance schedule can't meet reliability and financial objectives, violated the request of simultaneous maintenance, mutex maintenance, least manpower and least loss of electricity sale for many times. After optimization, the maintenance schedule could satisfy the request of simultaneous maintenance, mutex maintenance, and least manpower in the same time. While total adjust date is only 27 and the loss of electricity sale can be reduced to 1.677MW.

5. Conclusion

Target at the two major issues in Maintenance Schedule Optimization: model and algorithm, many improvements are making. In modeling, apply AHP to determine the weight coefficient, accurately reflect the importance of each objective. In algorithm, many improvements have been introduced, such as a special set of initial population, using SUS to generate parent population, adaptive crossover and mutation coefficient,. Effectively reduce iterations times, overcome premature phenomenon, and stable the calculation results.

References

[1] XU Xufeng，HUANG Minxiang，etal．Optimization Algorithm of Power Supply Equipment Maintenance Scheduling and Its Application in Regional Power Network[J]．Power System Technology．2009，33(14)：31-35.

[2] HUANG Xianchao，ZHANG Lizi，ZHANG Jingwei．A Load Transfer Scheme for Distribution Maintenance with Distributed Generation Taken into Account[J]．Automation of Electric Power Systems．2008，32(12)：32-35.

[3] YUAN Xiaotao，YAO Jiangang， CHEN Liang．Solving Unit Maintenance Scheduling Problem by Use of Improved Ant Colony Algorithm[J]．Power System Technology．2008，32(21)：42-46.

[4] LI Chuan，YAO Jiangang，ZHANG Hongxu．Improved Multi-ant Colony Virtual Parallel Optimization Algorithm of Generator Maintenance Schedule[J]．Proceedings of the Chinese Society of Universities for Electric Power System and its Automation．2009，21(4)：120-124.

[5] SU Huiling， WANG Chun， QIN Rujing， ZHANG Zhongcheng．Multi-objective Optimization of Unit Maintenance Scheduling Based on Improved GA[J]．Proceedings of the Chinese Society of Universities for Electric Power System and its Automation．2008，20(6)：27-30.

[6] SHU Hongchun， HU Zejiang， XIE Yigong．An Optimized Scheduling Method for Transmission Network Maintenance with Minimum Hidden Losses[J]．Automation of Electric Power Systems．2008，32(9)：34-38.

[7] Chen Shaohua，Yang Peng，Zhou Yongwang，He Ruiwen．A Method Combining Genetic Algorithm With Simulated Annealing Approach For Thermal Unit Maintenance Scheduling[J]．Automation of Electric Power Systems．1998，22(7)：44-46.