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Application of BAT Algorithm for Optimal Power Dispatch

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Abstract*—Bat algorithm is a recent addition to the bio inspired algorithms, considered as a new metaheuristic algorithm based on Bat behaviour. This work presents, the optimal solution of economic load dispatch (ELD) is obtained using the proposed bat algorithm. Here the operating cost of a thermal power plant is optimized using Bat algorithm. Numerical results show that the proposed method has good convergence property and better in quality of solution than PSO and IWD reported in recent literature. The main advantage of the proposed technique is easy is implement and capable of finding feasible near global optimal solution with less computational effort. BAT Algorithm is easy to implement and priory in terms of accuracy and efficiency compared to other algorithms. In order to illustrate the effectiveness of the proposed method, it has been tested on 3 and 6-unit system..

Keywords*— Bat algorithm, Economic load dispatch, power balance, Mathematical modeling, Prohibited Zone, article swarm optimization, Valve point loading.

I. INTRODUCTION

This paper introduce the ELD problem in a power system to determine the least generation of all the operating generators which will minimizes the total fuel cost of the thermal power plant while satisfying the equality and inequality constraints in other word satisfying load and operational constraints. The operating cost of a thermal (coal/steam) power plant mainly depends upon the cost of the fuel and ELD problems are very important for operation and control purpose .Now a day's an electrical utility wants to maximize its profit, the optimization of economic dispatch is of economic value to the network operator. The economic dispatch is a relevant procedure in the operation of a power system. So, our objective is to optimize the total cost of the plant.

Well known techniques such as integer programming (Xin- She, 2010), dynamic programming (Wood and Wollenberg,1996), and lagarangian relaxation (Wang and Fung, 1993) [14] have been used to solve the economic dispatch problem. Now a day's with the development of the metaheuristic algorithms it is very efficient to solve ELD problems with less execution time, more accuracy and high reliability. Simulated Annealing (Damousis et al., 2003), Genetic Algorithm (Palanichamy and Srikrishna, 1991), Particle Swarm optimization [2-6] (Sudhakaranet al., 2004), and Tabu Search Algorithm (Immanuel et al., 2003) [16] are presented to solve the ELD problem. Many multi objective heuristic techniques like Nondominated Sorting Genetic Algorithm-II (Sudhakaran and Slochanal, 2005) (NSGA-II), Evolutionary Programming algorithm [17-19] (Rughooputh and King, 2003) (EP), Strength Pareto Evolutionary Algorithm (Tsay and Lin, 2001) (SPEA) and Multi-Objective Particle Swam Optimization algorithm (Abido, 2003) (MOPSO) may prove to be efficient in solving ELD problem [1][11][12].

In this paper a bio inspired optimization, i.e., BAT algorithm is proposed to solve combined economic dispatch problems is presented and the effectiveness of proposed algorithm is tested using three and six generating unit test systems.

The rest of the paper is organized as follows. Section 2, formally defines the ELD problem and reviews the previous works to solve it. A brief description of the PSO algorithm and IWD algorithm for solving ELD problem is given in section 3&4. Brief discussion about bat algorithm is presented in section 5. Simulation results are presented in Section 6. Finally section 7 concludes the paper.

II. ECONOMIC LOAD DISPATCH

The major component of generator operating cost is the fuel input/hour, while maintenance contributes only to a small extent. The fuel cost is meaningful in case of thermal and nuclear stations, but for hydro stations where the energy storage is 'apparently free'; the operating cost as such is not meaningful. Here we will concentrate on fuel fired stations. The input – Output curve of a unit can be expressed in a million Kcal per hour or directly in terms of Rs/hr vs. Output in MW. The cost curve can be determined experimentally. The input-output curve has discontinuities steam valve openings. By fitting a suitable degree polynomial, an analytical expression for operating cost can be written as F (Pgi) Rs/hr at output Pgi Where the suffix 'i' stand for the unit number. It generally suffices to fit a second degree polynomial.

A. Objective Function:

The objective of ELD problem is the minimization of total generation cost considering equality and inequality constraints.

The objective is:

$$\min\ F = \sum_{i=1}^{Ng} F_i(P_{gi}) = \sum_{i=1}^{Ng} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad \text{Rs/MWh} \tag{1}$$

where F is the total generation cost (Rs/h), F_i is the input output function of generator i, N_g is the total number of online generators, P_g is the active power output of generator 'i' (MW) and, a_i, b_i and c_i are the fuel-cost coefficients of generator 'i'.

