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Method of Reservoir Optimal Operation Based on Improved Simulated Annealing Genetic Algorithm

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Abstract: According to the specific circumstances of Wanjiazhai Reservoir, establish a reservoir optimal scheduling nonlinear mathematical model with a maximum generation capacity target, this paper uses an improved simulated annealing genetic algorithm to solve the model. The algorithm is in view of the defects of the traditional simulated annealing genetic algorithm to improve the algorithm from three aspects: introducing the niche technology, using adaptive crossover and mutation strategy, using the elitist strategy during the selection. Through examples are calculated and compared with the traditional simulated annealing genetic algorithm, the improved algorithm effectively overcomes the stagnation phenomenon, to enhance the global search ability. Its optimization performance is better than that of the traditional simulated annealing genetic algorithm. *Copyright © 2013 IFSA.*

Keywords: Reservoir optimal operation, Simulated annealing genetic algorithm, Ecological niche, Adaptive, Optimal preservation.

1. Introduction

The development and utilization of water resources, has been around the world hot topic in the production and construction and scientific practice. Reservoir optimal operation is based on the specific running conditions of the reservoir, built with the goal of the reservoir maximizing benefit, with water balance, the power output as the constraint condition of optimization scheduling model, use optimization theory to determine the mode of operation of water resources reservoir [1]. It is under the condition of that no change in the existing power equipment and the structure of the hydraulic structure of the hydropower station, using the optimization theory,

modern control theory and system engineering method, develop the reservoir optimal scheduling plan and map optimization scheduling, combined with the runoff forecasting, and comprehensive utilization department of electric power system, the reservoir optimal control is applied, to increase capacity or increase the power output, utmost ground once the purpose of energy saving [2-4].

Since the 1980s, has developed a novel algorithm, such as genetic algorithm, ant colony algorithm, particle swarm optimization (PSO), artificial immune algorithm and the hybrid optimization strategy, etc., which developed by simulation or reveal certain natural phenomena and processes, often referred to the intelligent optimization algorithm [5]. As the production of intelligent bionic algorithm, provides a

new way for reservoir optimal operation. Among them, the genetic algorithm because of its excellent global search ability and implicit parallel computing feature characteristics, and is considered to be the superior reservoir optimal operation algorithm [6-8]. But local optimization ability of genetic algorithm is poorer, prone to premature phenomenon.

The traditional simulated annealing genetic algorithm is based on the basic genetic algorithm, in its search process into the simulated annealing algorithm with a method of optimization idea. Although the traditional simulated annealing genetic algorithm is through ideas of the integration to realize the complementary advantages of the algorithm, achieved the purpose of improve the algorithm performance [9]. But it's in evolution obviously lack of history information communication and feedback between populations, and population evolution of the reference standard, so in a short period of time not only easy to cause the evolution direction deviating from the theory of the defect of the target, and can cause within the limited search time may miss out on the optimum solution. Aiming at the defects of the traditional simulated annealing genetic algorithm, an improved algorithm, the algorithm is to introduce niche technology, adaptive crossover and mutation strategy and optimal preservation strategy. Using its single reservoir optimal scheduling calculations, and compare the optimization results with the result of the traditional simulated annealing genetic algorithm, to illustrate the feasibility and optimization of the algorithm.

2. Improved Simulated Annealing Genetic Algorithm

Based on the defect analysis of the traditional simulated annealing genetic algorithm, this paper proposed an improved simulated annealing genetic algorithm, the idea of niche genetic algorithm is used to the choice of operation, through similar individuals in the population selection probability of uneven distribution, thus effectively avoid algorithm falls into local optimum and improve the search early lack of effective gene; using an improved adaptive crossover and mutation probability of combining the algorithms to improve the speed of evolution algorithm; using the optimal preservation strategy, at every stage of the evolutionary keep the best individual, to guide direction of the evolution of algorithm.

1) Niche technology.

