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Environmental/Economic Power Dispatch Considering Wind Power using Bat Algorithm

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ABSTRACT

This paper proposes a new meta-heuristic search algorithm, called Bat Algorithm (BA). Bat algorithm is an optimization technique motivated by the echolocation behavior of natural bats in finding their foods. The new algorithm is implemented to solve Environmental/Economic power Dispatch (EED) problem in power systems considering the transmission loss. The EED problem can be solved by summing up the minimization of generation cost and emission by considering weighting factor. The effectiveness of the proposed algorithm has been tested on the standard IEEE 30-bus power system with six-generating units with and without wind power. The results obtained were compared with other methods reported in recent literature.

Keywords *- Economic dispatch, emission dispatch, environmental economic dispatch, bat algorithm, wind power.*

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I. INTRODUCTION

The economic dispatch (ED) is one of the important problems in power system operation and control for allocating generation among the committed units. The objective of ED problem of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all unit and system equality and inequality constraints. This makes the ED problem a large-scale highly nonlinear constrained optimization problem. Therefore, recently most of the researchers made studies for finding the most suitable power values produced by the generators depending on fuel costs [1, 2]. In these studies, they produced successful results by using various optimization algorithms. Despite the fact that the traditional ED can optimize generator fuel costs, it still cannot produce a solution for environmental pollution due to the excessive emission of fossil fuels [3-5].

Currently, a large part of energy production is done with thermal sources. Thermal power plant is one of the most important sources of carbon dioxide (CO_2), sulfur dioxide (SO_2) and nitrogen oxides (NO_x) which create atmospheric pollution [6]. Emission control has received increasing attention owing to increased concern over environmental pollution caused by fossil based generating units and the enforcement of environmental regulations in recent years [7]. Numerous studies have emphasized the importance of controlling pollution in electrical power systems [8].

Renewable energy is energy resource that comes from sustainable natural processes, such as energy from wind energy, solar energy, hydropower, biomass and geothermal energy. Wind energy is a clean and rapidly growing renewable energy resources. They have shown great prospects in decreasing fuel consumption as well as reducing pollutants emission. However, the expected wind power is difficult to predict accurately, primarily due to the intermittent nature of the wind speed, coupled with the highly non-linear wind energy conversion. In order to adjust unforeseeable nature of the wind power, planned productions and uses in electricity market must be improved during the real operation of the power system. Due to the intermittent characteristic of wind power, EED is very suited for formulate the problem of optimal scheduling of generating units by including wind power. Until now, very limited research has been done to overcome the problem of EED with wind power [9-12].

Environmental economic dispatch problem has two objectives consisting of minimum fuel cost and minimum emission. A number of methods have been presented to solve EED problems such as simplified recursive method [13], genetic algorithm [14-16], simulated annealing [17, 18], biogeography based optimization [19], differential evolution [20], artificial bee colony algorithm [21, 22], and particle swarm optimization [23, 24].

Recently, a new meta-heuristic search algorithm, called Bat Algorithm (BA) [25], has been developed by Yang. In this paper, BA has been used to solve EED problem considering the transmission loss. Feasibility of the proposed method has been demonstrated on 6-generating units with and without wind power. The results obtained with the proposed method were analyzed and compared with other optimization results reported in literature.

II. PROBLEM FORMULATION

The EED problem consists of two objective functions, which are economic and emission dispatches. Then these two functions are combined to solve the problem. The EED problem can be formulated as follows [15]:

$$F_T = Min\ f\left(FC, EC\right) \tag{1}$$

where F_T is the total generation cost of the system, *FC* is the total fuel cost of generators and *EC* is the total emission of generators.

2.1 Economic Dispatch

The ED problem targets to find the optimal combination of power generation by minimizing the total fuel cost of all generator units while satisfying the total demand. The ED problem can be formulated in a quadratic form as follows [22]:

$$FC = \sum_{i=1}^{N}\left(a_i P_i^2 + b_i P_i + c_i\right) \tag{2}$$

where P_i is the power generation of the *i*th unit; a_i, b_i, and c_i are fuel cost coefficients of the *i* th generating unit and *N* is the number of generating units.

