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Short-Term Hydrothermal Scheduling using Imperialist Competitive Algorithm

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Abstract: In this study, the Imperialist Competitive Algorithm (ICA) is proposed to solve a multi-chain Short-Term Hydrothermal Scheduling problem (STHTS). It aims to minimize the generation cost of the thermal plants while satisfying the thermal and hydro plants constraints. In order to evaluate the effectiveness of the ICA, it has been tested on a system having a hydro plant with four-cascaded reservoir and a thermal plant. The results are compared with that obtained by other techniques. The ICA has the good convergence and the better results.

Keywords: Imperialist Competitive Algorithm, Short-Term Hydrothermal Scheduling.

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INTRODUCTION

Short-Term Hydrothermal Scheduling (STHTS) is the manner in which the fuel cost of the thermal plant is minimized for the economical operation of hydrothermal systems. It aims to get optimal operation scheduling involving the hydro and thermal constraints with minimizing the operational cost of the thermal units. The constraints of hydrothermal system include generation limits, water balance, power balance, the physical restrictions on the reservoir storage and discharge capacity. Therefore, STHTS is a non-smooth, non-linear, non-convex and large-scale optimization problem.

In recent years, Evolutionary Algorithms (EA) have been widely used due to their flexibility, versatility, and robustness in searching a globally optimal solution. Several Evolutionary Techniques, such as Genetic Algorithm (GA)[1] , Evolutionary Programming(EP) , Couple Based Particle Swarm Optimization (CPSO)[2] , Honey Bee Mating Optimization (HBMO)[3], Differential Evolution (DE)[4] , Modified Differential Evolution (MDE)[5] , Symbiotic Organisms Search(SOS)[6, 7], Teaching learning Based Optimization (TLBO)[8] , Crisscross Optimization (CSO)[9], and Modified Dynamic Neighborhood Learning Based Particle Swarm Optimization (MDNLPSO)[10] have been intended for scheduling of the hydrothermal problem.

This paper recommended new algorithm known as Imperialist Competitive Algorithm (ICA). The basis of ICA began from the attempting of the world countries to increase their power over the different countries for employing their resources and support their own government. Imperialist countries tried to state their power over the different countries to be from their colonies. Furthermore, compete with the each other to pick the ownership of the other countries. During this process, empires that have more powerful will gain more power and inefficient ones will finally slump. ICA attempt to model this procedure to obtain the best solution. Up to now, the ICA informed a good result in finding a global solution that encourage to use this algorithm in optimization problems in many applications [11-14].

PROBLEM FORMULATION

The main objective of Short-Term Hydrothermal Scheduling (STHTS) problem is to expose the optimal schedule of thermal and hydro plants to reduce the total production as possible while fulfilling all constraints. The total production cost function is usually expressed as

$$\min TC = \sum_{t=1}^{T} \sum_{j=1}^{Ng} \mathrm{a}_j \; p_{gj}^2 + b_j \; p_{gj} + c_j \tag{1}$$

Where TC is the total production cost. T is the number of scheduling time intervals. N_g is the thermal generation plants. P_{gj} is the thermal output power of the j th unit at t th time interval and a_j , b_j and c_j are the j th thermal plant cost coefficients.

2.1 System load balance

The system load balance equation can be given with neglecting the transmission losses as:

$$\sum_{j=1}^{Ng} p_{gj}^{\ t} + \sum_{i=1}^{N_h} p_{hi}^{\ t} = p_D^{\ t} \tag{2}$$

$$j = 1, 2, \ldots, N_g , \; i = 1, 2, \ldots, N_h; \; t = 1, 2, \ldots, T$$

Where N_h is the number of hydro plants. $P_{hi}^{\ t}$ is output of the i th hydro unit at t th time interval. $P_D^{\ t}$ is the total load demand at the t th time interval.

2.2 Thermal plant generation limits

$$P_{gj}^{\min} \le P_{gj}^{\ t} \le P_{gj}^{\max} \tag{3}$$

Where, $P_{gj}^{\min}$, $P_{gj}^{\max}$ are minimum and maximum limits of the j th thermal plant.

2.3 Hydro plant generation limits

$$P_{hi}^{\min} \le P_{hi}^{t} \le P_{hi}^{\max} \tag{4}$$

Where, P_{hi}^{min} , P_{hi}^{max} are minimum and maximum limits of the ith hydro plant.

