SHORT-TERM HYDRO-THERMAL SCHEDULING WITH ARTIFICIAL BEE COLONY

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Abstract:

This paper reported the use of artificial bee colony to short-term hydro-thermal scheduling problem. Simulation studies demonstrated that it is possible to find a workable solution and the approach to implement the algorithm will be discussed too.

Keywords:

Scheduling; Artificial Bee Colony; Optimization

1. Introduction

Energy system today is mainly established on fossil energy resources. Traditionally it is designed in a period of stable energy prices, which considering less environmental impacts. Nowdays the price stability is violated by significantly increasing speed in energy demand worldwide. The oil price increase from 1998 to 2008 is about 800%, as well as the natural gas [1]. On the other hand, more energy consumption without considering much on environment impacts leads to dangerous climate change and pollutions. Business As Usual (BAU) scenarios project extreme temperature rise in the rage of 4-7° C by the end of this century [2]. The severe terrain of energy supply and consumption force us to consider clean energy utilization.

Most of generation in power system are thermal plants. It has substantial advantages in generation stability, easier for generation planning and no limits on locations. But they produce various greenhouse gas and pollutions from burning fossil resources. Meeting requirement of clean energy utilization, hydro plants is introduced for much less carbon emits and less fossil consumptions. But unlike thermal plants, water flow is the energy input for hydro plant and thus water flow dynamics influences hydro plants generation deeply. Short-Term Hydro-Thermal Scheduling (STHTS) is a generation scheduling problems to minimize the total operational cost subjected to a variety of constraints while introducing hydro plants into power generation. Comparing to static optimization in pure thermal plants scheduling, STHTS is a dynamic optimization problem for dynamic water availability.

Due to that input-output curve of hydro plants are normally nonlinear and non-convex, the easily converge to local minimum is unavoidable for several traditional optimization algorithms. Dynamic programming is the earliest stage for solving STHTS. In recent years, multiple metaheuristics algorithms have successfully applied in STHTS, including genetic algorithm [3], evolutionary programming [4], simulated annealing [5], differential evolution [6] and particle swarm optimizations [7].

This paper is targeted on solving STHTS by a newly developed algorithm. Section 2 introduces STHTS in details and summarizes the optimization model. Section 3 reveals how Artificial Bee Colony (ABC) operates. Section 4 introduces the simulation result on supporting the problem solving.

2. Short-Term Hydro-Thermal Scheduling

The energy supply of hydro plant is water flow, which is nearly free. So STHTS aims at minimizing the thermal cost in generation. For short-term scheduling, the entire period of demand curve is separated into several intervals. The total object function for optimization is [8]:

$$Min.\ \ F=\sum_{t=1}^{T}\sum_{i=1}^{Ns} f_{it}(P_{sit}) \tag{1}$$

Where

P_{sit} --- Power generation of i^{th} thermal unit at interval t.

$f_{it}(P_{sit})$ --- Fuel cost function.

T --- Total number of time interval for scheduling period.

Ns --- Total number of thermal unit.

Traditionally, thermal generation unit's fuel cost curve can be expressed by segments of quadratic functions of the active power output of the generator. In modern thermal power plants, an extra consideration of multi-value steam turbines should be included. So the fuel cost function could be expressed in equation (2):

$$f_{it}(P_{sit}) = a_{si} + b_{si} \cdot P_{sit} + c_{si} \cdot P_{sit}{}^2 + \left| d_{si} \cdot \sin(e_{si} \cdot (P_{si}^{\min} - P_{sit})) \right| \tag{2}$$

Where

$a_{si}, b_{si}, c_{si}, d_{si}, e_{si}$ --- Fuel cost coefficients.

$P_{si}^{\min}$ ---The lower generation limits for i[th] thermal unit.

2.1. Load Balancing Constraint

Active power generation is targeted on the actual demand. So the total power generated must satisfy the power demand with power losses at each interval:

$$\sum_{i=1}^{Ns} P_{sit} + \sum_{j=1}^{N_h} P_{hjt} - P_{Dt} - P_{Lt} = 0 \tag{3}$$

Where

P_{hjt} --- Power generation of j[th] hydro unit at interval t.

P_{Dt} --- Power demand at interval t.

P_{Lt} --- Power loss at interval t.

N_h --- Total number of hydro unit.

