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Improved Bacterial Foraging Algorithm for Optimum Economic Emission Dispatch with Wind Power

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Abstrak

Pada makalah ini, algoritma penuaan bakteri (IBFA) yang telah diperbaharui diterapkan untuk memecahkan permasalahan operasi ekonomis sistem tenaga (EED). Dengan memperhatikan keberadaan sumber daya energi terbaharukan yang makin menarik beberapa tahun terakhir ini, penting sekali untuk memasukkan pembangkit tenaga angin dalam permasalahan EED. Kondisi nyata yang harus diperhatikan, telah membuat EED memiliki dua obyektif yakni biaya dan pengurangan emisi gas NOx. Permasalahan yang timbul dalam penerapan BFA adalah penghilangan bakteri yang tidak efektif yang mengakibatkan kinerja yang buruk. Untuk mengatasi hal ini, BFA yang diperbaharui diusulkan dalam alur langkah reproduksi dan diberi nama algoritma penuaan bakteri yang diperbaharui (IBFA). EED diselesaikan dengan dan tanpa menyertakan pembangkit tenaga angin, hal ini dimaksudkan sebagai batasan dan perbandingan dalam penggunaan BFA. Hasil simulasi menunjukkan peningkatan ketepatan konvergensi dengan IBFA yang lebih baik dibandingan BFA.

Kata kunci*: algoritma penuaan bakteri, operasi ekonomis sistem tenaga, pareto-optimal front, permasalahan multi-obyektif, tenaga angin*

Abstract

In this paper, an improved bacterial foraging algorithm (IBFA) is employed to solve economic-emission dispatch (EED) problem. Regarding to more interest to renewable energy sources especially wind energy in recent years, it is necessary to use of incorporate wind power plants into EED problem. To consider realistic conditions, EED is included bi-objective of cost and NOx emission. The problems encountered with BFA are ineffective bacteria elimination resulted in poor performance. To overcome this, a modified BFA is proposed in reproduction step termed as Improved Baterial Foraging Algorithm (IBFA). EED is solved, with wind power plant and without it, subjected to couple of constraintsusing BFA an BFA in a comparative manner.Simulation results show enhancement in convergence accuracy with IBFA rather than conventional BFA.

Keywords*: bacterial foraging algorithm, economic-emission dispatch, multiobjective problem, pareto-optimal front, wind power*

1. Introduction

Economic dispatch is one of the most important issues during the operation and programming of the power plants generation, being of great importance in financial saving especially due to the fossil fuel resources shortage. Hence, it is noticeably expected to obtain the most appropriate generation arrangement to power plants considering constraints in the power grid to minimize objective functions. In this study, in addition to generation cost, pollutant gas emission is considered in the optimization function[1]. It is fashionable to integrate thermal power plants in economic dispatch (ED) but in this study, in light of the advantages taken by renewable energy resources, there has been an attempt to contribute wind power plants[2-4]. According to the load profile and local wind characteristics, wind plant is able to produce 10%-40%out of the total demand load, in this case, is assigned as 10%[5].

Various evolutionary algorithms (EA) have been employed for ED such as genetic algorithm (GA) [6], [7], tabu search (TS) [8], and particle swarm optimization (PSO) [9], [10]. Recently, bacterial foraging algorithm (BFA) is applied to solve economic-emission dispatch (EED). The BFA simulates E.Coli bacterial foraging behavior, and it is an accurate algorithm. In this study, in order to augment algorithm efficiently in EED, a modification is made into

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conventional BFA, introducing IBFA.In Section 2, EED is mathematically represented and the problem constraints are defined. In this section, an improved BFA and its application in EED in two systems, with and without wind power plant are presented. In Section 3,details regarding to the proposed IBFA are presented. Section 4 is dedicated to convert the multi-objectiveoptimization EED problem to the single-objective optimization using weighted-sum technique. The simulation resultsfrom conventional BFA and IBFAare presented and compared for both with wind pland and without it in Section 4.

2. Problem Statement

EED is a multi-objective problem to obtain output power of the generative units so that all objectives meet minimum values based on their priority.

