



An Improved Chaotic Bat Algorithm for Daily Electrical Scheduling of Hydrothermal Energy Systems

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Abstract: Minimizing the cost of operation has always been the objective of power generation companies. Electrical scheduling of hydrothermal energy systems deals with minimizing the cost of thermal generation while taking care of various hydraulic and thermal constraints. Due to the non-convex and non linear nature of the problem, meta-heuristic techniques are preferred over the classical techniques. This paper presents the improved version of bat algorithm in order to solve the stated problem. The proposed technique tackles the problem of premature convergence by embedding the chaotic hybridized local search in basic bat algorithm. The complex constraints, like dynamic water balance, are handled using heuristic tools instead of any penalty factor approach. In order to test the efficiency of the developed technique it was applied on three hydrothermal test systems. The proposed methodology produces encouraging results as compared to many other recently established approaches.

Keywords: Constraint Handling, Valve-point Loading Effect, Local Search, Improved Bat Algorithm, Chaotic Sequences

1. **INTRODUCTION**

Daily Electrical Scheduling of Hydrothermal Energy Systems (DESHES) is one of the most important problems in Electrical operation of power system. It refers to the coordinated operation of hydel and thermal plants in such a way that total rate of production is minimum, subject to the satisfaction of constraints. As hydro generation is done without conventional fuels, therefore using the water effectively results in a huge saving of electricity production. The constraints to be satisfied while solving this problem include; dynamic water balance, active power balance, discharge rate limits of hydel plants, prohibited discharge zones, the maximum and minimum generation limits of hydel and thermal plants, reservoir storage capacity and initial and final storage volumes of reservoirs. These constraints make the stated problem very challenging to find the global optimal solution.

Hydrothermal scheduling problem has been extensively studied for the last few decades by a number of researchers using many renowned techniques like quadratic programming (QP) (Petcharak and Ongsakul, 2007), mixed integer linear programming (MILP) (Chang *et al.*, 2001), dynamic programming (DP) (Yang and Chen, 1989; Chang *et al.*, 1990), linear programming (LP) (Programming, 1992), network flow programming (NFP) (Heredia and Nabona, 1995; Oliveira and Soares, 1995), extended dynamic programming (EDP) (Tang and Luh, 1995), Lagrange relaxation (LR) (Salam, 1998; Jiménez *et al.*, 1999;

(Petcharak and Ongsakul, 2007), progressive optimality algorithm (POA) (Turgeon, 1981) and decomposition methods (Pereira and Pinto, 1983; Programming, 1992). The performance of all these methods decreases drastically due to a large number of constraints with many local optima and the non linear characteristics of hydrothermal scheduling problem. In LP the varying head of reservoirs is to be neglected due to the linear model requirement which results in a large error. LR suffers from the oscillation problem and success of LR mainly lies in updating of lagrange multipliers which needs major consideration. Although dynamic programming doesn't need a linear and continuous objective function but it suffers badly from the "curse of dimensionality". POA is an extended version of dynamic programming and it greatly reduces the dimensionality problem but it is easily trapped in local optima which reduces the solution accuracy.

In addition to these classical methods many heuristic algorithms like genetic algorithm (GA) (Gil, Bustos and Rudnick, 2003; Zoumas *et al.*, 2004; Kumar and Naresh, 2007), particle swarm algorithm (Mandal, *et al.*, 2008; Zhang, and Yue, 2012), evolutionary programming (Hota, *et al.*, 1999; Sinha, *et al.*, 2003), differential evolution (Mandal and Chakraborty, 2008), cuckoo search algorithm (Nguyen and Vo, 2015a, 2015b), ant colony optimization (Huang, 2001) and simulated annealing (Wong and Wong, 1994) have also been applied for solving the problem of daily Electrical scheduling of hydrothermal energy systems. As these

techniques pose no restriction on the characteristics of the objective function, these techniques drew more attention and resulted in reasonable solutions in very short time as compared to the other classical techniques. The stated problem has already been investigated extensively but still attracts the attention of the researchers due to the stronger requirement of Electrical scheduling. In recent years a new population based meta-heuristic algorithm, named bat algorithm, was developed by (Yang, 2010). Various power system problems like Electrical load dispatch (GHERBI, *et al.*, 2014), power system stabilizer optimization (Sambariya and Prasad, 2014), load frequency controller design (Abd-Elazim and Ali, 2016) etc. have already been solved using bat algorithm. But conventional bat algorithm has very slow convergence rate (Xie, *et al.*, 2013), which makes it improper to solve a large scale problem like variable head hydrothermal scheduling.

