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Multi-objective Economic Emission Dispatch Solution Using Dance Bee Colony with Dynamic Step Size

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Abstract

Energy planning considering environment aspect is a vital research area for power system operation and control. This paper introduces an efficient variant namely dance bee colony with dynamic step size adjustment for solving the multi objective economic emission dispatch considering valve point effects. The particularity and robustness of the proposed algorithm is validated on two practical test systems IEEE 30-Bus and to 40 units considering valve point effect and power losses. Results compared to many recent competitive methods confirm the efficiency of the proposed method in term of solution quality and convergence characteristics.

Peer-review under responsibility of the Euro-Mediterranean Institute for Sustainable Development (EUMISD)

Keywords: Multi Objective, Dance Bee colony, Environmental/economic dispatch, fuel cost, Emission, Step size.

Nomenclature

ED	Economic Dispatch
DBC	Dancing Bee colony
Cost	fuel cost
Emi	Emission

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1. Introduction.

Energy planning considering emissions control is a vital research area for power system operation and control, this type of problem is complex with non-linear fuel cost functions and constraints. Determining the optimal capacity of units considering emissions and practical generator constraints such as valve point effect and prohibited zones is a complex and important subject for experts and researchers [1].

ED problems have been investigated and a large number of mathematical methods developed and applied to solving the combined economic dispatch and environment. Methods such as lambda iteration method, gradient method, linear programming, quadratic programming and interior point methods [2-3], have been applied with success to solving many problems related to power system planning and operation. However all these developed mathematical methods rely on the form of the objective function and fail to find the near global solution when considering practical generator constraints, authors in [4] surveys the conventional optimization methods.

To overcome the major problems related especially to restriction on the nature of the objective function and to take in consideration the real nature of constraint associated to generators such as valve point effect, and prohibited zones, an alternative optimization category based stochastic heuristic aspect is proposed by experts and researchers for enhancing the solution of practical power system planning and control, particularly the combined economic dispatch. In the literature a large number of meta heuristic methods have been proposed, adapted and applied with success to solving many complex problems such as: Improved genetic algorithm (IGA) [5], Particle swarm optimization[6-7], Stochastic optimal strategy [8], modified NSGA-II algorithm [9], niched Pareto genetic algorithm [10], new honey bee mating optimization algorithm [11], fuzzified multi objective particle swarm optimization algorithm [12], multi objective evolutionary algorithms [13], novel multi objective evolutionary algorithm [14], Elitist multi objective evolutionary algorithm [15], an interactive fuzzy satisfying method [16], multi objective particle swarm algorithm with fuzzy clustering [17], artificial immune system [18], incremental artificial bee colony with local search [19], artificial bee colony algorithm with dynamic population size [20], artificial bee colony algorithm [21], Enhancing artificial bee colony algorithm [22], fuzzy based bacterial foraging algorithm [23], New multi-objective stochastic search technique [24], multi-objective differential evolution [26], A hybrid multi-agent based particle swarm optimization algorithm [26] and an improved Artificial Bee Colony Method [27]. The major contributions related to this category and others hybrid methods reviewed by authors in [28].

In this paper, an efficient variant named Dance bee colony with dynamic step size is adapted and applied for solving the multi objective environment economic dispatch considering practical generator constraints. The performances and robustness of the proposed variant validated on many practical test systems considering the effect of valve point and total active power losses.

2. Economic and emission load dispatch

The environmental/economic dispatch problem is to minimize two competing objective functions, fuel cost and emission, while satisfying several equality and inequality constraints. Generally, the mathematical formulation of the problem is described as follows [1].

2.1. *Economic dispatch formulation with valve point effect*

The cost function of economic load dispatch problem is defined as follows:

$$F\left(P_g\right)=\sum_{i=1}^{n}\left(a_i+b_n P_{gi}+c_i P_{gi}^2\right)+\left|e_i \sin\left(f_i\left(P_{gi}-P_{gi}^{\min}\right)\right)\right| \quad (1)$$

Where P_{gi} is the power generation of unit *i*, a_i, b_i, c_i, are fuel cost coefficients of unit *i*. e_i and f_i are two coefficients, required for introducing valve point effect.