2.4 Hydro plant power generation

The hydro plant power generation is a function of water discharge rate through turbine and reservoir storage volume and it expressed as:

$$P_{hi}^{t} = C_{1j}(V_j^{t})^2 + C_{2j}(q_j^{t})^2 + C_{3j}V_j^{t}q_j^{t} + C_{4j}V_j^{t} + C_{5j}q_j^{t} + C_{6j} \tag{5}$$

Where C_{1j}:C_{6j} are the generation coefficients of the ith hydro plant. V_j^t is the reservoir storage volume level of jth reservoir at tth time interval. q_j^t is water discharge rate of jth reservoir at tth time interval.

2.5 Hydro plant water discharge limits

$$q_j^{\min} \le q_j^{t} \le q_j^{\max} \tag{6}$$

Where, q_j^{min} , q_j^{max} are the minimum and maximum water discharge limits of ith hydro plant.

2.6 Reservoir storage volume limits

$$V_j^{\min} \le V_j^{t} \le V_j^{\max} \tag{7}$$

Where, V_j^{min} , V_j^{max} are the minimum and maximum limits of reservoir storage volume of ith hydro plant.

2.7 Water dynamic balance equation

$$V_j^{t} = V_j^{t-1} + I_j^{t} - q_j^{t} - \sum_{m=1}^{Nui} q_m^{t-r_j^m} \tag{8}$$

Where I_j^t is the water inflow rate of jth reservoir at tth time interval, r_j^m is the time delay between the hydro plant and its upstream plants at tth interval, N_u number of upstream plants above to the ith hydro plant.

2.8 Initial and final reservoir storage volume limits

$$V_j^{o} = V_j^{initial}\ ;\ V_j^{T} = V_j^{End} \tag{9}$$

Where, $V_j^{\ initial}$, $V_j^{\ End}$ are the initial and final reservoir storage volume of jth reservoir.

V_j^o, V_j^T are the jth reservoir storage volume at the beginning and ending of the time horizon, respectively.

AN OVERVIEW OF IMPERIALIST COMPETITIVE ALGORITHM AND IMPLEMENTATION TO THE PROBLEM

The rule of ICA was made by Atashpaz-Gargari and Lucas (2007) [14]. The ICA simulated the social political development of imperialism and compete the imperialist. ICA began with initial population called countries that were divided into two kinds of countries; the strongest countries were chosen to be the imperialist and the residual countries establish the colonies of these imperialists. The colonies of initial countries were distributed among the imperialists constructed on the imperialist's power. All the imperialists and their colonies united together to form empires.

After empires formation, the competition between empires begin. The weaker empires miss out their colonies to the strong empires until we reach one empire and the other rest of their colonies. This empire represents the finial best solution. The application steps of ICA algorithm on (STHTS) problem are shown on Figure 1. And the algorithm is divided into the following five stages:

3.1 Initializing phase:

Firstly, Preparation of initial populations. Each solution (i.e., country) in form of an array as (10).

$$X = [P_1, P_2, P_3, \ldots, P_{Ng}] \tag{10}$$

Where P are represent a variables, and Nvar n–dimension of the optimized problem. The cost function the countries can depicted as (11).

$$\text{Cost}=f\ (\text{country}) =f\ (P_1P_2P_3,......,P_{N_{var}}) \tag{11}$$

Then Initializing the empires with initial populations (Npop) involved two types of countries [i.e., colony (Ncol) and imperialist (Nimp)] which together form the empires. The normalized cost C_n of an imperialist was depicted as.

$$C_n = c_n - \max\{c_i\} \tag{12}$$

Whereas, c_n was the nth imperialist cost.

The colonies of initial countries were distributed among the imperialists constructed on the imperialist's power. The normalized power P_n of each imperialist was depicted as.

$$p_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \tag{13}$$

3.2 Moving phase:

Colonies moved toward their imperialist with x units as depicted in (14).

$$x : U(0, \beta \times d) \tag{14}$$

Where x is a random variable with uniform distribution, β is a number greater than 1, and d is the distance between an imperialist and its colony. And the direction of movement of colonies were depicted as (15).

$$\theta : U(-\gamma, \gamma) \tag{15}$$

Where θ was a random variable with uniform distribution, and ɣ was a parameter that regulated the change from the original direction.