In this paper, an Improved Chaotic Bat Algorithm (ICBA) technique is proposed to solve the DESHES problem. The proposed technique makes use of chaotic local search to overcome the slow convergence problem of conventional bat algorithm. The complex constraints; especially water flow and power balance constraints, were handled without using any penalty factor approach. The feasibility of the proposed technique is demonstrated by solving the three standard hydrothermal test systems. The results indicate that the proposed technique can produce promising results as compared to other techniques found in literature.

Rest of the paper is organized as follows: In section 2, the mathematical formulation of DESHES is done. Section 3 discusses the basic bat algorithm. Section 4 lists the improvements made in basic bat algorithm to achieve an ICBA. Section 5 shows the simulation results of the proposed technique on standard hydrothermal test systems. And, the final section outlines the conclusion.

2 DESHES PROBLEM FORMULATION

The problem of daily Electrical scheduling of hydrothermal energy systems has a non-convex objective function with a number of constraints on thermal and hydel plants. The mathematical formulation of DESHES problem is described as below as in (Haroon and Malik, 2017):

2.1 Objective Faction

$$\text{minimize } FC(P) = \sum_{t=1}^T \sum_{i=1}^{N_s} f_i(P_{si}^t) \quad (1)$$

Where N_s is the number of thermal units, FC is the total fuel rate of thermal plants, the total number of intervals are represented by T and P_{si}^t is the generated power in

interval t by i th thermal plant and $f_i(P_{si}^t)$ is the corresponding fuel rate.

The quadratic fuel rate function for thermal plants is formulated as shown below:

$$f_i(P_{si}^t) = \alpha_i + \beta_i P_{si}^t + \gamma_i (P_{si}^t)^2 \quad (2)$$

Where α_i, β_i and γ_i are quadratic rate curve coefficients of i th thermal plant. Practically, multi-valve steam turbines are used with thermal plants and unlike the quadratic rate function shown above, the actual rate curves are nonlinear and turbulent. So, the more accurate model of thermal plants with valve point loading effect can be shown as below:

$$f_i(P_{si}^t) = \alpha_i + \beta_i P_{si}^t + \gamma_i (P_{si}^t)^2 + |\delta_i \sin \varepsilon_i (P_{si}^{min} - P_{si}^t)| \quad (3)$$

Where δ_i and ε_i are the coefficients related to valve point loading effect and P_{si}^{min} is the minimum generation limit of i th thermal plant.

2.2 Constraints

(1) The total electrical energy produced by hydel and thermal plants should meet the demand in each interval.

$$\sum_{j=1}^{N_h} P_{hj}^t + \sum_{i=1}^{N_s} P_{si}^t = P_D^t \quad (4)$$

Where P_{si}^t and P_{hj}^t are the generated power of i th thermal plant and j th hydel plant and P_D^t is the power demand in interval t . P_{hj}^t is the function of water discharge and reservoir volume of the respective hydel plant and it is modeled as below:

$$P_{hj}^t = C_{1j} (V_{hj}^t)^2 + C_{2j} (Q_{hj}^t)^2 + C_{3j} V_{hj}^t Q_{hj}^t + C_{4j} V_{hj}^t + C_{5j} Q_{hj}^t + C_{6j} \quad (5)$$

Where $C_{1j}, C_{2j}, C_{3j}, C_{4j}, C_{5j}$ and C_{6j} are the hydel generation coefficients of the j th hydel plant, Q_{hj}^t and V_{hj}^t are the water discharge rate and reservoir volume of j th plant during interval t .