2.1.Objective Function

The EED objectives can be listed as follows [11]:

Function 1: F_1 is total fuel cost of the thermal units that can be formulated approximately by using a quadratic polynomial in terms of the generative power, as

$$F_1 = \sum_{i=1}^{N} F_i(P_i) \tag{1}$$

$$F(P) = a_i + b_i P_i + c_i P_i^2 \tag{2}$$

whereP_i is the power of the i^{th} generating unit; a_i, b_i, and c_i are the cost coefficients of the ith generating unit.

Function # 2: F_2 as total emission gas $NO_x$is also represented in the quadratic equation.

$$F_2 = \sum_{i=1}^{N_g} (d_i P_i^2 + e_i P_i + f_i) \tag{3}$$

where, d_{1i}, e_{1i}, f_{1i} are emission coefficients.

2.2. Wightted-Sum Method

Weighted-sum method is extensively used to solve multi-objective problems [12]. Generic procedure to this method is based on allocating each of the functions according to their priority on interval [0 1] to form a new objective function. The sum of the assigned weights should be unity. This function is represented as follows:

$$Min\ (F = \sum W_k F_k (P_i)]) \tag{4}$$

subject to :

$$\sum_{k=1}^{M} w_k = 1 \quad (0 \le w_k \le 1) \tag{5}$$

where M is the number of objective functions and, w_k, is weight of the k^{th} assigned.

Regarding to above EED bi-objective function can be converted into a single objective function as:

$$F = w_1 F_1 + w_2 F_2 \tag{6}$$

subject to:

$$w_1 + w_2 = 1 \qquad 0 \le w_1, w_2 \le 1 \tag{7}$$

2.3. Constraints

There are some constraints on EED that should be taken account as follows:

Load Balance: Sum of load demand and power losses must equal to the total generating power.

$$\sum_{i=1}^{N} P_i = P_{Demand} + P_{Loss} \tag{8}$$

where P_{Loss}, network losses and P_{Demand}, load demand, respectively.

Generating Unit Capacity Limits: Each generator is allowed to generate at a predefined range due to the special operation.

$$P_{i,\min} \le P_i \le P_{i,\max} \tag{9}$$

where P_i is the output power of i^{th} generator; $P_{i,min}$ and $P_{i,max}$ are the minimum and maximum power outputs of i^{th}generator, respectively.

2.4. Network Losses

Losses of the transmission lines are described in terms of the active power of generating units and the *B*-coefficient matrix [13].

$$P_{Loss} = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} P_i B_{ij} P_j + \sum_{i=1}^{N_g} B_{i0} P_i + B_{00} \tag{10}$$

where B is coefficient matrix, $B_0$is column vector of the network losses and $B_{00}$is constant coefficient of the network losses.

2.5. Wind Power Plant Constraints

Considering the wind power plant as a generation unit in the power network, the power balance equation is changed as:

$$\sum_{i=1}^{N} P_i = (P_{Demand} - P_W) + P_{Loss} \tag{11}$$

where P_w is the load demand portion generated by the wind power plant.

The other constraint wind power plant imposes the wind power availability as:

$$P_{Demand} + P_{Loss} - \sum_{i=1}^{N_g} P_i \le P_{av} \tag{12}$$

3. Improved Bacterial Foraging Algorithm (IBFA)

In this section, BFA fundamental is introduced and required modification is made to improve the efficiency algorithm.

3.1. Bacterial Foraging Algorithm (BFA)

BFA is inspired by foraging behavior of E.Coli bacteria where they forage based on different principles such as the bacteria with more poor foraging strategy are almost eliminated. Various biological aspects and bacteria behavior is available in [14].