The population of each generation as composed by a number of subgroups, Selected from each subgroup some better individuals to form a new group, then in this group, and other groups, constantly evolve a new population, adopting mechanism of sharing mechanisms or exclude or complete selection operation, this is called niche technology. The mechanism of the third option with most, the idea is the fitness of the individuals in a population is adjusted by sharing degree. After the adjustment of individual fitness is f_i' :

$$f_i' = \frac{f_i}{m_i},\qquad(1)$$

$$m_i = \sum_{j=1}^{M} S(d_{ij}),\qquad(2)$$

where m_i is the number of niches, d_{ij} is the Hamming distance between two bodies.

Based on Niche Genetic Algorithm technique is the basic idea [10]: First, according to formula (2) to calculate the population of two Hamming distance between two individuals, if the distance is less than the threshold set distance, and then the two fitness comparison. In order to set the threshold within a distance of only a fine individual existence, out of which as soon as lower fitness of the individual, the measures imposed on the latter is a stronger penalty function, to increase its evolution probability of being eliminated. This approach enables individuals evenly dispersed throughout the solution space to ensure that the diversity of the population, thus achieving a Niche Genetic Algorithm.

2) Adaptive crossover and mutation probability.

For Srinvivas [11] and Ren Ziwu [12], who proposed two adaptive genetic algorithm shortcomings, this paper uses a new adaptive genetic algorithm [13] p_c and p_m is calculated as follows:

$$p_c = \begin{cases} p_c \dfrac{1}{1-\dfrac{1}{\dfrac{f\,min}{f\,max}}}, & \dfrac{f_{avg}}{f_{max}} > a,\ \dfrac{f_{min}}{f_{max}} > b \\[2ex] p_c, & otherwise \end{cases}\qquad(3)$$

$$p_m = \begin{cases} p_m \dfrac{1}{1-\dfrac{1}{\dfrac{f\,min}{f\,max}}}, & \dfrac{f_{avg}}{f_{max}} > a,\ \dfrac{f_{min}}{f_{max}} > b \\[2ex] p_m, & otherwise \end{cases}\qquad(4)$$

From the above formula, we can see that the algorithm is the use of population maximum fitness f_{max}, minimum fitness f_{min} and average fitness f_{avg} these three variables to measure the concentration of fitness of the population. Wherein, f_{max} and f_{min} reflects the proximity of the concentration of the entire population, the closer the adaptation level also represents more concentrated, genetic algorithms may be more easily into local optimum; f_{avg} and f_{max} within proximity of fitness of the population reflects distribution, the closer, the more concentrated reflect the generation of individual.

3) Optimal preservation strategy.

In the evolution of the population, selection, crossover and mutation operation will produce more and better performance of the individual, but the failure to take effective measures, these individuals will also be destroyed by these operations, resulting in the operating efficiency of the genetic algorithm and convergence reduced. Survival of the fittest operation using the optimal preservation strategies to avoid the destruction of the best individual occurrence, the basic idea is: the best individual in the current population does not participate in the crossover and mutation operators, and it's directly into the offspring population, Adopting this strategy can be preserved throughout the optimal individual, have to make random process.

Improved simulated annealing genetic algorithm process:

Step 1: Parameter Initialization: Including annealing coefficient α, Initial temperature t_o, Accuracy requirements E, Population size M, Penalty factor, etc.

Step 2: The population size M which is randomly generated and satisfy the constraints is the initial population $P_0(t)$;

Step 3: Calculate the fitness of the population, and its descending order, the best performance of the individual and its corresponding optimal solution stored in the centralized optimal solution;

Step 4: Termination condition is determined, if satisfied, then stop operations, and the current results as the optimal results; if not met, turn Step 5.

Step 5: Niche operation selection process: M individuals are obtained by Step 2, calculate the Hamming distance of between two individuals' fitness value, the formula (5) below:

$$d_{ij} = \sqrt{\sum_{i=1}^{M}\sum_{j=1}^{N}\sum_{K=1}^{N}(f(i,k)-f(j,k)^2)} \quad (5)$$
$$a \neq b,$$

where f is the individual fitness value; k is the number of decision variables.

When $d_{ji} < L$ (where L is the distance threshold value Hamming distance), the comparison of the size of $f(i,k)$ and $f(j,k)$, where f is the smaller of the individual by applying a penalty function $f_{min(x_i,x_j)} = F_{pensity}$.