3.3 Exchanging phase:

During movement of colonies, if the new situation of the colony is better (based on the cost function) than the corresponding imperialist so imperialist and the colony change their positions.

3.4 Competition phase:

Firstly, calculated the total power of an empire as (16).

$$T.C_n = \text{cost}(\text{imperialist}_n) + \xi \text{ mean}(\text{cost}(\text{colonies of empire}_n)) \qquad (16)$$

Where, $T.C_n$ was the total power of the n^{th} empire and ξ is a positive number less than 1.

Then all empires were tried to acquire more colonies from other empires. The weakest empires loose it's colonies during competition between them.

3.5 Eliminating phase:

The empires that lose their colonies were collapsed and eliminated. Finally, all the colonies will be under the dominance of the most powerful empire.

CASE STUDY AND NUMERICAL RESULTS

To examine the flexibility of the ICA to find the optimal solution of STHTS problem, the ICA algorithm has been applied on a case study and also that the results were compared with different algorithms within the literature. The program was processed using MATLAB 2016 on a Pentium i3 laptop computer, 2.53 GHz processor speed and 4 GB RAM.

4.1 Test System

This test system considers a multi-chain cascade of four hydro plants and a thermal plant represented by an equivalent thermal plant including power balance, water balance, generation limits, the physical restrictions on the discharge capacity and reservoir storage. The hydro system is shown in Figure 2. In this case, the fuel cost of the equivalent thermal plant is considered to be of quadratic in nature, i.e., the valve point effect has been neglected. The total scheduling period is 1 day which has been divided into 24 intervals all data are taken from [15].

Table 1 Show the optimal hydro discharges for this system, and Table 2 Shows the individual hydro power and thermal power generated and Table 3 shows the comparison of best and worst cost as well as the computation time among ICA and other methods. It show that some of other algorithms have less time solution than ICA, but still its simulation time is good enough. The cascaded reservoir storage volumes for the test system is presented in Figure 3. The convergence curve of the proposed algorithm is given in Figure 4 and show that ICA algorithm reach to optimal solution with very small number of iterations.

