Sensors & Transducers, Vol. 159, Issue 11, November 2013, pp. 149-154

Sensors & Transducers

© 2013 by IFSA

http://www.sensorsportal.com

Method of Optimal Scheduling of Cascade Reservoirs based on Improved Chaotic Ant Colony Algorithm

[1] Hongmin Gao, [2] Baohua Xu, [1] Zhenli Ma, [1] Lin Zhang, [1*] Chenming Li

[1] College of Computer and Information Engineering, Hohai University, Nanjing 211100, P. R. China

[2] Yangtze River Estuary Survey Bureau of Hydrology and Water Resource CWRC, Ministry of Water Resources, Shanghai 200136, P. R. China

[*] Tel.: +86 25 58099112, fax: +86 25 58099136

[*] E-mail: banjamin2006@163.com; lcm@hhu.edu.cn

Received: 1 August 2013 /Accepted: 25 October 2013 /Published: 30 November 2013

Abstract: On the basis of the analysis of the basic information of the river basin reservoirs and application of chaotic ant swarm algorithm, the medium-and long-term optimization operation model is established, which regards the maximum annual generation capacity of the cascade hydropower stations as the main purpose. The simulation result shows the algorithm improves the total annual power generation of the cascade reservoirs, and is better than the basic chaotic ant colony solving method of reservoir operation model, finally provides an effective solution to solve the cascade reservoirs optimization operation problem. *Copyright © 2013 IFSA.*

Keywords: Reservoir optimal operation, Cascade reservoirs, Ant colony algorithm, Chaos theory.

1. Introduction

The Reservoir Operation is the reasonable and effective control of the use of water conservancy and hydropower project, which plays a key role in regulating floods, the supply of clean energy, improving water pollution and many other aspects. Based on existing water resources infrastructure, the reservoir operation maximizes social and economic benefits, and ultimately achieves the full advantage of the purpose and allocation of water resources. In recent days, machine intelligence theory is gradually replacing the traditional optimization algorithm which restricted the development of reservoir operation technology due to the defects of the low efficiency of calculation and easy to fall into local optimum. Machine intelligence theory plays an important role in reservoir operation which has multi-objective, multi-constrained, non-linear characteristics [1].

2. Cascade Hydropower Reservoir Optimal Scheduling Model

2.1. Concepts Cascaded Hydroelectric Stations and Features

The reservoir group which is in the river's tributaries on the development of a series of reservoirs and the formation of mutual cooperation and jointly regulate a common reservoir runoff overall, the whole basin for the dual purpose of prevention and Hennessey that is in the river water conservancy project construction. Reservoirs are arranged in accordance with the way the series on the river is called cascade reservoirs.

Operation of cascaded hydroelectric stations have the following characteristics, first, water power generation associated downstream cascade hydropower generation depends on water discharged upstream water cascade hydropower stations downstream hydropower generating capacity by the upstream reservoir effect. Second, the power head association, if the water level is too high downstream reservoirs, will raise the water level upstream hydropower reservoirs tail, making the upstream reservoir of power head can decrease the upstream power generation, but the downstream reservoir water level is too low will affect their own power head, can lead to generating capacity reduction. Third, FM, peaking association often cascaded hydroelectric stations in the same power the main network, through a joint operation, the system can adjust the FM, peaking task, through the rational allocation, improve security and stability of the grid [2].

2.2. Optimization Model

For long-term scheduling problem reservoir description, mainly through a mathematical model to describe the reservoir scheduling process, considering the constraints between cascade reservoirs, the cascade reservoirs such as the long-term optimization model formula (1) shown in the target function description:

$$E_i = \max \sum_{k=1}^{n} \sum_{t=1}^{T} A_k Q_{k,t} H_{k,t} M_t \qquad (1)$$

The formula E_i for the i year the largest hydropower generating capacity, measured in MWh; A_k denote the k hydropower stations integrated output coefficients, $Q_{k,t}$ denote the k hydropower stations in t period generating traffic (m^3/s), $H_{k,t}$ denote the k hydropower stations in t period average generating net head (m), M_t denote the t period the total number of hours (h); n - the total number of cascade hydropower stations within the watershed; T - calculates the total number of time periods during the year (calculation period for the month, then T = 12).