2.2. *Emission dispatch formulation*

The emission function of economic load dispatch problem is defined as follows:

$$E\left(P_g\right)=\sum_{i=1}^{n}10^{-2}\left(\alpha_i+\beta_i P_{g_i}+\gamma_i P_{g_i}^2\right)+\xi_i exp\left(\lambda_i P_{g_i}\right) \tag{2}$$

Where α_i, β_i, γ_i, ζ_i, and λ_i are coefficients of the *ith* generator emission characteristics.

2.3. *Minimization of fuel cost and emission:*

The Multi-objective combined economic and mission problem with its constraints can be mathematically formulated as a nonlinear constrained problem as follows [20]:

$$OF=\omega\sum_{i=1}^{n}F(P_{gi})+(1-\omega)\sum_{i=1}^{n}E(P_{gi}) \tag{3}$$

The solution of the problem is achieved by minimizing the objective function (OF), the fuel cost rate ($/h) is shown with, F(Pg) and NOx emission rate (ton/h) with E(Pgi).

2.4. *Constraints*

Power equality constraint in the system with transmission losses is given as follows:

$$\sum_{i=1}^{n}P_{g_i}-P_{load}-P_{loss}=0 \tag{4}$$

Where P_{load} is the total load demand and P_{loss} is the total power loss in transmission lines.

The P_{loss} , Since the power stations are usually spread out geographically, the transmission loss has to be taken into account. The commonly used method in power utility industry is the B coefficients method [20], which is expressed as follows:

$$P_{loss}=\sum_{i=1}^{n}\sum_{j=1}^{n}P_{g_{i,n}}B_{i,j}P_{g_{j,n}}+\sum_{j=1}^{n}P_{g_{j,n}}B_{0j}+B_{00} \tag{5}$$

Where B, B_0 and B_{00} are all transmission loss coefficients, and B is a n×n matrix, B_0 is a 1 x n vector, B_{00} is a constant.

The generation capacity constraints of the thermal generation units are taken from [20].

$$\mathrm{P}_{\mathrm{g_i}}^{\min}\le\mathrm{P}_{\mathrm{g_i}}\le\mathrm{P}_{\mathrm{g_i}}^{\max} \tag{6}$$

Where $P_{g_i}^{min}$ and $P_{g_i}^{max}$ are the minimum and maximum range of power loading limit for *nth* generator unit respectively.

3 Dance Bee colony

3.1 *Overview*

The DBC (Dancing Bee colony) algorithm was developed by Laga and Nouioua 2009, to solve the problem of T-coloring of graphs. This algorithm is inspired by bee behavior when foraging. In this paper a variant of the original DBC is proposed and adapted for solving environmental economic dispatch problem. Figure 1 shows the flowchart of DBC, mechanism search.