(2) The power generated from hydel and thermal plants should be within the allowed maximum and minimum limits of generation.

$$P_{si}^{min} < P_{si}^t < P_{si}^{max} \quad (6)$$

$$P_{hj}^{min} < P_{hj}^t < P_{hj}^{max} \quad (7)$$

Where $P_{si}^{min}, P_{si}^{max}$ denote the minimum and maximum power generation limits of i th thermal plant and $P_{hj}^{min}, P_{hj}^{max}$ indicate the minimum and maximum power generation limits of j th hydel plant.

(3) Practically, for a hydel plant there are certain prohibited discharge zones (PDZ). It means that the water discharges should not be within those zones. So, the discharge rate of j th hydel plant having PDZs can be modeled as shown below:

$$\begin{aligned} Q_{hj}^{min} &< Q_{hj}^t < Q_{hj,1}^L \\ Q_{hj,k-1}^H &\leq Q_{hj}^t \leq Q_{hj,k}^L \\ Q_{hj,n_j}^H &\leq Q_{hj}^t \leq Q_{hj}^{max} \end{aligned} \quad (8)$$

Where Q_{hj}^{min} , Q_{hj}^{max} are the minimum and maximum water discharge rate limits of j th hydel plant, and $k = 1, 2, \dots, n_j$, n_j is the number of PDZs for j th hydel plant, $Q_{hj,k}^L$, $Q_{hj,k}^H$ are the lower and upper bounds of k th prohibited water discharge zone of j th hydel plant.

(4) The reservoir volume of all hydel plants in each interval must be within the allowed maximum and minimum storage capacities of reservoirs.

$$V_{hj}^{min} < V_{hj}^t < V_{hj}^{max} \quad (9)$$

Where V_{hj}^{max} and V_{hj}^{min} are the maximum and minimum storage capacities of j th hydel plant.

(5) For cascaded hydel plants water transport delays have to be considered for practical modeling. Water dynamic balance constraint relates the reservoir volumes in current interval with previous storage volume.

$$\begin{aligned} V_{hj}^t &= V_{hj}^{t-1} + I_{hj}^t - Q_{hj}^t - S_{hj}^t \\ &\quad + \sum_{n=1}^{R_{uj}} (Q_{hn}^{t-\tau_{zj}} + S_{hn}^{t-\tau_{zj}}) \end{aligned} \quad (10)$$

Where S_{hj}^t and I_{hj}^t are the spillage and inflow in interval t for j th hydel plant, τ_{zj} is the delay in water transport from plant z to plant j and R_{uj} indicates the number of hydel reservoirs immediately upstream the j th hydel plant.

(6) There are certain final and initial reservoir volume restrictions on each hydel plant.

$$V_j^0 = V_j^{Ini}, V_j^T = V_j^{End}; j = 1, 2, \dots, N_h \quad (11)$$

Where V_j^{Ini} and V_j^{End} are the reservoir volume restriction on j th hydel plant at start and end of the day.

3. BASIC BAT ALGORITHM (BBA)

Bat algorithm is relatively a new meta-heuristic optimization technique proposed by X. S. Yang in 2010 (Yang, 2010). Bat algorithm uses the amazing echolocation property of micro-bats which is a

fascinating phenomenon and it enables the bats to find and differentiate in their prey and obstructions in the background even in complete darkness. The intention of the study was to join the advantages of different meta-heuristic algorithms into a new bat algorithm. Bat algorithm uses some idealizations which are listed below:

- To sense distance the bats use echolocation and in some magical way, they can differentiate between their prey and the barriers in the path.
- Bats make random flights with frequency f_p , loudness A_p , pulse emission rate r_p , velocity v_p and position x_p .
- Loudness A_p of the bats is thought to vary from a large positive value to a small minimum value A_{min} .

