A Meta-Heuristic Approach of Bat Algorithm to Evaluate the Combined EED Problem

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Abstract: **Electrical Power Systems are designed and operated to meet continuous variation of power demand. In power system, minimization of operation cost is very important. This paper presents an application of BAT algorithm for multi-objective optimization problem in power system. Considering the environmental impacts that grow from the emissions produced by fossil-fuelled power plant, the economic dispatch that minimizes only the total fuel cost can no longer be considered as single objective. Application of BAT algorithm in this paper is based on mathematical modelling to solve economic, emission and combined economic and emissions dispatch problems by a single equivalent objective function. BAT algorithm has been applied to two realistic systems at different load condition. Results obtained with proposed method are compared with other techniques presented in literature. BAT algorithm is easy to implement and much superior to other algorithms in terms of accuracy and efficiency.**

Index Terms: Economic dispatch, BAT algorithm, Artificial Bee Colony algorithm, Combined economic and emission dispatch, Mathematical modelling.

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1 INTRODUCTION

Economic load dispatch can be defined as process of allocating generation levels to generating units so that the system load is supplied entirely and most economically. This paper introduces the economic dispatch problem in a power system to determine the optimal combination of power output for all generating units which will minimize the total fuel cost while satisfying load and operational constraints. The economic dispatch problem is very complex to solve because of its colossal dimension, a non-linear objective function and a large number of constraints.

Well known long-established techniques such as integer programming [2], dynamic programming [3] and lagarangian relaxation [4] have been used to solve the economic dispatch problem. Recently other optimization methods such as Simulated Annealing [5], Genetic Algorithm [6], Particle Swarm optimization [7] and Tabu Search Algorithm [8] are presented to solve the economic dispatch problem. This single objective economic dispatch can no longer be considered along due to the environmental concerns that arise from the emission produced by fossil-fuelled electric power plants. Economic and environmental dispatch is a multi-objective problem.

Recently, various modern heuristics multi-objective evolutionary algorithms such as Non-dominated Sorting Genetic Algorithm- II (NSGA-II) [9], Evolutionary Programming algorithm (EP) [10], Strength Pareto Evolutionary Algorithm (SPEA) [11] and Multi-Objective Particle Swam Optimization algorithm (MOPSO) [12] may prove to be efficient in solving EED problem by tackling both two objectives of EED problem simultaneously as competing objectives. But all these methods seem to be lack of ability to find the Pareto-optimal front due to their drawbacks: NSGA-II and SPEA may obtain only near Pareto-optimal front with long simulation time when applied to solve EED problem because of the premature convergence of Genetic Algorithm (GA). EP suffers from the oscillation of the solution and computational time may be too long when applying EP to solve EED problem. The premature convergence of PSO may lead optimization progresses of MOPSO methods to the local Pareto-optimum front, which would degrade their performance in solving EED problem. Including emission constrains to the economic dispatch and unit commitment problems have been analysed under cost-minimization environment.

In this paper a multi-objective optimization problem i.e., BAT algorithm is proposed to solve combined economic and emissions dispatch problems and the effectiveness of proposed algorithm is demonstrated using three and six generating unit test systems.

2 COMBINED ENVIRONMENTAL ECONOMIC DISPATCH (CEED)

The traditional economic dispatch problem has been defined as minimizing of an objective function i.e., the generation cost function subject to equality constraints i.e., total power generated should be equal to total system load plus losses for all solutions and inequality constraints i.e. generations should lie between their respective maximum and minimum specified values.

The objective function equation (1) is minimised subjected to equality constraint equation (2) and inequality constraints equation (3).

$$\varphi(x,P)\varphi_t(P_i) = \sum_{i=1}^{n} \varphi_i(P_i) \text{ ....} \quad (1)$$

$$g(x,P)\ \sum_{i=1}^{n} P_i - P_L - P_D = 0 \text{ ....} \quad (2)$$

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$$H(x,P) \leq 0 \quad P_{imin} \leq P_i \leq P_{imax} \text{ .... } (3)$$

Where x is a state variable, Pi is the control variable, i.e., real power setting of i_{th} generator and n is the number of units or generators.