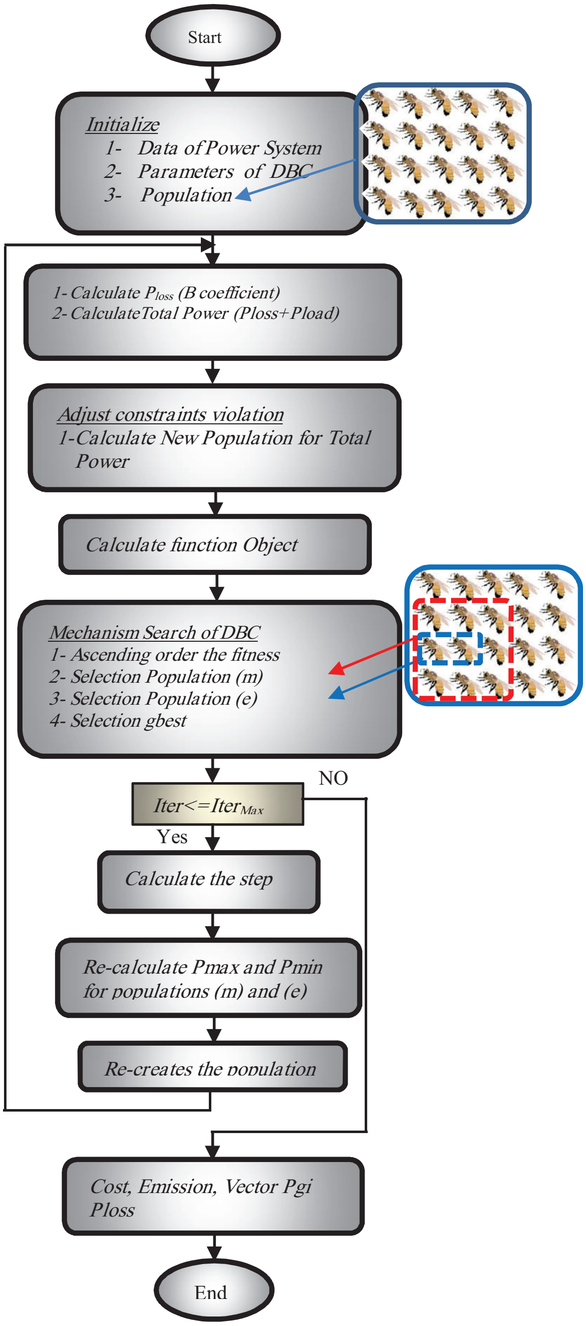

Fig.1 Flowchart of *DBC*

3.1.1. *Initialization*: The algorithm starts by randomly placing N bees in the search space. The distribution of N bees in the search space is shown in Figure 2.

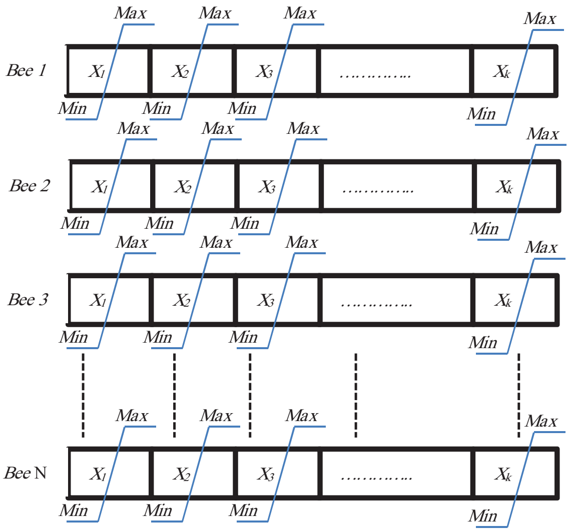

Fig 2 Distribution of a bee in the search space

3.1.2. *Evaluation*: calculate the fitness for these bees, the entire population arranged and sorted according to their fitness value.

3.1.3 *Decomposition process*: in this step, the search space is decomposed, first a sub group of ‘m’ bees are selected form the entire population, and then a sub group named ‘e ’ containing bees with the best fitness is selected from the sub group ‘m’.

3.1.3. *The search process adapted described as follows:*

a) The search space will be guided principally to the region containing sub group ‘e’ using an adaptive step size with (*Nem*) bees .
b) From (m-e) space search we recruited a number of bees (*Nes*) for search.
c) The rest of bees (*Ngs*) related to other sub groups (*N-m*) affected for random search.

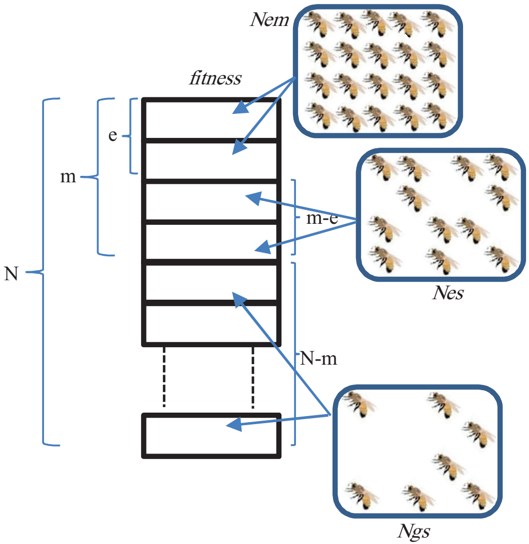

Fig 3 Distribution of all bees in the search space

3.2. *Proposed variant*:

In this section we will introduce the variant proposed to enhance the performances of the original DBC. The main particularity of the proposed variant is that the search space is dynamic and change dynamically during process search. The following description summarizes the steps of the dynamic steps introduced within the standard DBC algorithm.