This optimization problem has an equality constraint known as the power balance constraint and basic inequality constraints representing the machines generation limits. To take care of valve point effects, a sinusoidal function is added to the fuel cost function and is represented as:

$$C_i(P_i) = a_i P_{gi}^2 + b_i P_{gi} + c_i + \left|e_i \sin\left(f_i\left(P_i^{\min} - P_i\right)\right)\right| \quad (2)$$

B. Subject to

1) Power balance constraint:

The total power generated by the units must be equal to the sum of total load demand and total real power loss in the transmission lines.

Hence the Constraint is: $\sum_{i}^{Ni} Pgi = P_D + P_L$ (3)

where P_D is the total load on the system and P_L is the transmission loss (MW). In this paper, in the case where the transmission losses are considered, these are calculated using B-coefficients.

where $P_L = \sum_{m=1}^{Ng} \sum_{n=1}^{Ng} P_{Gm} B_{mn} P_{Gn}$ (4)

where $P_{Gm}\, P_{gn}$ = real power generation at m, n^{th} plants

B_{mn} = Loss coefficients which are constraints under certain assumed operating conditions.

2) Generation capacity constraints:

The real power output of generating units must be restricted within their respective lower and upper bounds as follows:

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \quad (5)$$

For i=1... N_G

where $P_{gi}^{\min}$ and $P_{gi}^{\max}$ are the minimum and maximum power outputs of the i^{th} unit.

3) Prohibited operating zones constraints:

The input-output performance curve for a typical thermal unit with many valve points. These valve points enerate many prohibited zones. In practical operation, adjusting the generation output of a unit must avoid unit operation in the prohibited zones. The feasible operating zones of unit can be described as follows:

$$P_i \in P_{gi\min} \le P_i \le P_{i,1}$$

$$P_{i,k-1}^{u} \le P_i \le P_{i,k}^{l} \quad \text{where } K=1, 2, 3....X_i$$

$$P_{i,X_i}^{u} \le P_i \le P_{gi\max} \quad (6)$$

III. PARTICLE SWARM OPTIMIZATION

PSO is similar to other evolutionary algorithms where the system is initialized with a population of random solutions. Each potential solution, called a particle, flies in N-dimensional problem space with a velocity, which is dynamically adjusted according to the flying experiences of its own and the best particle in the swarm.

$$v_{ij} = w * v_{ij} + c1 * rand()\left(p_{ij}^{best} - p_{ij}\right) + c2 * rand()\left(g_{gi}^{best} - p_{ij}\right) \quad (7)$$

$$p_{ij} = p_{ij} + v_{ij} \quad (8)$$

The location of the i^{th} particle is represented as $P_i = [p_{i1}, p_{i2}, , , , p_{iN}]T$

The best previous position of the i^{th} particle is recorded as $Pbesti$. The index of the P_{best} among all the particles is represented by the symbol 'g'. The location P_{best} is called g_{best}. The velocity of ith particle is represented as = $[v_{i1}, v_{i2}, , , , v_{iN}]T$. Next velocity and position of each particle are calculated using current velocity and the distances from P_{best}, g_{best}.

*A. **THE PSEUDO CODE OF THE PSO IS AS FOLLOWS**:*

Step1. *For each particle*

Step 2. *Initialize particle*

END

***Step** 3. Do*

***Step** 4.For each particle*

Step 5.*Calculate fitness value*

Step 6.*If the fitness value is better than fitness value* p^{best} *in history*

Step 7.*Set current value as the new* G^{best}
End

Step 8.*Choose the particle with the best fitness value of all the particles as the* G^{best} *For each particle*
Step 9.*Calculate particle velocity according equation ------ (a)*
Step 10.*Update particle position according equation --------- (b)*
Step 11.*End*
Step 12.*While maximum iterations or minimum error criteria is not attained*

IV. INTELLIGENT WATER DROP ALGORITHM

Intelligent Water Drops or IWD [20][21][22] is a new swarm intelligence technique, first time proposed by Hamed Shah- Hosseini (2009) based on observation of natural water drops moving in rivers, lakes and seas.
This Intelligent Water Drop has two important properties:
1. The amount of the soil it carries now, Soil (IWD).
2. The velocity that it is moving now, Velocity (IWD).