The water discharge rate and reservoir storage volume influences the hydro generation. The relationship can be described in equation (4) [8]:

$$P_{hjt} = C_{1j}V_{hjt}^2 + C_{2j}Q_{hjt}^2 + C_{3j}V_{hjt}Q_{hjt} + C_{4j}V_{hjt} + C_{5j}V_{hjt} + C_{6j} \tag{4}$$

Where

V_{hjt} --- The storage volume of j[th] reservoir.

Q_{hjt} --- Water discharge rate of j[th] reservoir.

$C_{1j}, C_{2j}, \cdots, C_{6j}$ --- Generation coefficient of hydro unit.

2.2. Water continuity Constraint in reservoir network

$$V_{hjt} = V_{hj,t-1} + I_{hjt} - Q_{hjt} - S_{hjt} + \sum_{m=1}^{R_{uj}} (Q_{hm,t-\tau_{mj}} + S_{hm,t-\tau_{mj}}) \tag{5}$$

Where

I_{hjt} --- Natural inflow of j[th] hydro reservoir.

S_{hjt} --- Spillage discharge rate of j[th] hydro unit.

τ_{mj} --- Water transport delay from reservoir m to j.

R_{uj} --- The number of upstream hydro plants immediately above j[th] reservoir.

2.3. Water Storage and Discharge Constraints

$$\begin{aligned} V_{hj}^{\min} \le V_{hjt} \le V_{hj}^{\max} \\ Q_{hj}^{\min} \le Q_{hjt} \le Q_{hj}^{\max} \end{aligned} \tag{6}$$

Where

$V_{hj}^{\min}, V_{hj}^{\max}$ --- The minimum and maximum storage volume.

$Q_{hj}^{\min}, Q_{hj}^{\max}$ --- The minimum and maximum water discharge rate.

2.4. Power generation constraints

$$\begin{aligned} P_{si}^{\min} \le P_{sit} \le P_{si}^{\max} \\ P_{hj}^{\min} \le P_{hjt} \le P_{hj}^{\max} \end{aligned} \tag{7}$$

Where

$P_{si}^{\min}, P_{si}^{\max}$ --- The minimum and maximum power generation by i[th] thermal unit.

$P_{hj}^{\min}, P_{hj}^{\max}$ --- The minimum and maximum power generation by j[th] hydro unit.

3. Artificial Bee Colony Algorithm

3.1. Standard Artificial Bee Colony Algorithm

The Artificial Bee Colony (ABC) algorithm is introduced by Karaboga for numerical optimization problem. Same as PSO, it is a swarm based metaheuristic algorithm. It simulates the foraging behaviour of a honey bee swarm [9].

There three essential components in Bee foraging intelligence: food sources, employed foragers and unemployed foragers. In a real bee colony, division of labour is for maximize he nectar quantity in their hive. The employed bees, which constructs half of the colony, are responsible from exploiting the nectar sources explored before and giving information to the other waiting bees in the hive. The information passed includes food source distance, amount rest and so on. Unemployed bees can be separated into two groups: onlooker bees and scouts.

Onlookers wait at the dance area in the hive and decide a food source to exploit basing on the information passed from employed bees. Scouts randomly search the environment to find a new food source depending on an internal motivation or possible external clues or randomly [10].

Abstracting the behaviour in mathematics, Artificial Bee Colony (ABC) can be separated into the following steps [10]:

Step 1. Initialization Phase
Step 2. Employed Bees Phase
Step 3. Onlooker Bees Phase
Step 4. Scout Bees Phase
Step 5. Memorize the best solution so far
Step 6. If not meet the stop conditions, go to **Step 2**, otherwise stop.

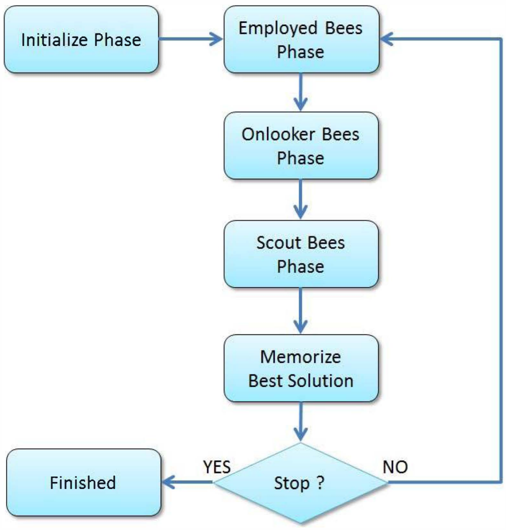

Figure 1. Standard Artificial Bee Colony Procedure

In Initialization Phase, food sources are initialized. Each food source is representing a candidate solution in the optimization. In standard ABC optimization problem, equation (8) suggests a path to initialize each element of a solution vector [10]:

$$x_m = l_m + rand(0,1) \cdot (u_m - l_m) \tag{8}$$

Where

x_m --- The m[th] element in candidate solution vector.

l_m, u_m --- The lower limit and the upper limit of x_m.