2.2 Emission Dispatch

The classical ED problem can be obtained by the amount of active power to be generated by the generating units at minimum fuel cost, but it is not considered as the amount of emissions released from the burning of fossil fuels. Total amount of emissions such as SO_2 or NO_x depends on the amount of power generated by units and it can be defined as the sum of a quadratic function as follows [22]:

$$EC = \sum_{i=1}^{N}\left(\alpha_i P_i^2 + \beta_i P_i + \gamma_i\right) \tag{3}$$

where α_i ,β_i and γ_i are emission coefficients of the *i*th generating unit.

2.3 Environmental Economic Dispatch

The EED problem can be formulated by using generation cost and amount of emission and converting them into the single optimization problem as shown in equation (4):

$$F_T = (w * FC + (1-w) * h * EC) \tag{4}$$

under the following condition,

$$0 \le w \le 1 \tag{5}$$

where *w* is weighting factor: *w*=1 (fuel cost minimization), *w*=0 (NOx emission minimization), and *w*=0.5 (EED minimization) and *h* is the price penalty factor [15, 22].

2.4 Problem Constraints

There are two constraints in the EED problem which are power balance constraint and maximum and minimum limits of power generation output constraint.

Power balance constraint [8, 9]:

$$\sum_{i=1}^{N} P_i + P_W = P_D + P_L \tag{6}$$

$$P_L = \sum_{i}^{N}\sum_{j}^{N} P_i B_{ij} P_j \tag{7}$$

Generating capacity constraint:

$$P_{i\min} \le P_i \le P_{i\max} \tag{8}$$

where P_W is power output of wind farm; P_D is total demand of system (MW); P_L is total transmission loss; $P_{i\,min}$ and $P_{i\,max}$ are minimum and maximum generation of unit *i* (MW); and B_{ij} is coefficients of transmission loss.

III. BAT ALGORITHM

Bat algorithm is a meta-heuristic approach based on the behavior of bat echolocation. The bat has the capability to find its prey in complete darkness. It was developed by Xin-She Yang in 2010 [25]. The algorithm mimics the echolocation behavior most prominent in bats. Bats send out streams of high-pitched sounds usually short and loud. These signals then bounce off nearby objects and send back echoes. The time delay between the emission and echo helps a bat navigate and hunt. This delay is used to interpret how far away an object is. Bats use frequencies ranging from 200 to 500 kHz. In the algorithm pulse rate ranges from 0 to 1 where 0 means no emissions and 1 means maximum emissions.

Natural bats are using the echolocation behavior in locating their foods. This echolocation characteristic is copied in the virtual Bat algorithm with the following assumptions [25]:

1. All the bats are following the echolocation mechanism and they could distinguish between prey and obstacle.
2. Each bat randomly with velocity v_i at position x_i with a fixed frequency f_{min}, varying wavelength λ and loudness A_0 while searching for prey. They adjust to the frequency (or wavelength) of the transmitted pulse and set the pulse emission rate $r \in [0,1]$, depending on the distance of the prey.
3. Although the loudness can vary in many ways, we assume that the loudness varies from a large (positive) A_0 to a minimum constant value A_{min}.

3.1 Initialization of Bat Algorithm

Initial population is generated randomly for n number of bats. Each individual of the population consists of real valued vectors with *d* dimensions [25]. The following equation is used to generate the initial population:

$$x_{ij} = x_{\min j} + rand(0,1)(x_{\max j} - x_{\min j}) \quad (9)$$

where $i = 1,2,\cdots,n;\ j = 1,2,\cdots,d$; $x_{\min j}$ and $x_{\max j}$ are lower and upper boundaries for dimension *j* respectively.

3.2 Movement of Virtual Bats

Defined rules are necessary for updating the position x_i and velocity v_i. The new bat at the time step *t* is found by the following equations.

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta \quad (10)$$

$$v_i^t = v_i^{t-1} + (x_i^t - x_{best}) f_i \quad (11)$$

$$x_i^t = x_i^{t-1} + v_i^t \quad (12)$$

where $\beta \in [0,1]$ indicates randomly generated number, x_{best} represents current global best solutions.

For most of the applications, f_{min} = 0 and f_{max} = 100, depending the domain size of the problem of interest. Initially, each bat is randomly assigned a frequency which is drawn uniformly from [f_{min}, f_{max}].