Step 6: Use genetic algorithm in selection, crossover and mutation operation, etc. In this paper:

- Roulette wheel selection is carried out on the population $P_0(t)$ firstly, then uses the optimal preservation strategy

- Crossover operation (this article uses single-point crossover) is according to the improved adaptive crossover probability, generate populations.

- The mutation operation(this article uses the arithmetic variation) is according to the improved

adaptive mutation probability p_m to generate population $P_2(t)$.

Step 7: To do simulated annealing operation for population $P_2(t)$, to do local optimization, to obtain a new scale of m groups $P_3(t)$;

cool down $t_{k+1} = \alpha(t_k)$, $k = k+1$;

Step 8: $P_1(t)$ and $P_2(t)$ merge to form a new group, and its fitness sorting, updating the individual of $P_3(t)$, and go to Step 3.

3. Reservoir Optimal Operation Based on Improved Simulated Annealing Genetic Algorithm

3.1. Mathematical Model of Hydropower Station Reservoir Optimal Operation

For long-term deterministic optimal operation of single reservoir, with the optimal criterion of maximizing the power generation scheduling period to establish mathematical model. Scheduling period can be divided into T, that is, for each period for the sum capacity is the largest.

The objective can be seen as follows:

$$E = max\sum_{t=1}^{T}E_t = max\sum_{t=1}^{T}N_t \varDelta_t , \quad (6)$$

where E is the total generating capacity in optimal scheduling period, E_t is the generating capacity on the time t, N_t is the average output on the time t, $\varDelta_t$ is the number of hours in the time t, T is the total time of the hydropower operation calculation.

Constraints of the model set includes reservoir storage capacity constraint, hydropower station output constraint, reservoir discharged flow constraint, reservoir water balance constraint, boundary constraint and nonnegative variable constraint.

1) Reservoir storage capacity constraint.

$$V_{t,min} \leq V_t \leq V_{t,max}, \quad (7)$$

where $V_{t,min}$ is the allowed minimum reservoir capacity on the time t, $V_{t,max}$ is the allowed maximum reservoir capacity on the time t.

2) Hydropower station output constraint.

$$N_{t,min} \leq N_t \leq N_{t,max} , \quad (8)$$

where $N_{t,min}$ and $N_{t,max}$ are the minimum and maximum output respectively, which hydropower station allowed on the time t.

3) Reservoir discharged flow constraint

$$q_{t,min} \leq q_t \leq q_{t,max}, \quad (9)$$

where $q_{t,min}$ and $q_{t,max}$ are the minimum and maximum discharge on the time t respectively.

4) Reservoir water balance constraint.

$$V_{t+1} = V_t + Q_t \cdot \Delta t - q_t \cdot \Delta t - W_t , \qquad (10)$$

where V_t is the reservoir storage capacity at the beginning of time t, V_{t+1} is reservoir storage capacity at the end of the t period. Q_t is the average inbound flow on the time t. $q_t \cdot \Delta t$ is the outflow water on the time t, q_t is the average outflow on the time t, Δt is the size of time at t period, W_t is the reservoir seepage and evaporation resulting in an average water loss.

5) Boundary constraint.

$$V_1 = V_{initial} , V_{T+1} = V_{finish} \;, \qquad (11)$$

where $V_{initial}$ is the storage capacity which the reservoir water level corresponds at the beginning of scheduling, V_{finish} is the storage capacity which the reservoir water level at the end of scheduling. For many years scheduling reservoir, V_{finish} conditions are generally no restrictions, for other regulation performance of the reservoir at the end of scheduling, boundary conditions may be restricted.

6) Nonnegative variable constraint.
All of the above decision variables are nonnegative variables.

3.2. Algorithm Implementation

A key part for solving the problem of reservoir optimal operation is to solve the model. Because reservoir optimal scheduling problem with nonlinear, multi-constraint, etc., it basically uses the mathematical model which also has these characteristics, this paper used the previous section model and the simulated annealing algorithm to optimize scheduling is calculated. Selecting three years including wet years, the water level, the dry years to calculate, calculate their generating capacity, and then calculate their average $\bar{E}$, $\bar{E}$ (kW·h) is a multi-year average annual generation capacity of hydropower. $\bar{E}$ is calculated as follows:

$$E = (E_I + E_{II} + E_{III}) / 3 \qquad (12)$$

where E_I, E_{II}, E_{III} is the wet year, the water level, the dry years generating capacity, kW·h.