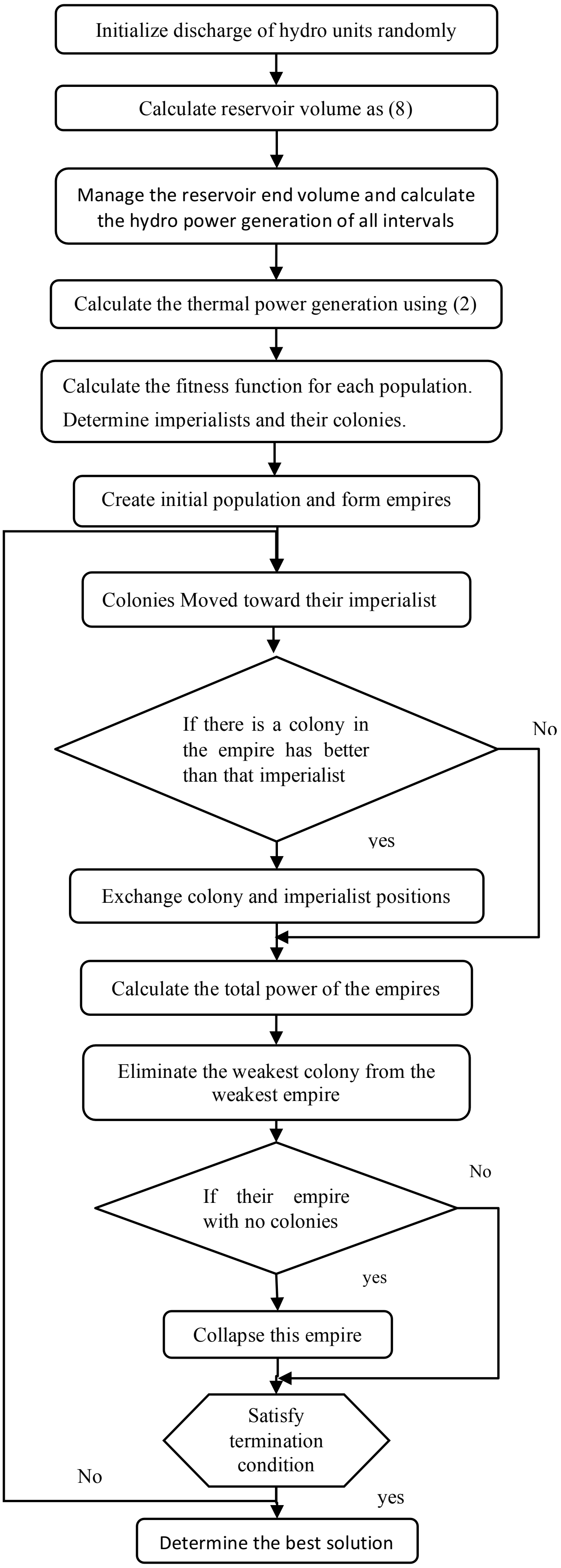

Figure 1. Flow chart of the proposed algorithm

Table 2. Hydro and thermal generation power

	Hydro Power Gen. (MW)				Thermal Power Gen. (MW)	Power Demand (MW)
	P_{h1}	P_{h2}	P_{h3}	P_{h4}		
1	97.65151	81.27684	0	246.0455	945.0262	1370
2	93.4365	68.61934	0	199.9794	1027.965	1390
3	71.47132	74.25258	0	186.5859	1027.69	1360
4	88.88353	80.72279	35.3986	170.3615	914.6336	1290
5	76.25723	51.63139	0	190.6629	971.4484	1290
6	84.11946	56.75525	0	208.156	1060.969	1410
7	81.55369	69.10467	0	225.3103	1274.031	1650
8	54.85934	54.37668	51.27365	281.1088	1558.382	2000
9	80.08311	67.32385	28.51075	277.9989	1786.083	2240
10	85.9503	65.44247	37.84124	250.6825	1880.083	2320
11	60.50938	68.3543	48.73976	271.6118	1780.785	2230
12	61.02126	67.14944	48.75015	282.682	1850.397	2310
13	52.49306	45.63351	54.04749	293.1132	1784.713	2230
14	79.63589	38.15865	56.64283	313.1597	1712.403	2200
15	84.33989	58.39447	43.7102	272.263	1671.292	2130
16	77.96906	59.37094	41.12587	275.6027	1615.931	2070
17	88.19862	36.87301	58.74001	314.8479	1631.34	2130
18	59.47086	36.87301	59.83014	277.1496	1706.676	2140
19	54.20861	37.60531	61.19554	271.5555	1815.435	2240
20	54.32849	39.0459	28.19569	297.8702	1860.56	2280
21	62.18572	43.31517	52.42664	281.1843	1800.888	2240
22	74.22821	42.93958	56.18937	302.4659	1644.177	2120
23	67.75848	53.98338	51.91712	264.1938	1412.147	1850
24	59.87897	59.63356	56.04564	270.4421	1144	1590

Table 3. Comparison of performance

Methods	Min cost	Max cost	Average cost	Time
MDNLPSO [10]	922336.3	923404.5	922676.2	35
DNLPSO [10]	922,498	923,580	922,837	37
SOS[7]	922332.169	922482.895	922338.1982	6.21
SOS [6]	922295.25124	-	-	-
CSO [9]	922316.16	922373.10	922326.70	36
CPSO [2]	922,328.64	922,508.67	922,346.33	20.8
HBMO [3]	923300	927790	925905	153.8
ICA	921612.3478	926810.09	924211.17	53.19