Each E.Coli always has movements between the swimming and tumbling modes. If it takes the path with more food than the previous path, it resumes thatpath; otherwise, it will be stopped. In other words, bacterium takes the path where the energy from access to food, per time unit along the path and encounter with different constraints is maximized. After these advances, bacteria with more poor foraging strategy are eliminated and more powerful bacterium will be generated. The aim of the algorithm is to find a minimum value ofthe function $J(\theta)$, subject to $\nabla J(\theta)$, where, θisbacterium positionand $J(\theta)$ attract and repellant value. The value $J>0$, $J=0$ and $J<0$representing the position of each member in population set containing S

bacterium in j-th movement step, k^{th}generation step ,l^{th} elimination and dispersion step. $J(i,j,k,l)$ denotes the cost function of i^{th}bacterium position$\theta^i(j,k,l)$ and N_c refers to the bacterium life time measured by the number of movement steps. To model swimming, a random movement of length $\varphi(j)$ is produced:

$$\theta^i(j+1,k,l)=\theta^i(j,k,l)+C(i)\varphi(j) \qquad (13)$$

where $C(i)>0$ is the step length randomly taken by swimming performance. If the bacterium cost function $J(I,j+1,l)$ in position$\theta^i(j+1,k,l)$ less than the bacteriumcost in position$\theta^i(j,k,l)$, this task is accomplished to maximum steps number (N_S). After $N_c$movementstep, ageneration step is taken. In generation, the most proper bacteria (from stand point of the least cumulative cost per life time) are reproduced and the others are eliminated. Thus, the population is maintained constant. After the reproduction steps, elimination and disperse step is taken how each bacterium in population of possibilityP_{ed} *is* eliminated and a newbacterium replaced for eliminated. Bacteria always have attracted and repellant mode, in other words, bacteria colony containing better position, attracts the others and bacteria colony with worse position repels.

$$\begin{aligned} J_{cc}(\theta, \mathrm{P}(j,k,l)) &= \sum_{i=1}^{S} J_{cc}^{i}\left(\theta, \theta^{i}(j,k,l)\right) \\ &= \sum_{i=1}^{S}\left[-d_{attract}\exp\left(-w_{attract}\sum_{m=1}^{p}(\theta_m-\theta_m^i)^2\right)\right] \\ &+ \sum_{i=1}^{S} h_{repellant}\exp\left(-w_{repellant}\sum_{m=1}^{p}(\theta_m-\theta_m^i)^2\right) \end{aligned} \qquad (14)$$

where $W_{repellant}$, $h_{repellant}$, $W_{attract}$ and $h_{attract}$ are repellant and attract index coefficients. So the general objective function is:

$$J(i,j,k,l)+J_{cc}(\theta,P) \qquad (15)$$

The BFA conventional code is summarized as below:

```
FOR (each bacterium i =1:S)
    $\theta^i(1,1,1)$= rand_post( )
    J(i,1,1,1)= derivative_value($\theta^i(1,1,1)$)
END FOR
FOR (elimination-dispersal loop l =1: Ned)
    FOR (reproduction-loop k =1: Nre)
        FOR (chemotactic-loop j =1: Nc)
            FOR (each bacterium i =1: S)
                Calculate
                J(i, j, k, l)= J(i, j, k, l)+ $J_{cc}(\theta^i(j, k, l), \theta(j, k, l))$
                Set $J_{last}$ = J(i, j, k, l)
                Tumble:
                Find the direction of possible movement from thedirection probability matrix.
                Move:
                $\theta^i(j+1, k, l)= \varphi[m',n',i,j+1,k,l]$
                Compute J(i, j +1, k,l)
                m =0
                WHILE (m < Ns)
                    m = m +1
                    IF (J(i, j +1, k,l)<$J_{last}$)
                        $J_{last}$= J(i, j +1, k, l)
                        Update $\theta(i, j +1, k, l)$
                        Recalculate J(i, j +1, k, l)
                    ELSE
                        m = Ns
                    END IF
                END WHILE
            END FOR (Bacterium)
        END FOR (Chemotaxis)
```

```
Reproduction:
For given k and l, and each bacterium i =1,2, ... ,S
Sum:
$J^{i}_{health}=\sum_{j=1}^{Nc+1}J(i,j,k,l)$
Sort:
Sort bacteria and chemotactic parameters C(i) in order
of ascending cost $J_{health}$.
Split and Eliminate:
The Sr bacteria with the highest $J_{health}$ values die and the
remainingSr bacteria with the best values split.
END FOR (Reproduction)
Disperse:
For i = 1, 2, ... , S, with probability $P_{ed}$, randomize a
Bacterium’s position
END FOR (Elimination and Dispersal)
END
```