In Employed Bees Phase, all employed bees are targeted to the food sources. The number of employed bees is exactly the same as food sources' quantity, so each food source is targeted by only one employed bee. When an employed bee targets at a food source, it will find a new food source in the food source neighbourhood and evaluate the profitability of new food source. If the profitability of new food source is better than the one targeted by the bee, this employed bee will arrive to the new food source. Otherwise it will still back to the one it targets to. Equation (9) provides one of the methods for employed bees searching new food source [11]:

$$v_m = x_m + \phi \cdot (x_m - x_m^k) \tag{9}$$

Where

v_m --- The m[th] element in new food source.

x_m^k --- The m[th] element in a randomly selected new food source targeted by one of other employed bees.

ϕ --- Random number within the range [-a, a].

In Onlooker Bees Phase, the onlooker bees will separately target to the food sources selected by employed bees. They tend to target at a food source with better food source quality. Equation (10) introduces one of ways that onlooker bees select their food sources [10]:

$$p_k = \frac{fit_k(\vec{x}_k)}{\sum_{k=1}^{SN} fit_k(\vec{x}_k)} \tag{10}$$

Where

$\vec{x}_k$ --- The solution vector of the k[th] food source.

SN --- The total quantity of food sources.

$fit_k(\vec{x}_k)$ --- The fitness function.

p_k --- The selection possibility for onlooker bees to the k[th] food source.

When all onlooker bees finishing their food sources selection, they will firstly fly to a new food source in their target food sources' neighbourhood as employed bees did. The new food sources selection is the same as employed bees in equation (9). For all onlooker bees targeting to a same food source, the food source which has the best profitability will be the final selection of this section of onlooker bees. Total onlooker bees sections' quantity will be SN, the same as food sources quantity.

In Scout Bees Phase, once employed bees whose solutions cannot be improved through a predetermined number of limit, the food source it targeted to will be given up and this employed bee will become a scout, which will randomly search a new food source in solution space as initialization.

3.2. Constraints Handling

The standard ABC is a meta-heuristics algorithm without considering constraints. In STHTS the hydro discharges constraints and thermal generation constraints are the two critical that easy to be violated. The end storage volume constraints for any reservoir could be expressed as a function of hydro discharges according to equation (5).

The discharge of reservoir j at interval t is given by equation (11):

$$Q_{jt} = V_j^{initial} + V_j^{final} - \sum_{l=1, l\neq t}^{T} Q_{jl} + \sum_{l=1}^{T} I_{jl} \qquad (11)$$

Where

$V_j^{initial}$ --- The starting volume of reservoir j.

V_j^{final} --- The end volume of reservoir j.

Q_{jl} --- The lth interval discharge of reservoir j.

I_{jl} --- The lth interval inflow of reservoir j.

If the above calculated discharge does not violate the limit, then go to the next reservoir. Otherwise, set the violate discharge rate into its bound then calculate the mismatch in equation (12):

$$Q_{mis} = V_j^{initial} + V_j^{final} - \sum_{l=1}^{T} Q_{jl} + \sum_{l=1}^{T} I_{jl} \qquad (12)$$

Where Q_{mis} is the mismatch value. Add the above mismatch to one of the randomly picked interval's discharge and check for its limits. If within the limits then go for next reservoir, otherwise set the exceeding discharge rate at its limit and repeat the above procedure until mismatch becomes zero.

The thermal constraints are based on B matrix [12]. In each interval a dependent element Pg(d, t) from the thermal plants is randomly chosen and the dependent thermal generation is calculated by solving the fallowing quadratic equation(27) which is also incorporating losses.

$$B_{dd} \cdot P_g(d,t)^2 + (B0_d - 1 + \sum_{i\neq d}^{N_s+N_h} P_g(i,t)\cdot(B_{id}+B_{di}))\cdot P_g(d,t) +$$
$$\sum_{i\neq d}^{N_s+N_h} P_g(i,t)\cdot(B0_i - 1 + \sum_{j\neq d}^{N_s+N_h} P_g(j,t)\cdot B_{ij}) + P_D(t) + B00 = 0 \qquad (27)$$

Where

$P_g(d,t)$ --- represents combination of thermal and hydro generations

Ns --- The number of thermal plants.