Virtual bats are used in simulation and the rules for updating their velocities, positions and frequencies are given below:

$$f_p = f_{min} + (f_{max} - f_{min})\beta \quad (12)$$

Where f_{min} , f_{max} are the minimum and maximum allowed limits of frequencies and β is a random number between 0 and 1 drawn from uniform distribution ($\beta \in [0, 1]$).

$$v_p^{iter} = v_p^{iter-1} + (x_p^{iter} - x^*)f_p \quad (13)$$

Velocity update is done using (13). Here v_p^{iter} , v_p^{iter-1} are the current and previous velocities of p th bat. x_p^{iter} is the current position of p th bat and x^* indicates the current iteration's best bat position.

$$x_p^{iter} = x_p^{iter-1} + v_p^{iter} \quad (14)$$

Position update is performed on all bats using (14). There are some similarities between standard particle swarm optimization (PSO) and bat algorithm in updating velocities and positions of bats (Kennedy, 1995). To a degree, bat algorithm can be seen as a balanced combination of the standard PSO and a local search which can be controlled by varying loudness and pulse emission rate.

The loudness A_p and pulse emission rate R_p of all the bats are also to be updated as the iterations proceed, using the equations given below:

$$A_p^{iter} = \theta A_p^{iter-1} \quad (15)$$

$$R_p^{iter} = R_p^0 [1 - e^{-\omega * iter}] \quad (16)$$

Where θ and ω are the constant updating parameters related to loudness and pulse rates respectively.

4. IMPROVED CHAOTIC BAT ALGORITHM

In this section the proposed improved chaotic bat algorithm (ICBA) for solving the DESHES problem is discussed in detail. Premature convergence problem of basic bat algorithm was taken care of, by embedding chaotic hybridized local search in basic bat algorithm. The loudness and pulse emission rate updating parameters were also changed. These variations along with the constraint handling strategies are also discussed here.

4.1 Improvements Made in BBA

This section presents in detailed discussion of the improvements made for improving the performance in basic bat algorithm.

4.1.1 Loudness And Pulse Emission Rate

All the research studies seem to suggest that the loudness and pulse emission rates are to be initialized between [1,2] and [0,1] respectively but after a keen observations of the produced results these ranges were changed to [1,6] and [1,4] respectively.

4.1.2 Chaotic Hybridized Local Search

This paper suggests a chaotic hybridized local search to be embedded in basic bat algorithm in order to keep population diversity. This scheme amplifies the exploitation capacity of bat algorithm. Chaotic tent map (Shan *et al.*, 2005) is used for hybridized local search mechanism. Tent map is formulated as below:

$$h_i^{n+1} = \begin{cases} h_i^n / a & \text{if } h_i^n < a \\ h_i^n * (1 - h_i^n) & \text{Otherwise} \end{cases} \quad (17)$$

Here, n shows the iteration number, and h_i^{n+1} represents i th chaotic parameter and its value generally lies between 0 and 1. The value of a is taken to be 0.7 for this study.

STEP 1: Take the best vector of the current iteration and its fitness value.

STEP 2: Set the initial value of h_i^n and start the iteration counter n equal to 1.

STEP 3: Calculate the values of chaotic sequences for the next iteration using eq. (17) then convert the generated variable h_i^n to the decision variable using eq. (18)

$$DV_i^n = DV_i^{min} + h_i^n * (DV_i^{max} - DV_i^{min}), \quad (18) \\ i = 1, 2, 3, \dots, D$$

Here, DV_i^{max} and DV_i^{min} are the upper and lower bound for the i th decision variable.

STEP 4: Now a new point is generated in search space using the above calculated decision variable as follows

$$h_{c,i}^n = \omega * h_{best} + h_i^n * (1 - \rho) \quad (19)$$

Here, ρ controls the perturbation rate and generally its value lies in [0,1]. If the resulted vector violates any constraint, the constraint handling approach discussed below is used and then fitness value is calculated.

STEP 5: If the new vector has better fitness value than the best vector, it is taken as the new best vector

STEP 6: If n iterations are not complete, then $n = n + 1$; and the above procedure is repeated again.