3.2. Improved Bacterial Foraging Algorithm (IBFA)

In conventional BFA structure, once the N_C movement steps were performed for each bacterium, the values of J_{health} can be calculated as below.

$$J^{i}_{health}=\sum_{j=1}^{Nc+1}J(i,j,k,l) \tag{16}$$

According to the above equation, J_{health} is equal to the sum of each bacterium’s positions in each movement step. In the other word, the propriety rate of each bacterium is equal to the sum of its costs in each movement step. Then, as mentioned in the trend of the BFA, the value of J_{health} for each bacterium is sorted based on its value from the biggest J_{health} to the smallest one. The bacteria with higher value of J_{health} (the above half of the sorted values) should be eliminated. Now, it is possible for a bacterium in a movement step to reach near the global optimum point, while has experienced a high objective function value in its own other movement steps, consequently, a high value of J_{health}, which leads to the elimination of this bacterium, while it had this capability to locate in a proper position near the global optimum point. To solve this problem, the all movement steps of the bacterium is also verified after finishing the movement steps. In the other word, the BFA structure is improved by saving all the movement steps for each bacterium and revising the all positions of the bacteria in various movement steps.

4. Simulation Results

A proposed IBFA is used to solve EED for a test power grid, both without and with wind plant using BFA and IBFA. An EED simulation is performed on the 30-bus IEEE test system including six generators and 1800 MW load demand. Computer simulator specifications are CPU Intel® core™ i.3 (1.66 GHz) and 4 GB of RAM. Generators parameters and cost and emission coefficients are shown in Tables1 and 2 respectively [13].

Multiobjective EED problem is convertible through sum-weighted method.Initially, sum weighting method optimally is done and pareto-optimal front is obtained with BFA and IBFA.Furthermore, minimum and mean values sum functions are calculated for each pair weights with and without wind plant, as shown in Table 3. Generated power, network losses are calculated and indicated in Tables4 and 5 respectively. Different values of the objectives for proposed pair weights(Table 3) are established, for cases with wind plant and without wind plant, using BFA and IBFA (Tables6 and 7).Pareto-optimal fronts for without and with wind plant are comparatively obtained with BFA and IBFA asFigures 1 and 2, respectively.Regarding to data to Tables 6 and 7 and pareto-optimal fronts (Figures 1 and 2), it has been observerved the convergence accuracy associated to the proposed IBFA,to obtain the global optimum point, in comparison to conventional BFA show enhancement. In other words, IBFA results in more efficient optimum point, for this bi-objective as generation cost andpollutant gas emission, rather than conventional BFA.

Table 1. Data for the 6-generator system

Unit	ai $/MWh	bi $/MWh	ci $/MWh	Pi,min MW	Pi,max MW
	Parameter				
1	0.002035	8.43205	85.6348	150	600
2	0.003866	6.41031	303.7780	150	600
3	0.002182	7.42890	847.1484	150	600
4	0.001345	8.30154	274.2241	150	600
5	0.002182	7.42890	847.1484	150	600
6	0.005963	6.91559	202.0258	150	600

Table 2. Coefficients for cost and emission equation

		Generator					
Obj.	Coef.	1	2	3	4	5	6
Cost F1($/h)	ai	0.002035	0.003866	0.002182	0.001345	0.002182	0.005963
	bi	8.43205	6.41031	7.4289	8.30154	7.4289	6.91559
	ci	85.6348	303.778	847.1484	274.2241	847.1484	202.0258
NOx F2(kg/h)	di	0.006323	0.006323	0.003174	0.006732	0.003174	0.006284
	ei	-0.38128	-0.79027	-1.36061	-2.39928	-1.36061	-0.39077
	fi	80.9019	28.8249	324.1775	610.2535	324.1775	50.3808