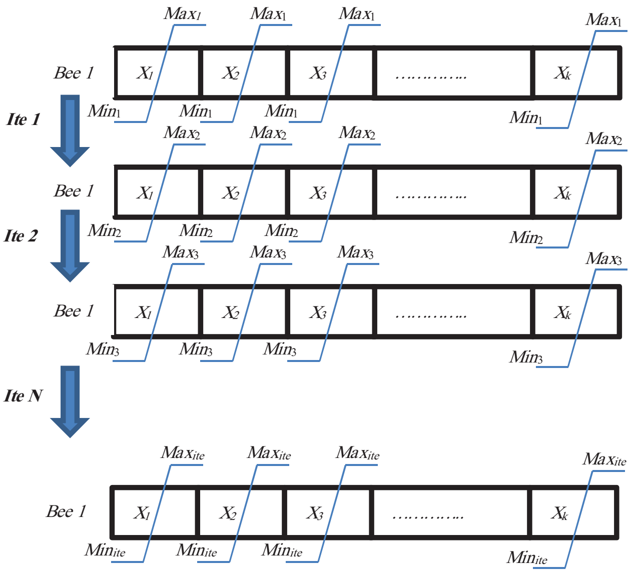

Fig 4 Dynamic evolution of space search during generation

3.2.1. The step is calculated using the following the following relation:

$$S_{now} = S - S \times (itr - 1) / ite \tag{7}$$

Where, S is the initial step, S_{now} is a new step, *itr* is the actual iteration, and *ite* is the total number of iteration,

3.2.2. The new search space corresponding to the limits (min and max) of each variable is calculated dynamically during the process search using the following expressions:

$$Max_{now} = x + S_{now} \tag{8}$$

$$Min_{now} = x - S_{now} \tag{9}$$

Where, Max_{now} and Min_{now} are the new estimated limits corresponding to the variable x. Figure 5 shows the direction of the bees to the new estimated space search.

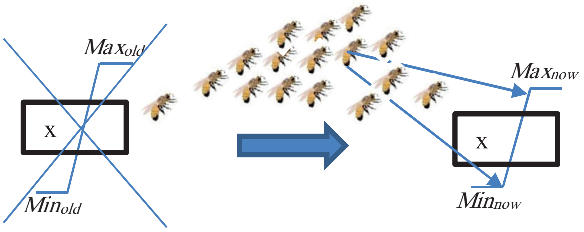

Fig.5 Direction of bees towards the new estimated search space

4 Description of the test systems

4.1 *Test system 1:IEEE 30-bus system*

This test system consists of 6 generators, the total load to be satisfied is 283.4 (MW). The initial parameters of the DBC algorithm used for this test system are presented in Table 1, the fuel cost rate coefficients, the emission rate coefficients and the B coefficients are given in Tables 6-8. Three cases are considered:

-case1: minimization of fuel cost
-case2: minimization of emission
-case3: minimization of cost and emission

For the first case, the total fuel cost optimized is 605.345$/h, the convergence characteristic of the algorithm is shown in figure.6. The corresponding total power loss and total emission achieved are 2.2617 (MW) and 0.2207 (ton / h) respectively. In the second case, the total emission is optimized individually, the best value found is 0.19420 (ton/h), the corresponding total fuel cost and power losses achieved are 645.825($/h) and 3.39490 (MW). Figure 7 shows the convergence characteristic of the total emission. Details results for optimized control variables are shown in Table 2. In the third case the two objective functions (fuel cost and emission) are optimized simultaneously, the characteristic of the Pareto optimal front corresponding to these two objective functions are shown in Figure 8. In order to verify the efficiency of the proposed variant based DBC, a comparative study in term of solution quality is well presented in Tables 2-3.

Table 1. Parameters of the DBC

Parameters	*N*	*m*	*e*	*Nem*	*Nes*	*Ngs*	*step*
Value	100	20	5	20	30	50	20

Table 2. Comparison of compromising solutions for Test system 1.

Generation	**ω=1.0**		**ω=0.0**	
	DBC	ABCDP[20]	**DBC**	ABCDP[20]
G1	11.4074	11.2192	41.0803	41.0177
G2	29.0781	29.1144	46.2938	46.3689
G3	58.5793	57.9711	54.4186	54.4481
G4	98.8418	99.4465	39.0882	39.0432
G5	52.5140	52.4485	54.3648	54.4513
G6	35.2412	35.5212	51.5490	51.5520
Cost($/h)	**605.3456**	605.425	645.825	646.045
Emi(ton/h)	0.2207	0.22090	**0.19420**	0.19420
Ploss(MW)	2.2617	2.32110	3.39490	3.48150