There are several ways to include emission into the problem of economic dispatch. There are various algorithms for solving environmental dispatch problem with different constraints [19]. One approach is to include the reduction of emission as an objective. In this work, only NO_x reduction is considered because it is a significant issue at the global level. A price penalty factor (h) is used in the objective function to combine the fuel cost, Rs/hr and emission functions, kg/hr of quadric form.

The combined economic and emission dispatch problem can be formulated as to minimize

$$\varphi_i = \sum_{i=1}^{n} E_i(P_i)\ Rs/hr \quad \text{................} \quad (4)$$

$$\varphi_i = \sum_{i=1}^{n}(a_i\ P_i^{\ 2} + b_i P_i + c_i) + h\sum_{i=1}^{n}(d_i\ P_i^{\ 2} + e_i P_i + f_i)Rs/hr \quad \text{..............} (5)$$

Subject to equality and inequality constraint defined by equations (2), (3). Once price penalty factor (h) is known, equation (5) can be rewritten as

$$\varphi_i = \sum_{i=1}^{n}\{(a_i + h\ d_i)P_i^{\ 2} + (b_i + he_i)P_i + (c_i + f_i)\}\ Rs/hr \quad \text{...........} (6)$$

This has the resemblance of the familiar fuel cost equation, once h is determined. A practical way of determining is discussed by Palanichamy and Srikrishna [6]. Consider that the system is operating with a load of PD MW, it is necessary to evaluate the maximum cost of each generator at its maximum output, i.e.

(i) Evaluate the maximum cost of each generator at its maximum output, i.e.,

$$F_i(P_{imax}) = (a_i\ P_{imax}^{\ \ 2} + b_{imax}P_i + c_{imax})\ Rs/hr \quad \text{..} (7)$$

(ii) Evaluate the maximum NO_x emission of each generator at its maximum output, ie,

$$E_i(P_{imax}) = (d_i\ P_{imax}^{\ \ 2} + e_{imax}P_i + f_{imax})\ \ kg/hr \quad (8)$$

(iii) Divide the maximum cost of each generator by its maximum NO_x emission, i.e.,

$$\frac{F_i(P_{imax})}{E_i(P_{imax})} = \frac{(a_i\ P_{imax}^{\ \ 2} + b_{imax}P_i + c_{imax})}{(d_i\ P_{imax}^{\ \ 2} + e_{imax}P_i + f_{imax})}\ Rs/kg \quad \text{...........} (9)$$

Recalling that

$$\frac{F_i(P_{imax})}{E_i(P_{imax})} = h_i \text{ Rs/kg} \quad \text{...................} \quad (10)$$

(iv) Arrange h_i (i = 1, 2,......,n) in ascending order.

(v) Add the maximum capacity of each unit, one at a time, starting from the smallest h_i unit until total demand is met as shown below.

$$\sum_{i=1}^{n} P_{imax} \geq P_D \quad \text{..................} \quad (11)$$

At this stage, h_i associated with the last unit in the process is the price penalty factor h Rs/Kg for the given load.

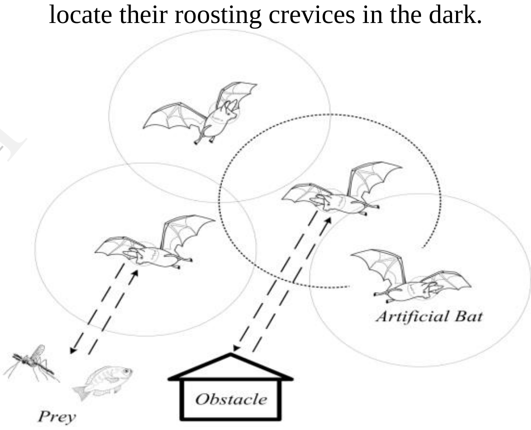
Arrange h_i in ascending order. Let 'h' be a vector having 'h' values in ascending order.