In the local search section, once the solution is selected among the best current solutions, a new solution for each bat is generated locally using a random walk.

$$x_{new} = x_{old} + \varepsilon A^t \quad (13)$$

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

3.3 Loudness and Pulse Emission

As iteration increases, the loudness and pulse emission have to updated because when the bat gets closer to its prey then their loudness *A* usually decreases and pulse emission rate also increases. The updating equation for loudness and pulse emission is given by

$$A_i^{t+1} = \alpha A_i^t,\ r_i^{t+1} = r_i^0[1 - \exp(-\gamma t)] \quad (14)$$

where α and γ are constants. In fact, α is similar to the cooling factor of a cooling schedule in the simulated annealing. For any $0 < \alpha < 1$ and $\gamma > 0$, we have

$$A_i^t \to 0,\ r_i^t \to r_i^0 \text{ as } t \to \infty \quad (15)$$

where α and γ are constants. Actually, α is similar to the cooling factor of a cooling schedule in the simulated annealing. For simplicity, we set $\alpha = \gamma = 0.9$ in our simulations.

The basic step of BA can be summarized as pseudo code shown in Figure 1.

Bat Algorithm
Objective function $f(x),\ x = (x_1,\cdots,x_d)^T$
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 (10) to (13))
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 & $f(x_i) < f(x_{best})$)*
Accept the new solutions
Increase r_i and reduce A_i
end if
Rank the bats and find the current best x_{best}
end while
Postprocess results and visualization

Figure 1. Pseudocode of BA

IV. SIMULATION RESULTS

The proposed BA is tested on the standard IEEE 30-bus power system with six-generating units in order to investigate its effectiveness. The single-line diagram of the IEEE 30-bus test system is shown in Figure 2. The parameters of all thermal units (generation limits, fuel cost and NO_x emission coefficients) are presented in Table 1, followed by *B*-loss coefficients [13, 15, 22]. The load demand of the system is 700 MW. The values of BA for solving EED problem in this paper are designated as follow: max generation = 100; population size = 30; *A* = 0.9; *r* = 0.1; f_{min} = 0 and f_{max} = 2.

Table 1: Generator capacity limits, fuel cost and emission coefficients

Unit	$P_{i\,min}$ (MW)	$P_{i\,max}$ (MW)	a_i ($/MW^2)	b_i ($/MW)	c_i ($)	α_i ($/MW^2)	β_i ($/MW)	γ_i ($)
1	10	125	0.15240	38.53973	756.79886	0.00419	0.32767	13.85932
2	10	150	0.10587	46.15916	451.32513	0.00419	0.32767	13.85932
3	35	225	0.02803	40.39655	1049.9977	0.00683	-0.54551	40.26690
4	35	210	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.26690
5	130	325	0.02111	36.32782	1658.5596	0.00461	-0.51116	42.89553
6	125	315	0.01799	38.27041	1356.6592	0.00461	-0.51116	42.89553

$$B_{ij} = \begin{bmatrix} 0.002022 & -0.000286 & -0.000534 & -0.000565 & -0.000454 & -0.000103 \\ -0.000286 & 0.003243 & 0.000016 & -0.000307 & -0.000422 & -0.000147 \\ -0.000534 & 0.000016 & 0.002085 & 0.000831 & 0.000023 & -0.000270 \\ -0.000565 & -0.000307 & 0.000831 & 0.001129 & 0.000113 & -0.000295 \\ -0.000454 & -0.000422 & 0.000023 & 0.000113 & 0.000460 & -0.000153 \\ -0.000103 & -0.000147 & -0.000270 & -0.000295 & -0.000153 & 0.000898 \end{bmatrix}$$

For the purpose of comparison with the reported results, the test system is considered for two cases as follows:
Case A: In this case, the system without considering wind power.
Case B: In this case, the system with considering wind power. The higher output of wind-powered generator is 30 MW [9].