4.2 Initialization

Initialization for all the decision variables is done randomly using eq. (21) and (22).

$$Q_{hj}^t = Q_{hj}^{min} + rand(0,1) * (Q_{hj}^{max} - Q_{hj}^{min}) \quad (20)$$

$$P_{si}^t = P_{si}^{min} + rand(0,1) * (P_{si}^{max} - P_{si}^{min}) \quad (21)$$

Here $rand(0,1)$ is the random number between 0 and 1 which is drawn from uniform distribution.

4.3 Constraint Handling

To meet all the constraints in less time, the heuristic rules without any need of penalty factor approach are used in this paper.

4.3.1 Inequality Constraint Handling

If any of the decision variables violate the upper or lower limit they are clipped to upper or lower limits respectively, as shown below:

$$P_{si}^t = \begin{cases} P_{si}^{min} & \text{if } P_{si}^t < P_{si}^{min} \\ P_{si}^t & \text{if } P_{si}^t \geq P_{si}^{min} \end{cases} \quad (22)$$

$$Q_{hj}^t = \begin{cases} Q_{hj}^{min} & \text{if } Q_{hj}^t < Q_{hj}^{min} \\ Q_{hj}^t & \text{if } Q_{hj}^t \geq Q_{hj}^{min} \end{cases} \quad (23)$$

4.3.2 Equality Constraint Handling

Although many studies use the penalty factor approach for this purpose but these approaches degrade the performance of the proposed algorithm as many runs are needed to properly tune the penalty rates (Lu *et al.*, 2010).

4.3.2.1 Dynamic Water Balance Constraint

The initial and final reservoir storage volume conditions are met using eq. (10). A dependent interval d is selected and the water discharge rate for j th hydel plant in this interval is calculated as below.

$$Q_{hj}^d = V_{hj}^0 - V_{hj}^T - \sum_{\substack{t=1 \\ t \neq d}}^T Q_{hj}^t - \sum_{t=1}^T \sum_{m=1}^{R_{uj}} (Q_{hm}^{t-\tau_{mj}}) + \sum_{t=1}^T I_{hj}^t \quad (24)$$

If the computer water discharge rate violates the upper or lower bound then eq. (24) is used to adjust the water release element and then a new random interval is selected and the process is repeated again until the computed water discharge doesn't violate the constraint.

4.3.2.2 Active Power Balance Constraint

A dependent thermal unit is selected randomly and the thermal output of selected unit is computed as below:

$$P_{sd}^t = P_D^t - \sum_{\substack{i=1 \\ i \neq d}}^{N_t} P_{si}^t - \sum_{j=1}^{N_h} P_{hj}^t \quad (25)$$

If the calculated thermal generation violates the mentioned inequality constraint mentioned in (6) and (7) then eq. (23) is used to adjust the thermal output of dependent unit.

4.4 Steps to Solve DESHES Using ICBA

The steps to solve the hydrothermal scheduling problem using the proposed technique are listed below:

STEP 1: Initialization is done randomly using the eq. given in (21) and (22) and the iteration count is set to 1 ($it = 1$). The frequency, Loudness and Pulse emission rates are also initialized randomly

STEP 2: The constraint handling mechanism discussed above are employed to satisfy all the constraints.

STEP 3: The fitness values of all the bats are calculated using (2) or (3) and the best bat is selected as the initial best vector h_{best} .

STEP 4: Then Chaotic hybridized local search is implemented using the best bat as described above.

STEP 5: The velocity is updated using the eq. (13). The initial velocity v_p^0 is calculated as below:

$$v_p^0 = v_{min} + rand * (v_{max} - v_{min}) \quad (26)$$

$$\begin{aligned} v_{max} &= 0.6 * (DV_{max} - DV_{min}) \\ v_{min} &= -v_{max} \end{aligned} \quad (27)$$

STEP 6: The positions of all the bats are updated using eq. (14).

STEP 7: After updating the positions, the new bats may or may not satisfy all the above given constraints. So the constraint handling mechanism of step 2 is repeated again.