The scheduling constraints of the model are as follows:

1) Water balance constraints:

$$V_{k,t+1} = V_{k,t} + q_{k,t} - Q_{k,t} - S_{k,t} \quad (\forall t \in T) \qquad (2)$$

The above formula $V_{k,t+1}$ denote the end of t period of the k hydropower reservoir storage capacity, $V_{k,t}$ denote the beginning of t period of the k hydropower reservoir storage capacity, $q_{k,t}$ denote the t period of the k hydropower reservoir storage time traffic flow, $Q_{k,t}$ denote the t period of the k hydropower reservoir generate electricity flow, $S_{k,t}$ denote the t period of the k hydropower reservoir abandoned water flow, all above units are as m^3/s.

2) Reservoir storage capacity constraints:

$$V_{kt,\min} \le V_{k,t} \le V_{kt,\max} \quad (\forall t \in T) \qquad (3)$$

In the formula, $V_{k,t}$ denote the t period of the k hydropower reservoir storage capacity, $V_{kt,\min}$ denote the minimum storage capacity of the reservoir, $V_{kt,\max}$ denote the largest reservoir storage capacity, all above units are as m^3.

3) Discharge reservoir constraints:

$$Q_{kt,\min} \le Q_{k,t} \le Q_{kt,\max} \quad (\forall t \in T) \qquad (4)$$

$$S_{k,t} \ge 0 \quad (\forall t \in T) \qquad (5)$$

In the formula, $Q_{kt,\min}$ and $Q_{kt,\max}$ denote the t period of the k hydropower reservoir the minimum and maximum discharge flow, minimum discharge is determined by the need to ensure a minimum amount of water downstream of the decision, the biggest discharged flow is considered discharged downstream of the maximum amount of safety, all above units are as m^3/s.

4) Hydroelectric output constraints:

$$N_{k,\min} \le A_k Q_{k,t} H_{k,t} \le N_{k,\max} \qquad (6)$$

The above equation $N_{k,\min}$ - the k hydropower stations hardware conditions determined the minimum output value (MW); $N_{k,\max}$ - installed capacity of the k hydropower stations (MW).

5) Variable non-negative constraints:

Since the above condition variables are involved in meaningful quantities, so all of the above variables are non-negative variables (≥ 0).

3. Improved Chaos Ant Colony Algorithm

3.1. Chaotic Ant Colony Algorithm

Chaotic phase space algorithm ergodicity and internal randomness, you can use this feature makes the ant colony algorithm escape from local optima. When the ant colony algorithm to find the local optimal solution, through the carrier's way, in the vicinity of local optima, then chaos disturbance variables, avoid falling into local optimum.

In finding the optimal solution, in order to improve the optimization path is also poor when the residual pheromone, ants interfere with subsequent optimization strategies, resulting in an invalid search, wasting time, improved method is a better path to be screened, only path is less than a given value increased pheromone, adjust the amount of information added in chaotic interference, so that the optimization results out of local minima.

The basic ant colony algorithm in the amount of information update, the update formula as formula (7) and (8) [3], the basic idea is chaotic ant colony algorithm update equation in the amount of interference by adding chaos.

$$\tau_{ij}(t+n) = \rho \bullet \tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}{}^{k} \quad (7)$$

$$\Delta\tau_{ij}(t) = \sum_{k=1}^{m} \Delta\tau_{ij}{}^{k}(t) \quad (8)$$

Ergodicity of chaotic systems with randomness, the introduction of typical chaotic Logistic Model:

$$x_{n+1} = \mu x_n(1-x_n), \quad (9)$$

Wherein $\mu \in [0,4]$, $n = 0,1,2,\cdots$, $x \in [0,1]$.

In the ant colony algorithm update informative way when the carrier has Logistic chaotic system introduced into the model, optimize updated effects, improve efficiency, iterative formula as formula (10) below [4-5].

$$\tau_{ij}(t+n) = \rho \bullet \tau_{ij}(t) + \sum_{k=1}^{m} \Delta\tau_{ij}{}^{k} + \lambda x_i \quad (10)$$

Through in-depth research in recent years, researchers found that individual ant carrying a search, there is chaos in their behavior, for this, the initial value for the ant colony optimization algorithm to shorten the search for the optimal value of the time. Chaos chaotic ant colony algorithm based on the selected systems, and combined with ant colony algorithm point difference, research direction is different.

