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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet

Asian Network for Scientific Information

308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (19): 4838-4844, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.4838.4844
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Research of Cascaded Hydropower Stations Short-time Optimize Dispatcher Based on Improvement A-NGA

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Abstract: The optimal operation of cascade hydropower stations is a high dimension, non-protruding, dispersed, non-linear dynamic optimization question, at present, though the researchers have put forward some methods to solve this question but always there are certain defects during the process of solving. This study analyses the characteristic of the niche genetic algorithm, direct against the question that the traditional niche genetic algorithm exists, improve the niche genetic algorithm, has proposed a kind of self-adaptation niche genetic algorithm with predator and applied it to solve the problem of cascade hydropower stations optimal operation that the result of the example shows, this algorithm can well solve the optimal operation problem of cascade hydropower stations which has high speed of operation and precision of solution.

Key words: Cascade hydropower stations, short-time optimize dispatcher, niche genetic algorithm, self- adaptation, educlidean distance

INTRODUCTION

With the development of power market, the cascade hydropower station group short-term optimization scheduling problem has been paid more attention to by scheduling management and power station owners but also attracted the attention of many scholars at home and abroad, they have been under active study, intention to seek a good method to draft the cascade hydropower stations optimization scheduling. After years of research, many researchers have proposed some methods, such as dynamic programming method, artificial neural network algorithm, particle swarm optimization and so on (Mei *et al*., 2007; Zhang *et al*., 2009; Wang *et al*., 2012; Shu *et al*., 2011) but because of the cascade hydropower stations short term optimization scheduling problem has the high dimension, non convex, discrete, nonlinear characteristics, so there are some defects when use these method to solve this problem, such as "dimension disaster", slow convergence, et. Genetic Algorithm (GA) is a solution of the cascade hydropower stations short-term optimization scheduling problem, because of which has less restrictive to the problem, does not require the objective function is continuously and differential, so which is paid close attention to by scholars.

Genetic Algorithm (GA) is a random search method based on natural selection and genetics principle, is an efficient optimization method to find the global optimal solution without any initial information. Because it exhibit strong robustness, global optimization and parallel processing in solving nonlinear problems, so which has been largely used to solve the optimization scheduling of cascade hydropower stations (Chen *et al*., 2008; Wu *et al*., 2011; Zheng *et al*., 2013). Though the traditional GA is good at global search but which is insufficient at local search ability, so use it to solve the optimization problem to the true optimal solution will take longer time than traditional search method. Therefore, many researchers proposed many improved genetic algorithm, among them, the Niche Genetic Algorithm (NGA) due to its high global search ability and convergence speed while maintaining the diversity of solutions, is widely used in solving function optimization problems. However, traditional NGA has the following two questions (1) Individual Euclidean distance criterion are generally set as a fixed value, don't develop and change with the evolutionary process to, so the character of the algorithm to maintain the diversity of the population can not fully realized and (2) While maintaining the diversity of the solution, don't avoid inferior solution to multiply, reduces the efficiency of convergence and running.

In view of the above problems existing in the traditional NGA, this study proposes an adaptive NGA with predator. In the algorithm, firstly, the individual Euclidean distance criterion was improved which adaptive

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adjust according to the process of evolution, then introduce the predator concept of artificial life, under the conditions to maintain the diversity of the population to comprehensive clean-up and limit inferior solution to breed, to accelerate the convergence and the running efficiency of the algorithm; then apply this algorithm to solve the short-term optimization scheduling of cascade hydropower stations, so to improve calculation accuracy and speed.

Niche genetic algorithm (NGA)

Niche is a concept from the biological, refers to a kind of living environment of organisms in particular environment, namely in the evolutionary process, the organisms always with the same species communities live together in offspring and survival in specific geographical areas, thus forming a kind of living environment under specific environment. Niche Genetic Algorithm (NGA) applied this kind of thought in the traditional GA, in order to improve the optimization calculation efficiency of the genetic algorithm. The basic idea is to set the Euclidean distance to form one niche, the details is as follows: Firstly, establish an individual Euclidean distance criterion L, then judge the Euclidean distance of each two individuals in the population, if the distance is less than the individual Euclidean distance criterion L, then compare the fitness of two individual and applying a strong penalty function to the individual with the smaller fitness, reducing its fitness, so that the fitness of the poor individual among two comparison individuals becomes worse after treatment, so as to improve the probability to be eliminated of the individuals in the after evolution process, namely there is an excellent individuals in the Euclidean distance criterion L. This method not only can well maintain the diversity of the population and enable the individual from the constraint in the space dispersion which overcomes the shortcomings of traditional genetic algorithm to appear local optimal(Cui *et al*., 2011; Fu *et al*., 2008).