Nh --- The number of hydro plants.

The above step is repeated if the value of the dependent thermal generation violates its minimum and maximum limit. It is ensured that the dependent element is not repeatedly selected while generating the random element.

4. Simulation

In this paper a testing system [3] is selected for simulation to evaluate the ABC consists of a multi-chain cascade of 4 hydro units and a number of thermal units represented by an equivalent thermal plant as shown in Figure 2. The scheduling period is 24 hours with one hour time intervals. [3] provides all the system data. The food source number is set to 100. The limit for unimproved food source is 100.

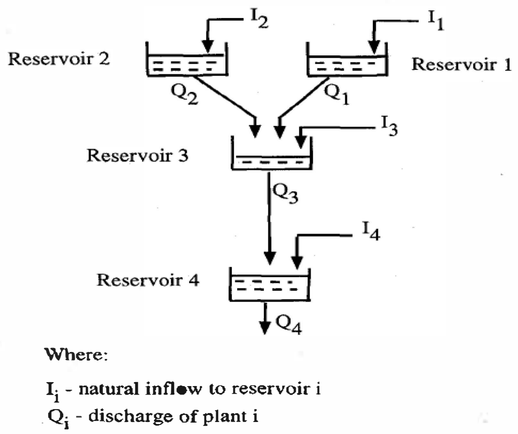

Figure 2. Hydraulic system test network

Figure 3 reveals the optimization procedure of the testing system.

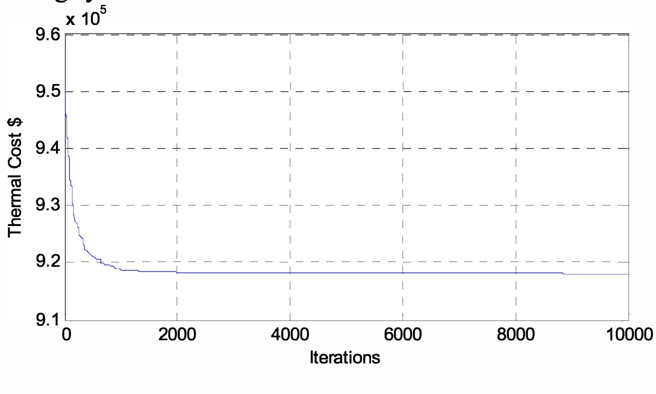

Figure 3. ABC optimization for 4h system

The final optimal cost is 9.1802×10^5, with the food source in Table 1.

TABLE 1: DISCHARGE RATE OF RESERVOIR 1 TO RESERVOIR 4 WHEN OPTIMAL THERMAL COST ACHIEVED.

Hour	R-1 Dis	R-2 Dis	R-3 Dis	R-4 Dis
1	5.885	6.712	30	13
2	7.776	6	30	13
3	8.066	6	30	13
4	8.242	6	30	13
5	8.433	6	30	13
6	8.824	6.376	30	13
7	9.344	6.77	30	13
8	9.432	7.531	30	13
9	9.42	8.744	12.065	13
10	9.254	7.629	11.052	13
11	9.103	7.032	12.754	13
12	8.995	8.033	13.37	13
13	8.834	9.926	11.807	13
14	8.569	8.293	11.39	13.619
15	8.6	7.967	10.576	14.237
16	8.407	11.518	11.678	14.904
17	8.113	8.598	11.777	15.952
18	8.039	9.015	11.722	16.794
19	8.066	9.935	10.534	17.782
20	7.93	10.229	10.453	18.968
21	7.907	13.794	10	19.623
22	7.54	9.166	10	20.706
23	5.218	9.919	10	21.71
24	5	10.814	10.005	22.682

5. Conclusions

This paper has reported the use of artificial bee colony to short-term hydro-thermal scheduling problem. Simulations have been carried on a system with 4 hydro units and a number of thermal plants. The results show that artificial been colony is a feasible method to obtain a workable solution for such problems. The future work will look into the comparison of the method with other intelligent techniques.

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