3.2. Improved Chaos Ant Colony Algorithm

This paper presents an improved chaotic ant colony algorithm, ant colony algorithm is initialized made corresponding improvements. The main idea is to join at initialization time chaotic systems and the introduction of a chaotic system by adding random perturbations ergodic properties of chaotic systems to increase random features, making ant in the initial cluttered environment quickly find a better solution, in order to continue iteration select Global lay the foundation for the optimal solution to shorten the search time; pheromone evaporation coefficient for the introduction of adaptive improvement strategies, within the scope of the search iteration, according to evolutionary effects, adaptive adjustment of the size of the overall increase global search ability and convergence speed; further improvement strategy is to form the chaotic noise into the carrier pheromone iterative formula, the randomness and chaos noise ergodicity, making colony in obtaining local search near optimal value by comparing the extreme point with the size of other nearby guide the ant moves in the direction toward the better evolution of ant colony algorithm can avoid local optimum and improve their ability to select the global optimum.

In order to be able to maximize their chaotic randomness initialization, in the formula (9), based on the μ increase in the parameter random disturbance factors σ [6]:

$$x_{n+1} = (\mu+\sigma)x_n(1-x_n) \quad (11)$$

$$\sigma = \frac{rand}{10}, \quad (12)$$

where rand is $[0,1]$ the random number.

This article will adjust an adaptive pheromone evaporation coefficient improvement strategies into chaos ant colony algorithm to optimize information iterative effect [7]. Assuming the initial pheromone evaporation coefficient value $\rho(t_0) = 1$, if chaotic ant algorithm seeks the optimal solution in a limited circulation, no appreciable improvement, then right according to the formula (13) to make ρ adaptive adjustments:

$$\rho(t) = \begin{cases} 0.95\rho(t-1), & \text{if } 0.9\rho(t) > \rho_{\min} \\ \rho_{\min}, & others \end{cases} \quad (13)$$

Wherein set the minimum value of ρ is $\rho_{\min}$, to avoid too small lead convergence speed decreases.

For ant colony algorithm easy to fall into local optimum defect, the basic algorithm proposed chaotic ant pheromone update when the carrier joins chaotic noise, the paper added initialization and chaotic random number pheromone evaporation coefficient adaptive improvements, but also taken with the chaotic carrier noise the whole algorithm escape from local optima, which uses the formula (10) for pheromone chaotic disturbance, making it a better choice for global optimal solution.

4. Improved Chaotic Ant Colony in the Application of Cascade Reservoirs

This paper studies the improved chaotic ant colony algorithm to reservoir applications, so the selected data to the references of average runoff runoff as deterministic goal, the main research algorithm to solve the scheduling model effects. By selecting a cascade hydroelectric stations for the study, with the largest generating capacity Herald Dispatch targeting runoff in the case of certainty for long-term optimal operation [8].

Reservoir according to previously established mathematical model, the objective function is a solution in the number of n reservoir cascades which flow generating capacity Q determines the sum of the maximum amount T of power, in which the amount of generating capacity Q and the reservoir V has a certain function, so the problem is transformed into the capacity of the discrete as a number of points, in considering the constraint conditions, by the chaos ant colony algorithm and its improved algorithm a number of discrete points on this path between the optimal solution search, you can find the maximum amount of power.

Selected cascade reservoirs to water conservancy A is the leading cascade reservoirs, select region B, C, D, E four hydroelectric reservoirs constituted, there is a tributary of the downstream hydropower station C and D are imported, five the basic parameters of hydropower in Table 1.

In the deterministic runoff, based on the chaos through the basic ant colony algorithm and improved algorithm to solve the cascade reservoirs result, the output value for each reservoir and power generation combined with the length of time the two methods for each hydropower reservoir scheduling results are shown in the Tables 2-4.

Combining these scheduling result of each month, and ultimately obtained two algorithms calculated total generating capacity of the reservoir and the results are shown in Table 5.