ADAPTIVE NICHE GENETIC ALGORITHM WITH PREDATOR

Improvement of the algorithms

Adaptive setting of euclidean distance: In the calculation process of the NGA, in order to improve the convergence speed and efficiency, it is necessary that the Euclidean distance discriminate value L is set to change. Adaptive Euclidean distance is set as follows:

At the Evolver count t = 1, adapt the Euclidean distance between the individual with the maximum fitness and the individual with the minimum fitness as the niche radius and when the Evolver count t>1, adopt the average Euclidean distance value of the individuals in former generation population as this generation Euclidean distance discriminate criteria. The concrete calculation equation is as follows:

$$L_t = \begin{cases} \left\| X_{f_{max}} - Y_{f_{min}} \right\| & t = 1 \\ \bar{L}_{t-1} = \dfrac{\sum_{i=1}^{\mu+\lambda-1} \sum_{j=1}^{\mu+\lambda} d_{ij}}{C^2_{\mu+\lambda}} & t > 1 \end{cases}$$

$$i = 1, 2, \dots \mu+\lambda-1;\ j = I+1, \dots, \mu+\lambda$$

In the equation, $X_{f_{max}}$, $Y_{f_{min}}$ are the individuals with the maximum fitness and the minimum fitness, respectively, L_t is the Euclidean distance discriminate value of the t generation; $\bar{L}_{t-1}$ is the average value of the t-1 generation Euclidean distance, $C^2_{\mu+\lambda}$ is combinations calculation take 2 from $\mu+\lambda$, namely the number of Euclidean distance that $\mu+\lambda$ pieces of individuals calculate the Euclidean distance.

Introduction of predator: In recent years, people have put forward a series of Artificial Life Algorithm (ALA) to improve the genetic optimization method, for example, the Japanese scholar Taiji Satoh and Yoshiki Mizukami proposed the concept of Predator to improve the algorithm convergence precision and reduce the cluster formation time. Predator hunt inferior individual free outside of clustering under appropriate conditions can accelerate the formation of clustering and optimization.

For to reduce the number of non dominated solutions in the late of algorithm, introducing the concept of predator, set the corresponding predators in the algorithm, in the premise of maintain the diversity of population, comprehensive clean-up and limit inferior solution to breed, thus accelerate the convergence and running efficient of algorithm.

Operation steps of the adaptive niche genetic algorithm with predators: In the former period of algorithm, use NGA to carry on genetic manipulations to the population and with the help of elite selection and establishment niche to retain the excellent solution set, form a certain cluster. Don't hunt in the former period of algorithm, in order to avoid premature convergence, trapped in a local optimum, therefore, the predator has higher fitness and wait in the early stage of algorithm, until the fitness is lower than a certain value, algorithm has formed certain cluster, began hunting behavior, so to accelerate the convergence speed and comprehensive clean-up and restrict the inferior solution reproduction. Accordingly, the operation steps of adaptive niche genetic algorithm with predator can be divided into two levels of calculation:

- **Calculation process of the main algorithm:** When apply this algorithm to calculate, most of the calculation steps same to the traditional NGA, only add the adaptive setting of Euclidean distance in the calculation steps and add the predator algorithm in the late of calculate steps. Specific calculation steps are as follows:

S1 = Randomly generated initial population P(t) with μ pieces of individuals, calculate the fitness of each individual $f_i(i = 1, 2,\dots, \mu)$

S2 = Descending order individuals according to the fitness value of the individual, memory before λ pieces of individuals (λ<μ)

S3 = Carry on selection, crossover and mutation operations to the population, produce new population P'(t)

S4 = Merge the μ pieces of individuals of population P'(t) with the λ pieces of individuals memorized at former, form new population P"(t)

S5 = Carry on niche eliminate calculate for the μ+λ individuals of the population P"(t), the specific operation as follows:

- Calculate the Euclidean distance each two individuals X_i, X_j within population P"(t):

$$d_{ij} = \|X_i - X_j\| = \sqrt{\sum_{k=1}^{n}(x_{ik} - x_{jk})^2},\ i = 1, 2, \dots, ,\mu+\lambda-1;\ j = i+1, \dots, \mu+\lambda$$

- When $\|X_i\text{-}Y_j\|<L_t$, compare the fitness value of individuals X_i, X_j and carry on punish to the lower fitness individuals, obtained the μ+λ pieces of individual through niche elimination calculation;

S6 = Judge the predator whether to begin hunting, if don't need to begin hunting, continue the operation of following steps S7, if need to hunt, begin hunting behavior. After finish hunting, obtain μ+λ pieces of individuals through hunting

S7 = Form the new population P"(t) above μ+λ pieces of individuals, calculate average value of Euclidean distance, as the Euclidean distance discriminate value of next generation and descending order individuals based on the new fitness of these new individuals, take out former μ pieces of individuals to construct the population $P^4(t)$

S8 = Judge the termination condition. If the termination condition is not satisfied, then update the evolution count to t = t+1 and the population $P^4(t)$ as the initial population of the next generation evolutionary computation and then go to step S2 to start a new round of calculation. Until the termination condition is satisfied, output results, the algorithm terminates

- **Predator calculation:** The predator only start hunting behavior in algorithm later but early in the algorithm, need to set the initial fitness, then according to certain rules, the fitness increases along with the evolution count, until to the certain value E, begin hunting behavior. In the hunting process, involving the transform of fitness between the predator and the hunted individuals, the calculation of evaluation functions of individual is as follows:

$$G(X, \bar{0}) = d_{X\bar{0}} + \omega\sum_{k=1}^{n} x_{ik}$$

In equation, $d_{X\bar{0}}$ is absolute Euclidean distance of the solutions of individual X, x_{ik} is the No. k objective function value of individual X, ω is the evaluation parameters, $\bar{0}$ is the 0 element vector (0, 0,… 0).

The specific steps are as follows:

S1 = Initialization predator Pr, set the predator has higher fitness and put it in the population P(t), the number of individuals becomes to μ+1 in the initial population but Pr does not participate in the sorting computation

S2 = The fitness of predator self reduce according to the law when the evolution count is increase one, until its fitness is reduced to the limit value E, then executing step S3

S3 = Calculate evaluation function value of all individuals in the population, for to the individual X with the highest evaluation function value, predator Pr get to certain value ΔE from individual X; for to the individual Y with the lowest evaluation function value, copy the predator Pr instead

In the process of calculation, the calculation formulas of E, e, ΔE are as follows:

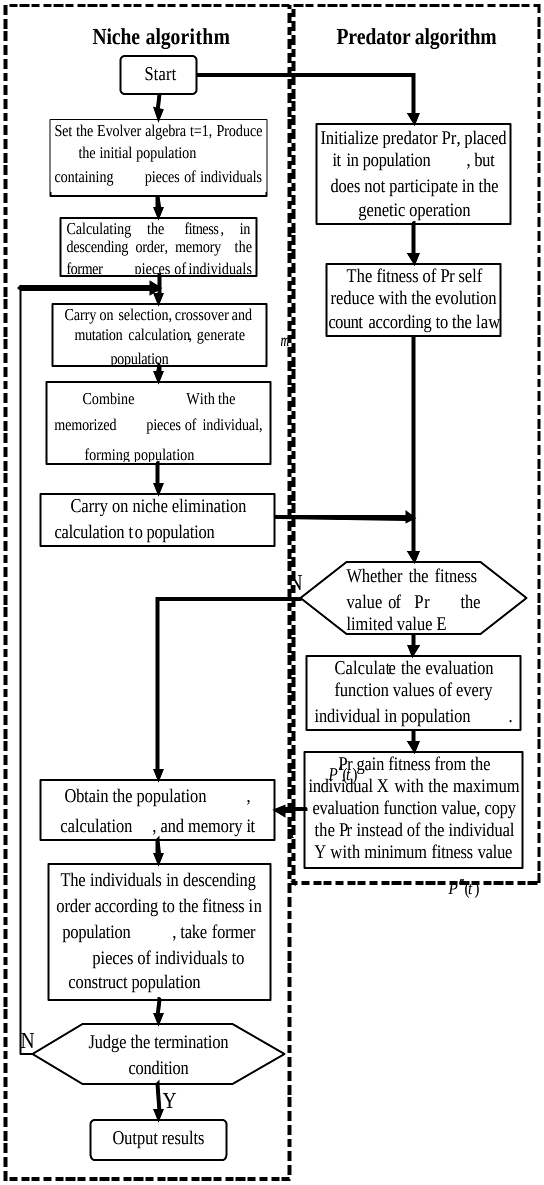

Fig. 1: Algorithm flow chart

$$E = \sum_{i=1}^{\mu} \frac{f_i}{\mu};\ e = \frac{f_{Pr1}}{T};\ \Delta E = \frac{f_X - f_{Pr}}{\mu}$$

In equation, f_{Pr1} is the initial fitness of predator Pr, f_{Pr} is the now fitness of predator Pr, f_X is the fitness of individual with the highest evaluation function value, T is the biggest evolution count, the mean of other symbols same as former.

According to the above two levels of calculation steps, the calculation process of adaptive NGA with predator can be draw to the flow chart, the flow chart is as Fig. 1.

OBJECTIVE FUNCTION AND CONSTRAINT CONDITIONS

Objective function and restraint conditions

Objective function: The goal of cascade hydropower stations optimal scheduling is to solve the maximum benefit of cascade hydropower stations short-term operation, namely the maximum total generation power benefit of cascade hydropower station group as optimization criterion, the objective function can be constructed to:

$$P = \max \sum_{t=1}^{T} \sum_{m=1}^{M} [c(t)p(m,t)]\Delta t \tag{1}$$

In equation: t is the number of time period t = 1, 2,..., 96, T is the time period set that need to considered, m is the number of the hydropower station and the corresponding reservoir, the order of m = 1, 2,..., M from the upstream to the downstream; c(t) is the price of power at t time period; p(m, t) is the generation power at t time period of m hydropower station.

Restrain conditions:

- The water storage restraining of the reservoir: $v_{min}(m) \leq v(m, t) \leq v_{max}(m)$
- The output power restraining of hydropower station: $p_{min}(m) \leq p(m, t) \leq p_{max}(m)$
- The total electricity restraining of the cascade hydropower stations:

$$P(t) = \sum_{t\in T} \sum_{m\in M} p(m,t)$$

- The water yield balance restraining:

$$v(m, t+1) = v(m,t) + q(m,t) - Q(m,t) - S(m,t)$$

- The let out flow restraining:

$$\begin{cases} Q_{min}(m,t) \leq Q(m,t) \leq Q_{max}(m,t) \\ S(m,t) \geq 0 \end{cases}$$

- The waterpower space-time connection restraining of cascade hydropower stations:

$$Q(m+1,t)\begin{cases} = Q(m,t-\tau) + Q'(m+1,t) + S(m,t) \\ (m+1 \text{ reservoir is no regulating reservoir}) \\ \leq Q(m,t-\tau) + Q'(m+1,t) + S(m,t) \\ (m+1 \text{ reservoir is regulating reservoir}) \end{cases}$$

In function: $v_{min}(m)$, $v_{max}(m)$ are the minimum, maximum storage capacity of the n reservoir separately; $p_{min}(m)$, $p_{max}(m)$ are the minimum, maximum generating electricity of the m station. P(t) is the total generating electricity in the t period; Q(m, t) is the generating electricity flow of the m station; $Q_{min}(m)$, $Q_{max}(m)$ are the minimum, maximum generating electricity flow of the m station; q(m, t) is the natural input flow of the m reservoir in t period; S(m, t) is the m reservoir in t period; Q(m+1, t) is the generating electricity flow of the m+1 station in t period; Q(m, t-τ) is the generating electricity flow of the m station in t-τ period; Q'(m+1, t) is the input flow of the m+1 station in t period.

Determine the genetic strategy

Selection: This study uses the method that combine the roulette selection and retain the best selection, roulette selection product next generation according to the proportional each fitness value with total fitness; retain the best selection guarantee the excellent solution is retained to next generation.