In the dispatching of hydropower station, asking questions of solution in each period is during the period of the reservoir control the value of the initial control water level. Since hydropower use of water depends on the reservoir water level changes and inflow. So for hydropower optimal scheduling SAGA can be understood to meet the operational level in the relevant constraints, Randomly selected m groups of water level change sequence $(Z_1^1, Z_2^1, ..., Z_n^1)$,...,$(Z_1^m, Z_2^m, ..., Z_n^m)$. In serial, m is the population size, n is the number of periods. To meet the given constraints, using predetermined algorithm criteria iteration until the termination condition is satisfied the algorithm, the optimal solution output.

1) Encoding and decoding.
Due to some multidimensional, precision continuous function optimization problem, binary code will have slow speed optimization and solution accuracy under the control of the encoding string length such as faults, so this article using the decimal coding for optimal operation of hydropower station is simulated annealing genetic algorithm research.

The order of time, using the decimal encoding, time t allow reservoir is divided into m equal parts

$$m = \frac{Z_{t,max} - Z_{t,min}}{\alpha} \qquad (13)$$

Among them, Z_{min}, Z_{max} are the reservoir water level to allow the minimum and maximum value at t time respectively, the accuracy of coding allows for α.

So chromosomal gene can be used to represent integers A, Individual vectors (gene) is the true value of the reservoir water level, the corresponding decoding formula:

$$Z_t = Z_{t,min} + (n - 1) \times \frac{Z_{t,max} - Z_{t,min}}{m} \qquad (14)$$

If the calculated optimal scheduling time for the month, then each chromosome contains 12 vectors. If the water level in a certain period known maximum, minimum, respectively, 680 and 690, $\alpha = 0.1$. Then according to the formula(14), calculate the changes in water level between 100, the chromosome (1, 31, …, 101), on behalf of the corresponding water level value (680, 683, …, 690).

2) Fitness function.
This paper directly makes the objective function as the fitness function to evaluate the merits of the individual.

3) Genetic operations.
a) Selecting operation is a key link of the genetic algorithm "survival of the fittest". The most widely used method of choice is roulette method. Its advantage is to give choices to the low fitness of the individual, but its disadvantage is the high fitness individuals that also have the chance to be eliminated. And the optimal preservation strategy evolution model is by far the best individual instead of the worst in the group, the strategy is an important guarantee condition of convergence, it can ensure the optimal individuals obtained so far over genetic

operation such as crossover and mutation, smoothly into the next generation [14]. But because of its probability factor in population expanded rapidly in the large and easy to cause local early convergence. Therefore, the combination of both can obtain good effect.

b) Crossover operation is the salient feature of genetic algorithm with other evolutionary algorithms. It is the main method to generate new individual. In the role of genetic algorithm it cannot be ignored. Cross with one point crossover operator, crossover probability adopts adaptive method selected, calculated as formula (3).

c) Mutation operation has two main functions: One is to maintain the diversity of population; then it is to improve the local search ability of the algorithm. Mutation operator USES the arithmetic, mutation probability is also selected by the adaptive mode, calculated as formula (4).

4. Application and Analyses

The tasks of Wan Jiazhai Reservoir include mainly water supply combined with power generation peaking, at the same time both flood control, ice prevention effect, etc. [15]. The total reservoir capacity is 8.96 billion m³, regulating capacity is 4.45 billion m³, the normal water level is 977.00 m, the highest water level is 980.00 m, the coefficient of output power takes 8.3, guaranteed output is 185 MW, power plant design guaranteed rate is 90 %, installed capacity is 1080 MW, average annual energy output is 27.5 billion kW·h. In this paper, set the initial level as the decision variable, aim to calculate the sequence of the reservoir water level which satisfies the constraints, to make maximum reservoir generating capacity. Here take the normal flow year for example that to describe briefly the

solution process of model. The final results of improved simulated annealing genetic algorithm optimization scheduling are shown in Table 1.