From the above table it can be seen, the annual generation of cascade reservoirs largest mathematical models were used to solve the two algorithms, improved chaotic ant colony algorithm for A, B, D solution obtained on a total generating capacity increases, the remaining two power stations total generating capacity decreased slightly, but the overall annual generation capacity is increased, which shows the improved algorithm to achieve the optimization purposes.

Table 1. Basic parameters of a Cascaded Hydropower Stations.

Hydropower / Reservoir Items	A	B	C	D	E
Drainage area (km^2)	17176	17244	17359	18828	18973
Average annual flow (m^3/s)	121.3	122.0	122.0	130.0	131.0
Mean annual runoff (100 million m^3)	38.25	38.5	38.5	41.9	42.3
Normal water level (m)	2202	2065	2035	2002	1968
Flood control level (m)	2199				
Flood month (month)	7-9	7-9	7-9	7-9	7-9
Dead water level (m)	2166			2000	
Normal tail water level (m)	2067.7	2036.5	2021.58	1970.86	1950.75
Normal water level the following capacity (100 million m^3)	8.67			0.143	
Regulating capacity (100 million m^3)	5.72				
Regulation performance	Year	——	——	Day	——
Installed capacity (MW)	300	66	37.5	60	31.5
Guaranteed output (MW)	61.8	13.58	5.966	15.4	7.22
Maximum flow rate over machine (m^3/s)	280	266.1	266.4	246	186.4
Minimum flow rate over machine (m^3/s)	42				
Composite output coefficient	8.5	8.5	8.5	8.5	8.5
The average annual generation capacity (100 million kWh)	9.94	2.28	1.427	2.411	1.36

Table 2. Hydropower A basic algorithm and improved algorithm to optimize the scheduling result.

Monthly	Inflow (m^3/s)	Power Flow (m^3/s)	Abandoned water (m^3/s)	End water level (m)	Head (m)	Basic output (Ten thousand kW)	Improved output (Ten thousand kW)
5	176	121.38	0	2174.42	101.69	10.42	10.43
6	170	137.66	0	2178.16	105.74	12.12	12.04
7	227	182.95	0	2183.84	109.25	17.22	17.29
8	174	160.49	0	2182.78	114.76	15.74	15.68
9	161	122.71	0	2190.56	114.81	11.93	12.05
10	276	159.21	0	2203.61	125.52	16.93	16.98
11	132	116.43	0	2203.85	133.77	12.76	12.74
12	64.8	63.89	0	2203.58	133.02	6.95	6.96
1	41.8	59.32	0	2197.7	134.43	7.02	7.12
2	43.9	62.27	0	2195.64	131.29	6.83	6.8
3	48.1	89.02	0	2185.95	127.92	9.17	9.43
4	77.3	209.36	0	2166.00	110.57	18.62	18.85

Table 3. Hydropower station downstream runoff basic algorithm and improved algorithm to optimize the scheduling result (a).

M	Inflow (m^3/s)	B hydropower					C hydropower				
		Power Flow (m^3/s)	Abando-ned water (m^3/s)	Head (m)	Basic	Impro-ved	Power Flow (m^3/s)	Abando-ned water (m^3/s)	Head (m)	Basic	Impro-ved
5	121.38	121.38	0	28.5	2.92	2.91	121.38	0	13.42	1.37	1.39
6	137.66	137.66	0	28.5	3.34	3.31	137.66	0	13.42	1.57	1.53
7	182.95	182.95	0	28.5	4.42	4.43	182.95	0	13.42	2.07	2.1
8	160.49	160.49	0	28.5	3.81	3.8	160.49	0	13.42	1.78	1.77
9	122.71	122.71	0	28.5	3.01	2.93	122.71	0	13.42	1.4	1.35
10	159.21	159.21	0	28.5	3.92	3.94	159.21	0	13.42	1.84	1.87
11	116.43	116.43	0	28.5	2.82	2.75	116.43	0	13.42	1.31	1.24
12	63.89	63.89	0	28.5	1.51	1.53	63.89	0	13.42	0.7	0.73
1	59.32	59.32	0	28.5	1.36	1.38	59.32	0	13.42	0.64	0.65
2	62.27	62.27	0	28.5	1.55	1.54	62.27	0	13.42	0.72	0.68
3	89.02	89.02	0	28.5	1.88	2.03	89.02	0	13.42	0.88	0.9
4	208.36	208.36	0	28.5	5.15	5.19	208.36	0	13.42	2.42	2.45

Table 4. Hydropower station downstream runoff basic algorithm and improved algorithm to optimize the scheduling result (b).