$$h = [h_1, h_2, h_3, \dots, h_n] \quad \text{................} (12)$$

For a load of PD starting from the lowest hi value unit, maximum capacity of unit is added one by one and when this total equals or exceeds the load, hi associated with the last unit in the process is the price penalty factor for the given PD. Then equation (6) can be solved to obtain environmental economic dispatch using lambda iteration method.

3 BAT ALGORITHM

Bats are fascinating animals. They are the only mammals with wings and they also have advanced capability of echolocation. Most of bats uses echolocation to a certain degree, among all the species, microbats are famous example as microbats use echolocation extensively, while mega bats do not. Microbats use a type of sonar, called echolocation, to detect prey, avoid obstacles, and locate their roosting crevices in the dark.



If we idealize some of the echolocation characteristics of microbats, we can develop various bat-inspired algorithms or bat algorithms. For simplicity, we now use the following approximate or idealized rules:

1. All bats use echolocation to sense distance, and they also know the difference between food/prey and background barriers.
2. Bats fly randomly with velocity v_i at position x_i with a fixed frequency f_{min} (or wavelength λ), varying wavelength λ (or frequency f) 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 $r\epsilon[0,1]$, depending on the proximity of their targets.
3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_o to a minimum value A_{min}.

Another obvious simplification is that no ray tracing is used in estimating the time delay and three dimensional topography. In addition to these simplified assumptions, we also use the following approximations, for simplicity. In general the frequency f in a range

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$[f_{min}, f_{max}]$ corresponds to a range of wavelengths $[\lambda_{min}, \lambda_{max}]$. For example, a frequency range of [20 kHz, 500 kHz] corresponds to a range of wavelengths from 0.7mm to 17mm.

In simulation, we use virtual bats naturally. We have to define the rules how their positions x_i and velocities v_i in a d-dimensional search space are updated. The new solutions x_i^t and velocities v_i^t at time step t are given by

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad \text{............} \quad (13)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_*)f_i \quad \text{.................} \quad (14)$$

where β϶ [0, 1] is a random vector drawn from a uniform distribution. Here x_* is the current global best location (solution) which is located after comparing all the solutions among all the n bats. As the product $\lambda_i f_i$ is the velocity increment, we can use either f_i (or λ_i) to adjust the velocity change while fixing the other factor λ_i (or f_i), depending on the type of the problem of interest. 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

$$x_{new} = x_{old} + \epsilon A^t \quad \text{.......................} \quad (15)$$

Where $\epsilon \epsilon [-1, 1]$ is a random number, while A^t $= \langle A_i^t \rangle$ is the average loudness of all the bats at this time step.

Based on the above approximations and idealization, the pseudo-code of the Bat Algorithm (BA) can be summarized below.

3.1 PSEUDO-CODE OF THE BAT ALGORITHM

Objective function f(x), x = $(x1, \ldots, xd)^T$
Initialize the bat population x_i (i = 1, 2, .., n) *and* v_i
Define pulse frequency f_i *at* x_i
Initialize pulse rates r_i *and the loudness* A_i
while (t <*Max number of iterations)*
Generate new solutions by adjusting frequency,
and updating velocities and locations/solutions [equations (13) to (15)]
if *(rand >* r_i*)*
Select a solution among the best solutions
Generate a local solution around the selected best solution
end if
Generate a new solution by flying randomly
if *(rand <* A_i & f(x_i) < f(X_*))
Accept the new solutions
Increase r_i *and reduce* A_i
end if
Rank the bats and find the current best X_*
end while
Post process results and visualization

4 SIMULATION RESULTS AND DISCUSSIONS

The applicability and efficiency of BAT algorithm has been applied to two test cases. The programs are developed using MATLAB 7.14.