Crossover and mutation: Crossover and mutation adopt the adaptive adjustment method, namely each individual crossover and mutation probability is adaptively adjusted with the fitness value. The improved crossover operator and mutation operator are as follows:

$$p_c = \begin{cases} k_1(f_{max} - f_c)/f_{avg} & f_c \geq f_{avg} \text{ and } f_c \neq f_{max} \\ k_2 & f_c < f_{avg} \\ k_3 & f_c = f_{max} \end{cases}$$

$$p_m = \begin{cases} k_1'(f_{max} - f_m)/f_{avg} & f_m \geq f_{avg} \text{ and } f_m \neq f_{max} \\ k_2' & f_m < f_{avg} \\ k_3' & f_m = f_{max} \end{cases}$$

In equation, f_{max}, f_{min} and f_{avg} are the maximum fitness, minimum fitness and average fitness of the individuals in population; f_c is the fitness value of the individual that need to crossover; f_m is the fitness value of the individual that need to mutation; k_1, k_2, k_3, k'_1, k'_2 and k'_3 are the given parameters, span (0, 1).

Example verification

Relevant parameters: This study selected the data of some one cascade hydropower stations in some one province electric power market to calculation. This cascade hydropower station group includes three hydropower stations, the specific parameters as shown in Table 1. The average daily flow of cascade hydropower stations is 10.0 m^3 sec^{-1}. The interval flow of A, B and B, C are 8 and 5 m^3 sec^{-1}, respectively, determine cascade daily water consumption is 864000 m^3 according to the given A daily allow drawdown level, the goal of calculation is to determine the cascade hydropower stations daily optimal generation scheduling, so as the cascade generation power income to maximum.

Table 1: Parameters of some one cascaded hydropower station

	A	B	C
Normal water level (m)	2650	1678	1369.5
Dead water level (m)	2600	1666	1363.5
Regulation performance	Yearly	Daily	Daily
Installed capacity (MW)	240	132	120
Power station integrated output coefficient	8.56	8.75	8.03
Maximum flow rate (m^3 sec^{-1})	47.24	53.4	53.4

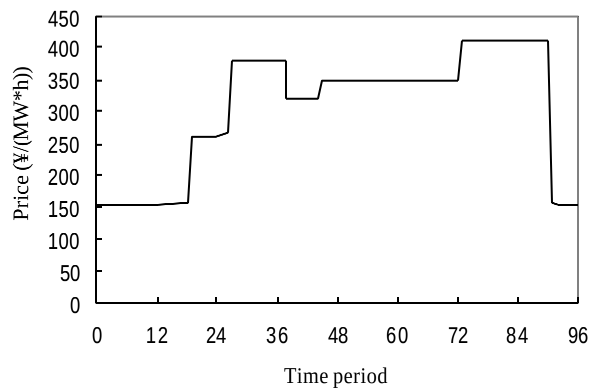

Fig. 2: Electricity market clearing price process line on November 15, 2005

In order to obtain the maximum daily income of cascade hydropower stations, need to obtain the market clearing price of the system. This study uses artificial neural network algorithm to predict the market clearing price of the daily 96 points, the calculation results are shown in Fig. 2.

When apply the adaptive NGA with predator to solve the short-term cascade hydropower stations problem, the parameters are selected as follows: maximum generation T = 200, population size is 40; k_1, k_2 and k_3, k'_1, k'_2 and k'_3 are the parameters when calculate the adaptive crossover rate and mutation rate, the general range (0, 1), in the process of this study, their values, respectively are as follows: k_1 = 0.7, k_2 = 0.9 and k_3 = 0.005, k'_1 = 0.05, k'_1 = 0.05 and k'_3 = 0.001.

Calculation results and analysis: Through the calculation, the daily water level change process line of the three reservoirs of cascade hydropower stations as shown in Fig. 3, the cascade hydropower stations daily output process as shown in Fig. 4.

It can be seen from Fig. 3, the water level change process of every reservoir are correspond to each other