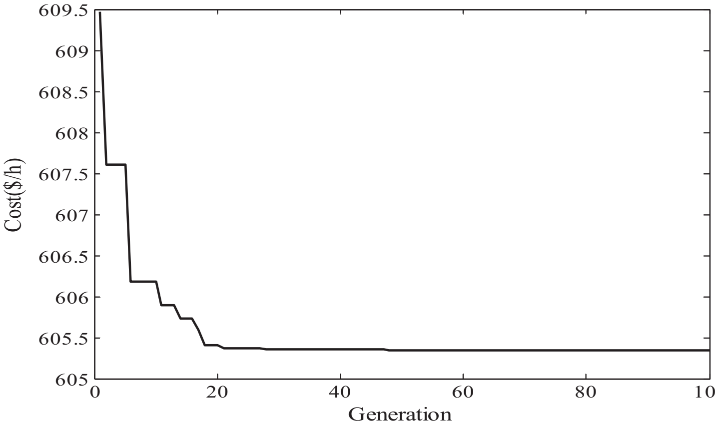

Fig.6.Convergence characteristic for six-unit system: cost minimization

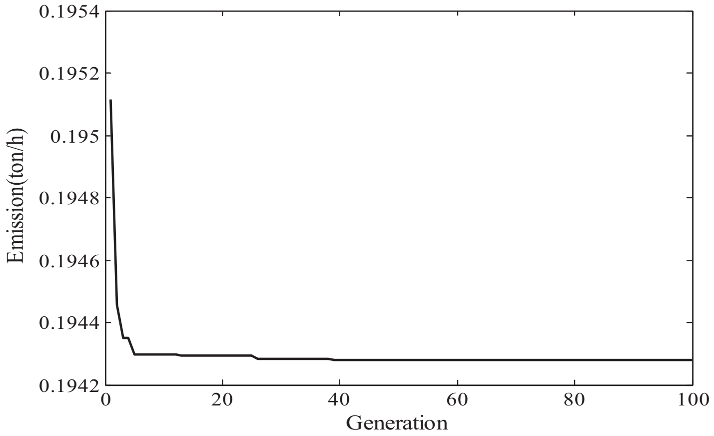

Fig.7 Convergence characteristic for six-unit system: emission minimization

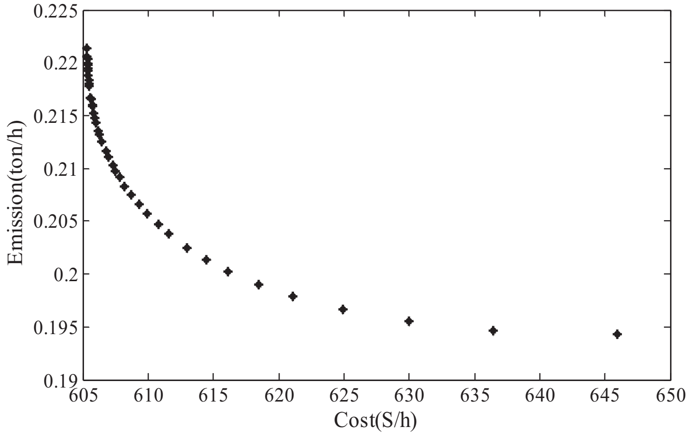

Fig.8. Combined economic emission convergence characteristic; Pareto-optimal front for six-unit system

Table.3.Comparison of the optimisation solution values obtained by different methods

Methods	ω=1.0			ω=0.0		
	Cost ($/h)	Emi (ton/h)	Ploss (MW)	Cost ($/h)	Emi (ton/h)	Ploss (MW)
MNSGA-II+DCD [9]	608.1283	0.2189	3.4548	645.3998	0.1942	3.2894
MNSGA-II[9]	608.1248	0.2199	3.4658	645.4787	0.1942	3.3313
MNSGA-II+DCD+CE [9]	608.1247	0.2198	3.4709	645.6472	0.1942	3.3173
MBFA [23]	607.6700	0.2198	3.2600	644.4300	0.1942	3.2800
FCPSO [23]	607.7860	0.2201	3.3500	642.8964	0.1942	3.0900
IABC [20]	605.4258	0.2209	2.3197	646.0455	0.1942	3.4815
IABC-LS [20]	605.4258	0.2210	2.3200	646.0455	0.1942	3.4815
IABCDP [20]	605.4258	0.2210	2.3191	646.0455	0.1942	3.4815
IABCDP-LS [20]	605.4259	0.2210	2.3200	646.0455	0.1942	3.4815
DBC	**605. 3456**	0.2207	**2.2617**	645.8250	0.1942	3.3949