It can be seen from Table 1, the initial and the final water level are meeting the upper and lower limits. The output value of each month is also within the control range. Therefore, the results meet the requirements. After the optimization scheduling the annual generation capacity is 29.2388 billion kW·h.

Use the same model and method for reservoir of the wet year and dry year runoff in case to optimize dispatch, to get station reservoir average annual output of hydroelectric power, as shown in Table 2.

In this paper, this improved algorithm solves the construction of the reservoir optimal scheduling model and gets annual average generating capacity of 28.5355 billion kW·h. The conventional scheduling mean annual generation capacity of 2.75 billion kW·h, the year after dispatching generating capacity increased 1.0355 billion kW·h, annual generation capacity increased 3.77 %, so based on improved simulated annealing genetic algorithm optimization scheduling result has important practical significance. In order to verify the effectiveness of the algorithm, the paper has adopted the traditional simulated annealing genetic algorithm optimization operation of reservoir, its objective function and constraints are unchanged. The results are shown in Table 3.

It can be seen from Table 3, the initial and the final water level are meeting the upper and lower limits. The output value of each month is also within the control range. Therefore, the results meet the requirements. After the optimization scheduling the annual generation capacity is 29.1387 billion kW·h.

Use the same model and method for reservoir of the wet year and dry year runoff in case to optimize dispatch, to get station reservoir average annual output of hydroelectric power, as shown in Table 4.

Table 1. The final result of improved SAGA optimal scheduling (normal flow year).

Month	Initial level (m)	Final level (m)	Generating flow (m³/s)	Power flow (m³/s)	Abandoned water flow (m³/s)	Output (10⁴ kW)	Generated energy (billion kW·h)
1	976.54	976.01	387	392.61	0	21.62	1.5779
2	976.01	975.27	429	435.94	0	24.14	1.7621
3	975.27	976.53	643	628.92	0	35.98	2.6267
4	976.53	976.76	573	572.05	0	32.79	2.3935
5	976.76	974.65	332	351.69	0	19.07	1.3922
6	974.65	976.47	381	364.26	0	19.91	1.4531
7	976.47	966.01	901	991.85	0	53.47	3.9031
8	966.01	948.12	1224	1317.99	0	55.91	4.0815
9	948.12	948.12	1299	1299.00	0	45.71	3.3369
10	948.12	976.35	995	811.31	0	37.88	2.7652
11	976.35	976.65	583	578.81	0	33.2	2.4234
12	976.65	976.54	373	375.57	0	20.87	1.5232
						Total	29.2388

Table 2. Based on the improved simulated annealing genetic algorithm Wan Jiazhai hydropower reservoir optimal scheduling results (Unit: billions kW·h).

Low flow year	Normal flow year	High flow year	Average annual energy generation
26.2316	29.2388	30.1360	28.5355

Table 3. The final result of traditional SAGA optimal scheduling (normal flow year).

Month	Initial level (m)	Final level (m)	Generating flow (m³/s)	Power flow (m³/s)	Abandoned water flow (m³/s)	Output (10⁴kW)	Generated energy (billion kW·h)
1	976.34	976.03	387	389.9490107	0	21.44	1.5649
2	976.03	975.14	429	437.4665145	0	24.01	1.7528
3	975.14	976.46	643	630.4429224	0	35.83	2.6158
4	976.46	976.66	573	571.0974125	0	32.57	2.3778
5	976.66	974.47	332	352.8333333	0	19.04	1.3896
6	974.47	976.32	381	363.4010654	0	19.86	1.4497
7	976.32	966.05	901	988.5095129	0	53.28	3.8897
8	966.05	948.4	1224	1316.77968	0	55.85	4.0773
9	948.4	948.1	1299	1300.19863	0	45.60	3.3286
10	948.1	976.32	995	813.5121766	0	37.78	2.7582
11	976.32	976.65	583	579.8607306	0	33.12	2.4174
12	976.65	976.34	373	375.9490107	0	20.78	1.5169
						Total	29.1387

Table 4. Based on the traditional simulated annealing genetic algorithm Wan Jiazhai hydropower reservoir optimal scheduling results (Unit: billions kW·h)

Low flow year	Normal flow year	High flow year	Average annual energy generation
25.6812	29.1387	30.0351	28.2850

Compare the simulation results of two algorithms, we can get the conclusions as follows:

1) From multiple runs of the program, we can see that ISAGA is proposed in this paper improves the ability of global optimization and convergence speed, the introduction of the Niche technology and adaptive crossover and mutation probability, to ensure the diversity of population better, the latter and the optimal preservation strategy also ensure the convergence of the algorithm and make the evolutionary process directed. Compared with traditional simulated annealing genetic algorithm, the improved algorithm proposed in this paper is more efficient and its solution process is more stable.