STEP 8: Against each bat, a new bat is formed using the equation given below:

$$x_{p,new}^{it} = \begin{cases} x_{best}^{it} + r_3 A_p^{it} & \text{if } r_2 > R_p^{it} \\ x_r^{it} + r_3 A_p^{it} & \text{otherwise} \end{cases} \quad (28)$$

Here, r_2 and r_3 are uniform random numbers lying in ranges of $[0,1]$ and $[-1,1]$ respectively. And r is a randomly chosen integer from $r = [1,2, \dots, N_b]$; $r \neq p$ and N_b is the total number of bats in the population.

STEP 9: The new formed population may violate any of the constraints, so the step 2 is again repeated here.

STEP 10: The fitness values for the new formed population are calculated.

STEP 11: The fitness values of the new and the old population are compared and if the new bat have better fitness than the old one, it replaces the old bat. Hence, fitter of the old and new solutions are selected in this step.

STEP 12: The loudness and pulse emission rates are updated using eqs. (15) and (16).

STEP 13: The best bat for the next iteration is selected.

STEP 14: $it = it + 1$, if $it < iter_max$, then repeat the steps from step 3, else print out the best bat of the final iteration and terminate the program.

5. SIMULATION RESULTS

Microsoft Visual Studio C++ 2008 was used for development on a Core 2 Duo 2.1 GHz Personal Computer. The feasibility of the proposed technique was checked on a standard hydrothermal test system. The system consists of a thermal plant and four cascaded hydel plants. The scheduling is done for the whole day (24 hours), with the time interval of 1 hour. The related data for this hydrothermal test system is taken from (Lakshminarasimman and Subramanian, 2006).

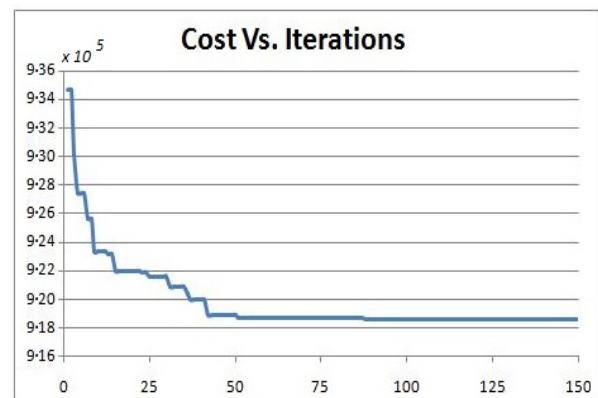
The optimal discharge rates of all the hydel plants and power output of thermal and hydel plants in (Table I).