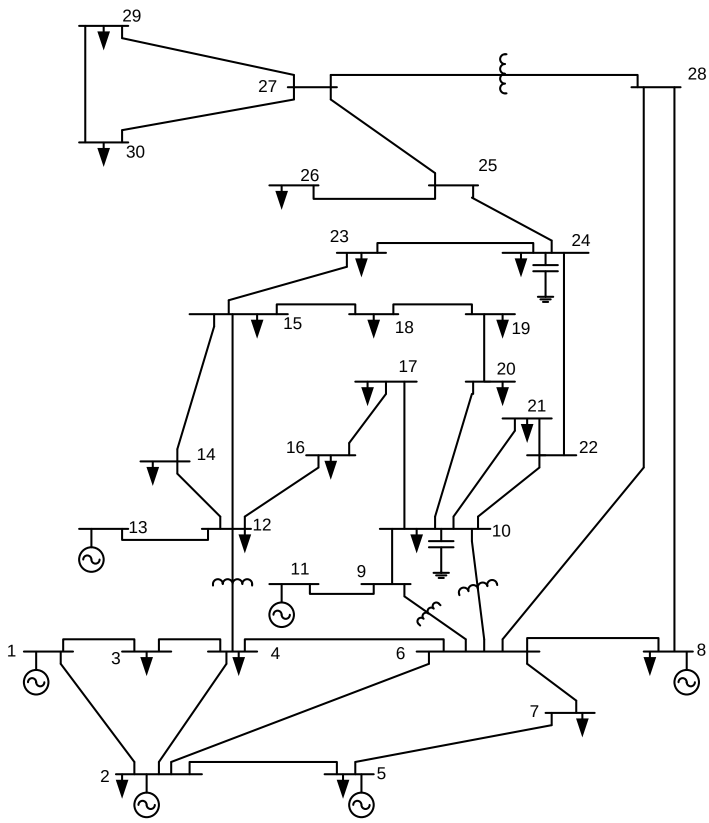

Figure 2. Single-line diagram of IEEE 30-bus test system [22]

In the first case, the best solutions for power outputs, fuel cost and NO_x emission obtained by using BA for *w*=1, *w*=0, and *w*=0.5 are given in Table 2. The results obtained by BA for the test system along with corresponding data from the literature are summarized in Table 3. As can be seen in Table 3, the proposed BA technique provided better values for the minimum fuel cost and NO_x emission in regard to the values obtained by the FCGA and NSGA-II [26]. Figure 3 shows the convergence characteristic of fuel cost optimization with BA. Figure 4 shows the Pareto optimal solution when fuel cost and emission optimized simultaneously.

In the second case, the best solutions for power outputs, fuel cost and NO_x emission obtained by using BA for *w*=1, *w*=0, and *w*=0.5 are given in Table 4. In the case of *w* = 1, the total active power output of the thermal generator is 708.7079 MW and the wind power output is 20.5451 MW. Furthermore, in the case of *w* = 0, the total active power output of the thermal generator is 715.3884 MW and the wind power output is 20.5451 MW.

Table 2: The best solutions obtained by using BA (Case A)

w	Generation (MW)						Fuel Cost ($/h)	NO_x Emission (kg/h)	P_{Loss} (MW)
	P_1	P_2	P_3	P_4	P_5	P_6			
1	76.0356	49.0555	44.9631	103.0434	266.5456	191.3164	38207.6022	537.1478	30.9631
0	105.3055	76.4273	92.8173	109.7886	183.2748	170.0442	39431.1210	462.7171	37.6675
0.5	94.8003	65.7695	82.9797	109.7478	202.1061	178.9976	38841.7433	467.8003	34.4088

Table 3: Comparison of best solution (Case A)

Methods	Fuel cost minimization (*w*=1)		NO_x emission minimization (*w*=0)		CEED minimization (*w*=0.5)	
	Fuel cost ($/h)	NO_x emission (kg/h)	Fuel cost ($/h)	NO_x emission (kg/h)	Fuel cost ($/h)	NO_x emission (kg/h)
FCGA	38384.09	543.48	39455.00	516.55	38408.82	527.46
NSGA-II	38370.746	534.924	39473.433	467.388	38671.813	484.931
BA	38207.6022	537.1478	39431.1210	462.7171	38841.7433	467.8003

With the inclusion of wind power into the existing power system, from Tables 4 and 2, it can be seen that at *w* = 1 (economic dispatch) operating costs can be saved by $ 25984.4616 per day and NO_x emissions can be reduced by 670.8984 kg/day; whereas in the condition *w* = 0 (emission dispatch) the operating costs per day can be saved by $ 28133.6208 and NO_x emissions can be reduced by 561.0624 kg/day.