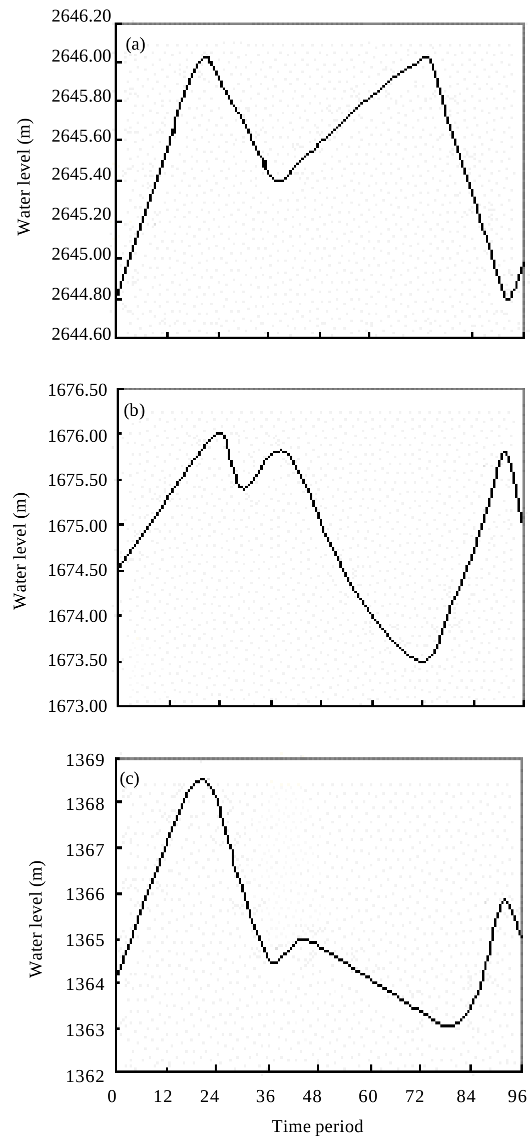

Fig. 3(a-c): Water level curve of every reservoir at the end of every period

which all increase the water release in high demand periods and storage water in low price periods. At the same time, A hydropower station play the role of multi-year regulating reservoir. Through calculation, the generating income of entire cascade hydropower stations is 1568280 Y for the day. It can be seen from Fig. 4, the whole cascade output is consistent with market clearing price each in the time period, generate more power at high price periods, generate less power or don't generate power in low price periods.

At the same time when apply this study's algorithm to calculate, this study applied the other algorithm such

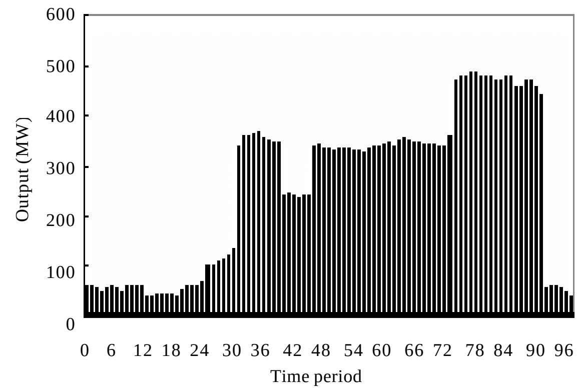

Fig. 4: Short-term optimization result of the cascade hydropower stations

Table 2: Comparison of results of various algorithms

Algorithm	Output (MW)	Calculation (times sec^{-1})
?	68.933	42
?	68.965	36
A-NGA	69.562	28

as traditional GA, traditional NGA to solve the same example, the results as shown in Table 2, it can be seen from the table, the adaptive niche genetic algorithm with predator greatly improves the convergence speed and improves the precision of calculation.

CONCLUSION

The short-term optimal scheduling of cascade hydropower stations is the dynamic optimization problem of a high dimension, non convex, discrete, nonlinear, it is difficult to find the optimal solution in theory but it can bring significant economic benefits, so many scholars have studied actively and puts forward some solving methods but so far, there is not a very efficient way to solve this problem. This study analyzes the characteristics of niche genetic algorithm, aiming at the two problems existing in the traditional genetic algorithm, one side, carry on adaptive set to the Euclidean distance which can adaptively changes with the increasing of evolutionary count, on the other hand, introduced the concept of predator, join the predator on the process in genetic manipulation, under the premise of maintain the diversity of the population to comprehensive clean-up and limit inferior solution breeding, so to improve the speed and the convergence efficiency of the algorithm, finally formed the adaptive niche genetic algorithm with predator. Then applied it to solve the short-term optimal scheduling problem of cascade hydropower stations, the calculation results show, the algorithm overcomes the problems of the traditional niche genetic algorithm, greatly improving the speed and accuracy of calculation.

ACKNOWLEDGMENT

The research of this study obtain the fund support from the National Natural Science Foundation of China (51069004) and the red youth funding schemes of Lanzhou University of Technology (201008).

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