Table 1: Optimal Discharges, Hydel & Thermal Generations

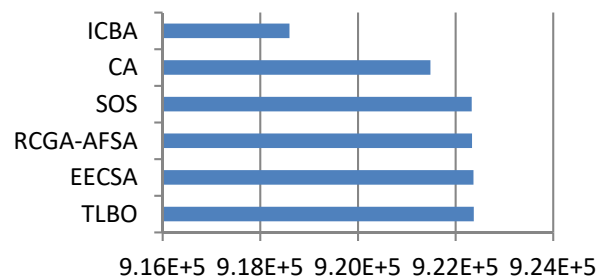
Hr.	Hourly discharge($\times 10^4 m^3$)				Hydel gen. (MW)				Thermal gen. (MW)	Total gen. (MW)
	Plant 1	Plant 2	Plant 3	Plant 4	Ph-1	Ph-2	Ph-3	Ph-4	Pt-1	
1	6.772	6.055	30.000	13.004	67.580	50.522	0.000	198.694	1053.204	1370
2	7.770	6.000	29.987	13.000	74.876	51.265	0.000	186.461	1077.397	1390
3	7.366	6.000	29.989	13.000	72.292	52.905	0.000	172.587	1062.216	1360
4	8.192	6.024	30.000	13.004	77.442	54.635	0.000	155.843	1002.081	1290
5	8.073	6.032	30.000	13.010	76.116	55.679	0.000	177.608	980.596	1290
6	8.887	6.394	30.000	13.000	80.342	58.573	0.000	197.510	1073.575	1410
7	8.515	7.936	29.986	13.002	78.062	67.709	0.000	215.783	1288.446	1650
8	8.693	8.367	29.945	13.007	79.181	69.538	0.000	232.357	1618.923	2000
9	9.015	9.166	10.820	13.000	81.297	73.331	13.632	247.085	1824.655	2240
10	10.102	7.925	29.864	13.013	87.042	66.856	0.000	260.278	1905.825	2320
11	9.459	8.207	10.010	13.015	84.744	68.981	11.597	271.621	1793.057	2230
12	8.463	8.520	11.823	13.120	79.586	70.519	16.102	282.328	1861.465	2310
13	8.021	8.497	12.230	13.483	77.542	70.115	20.639	284.977	1776.728	2230
14	9.530	9.237	10.970	15.093	87.077	74.060	25.686	309.944	1703.233	2200
15	9.118	9.311	11.020	15.510	85.249	74.268	29.654	311.361	1629.469	2130
16	9.128	8.786	11.462	15.641	85.499	70.992	33.403	310.547	1569.559	2070
17	8.069	10.037	10.230	16.800	79.108	75.624	37.172	318.760	1619.336	2130
18	9.287	10.378	10.311	17.962	86.321	74.420	40.943	324.087	1614.229	2140
19	7.911	11.526	10.000	17.575	77.643	76.036	43.281	316.274	1726.765	2240
20	7.221	12.725	10.000	19.966	72.579	76.545	46.426	327.142	1757.309	2280
21	8.244	12.938	10.000	19.867	79.318	74.073	49.220	318.163	1719.226	2240
22	7.829	7.211	10.000	21.906	76.632	49.798	51.777	318.304	1623.490	2120
23	5.000	6.882	10.014	21.928	54.647	48.492	54.212	305.847	1386.802	1850
24	5.004	8.542	10.000	23.590	55.023	57.935	55.967	296.361	1124.714	1590
Total fuel rate									\$918,598.59	

The results obtained from the proposed technique are compared with Teaching Learning Based Algorithm (TLBO) (Roy, 2013), Real Coded Genetic Algorithm with Artificial Fish Swarm Algorithm (RCGA-AFSA) (Fang *et al.*, 2014), Coua bird inspired Algorithm (CA), Effectively Enhanced Cuckoo Search Algorithm (EECSA) (Nguyen *et al.*, 2016), and Symbiotic Organisms Search (SOS) (Das and Bhattacharya, 2015) in (Table 2).

The percentage improvements compared to these techniques are 0.409, 0.406, 0.314, 0.409, 0.405 respectively. The convergence characteristics of the proposed technique for this case is shown in (Fig. 1) below:

**Fig. 1: Convergence Characteristics****Table 2: Test system 1 - Case 1 - Rate Comparison**

Methods	Best Rate (\$)	%age Improvement
TLBO	922,373.39	0.409
EECSA	922,366.84	0.409
RCGA-AFSA	922,339.63	0.406
SOS	922,332.16	0.405
CA	921,487.68	0.314
Proposed ICBA	918,598.59	-

**Fig. 2: Rate Comparison**

The comparison is also shown by bar charts in (Fig. 2). The optimum rate obtained by the proposed bat algorithm for this case is \$918,598.59. The control parameters in each case are set as $N_b = 250$, $f_{min} = 0$, $f_{max} = 10$, $A_{min} = 1$, $A_{max} = 6$, $R_{min} = 1$, $R_{max} = 4$, $\theta = 0.95$, $\omega = 0.85$. The number of iterations are set to be 150.

7. CONCLUSION

In this paper, daily Electrical scheduling of hydrothermal energy system is done using a new meta-heuristic technique named bat algorithm. Certain changes are made in the basic bat algorithm in order to increase the effectiveness of the proposed methodology. The non linear characteristics of the problem are dealt conveniently using the proposed technique. Moreover, heuristic rules are employed instead of penalty factor approach in this paper. The efficiency of improved chaotic bat algorithm is assessed by applying it on the three hydrothermal test systems which are taken from literature. The simulation results prove that the proposed technique can provide better solutions and convergence as compared to other recent meta-heuristic techniques.

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