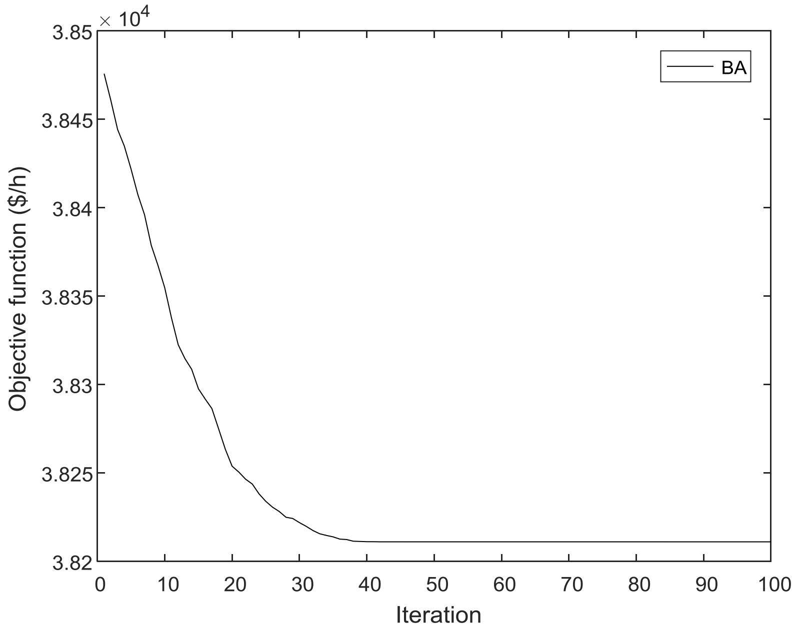

Figure 3. Fuel cost optimization with BA (Case A)

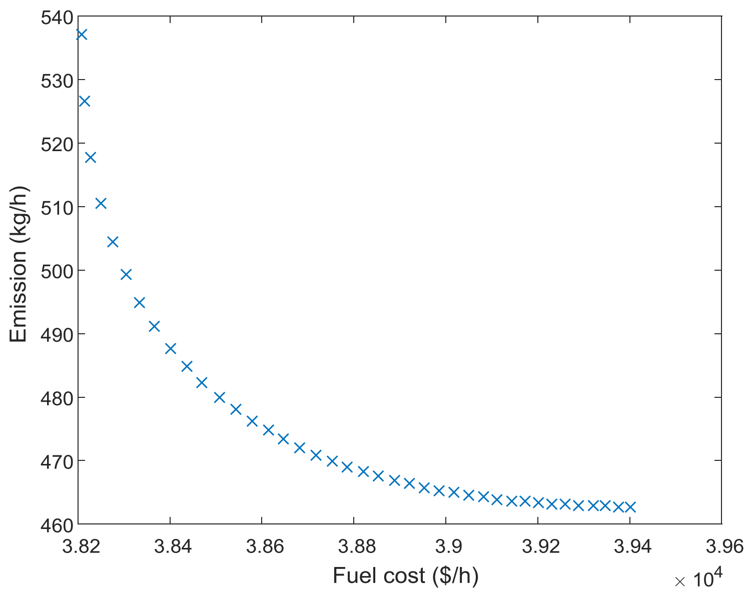

Figure 4. Fuel cost and emission optimization with BA (Case A)

Table 4: The best solutions with wind power obtained by using BA (Case B)

w	Generation (MW)						Fuel Cost ($/h)	NO_x Emission (kg/h)	P_{Loss} (MW)
	P_1	P_2	P_3	P_4	P_5	P_6			
1	73.4595	47.0463	43.5483	99.8718	258.8676	185.9357	37124.9163	509.1937	29.2775
0	100.3834	73.3097	91.0944	107.1239	177.8571	165.6279	38258.8868	439.3395	35.9507
0.5	90.9746	62.9213	81.3195	106.7199	196.0709	174.2206	37718.5779	443.9876	32.7792

V. CONCLUSION

In this paper, the proposed BA technique has been applied to solve EED problem of generating units considering transmission losses. The proposed technique has provided the global solution in the 6-generator system and the better solution than the previous studies reported in literature. The results obtained by proposed BA technique for EED with wind power were compared with EED without wind power. It is important to note that emission levels, related costs and fossil fuel costs were considerably reduced. Also, by applying the wind effect, this fact is achieved that all of the cost and emission in different scenario and case studies are reduced.

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