2) Examples show that the improved algorithm can converge quickly to the optimal value, and its optimal value is superior to the traditional algorithm. The convergence speed of the improved algorithm is fast, and its optimization effect is better than the traditional algorithm.

5. Conclusions

Improved simulated annealing genetic algorithm proposed in this paper, by the niche technologies for similar individuals' uneven distribution s of selection probability, to increase the diversity of population, to prevent effectively the algorithm from falling into local trap, to improve the performance of global convergence; to improve the evolution speed of the algorithm by the adaptive crossover and mutation operation; using good chromosomes template by the optimal preservation strategy, so that the individual in the iterative process effectively inherits the excellent characteristics of parent, to avoid the loss of the optimal solution, to ensure that the direction of the search process to accelerate to the optimal approach. The algorithm can be used to solve some non-convex, non-linear and discrete optimization problems. In this paper, it is applied to the optimal operation of reservoirs, the simulation test results

show that the ISAGA has strong robustness, high search efficiency and good global astringency, used for reservoir optimization scheduling is feasible and effective. How to create a theoretical guidance to select the most reasonable parameters, in order to further improve the search efficiency, which will be the next stage of the research work.

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References

[1]. Wu Xuewen, The study of considering ecological chaotic optimization dispatching of multi-objective Hydropower Station reservoir, *China Water Power Press*, 2011, pp. 1-2.

[2]. Yong Chuan, Hydroelectric system optimal control, *Huazhong University Press*, Wuhan, 1993.

[3]. Ye Bing, Hydraulic Calculation, *China Water Power Press*, Beijing, 1995.

[4]. Li Yu Xin, Hydropower economic operation*, China Electric Power Press,* Beijing, 1999.

[5]. Wang Dajiang, Cairui Ying etc., Swarm intelligence optimization algorithm, *Computer Knowledge and Technology*, 2010.

[6]. Ma Guang-Wen, Wang Li, Hydropower optimal scheduling FP genetic algorithm, *Hydroelectric Engineering*, 55, 4, 1996, pp. 21-28.

[7]. Chang Jian-Xia, Huang Qiang, Wang Yimin, Hydropower reservoir optimal scheduling several Method, *Hydroelectric Energy Science*, 18, 3, 2000, pp. 19-22.

[8]. Chang Jian-Xia, Huang Qiang, Wang Yimin, Based on improved genetic algorithm Optimization of hydropower station, *Hydroelectric Engineering*, 74, 3, 2001, pp. 85-90.

[9]. Yang Yu, Xing Qingsong, etc., With elitist strategy niche genetic annealing algorithm and its application, *China Mechanical Engineering*, 23, 5, 2012.

[10]. Genetic Algorithms Introduction .51 CTO Niche Technology blog.

[11]. Srinvivas M., Patnailk L. M., Adaptive probabilities of crossover and mutation in genetic algorithms, *IEEE Transaction on System, Man and Cybernetics*, 24, 4, 1994, pp. 656-667.

[12]. Ziwu Ren, Ye San, Adaptive genetic algorithm and applied research in system identification, *System Simulation*, 1, 2006.

[13]. Wang Lei, Shen Ting-Zhi, etc., An improved adaptive genetic algorithm, *Systems Engineering and Electronics*, 24, 5, 2002.

[14]. Chen Lihua, Mei Yadong, etc., Improved genetic algorithm and its reservoir optimal scheduling problem, *Hydraulic Science*, 39, 5, 2005.

[15]. Shang Zeyu, On objective management of Wanjiazhai Key Water Control Project Construction, *Shanxi Water Resources*, 1999.

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