The Parameters for BAT algorithm considered here 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 adapted from [1].

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Table: 1 Comparison of test results for Three Generating units

Load demand	h^*, Rs/kg	Performance	Conventional Method [7]	SGA [7]	RGA [7]	ABC	BAT
400MW	44.788	Fuel cost, Rs/hr	20898.83	20831.54	20801.81	20838.729	208378.277
		Emission, kg/hr	201.5	201.35	201.21	200.198	200.211
		Power loss, MW	7.41	7.69	7.39	7.403120	7.401407
		Total cost, Rs/hr	29922	29820	29812	29805.615	29804.905
500MW	44.788	Fuel cost, Rs/hr	25486.64	25474.56	25491.64	25494.904	254939.128
		Emission, kg/hr	312.0	311.89	311.33	311.125	311.133
		Power loss, MW	11.88	11.80	11.70	11.679210	11.67600
		Total cost, Rs/hr	39458	39441	39433	39429.646	39429.040
700MW	47.82	Fuel cost, Rs/hr	35485.05	35478.44	35471.4	35462.826	35462.501
		Emission, kg/hr	652.55	652.04	651.60	354.628	651.505
		Power loss, MW	23.37	23.29	23.28	23.334221	23.3300
		Total cost, Rs/hr	66690	66659	66631	66617.903	66617.505

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Table: 1 shows the summarized results of CEED problem for load demand of 400MW, 500MW and 700MW are obtained by the proposed BAT algorithm with stopping criteria based on maximum-generation=100.

Form Table: 1, it is clear that BAT algorithm gives optimum result in terms of minimum fuel cost, emission level and the total operating cost compared to other algorithms.

Table: 2 gives the best optimum power output of generators for CEED problem using BAT & ABC algorithm for load demand 400MW, 500MW and 700MW.

Table: 2 Optimum Power dispatch Results by ABC, Proposed BAT method for three units system

Load demand, MW	Algorithm	P1	P2	P3	Iterations
400MW	ABC	102.5546	152.7996	152.0485	29
	BAT	102.5589	153.7197	151.1228	8
500MW	ABC	128.8494	191.4610	191.3687	56
	BAT	128.8501	192.5603	190.2657	18
700MW	ABC	182.6259	270.3542	270.3541	44
	BAT	182.6477	271.2397	269.4426	7

The convergence tendency of proposed BAT algorithm based strategy for power demand of 400MW, 500MW and 700 MW is plotted in figure: 1. It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property.

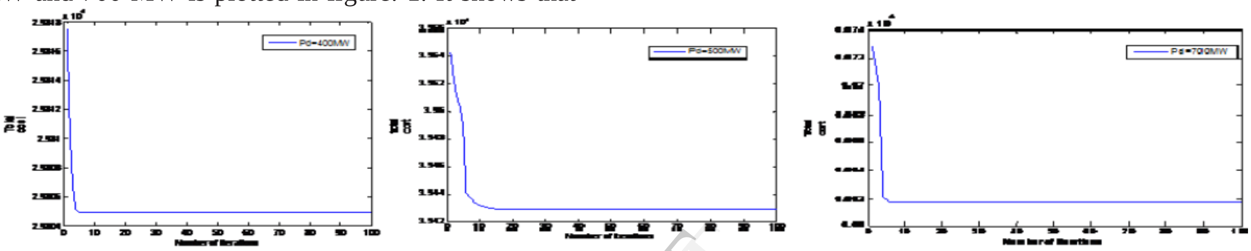

Figure: 1 convergence of three generating units system for load demand values 400MW, 500MW & 700MW.

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Test case II: The system consists of six thermal units. The parameters of all thermal units are adapted from [1]. The summarized result of CEED problem for load demand of 500MW and 900MW are obtained by the proposed BAT algorithm with stopping criteria based on maximum-generation=100 is presented in Table: 3.