A. The Pseudo Code of the IWD is as Follows:

BEGIN
Step 1. Static and dynamic Parameters initialization.
Step 2. Put all IWDs on the first node.
Step 3. Update the velocity of the IWD.
Step 4. Select an edge to reach to the next node.
Step 5. Compute the amount of soil (Δsoil) which is gathered by the IWD.
Step 6. Update the edge soil and the IWD soil.
Step 7. IF have all IWDs completed their solutions
THEN GOTO step 8 ELSE GOTO Step 4.
Step 8. Find the elitist IWDs.
Step 9. Perform the local search on elitist IWDs.
Step 10. Update the global best solution.
Step 11. IF all Elitist IWDs produce the same results THEN
GOTO Step 2.
ELSE Return the global best.
END

V. BAT ALGORITHM

Now nature inspired algorithms are the most powerful algorithms for optimization problems. Based on the echolocation behaviour of Bats a new nature-inspired metaheuristic algorithm, called BAT algorithm [7][8][9][10] has been proposed by Yang, 2010.

Bats are the only mammals having wings and high echolocation capability. In practical case they radiate a sound signal called sonar/echolocation to detect the objects surrounding them and find their way in the night. Actually the emitted sound signal is very loud so that they can be able to listen the echo that bounces back from the surrounding objects. In most of the cases they use short frequency modulated signals. Such echolocation behavior of micro bats can be formulated in such a way that it can be associated with the objective function to be optimized, and this makes it possible to formulate new optimization algorithms.

After idealize the some of echolocation characteristics we can develop bat algorithm. For simplicity, we are now considering following rules:

- *All bats use echolocation to sense distance, and they also "know" the difference between food/prey and background barriers in some way.*
- *Bats fly randomly with velocity* v_i *at position* x_i *with a fixed frequency* $f_{\min}$ *, varying wavelength* λ *and loudness* A_o *to search for prey. They can automatically adjust the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission r in the range of [0, 1], depending on the proximity of their target.*
- *Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive)* A_o *to a minimum constant value* $A_{\min}$

In general the frequency f in a range $\left[f_{\min}, f_{\max}\right]$ corresponds to a range of wavelengths $\left[_{\min,\max}\right]$. Furthermore, we do not necessarily have to use the wavelengths themselves; instead, we can also vary the frequency while fixing the wavelength λ. This is because λ and f are related due to the fact λf is constant. We will use this later approach in our implementation. For simplicity, we can assume $f \in [0, f_{\max}]$. We know that higher frequencies have short wavelengths and travel a shorter distance. For bats, the typical ranges are a few meters. The rate of pulse can simply be in the range of [0,1] where 0 means no pulses at all, and 1 means the maximum rate of pulse emission.

Based on these approximations and idealization, the basic steps of the Bat Algorithm (BA) can be summarized. In algorithm we have define the rules for the updating the positions z_i and velocities v_i in the search space. The new solutions i.e. position and velocity is given by:

$$f_i = f_{\min} + \left(f_{\max} - f_{\min}\right)\alpha \tag{9}$$

$$v_i^0 = v_i + (z_i - z_0) f_i \tag{10}$$

where α is the random number between [0, 1] and z_0 is the current global best location (or solution). Then the new solution or position for the bat can be generated by the equation given below:

$$z_i^t = z_i + v_i \tag{11}$$

For the local search part, once a solution is selected among the current best solutions, a new solution for each bat is generated locally using random walk:

$$z^{new} = z^{old} + A^t \mu \tag{12}$$

where μ is the random number between [0, 1] and A^t is the average loudness of all the Bats. Based on the above approximations and idealization, the pseudo-code of the Bat Algorithm (BA) can be summarized below.