4.2 *Test system 2*: *forty-unit system.*

In order to investigate the importance of the proposed approach, the algorithm is tested on a large test system. This test system consists of forty units with non-smooth fuel cost and emission level function. The DBC parameters related to this test system are shown in Table 4. The fuel cost and emission rate coefficients of the system are shown in Table 6, transmission loss has not been considered. Total load demand of the system is 10500 (MW). In the first case, the best cost achieved is 121417.00($/h), the corresponding emission is 356480.00 (ton/h), while during the emission optimization stage, the best emission achieved is 176682.90 (ton/h), the corresponding fuel cost increased to 130000.00 ($/h). Figure 9 shows the convergence characteristic of the total cost minimization. The best results of the proposed approach for two cases (fuel cost and emission) compared with other methods are illustrated in Table 5 shows clearly the efficiency of the proposed approach.

Table 4. Parameters of the DBC.

Parameters	*N*	*m*	*e*	*Nem*	*Nes*	*Ngs*	*step*
Value	160	20	5	60	40	60	30

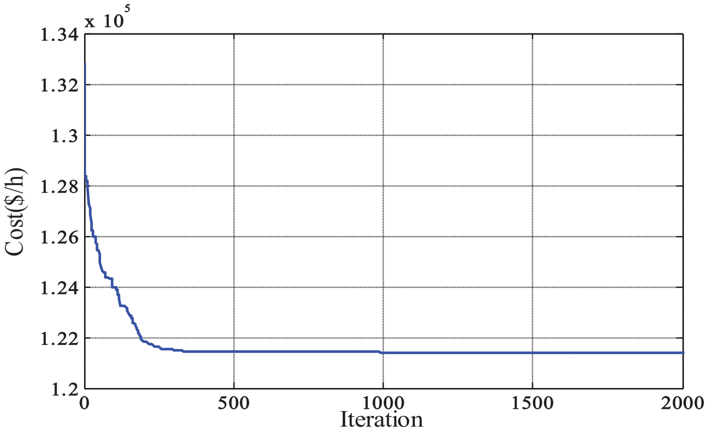

Fig.9.Convergence characteristic for 40 unit system: cost minimization

Table 5.Generation (MW),cost($/h),emission(ton/h), for 40-unit system: Pd =10500MW

Generation	ω=1.0			ω=0.0		
	DBC	DE[**25**]	HMAPSO[**26**]	DBC	DE[**25**]	MBFA[**23**]
G1	111.1591	110.9515	111.136	114.0000	114.0000	114.0000
G2	112.2120	113.2997	111.135	114.0000	114.0000	114.0000
G3	97.4007	98.6155	120.000	119.9997	120.0000	120.0000
G4	179.7341	184.1487	177.221	169.3422	169.2933	169.3671
G5	88.3434	86.4013	88.699	97.0000	97.0000	97.0000
G6	139.9997	140.0000	140.000	124.0863	124.2828	124.2630
G7	259.5996	300.0000	260.157	299.8078	299.4564	299.6931
G8	284.8900	285.4556	284.723	298.0407	297.8554	297.9093
G9	284.6025	297.5110	285.523	297.3179	297.1332	297.2578
G10	130.0016	130.0000	130.000	130.0030	130.0000	130.0007
G11	168.8000	168.7482	168.805	298.2186	298.5980	298.4210
G12	168.8006	95.6950	168.689	297.9521	297.7226	298.0264
G13	214.7599	125.0000	304.123	433.6722	433.7471	433.5590
G14	394.2794	394.3545	304.678	421.6718	421.9529	421.7360
G15	304.5198	305.5234	304.317	422.4145	422.6280	422.7884
G16	394.2792	394.71147	304.317	423.0113	422.9508	422.7841
G17	489.2796	489.7972	489.187	439.3258	439.2581	439.4078
G18	489.2796	489.3620	489.455	439.3993	439.4411	439.4132
G19	511.2797	520.9024	512.097	439.1740	439.4908	439.4111
G20	511.2805	510.6407	511.349	439.2771	439.6189	439.4155
G21	523.2805	524.5336	523.247	439.6522	439.2250	439.4421
G22	523.2814	526.6981	523.515	439.3394	439.6821	439.4587
G23	523.2857	530.7467	523.454	439.8210	439.8757	439.7822
G24	523.2798	526.3270	523.453	439.6367	439.8937	439.7697
G25	523.2800	525.6537	523.492	440.1316	440.4401	440.1191
G26	523.2803	522.9497	523.307	440.4029	439.8408	440.1219
G27	10.0027	10.0000	10.000	29.0831	28.7758	28.9738
G28	10.0008	11.5222	10.000	29.0527	29.0747	29.0007