Table: 3 comparison of test Results for six generating unit system

Load demand	h^*, Rs/kg	Performance	Conventional Method [9]	RGA [9]	Hybrid GA [9]	Hybrid GTA [9]	ABC	BAT
500MW	43.898	Fuel cost, Rs/hr	27638.300	27692.1	27695	27613.4	27613.247	27612.749
		Emission, kg/hr	262.454	263.472	263.37	263.00	263.013	263.006
		Power loss, MW	8.830	10.172	10.135	8.93	8.934145	8.933858
		Total cost, Rs/hr	39159.500	39258.1	39257.5	39158.9	39158.9	39158.199
900MW	47.822	Fuel cost, Rs/hr	48892.900	48567.7	48567.5	48360.9	48350.683	48350.163
		Emission, kg/hr	701.428	694.169	694.172	693.570	693.788	693.772
		Power loss, MW	35.230	29.725	29.718	28.004	28.009673	28.008975
		Total cost, Rs/hr	82436.580	81764.5	81764.4	81529.1	81529.00	81527.739

Form Table: 3, it is clear that BAT algorithm gives the optimum result in terms of minimum fuel cost, emission level and the total operating cost compared to other algorithms.

Table: 4 gives the best optimum power output of generators for CEED problem using BAT & ABC algorithms for load demand 500MW and 900MW.

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Table: 4 Optimum Power dispatch results by ABC Approach for six unit system

Load demand, MW	Algorithm	P1	P2	P3	P4	P5	P6	Iterations
500	ABC	33.2733	26.8554	89.9135	90.4852	135.6435	132.7631	120
	BAT	33.2703	26.85061	89.91347	90.48638	135.6411	132.762	18
900	ABC	92.3297	98.3912	150.1948	148.5588	220.4043	218.1307	132
	BAT	92.3288	98.3910	150.1132	148.5586	220.4007	218.1267	25

The convergence tendency of proposed BAT algorithm based strategy for power demand of 500MW and 900 MW is plotted in figure:2. It shows that the technique converges in relatively fewer cycles there by possessing good convergence property.

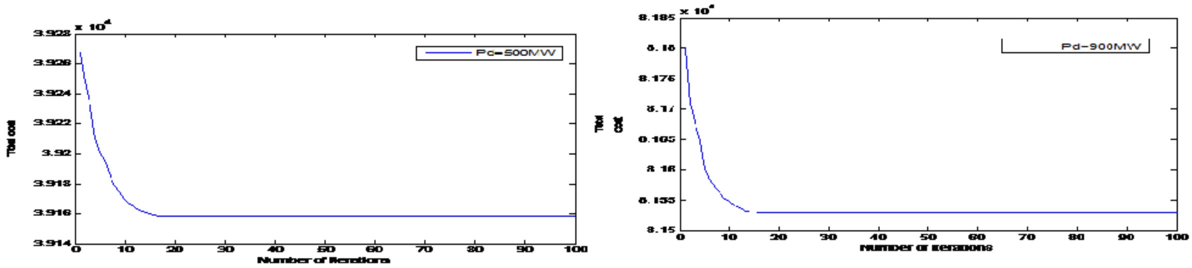

Figure: 2 convergence of six generating unit system for load demand values of 500MW and 900MW.

5 CONCLUSION

In this paper, a new optimization of BAT algorithm has been proposed. In order to prove the effectiveness of algorithm it is applied to CEED problem with three and six generating unit. The results obtained by proposed method were compared to those obtained conventional method, RGA and SGA and Hybrid GA and ABC. The comparison shows that BAT algorithm performs better than above mentioned methods. The BAT algorithm has superior features, including quality of solution, stable convergence characteristics and good computational efficiency. Bat algorithm gives optimum dispatch evaluation with less number of iterations. Therefore from the results it is concluded that BAT optimization is a promising technique for solving complicated problems occurring in power systems.

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*h values are considered based on literature.

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