A. THE PSEUDO CODE OF THE BAT ALGORITHM IS AS FOLLOWS:

The main steps of proposed BA are as follows:

Step1: *Initialize the bat population or their position z_i and their velocities v_i. Define pulse frequency f_i at z_i. Initialize pulse rates r and the loudness A.*
Step2: *Generate new solutions by adjusting frequency, and updating velocities and locations/solutions [Equations (7) to (10)].*
Step3: *if (rand > r)*
Select a solution among the best solutions. Generate a local solution around the selected best solution.
Step4: *Else generate a new solution by flying randomly.*
Step5: *If (rand < A && $f(z_i) < f(z_0)$)*
Where f (.) = Objective function
Accept the new solutions, increase r and reduce A.
Step6: *Rank the bats and find the current best z_0.*
Step7: *while (iteration < Max number of iterations) Post process results and visualization. The algorithm stops with the total-best solution.*

VI. SIMULATION RESULT AND DISCUSSIONS

In order to assess effectiveness the proposed BA-ELD algorithm is programmed in MATLAB environment and executed on a 3.2 GHz Pentium-4 processor with 2 GB RAM.
The parameters of algorithm used for simulation are:
n= 20; *A*= 0.9; *r*= 0.1; $f_{\min} = 0$; $f_{\max} = 2$.

Test Case 1: The system consists of three thermal units. The parameters of all thermal units are:

TABLE I
CAPACITY AND COST COEFFICIENT DATA OF THREE UNIT THERMAL SYSTEM

Unit	$P_{g\,\max} MW$	$P_{g\,\min} MW$	$a_i Rs/Mwh^2$	$b_i Rs/Mwh$	$c_i Rs$
1	600	100	0.0001562	7.92	561
2	200	50	0.00482	7.97	78
3	400	100	0.00194	7.85	310

The total load demand is P_D = 850 MW. Here we are neglecting the losses of the system and maximum number of iteration is 100.The convergence characteristic and result has been given in fig. 1 and table 2.

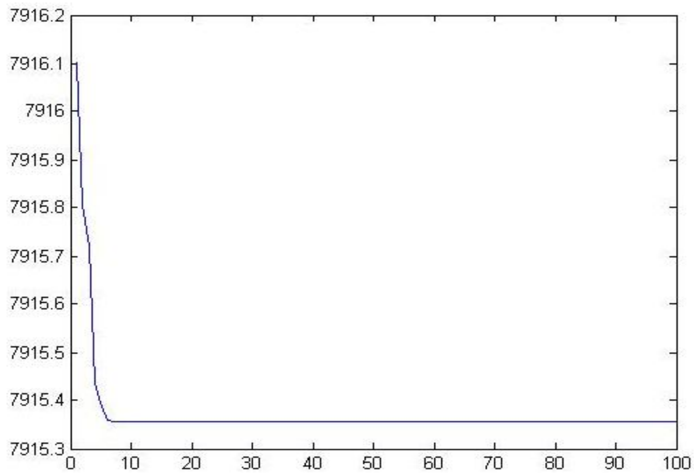

Fig.1. Convergence characteristics of BAT algorithm

TABLE II - BEST SOLUTION FOR 3-UNIT SYSTEM

Unit Output(MW)	BAT	IWD	PSO
P_1	393.1681	401.6605	401.7584
P_2	122.2709	104.7790	105.5897
P_3	334.561	342.6027	342.6025
Elapsed time	0.266284 sec	6.89907sec	6.904898 sec
Cost	7915.3561	8194.6541	8195.6628

***Test Case 2**: The system consists of six thermal units. The parameters of all thermal units are:*

TABLE III- CAPACITY AND COST COEFFICIENT DATA OF SIX UNIT THERMAL SYSTEM

Unit	$P_{g\max} MW$	$P_{g\min} MW$	$a_i Rs/Mwh^2$	$b_i Rs/Mwh$	$c_i Rs$
1	500	100	0.0070	7	240
2	150	50	0.0090	11	200
3	200	50	0.0080	10.5	220
4	120	50	0.0075	12	120
5	300	80	0.0090	8.5	220
6	200	50	0.0095	10	200

TABLE IV- PROHIBITED ZONE LIMITS OF SIX UNIT SYSTEM

Unit	ZONE 1	ZONE 2
1	210-240	350-380
2	80-90	110-120
3	90-1110	140-150
4	75-85	100-105
5	150-170	210-240
6	90-110	140-160