G29	10.0003	10.0000	10.000	29.0411	28.9047	28.9828
G30	88.4221	89.9076	88.691	97.0000	97.0000	97.0000
G31	189.9998	190.0000	190.000	172.3484	172.4036	172.3348
G32	189.9997	190.0000	190.000	172.2801	172.3956	172.3327
G33	189.9997	190.0000	190.000	172.4102	172.3144	172.3262
G34	165.1811	198.8403	164.218	200.0000	200.0000	200.0000
G35	165.7524	174.1783	200.000	200.0000	200.0000	200.0000
G36	165.1722	197.1598	200.000	200.0000	200.0000	200.0000
G37	109.9999	110.0000	110.000	100.8796	100.8765	100.8441
G38	109.9998	109.3565	110.000	100.8725	100.9000	100.8346
G39	109.9996	110.0000	110.000	100.8785	100.7784	100.8362
G40	511.2810	510.9752	511.009	439.4557	439.1894	439.3868
Cost($/h)	**121417,00**	121800.00	121586.90	130000,00	125730.00	129995.00
Emi(ton/h)	356480,00	374790.00	NR	**176682.90**	176680.00	176682.26

NR means not reported in the referred literature.

5 Conclusion

In this paper, a flexible and efficient variant-based bee colony named dance bee colony with dynamic step size adjustment has been successfully adapted and applied for solving multi objective economic emission dispatch considering valve point effect and total transmission losses. The robustness of the proposed approach has been tested and validated on two standard test systems, IEEE 30-Bus considering power losses and to the large test system with 40 units considering valve point effect. It is observed that the proposed variant is capable to enhancing the solution of the combined economic emission dispatch considering practical generator constraints.

6 Appendix:

Table 6. six-unit generator characteristics [20]

Unit	a_i	b_i	c_i	d_i	e_i	γ_i	β_i	α_i	η_i	δ_i	P_{min}	P_{max}
1	10	200	100	-	-	0.04091	-0.05554	0.0649	0.000200	2.857	5	10
2	10	150	120	-	-	0.02543	-0.06047	0.05638	0.000500	3.333	5	150
3	20	180	40	-	-	0.04258	-0.05.094	0.04586	0.000001	8.000	5	150
4	10	100	60	-	-	0.05326	-0.03550	0.03380	0.002000	2.000	5	150
5	20	180	40	-	-	0.04258	-0.05094	0.04586	0.000001	8.000	5	150
6	10	150	100	-	-	0.06131	-0.05555	0.05151	0.000010	6.667	5	150

Table 7.40-unit generator characteristics [8].