Table 3. Non-dominant solutions for cost and NOxobjectives

Solution Number	without wind power					with wind power				
	Weight		Objective			Weight		Objective		
	W1	W2	Min F1 (MW)	Min F2 (MW)	Mean (F1+F2) (MW)	W1	W2	Min F1 (MW)	Min F2 (MW)	Mean (F1+F2) (MW)
1	1.0	0.0	18721	2293.2	18888	1.0	0.0	16834	1842.2	16973
2	0.9	0.1	18725	2276.9	17226	0.9	0.1	16843	1835.9	15480
3	0.8	0.2	18731	2257.9	15569	0.8	0.2	16857	1821.6	13970
4	0.7	0.3	18754	2194.1	13904	0.7	0.3	16865	1808.7	12476
5	0.6	0.4	18767	2181.9	12257	0.6	0.4	16873	1784.5	10979
6	0.5	0.5	18834	2135.8	10628	0.5	0.5	16885	1759.0	9530.4
7	0.4	0.6	18856	2129.0	8940.5	0.4	0.6	16893	1747.9	8034.1
8	0.3	0.7	18878	2119.5	7316.3	0.3	0.7	16908	1736.2	6494.3
9	0.2	0.8	18887	2116.7	5683.0	0.2	0.8	16926	1731.5	4935.7
10	0.1	0.9	19105	2110.0	4022.8	0.1	0.9	17080	1718.4	3441.1
11	0.0	1.0	19209	2106.4	2309.3	0.0	1.0	17091	1716.5	1921.5

B-coefficient matrix:

$$B = 10^{-5}\begin{bmatrix} 20.0 & 1.0 & 1.5 & 0.5 & 0 & -3.0 \\ 1.0 & 30.0 & -2.0 & 0.1 & 1.2 & 1.0 \\ 1.5 & -2.0 & 10.0 & -1.0 & 1.0 & 0.8 \\ 0.5 & 0.1 & -1.0 & 15.0 & 0.6 & 5.0 \\ 0 & 1.2 & 1.0 & 0.6 & 25.0 & 2.0 \\ -3.0 & 1.0 & 0.8 & 5.0 & 2.0 & 21.0 \end{bmatrix} MW^{-1}$$

Table 4. Power generation dispatch and losses (without wind power)

Solution No.	Without wind power								
	Power Generation Dispatch (MW)						PLoss (MW)	F1 ($/h)	F2 (kg/h)
	P1	P2	P3	P4	P5	P6			
1	293.434	272.594	534.207	345.920	290.701	189.751	129.849	18721	2293.2
2	246.191	268.665	540.076	359.872	343.105	172.746	130.624	18725	2276.9
3	258.512	264.657	470.742	410.546	332.127	195.358	131.825	18731	2257.9
4	266.615	262.403	483.492	341.216	355.416	223.704	133.054	18754	2194.1
5	216.658	298.732	560.642	299.978	362.332	196.532	134.818	18767	2181.9
6	178.537	234.186	547.378	360.158	418.715	200.916	139.961	18834	2135.8
7	217.687	280.583	467.886	349.609	467.911	165.418	148.892	18856	2129.0
8	176.130	253.174	592.315	319.629	414.092	183.798	139.447	18878	2119.5
9	150.301	258.094	536.007	377.737	419.375	200.479	142.322	18887	2116.7
10	221.681	230.455	513.532	383.277	431.351	159.904	140.460	19105	2110.0
11	197.190	159.604	537.593	292.301	551.286	225.308	163.198	19209	2106.4

Table 5.Power generation dispatch and losses (withwind power)

Solution No.	With wind power								
	Power Generation Dispatch (MW)						PLoss (MW)	F1 ($/h)	F2 (kg/h)
	P1	P2	P3	P4	P5	P6			
1	251.462	246.755	461.762	262.995	310.518	192.144	105.593	16834	1842.2
2	222.411	280.740	436.096	310.851	263.769	211.208	104.924	16843	1835.9
3	201.671	295.821	482.315	260.073	314.652	174.158	108.730	16857	1821.6
4	236.654	233.688	485.716	281.028	306.981	180.014	104.160	16865	1808.7
5	187.785	256.600	502.383	295.268	317.882	166.368	106.196	16873	1784.5
6	173.488	232.874	482.734	305.535	349.723	184.332	109.053	16885	1759.0
7	213.854	273.247	425.612	300.618	350.080	167.373	111.077	16893	1747.9
8	188.637	200.985	482.580	261.555	384.704	214.024	112.900	16908	1736.2
9	167.519	207.368	441.043	361.300	367.864	186.494	111.869	16926	1731.5
10	175.756	170.500	451.864	293.692	471.267	182.002	125.238	17080	1718.4
11	168.504	175.171	467.653	341.377	384.408	195.910	113.075	17091	1716.5