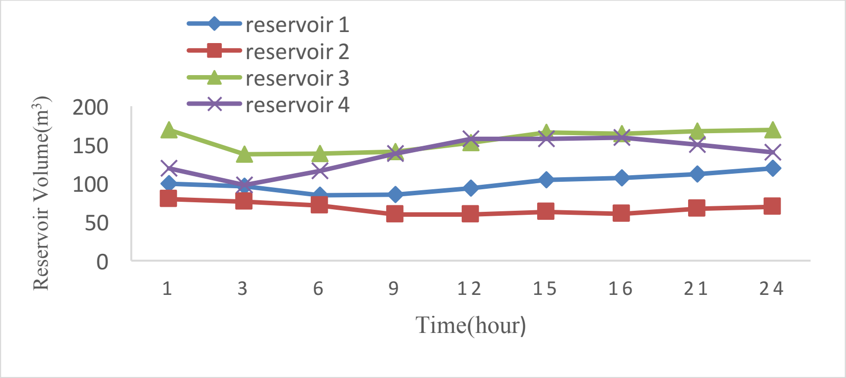

Figure 3. Reservoir storage volumes for Test system with ICA

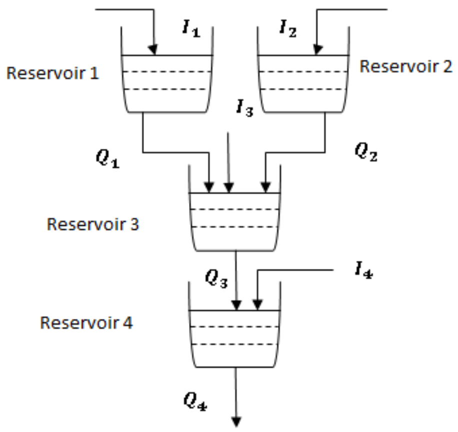

Figure 2. Multi-chain cascaded hydro system.

Table 1. The plants discharge.

	Water Discharge (×$10^4 m^3$)			
	Plant 1	Plant 2	Plant 3	Plant 4
1	13.9772	12.13787	29.50086	17.45051
2	12.57136	9.366476	28.31604	13.04379
3	7.581674	10.86375	29.49278	13.04379
4	11.60566	14.17643	20.27465	13.04379
5	8.855899	7.093392	25.8616	13.04379
6	11.19719	8.062055	27.16631	13.05722
7	10.87344	11.63672	27.29763	13.05722
8	5.780798	8.573783	14.80254	21.24859
9	10.04635	12.56906	21.40611	19.10552
10	11.9771	11.951	19.36763	13.81897
11	6.316855	12.94432	16.33246	15.33215
12	6.22672	12.50843	17.43874	16.89856
13	5	7.524021	15.93264	18.02701
14	8.577849	6	15.3694	21.83434
15	9.329667	9.580367	20.04299	15.585
16	8.152142	10.18261	20.47257	15.80107
17	10.04917	6	12.58909	23.77319
18	5.629341	6	13.78585	17.14567
19	5	6	12.92975	15.92482
20	5	6	23.40281	19.42329
21	5.878577	6.354643	17.62023	17.69259
22	7.411414	6	10	25
23	6.508597	7.677026	17.63775	17.69259
24	5.530087	8.780294	10	17.69259

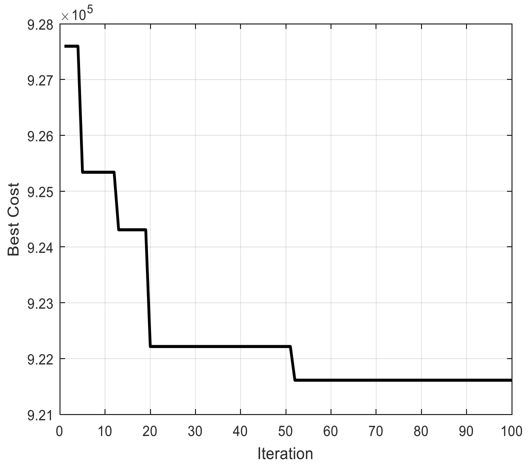

Figure. 4 Convergence characteristics of ICA.

5. CONCLUSIONS

Short Term Hydrothermal Scheduling problem (STHTS) has been solved by imperialist competitive algorithm. (STHTS) Considered one of non-linear and non-convex optimization problems in power systems. The proposed ICA algorithm has been successfully applied on a test system that consists four hydro and thermal plant. While satisfying the operational constraints, minimization of the fuel cost that is aimed in this problem. The results have been compared with similar algorithms. Reported in the literature, it is observed from the test results and comparisons that the proposed ICA algorithm performs well in solving hydrothermal scheduling problems. The minimum cost by ICA, MDNLPSO and SOS are 921612.3478, 922336.3, and 922295.2512, respectively. It is seen that ICA present a good result and can be used for solving other complex engineering problems.

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