M	Inflow (m^3/s)	D hydropower					E hydropower				
		Power Flow (m^3/s)	Abando-ned water (m^3/s)	Head (m)	Basic	Impro-ved	Power Flow (m^3/s)	Abando-ned water (m^3/s)	Head (m)	Basic	Impro-ved
5	121.06	133.06	0	31.14	3.6	3.63	133.06	0	17.25	2	2.01
6	138.93	154.93	0	31.14	4.08	4.05	154.93	0	17.25	2.26	2.25
7	183.86	199.86	0	31.14	5.26	5.33	199.86	0	17.25	2.93	2.93
8	158.88	182.88	0	31.14	4.81	4.75	182.88	0	17.25	2.67	2.65
9	124.62	145.62	0	31.14	3.84	3.82	145.62	0	17.25	2.12	2.13
10	158.89	176.89	0	31.14	4.75	4.76	176.69	0	17.25	2.63	2.6
11	117.59	125.09	0	31.14	3.3	3.25	125.09	0	17.25	1.83	1.79
12	62.49	67.49	0	31.14	1.67	1.73	67.49	0	17.25	0.93	0.95
1	58.6	62.1	0	31.14	1.52	1.55	62.1	0	17.25	0.84	0.86
2	63.19	67.19	0	31.14	1.81	1.74	67.19	0	17.25	1	0.95
3	86.78	92.68	0	31.14	2.33	2.37	94.68	0	17.25	1.27	1.32
4	207.52	217.42	0	31.14	5.81	5.82	217.51	0	17.25	3.22	3.25

Table 5. Two algorithms applied to a cascade reservoirs total generating capacity compared (one hundred million kWh).

	A	B	C	D	E	Total
Basic chaotic ant	10.6363	2.6049	1.2188	3.1213	1.7292	19.3105
Improved Chaos Ant Colony	10.6851	2.6084	1.2160	3.1229	1.7285	19.3609
Additional charge	0.0488	0.0035	-0.0028	0.016	-0.007	0.0504

5. Conclusions

Intelligent optimization algorithms in recent years in reservoir optimal scheduling and more widely, not only enrich the reservoir operation technology research, but also achieved better optimization results. In this paper, a cascade reservoirs within the watershed to establish long-term optimization scheduling model, the introduction of improved chaotic ant colony optimization algorithm to solve it. Combined with the scheduling feature cascade hydroelectric station, through theoretical arguments and examples of applications show that the optimized algorithm can achieve better optimization results.

Acknowledgements

This study is supported by the National Natural Science Foundation of China (No. 51179047).

References

[1]. Pan Li, Rui Xiao-Fang, Hydropower Reservoir Optimal Operation Research Progress, *Hydrology*, 6, 1999, pp. 37-40.

[2]. Maguang Wen, Liu Jinhuan, Li Ju, Roots group of Cascade Hydropower Joint optimization run, *China Electric Power Press*, Beijing, 2008.

[3]. Section seaside colony algorithm and its application, *Science Press*, Beijing, 2005.

[4]. Xie, Chaotic ant colony algorithm for traveling salesman problem, *Systems Engineering-Theory and Practice*, 9, 2005, pp. 100-104.

[5]. Wang Zhiliang, Chaos ant colony algorithm to reservoir optimal scheduling application, *Water Resources and Architectural Engineering*, 4, 2007.

[6]. Yu Wan, Chaos computational experiments and analysis, *Science Press,* Beijing, 2008.

[7]. Wang Ying, Xie Jianying, An Adaptive ant colony algorithm and its simulation, *System Simulation*, 14, 1, 2002, pp. 31-33.

[8]. Yang Juxiang, Tao Reservoir Optimal Operation of Cascade Hydropower Station, *Xi'an University of Technology*, 2007.

2013 Copyright ©, International Frequency Sensor Association (IFSA). All rights reserved.
(http://www.sensorsportal.com)