Unit	a_i	b_i	c_i	d_i	e_i	γ_i	β_i	α_i	η_i	δ_i	P_{min}	P_{max}
1	94.705	6.73	0.00690	100	0.084	0.0480	2.22	60	1.3100	0.05690	36	114
2	94.705	6.73	0.00690	100	0.084	0.0480	2.22	60	1.3100	0.05690	36	114
3	309.540	7.07	0.02028	100	0.084	0.0762	2.36	100	1.3100	0.05690	60	120
4	369.030	8.18	0.00942	150	0.063	0.0540	3.14	120	0.9142	0.04540	80	190
5	148.890	5.35	0.01140	120	0.077	0.0850	1.89	50	0.9936	0.04060	47	97
6	222.330	8.05	0.01142	100	0.084	0.0854	3.08	80	1.3100	0.05690	68	140
7	287.710	8.03	0.00357	200	0.042	0.0242	3.06	100	0.6550	0.02846	110	300
8	391.980	6.99	0.00492	200	0.042	0.0310	2.32	130	0.6550	0.02846	135	300
9	455.760	6.60	0.00573	200	0.042	0.0335	2.11	150	0.6550	0.02846	135	300
10	722.820	12.90	0.00605	200	0.042	0.4250	4.34	280	0.6550	0.02846	130	300
11	635.200	12.90	0.00515	200	0.042	0.0322	4.34	220	0.6550	0.02846	94	375
12	654.690	12.80	0.00569	200	0.042	0.0338	4.28	225	0.6550	0.02846	94	375
13	913.400	12.50	0.00421	300	0.035	0.0296	4.18	300	0.5035	0.02075	125	500
14	1760.400	8.84	0.00752	300	0.035	0.0512	3.34	520	0.5035	0.02075	125	500
15	1728.300	9.15	0.00708	300	0.035	0.0496	3.55	510	0.5035	0.02075	125	500
16	1728.300	9.15	0.00708	300	0.035	0.0496	3.55	510	0.5035	0.02075	125	500
17	647.850	7.97	0.00313	300	0.035	0.0151	2.68	220	0.5035	0.02075	220	500
18	649.690	7.95	0.00313	300	0.035	0.0151	2.66	222	0.5035	0.02075	220	500
19	647.830	7.97	0.00313	300	0.035	0.0151	2.68	220	0.5035	0.02075	242	550
20	647.810	7.97	0.00313	300	0.035	0.0151	2.68	220	0.5035	0.02075	242	550
21	785.960	6.63	0.00298	300	0.035	0.0145	2.22	290	0.5035	0.02075	254	550
22	785.960	6.63	0.00298	300	0.035	0.0145	2.22	285	0.5035	0.02075	254	550
23	794.530	6.66	0.00284	300	0.035	0.0138	2.26	295	0.5035	0.02075	254	550
24	794.530	6.66	0.00284	300	0.035	0.0138	2.26	295	0.5035	0.02075	254	550
25	801.320	7.10	0.00277	300	0.035	0.0132	2.42	310	0.5035	0.02075	254	550

26	801.320	7.10	0.00277	300	0.035	0.0132	2.42	310	0.5035	0.02075	254	550
27	1055.100	3.33	0.52124	120	0.077	1.8420	1.11	360	0.9936	0.04060	10	150
28	1055.100	3.33	0.52124	120	0.077	1.8420	1.11	360	0.9936	0.04060	10	150
29	1055.100	3.33	0.52124	120	0.077	1.8420	1.11	360	0.9936	0.04060	10	150
30	148.890	5.35	0.01140	120	0.077	0.0850	1.89	50	0.9936	0.04060	47	97
31	222.920	6.43	0.00160	150	0.063	0.0121	2.08	80	0.9142	0.04540	60	190
32	222.920	6.43	0.00160	150	0.063	0.0121	2.08	80	0.9142	0.04540	60	190
33	222.920	6.43	0.00160	150	0.063	0.0121	2.08	80	0.9142	0.04540	60	190
34	107.870	8.95	0.00010	200	0.042	0.0012	3.48	65	0.6550	0.02846	90	200
35	116.580	8.62	0.00010	200	0.042	0.0012	3.24	70	0.6550	0.02846	90	200
36	116.580	8.62	0.00010	200	0.042	0.0012	3.24	70	0.6550	0.02846	90	200
37	307.450	5.88	0.01610	80	0.098	0.0950	1.98	100	1.4200	0.06770	25	110
38	307.450	5.88	0.01610	80	0.098	0.0950	1.98	100	1.4200	0.06770	25	110
39	307.450	5.88	0.01610	80	0.098	0.0950	1.98	100	1.4200	0.06770	25	110
40	647.830	7.97	0.00313	300	0.035	0.0151	2.68	220	0.5035	0.02075	242	550

Table 8 .B coefficients matrix [20]

$$[B_{00}] = 0.00098573$$

$$[B_0] = 10^{-2} \times [-1.07 \quad 0.60 \quad -0.17 \quad 0.09 \quad 0.02 \quad 0.30]$$

$$[B] = 10^{-2} \times \begin{bmatrix} 13.82 & -2.99 & 0.44 & -0.22 & -0.10 & -0.08 \\ -2.99 & 4.87 & -0.25 & 0.04 & 0.16 & 0.41 \\ 0.44 & -0.25 & 1.82 & -0.70 & -0.66 & -0.66 \\ -0.22 & 0.04 & -0.70 & 1.37 & 0.50 & 0.33 \\ -0.10 & 0.16 & -0.66 & 0.50 & 1.09 & 0.05 \\ -0.08 & 0.41 & -0.66 & 0.33 & 0.05 & 2.44 \end{bmatrix}$$

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