Table 6.Comparsion between BFA and IBFA results without wind plant

Solution	BFA		IBFA	
Number	cost	emission	cost	emission
1	18725	2292.1	18721	2293.2
2	18728	2279.9	18725	2276.7
3	18735	2261.9	18731	2257.8
4	18757	2199.1	18754	2194.2
5	18771	2189.9	18767	2181.1
6	18838	2139.8	18834	2135.8
7	18860	2135.0	18856	2129.2
8	18882	2124.5	18878	2119.6
9	18891	2123.7	18887	2116.7
10	19109	2112.0	19105	2110.1
11	19215	2109.4	19209	2106.3

Table 7.Comparsion between BFA and IBFA results with wind plant

Solution	BFA		IBFA	
Number	cost	emission	cost	emission
1	16843	1842.5	16834	1842.2
2	16846	1835.3	16843	1835.9
3	16858	1820.8	16857	1821.6
4	16867	1808.4	16865	1808.7
5	16876	1782.1	16873	1784.5
6	16890	1759.7	16885	1759.0
7	16895	1748.3	16893	1747.9
8	16910	1738.4	16908	1736.2
9	16936	1731.6	16926	1731.5
10	17088	1720.3	17080	1718.4
11	17094	1718.5	17091	1716.5

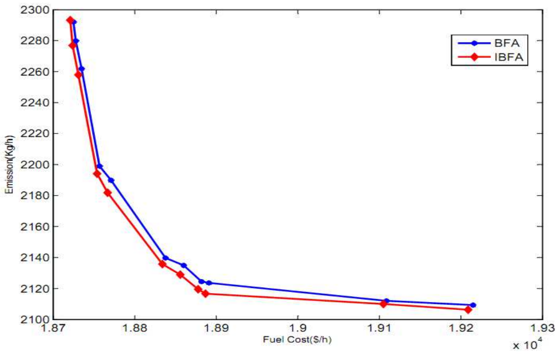

Figure 1. Pareto-optimal front obtained by for BFA and IBFA without wind plant

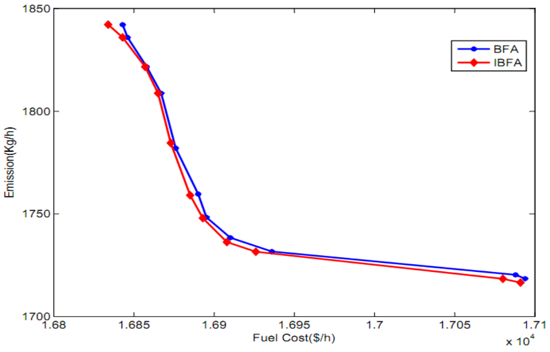

Figure 2. Pareto-optimal front obtained by for BFA and IBFA with wind plant

5. Conclusion

In this paper, the economic-emission dispatch(EED)problem is investigated. Usually, all generation units are considered as the thermal unit, meanwhile, due to the growth in renewable energy sources, the wind generation system is also considered as well as the thermal units.The EED is a bi-objective optimization problem; hence, the weighted sum method is used to solve such a problem. The results for the various weights are presented and pareto- optimal curve is drawn. This trend is achieved for both with and without wind generation system states (10% of the total load demand is supply by wind generation system).To solve this problem, initially, BFA is employed. Then, to augment the solution performace to obtain the global optimum point, a modification into the structure of convention BFA was made which tends into IBFA. EED problem was solved with proposed IBFA. Simulation results demonstrate the effectiveness of IBFA in convergence accuracy.

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