Here B-coefficients are taken as

$$B_{ij} = \begin{bmatrix} 0.0224 & 0.103 & 0.0016 & -0.0053 & 0.0009 & -0.0013 \\ 0.0103 & 0.0158 & 0.0010 & -0.074 & 0.0007 & 0.0024 \\ 0.0016 & 0.0010 & 0.0474 & -0.0687 & -0.0060 & -0.0350 \\ -0.0053 & -0.0074 & -0.0687 & -0.3464 & 0.0105 & 0.0534 \\ 0.0009 & 0.007 & -0.0060 & 0.0105 & 0.0119 & 0.0007 \\ -0.0013 & 0.0024 & -0.0350 & 0.0534 & 0.0007 & 0.2353 \end{bmatrix}$$

$$B_{ij} = \begin{bmatrix} -0.0005 & 0.0016 & -0.0029 & 0.0060 & 0.0014 & 0.0015 \end{bmatrix}$$

$$B_{ij} = 0.0011$$

This system supplies total load of P_D =1263 MW. Here we are considering the losses and prohibited zone constraints. In this case maximum number of iteration has been taken as 100. The convergence characteristic and result has been shown in fig. 2 and table 5. The validity of the proposed method is illustrated on a sample system comprising six thermal generating units. MATLAB code is developed to perform entire calculations and to generate the Table. A program has been developed in MATLAB platform based upon the proposed algorithm.

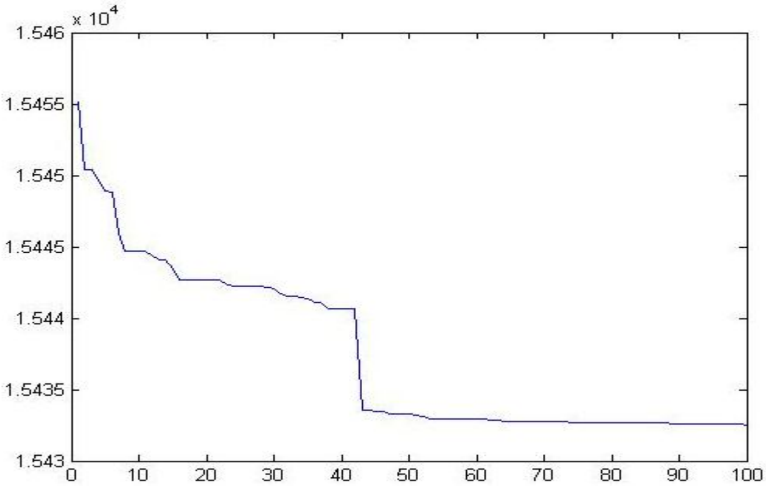

Fig.2. Convergence characteristics of BAT algorithm

TABLE V- BEST SOLUTION FOR 6-UNIT SYSTEM

Unit Output (MW)	BAT	SA-PSO	SOH-PSO	NPSO-LRS	IWD
P1	409.8868	446.71	438.21	446.96	447.4970
P2	134.0469	173.01	172.58	173.3944	173.3221
P3	243.5308	265.00	257.42	262.3436	263.4745
P4	86.29848	139.00	141.09	139.512	139.0954
P5	259.5851	165.23	179.37	164.7089	165.4761
P6	142.2824	86.78	86.88	89.0162	87.1280
Total Output	1189.332	1275.7	1275.55	1275.935	1276.01
P loss(MW)	12.238	12.733	12.32	12.9361	12.9584
Total Gen.Cost($/h)	15432	15447	15446.02	15449.94	15450

Based on the results obtained from table V, Bat algorithm is very efficient and takes very less time to converge around 2.537 sec where as PSO takes around 2.54 sec to converge. Bat algorithm has been compared with the various PSO algorithms and it has been found that, it gives minimum cost of 15,432 Rs/hrs with minimum loss of 12.23832 MW. The convergence characteristic of the BAT method for 6-unit system is shown in Fig. 2.

VII. CONCLUSION

This paper proposed a new nature inspired bat algorithm for solving the economic load dispatch problem and it has been compared with different PSO and IWD techniques with valve point effect and prohibited zone constraint. Although PSO and IWD techniques give nearly same result as bat algorithm but from the convergence graph it has been clear that the accuracy and computational time of bat algorithm optimization method is superior to that of other two methods. Many methods consisting of conventional approach and artificial intelligence approaches are used for optimization of the critical problem "Economical Load Dispatch" .This is an extension work in the same axis. Although the proposed algorithm had been successfully applied to ELD with valve-point loading effect and included a few constraints, the practical ELD problems should consider multiple fuels as well as spinning reserve, power flow constraint and ramp up & down rate constraints and also for hydrothermal scheduling problems. This remains a challenge for future work.

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