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Deregulated Multi-Objective Economic Load Dispatch using Cuckoo Search Algorithm

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Abstract

The recent trends in electrical system requires the deregulated environment where private players are involved in the supply of electricity. The cost of the energy is based on the manufacturer. So there a deregulation needed where to reduce the bidding prize. To minimize the bidding prize here the seller has to maintain few constraints also. One of the main constraints in power transmission are losses. So, cost of economic dispatch and minimization and power system balance like generated power subtracted with loss and demand should be minimum. Here these two objectives are taken as the multi-objective function and minimized using Particle swarm optimization (PSO), Genetic Algorithm (GA), Differential Evolution (DE) and Cuckoo Search Algorithm (CSA) are used and results are compared. The test systems are 3-seller and 8-seller system.

Keywords: *Particle swarm optimization, genetic algorithm, differential evolution, cuckoo search algorithm, deregulation*

1. Introduction

The economic dispatch problems can be solved in many methods. The meta-heuristic or stochastic search methods are used in many literatures, like genetic algorithms (GA), particle swarm optimization (PSO), simulated annealing (SA), evolutionary programming (EP), shuffled frog leap algorithm (SFLA), bacterial foraging algorithm (BFA), artificial bee colony algorithm (ABC), harmony search algorithm (HSA), firefly algorithm (FA), cuckoo search (CSA) and even more. But the results of each algorithm move to the optimal solution.

In 1993 Walters D.C has proposed that genetic algorithm is used to solve the economic dispatch problem with valve point effect and compared it with the dynamic programming. In 2003 Sinha N has presented economic load dispatch problem solution with evolutionary programming (EP). The results of EP are still enhanced by including some factors, which are newly derived. In 2004 T. Aruldoss Albert Vectoire has presented a hybrid particle swarm optimization with sequential quadratic programming and proved for better solution in economic load dispatch problem. In 2006 dos Santos Coelho L has discussed about the hybrid differential evolution with sequential quadratic programming for better results. Ji-Pyng Chiou in 2007 has presented variable scale differential evolution methods for improving the solutions. Wang in 2008 has proposed hybrid genetic algorithm with differential algorithm, and sequential quadratic programming to fine tune the genetic algorithm parameters. And for the first-time auction based economic dispatch is solved by differential algorithm by Swain RK.

In 2013 cuckoo search algorithm is compared with six of the new algorithms and proved it gives best results without any complex hybridization. Cuckoo search is invented in 2011 by Xin She Yang. While on multiple run the algorithms are not giving exact 100% result is identified and solved using cuckoo. In this paper auction based economic dispatch is evaluated using cuckoo search algorithm for the first time and compared for 10 runs with PSO, GA and DE. The CSA always converges nearer to solution in 10 runs while not other algorithm performs it. The test is made with the 3 seller and 8 seller system and results are tabulated and graphed.

The comparative study of 3-seller and 8-seller system with multi-objective is presented in this paper and the problem is defined in next section. The work carried out is the extension of [14].

2. Problem Definition

The seller cost is assumed as thermal power system and the incremental cost function is taken as the bidding cost. So the bidding cost function can be represented as below [6,14],

$$F_i(P_{gi}) = a_i + b_iP_{gi} + c_iP_{gi}^2 \quad (1)$$

Incremental cost is defined of the bidden cost function,

$$IC_i(P_{gi}) = b_i + 2c_iP_{gi} \quad (2)$$

The economic dispatch problem for deregulated environment can be defined as follows,
Cost function,

$$F1 = \sum_{i=1}^{n} F_i(P_{gi}) \quad (3)$$

Power system load and generation balance

$$F2 = \sum_{P_{gi}}^{N_g}(P_{gi} - P_d - P_l) \quad (4)$$

Multi-objective function,
Minimize F = F1+F2 (5)

$$P_{i\,min} < P_{gi} < P_{i\,max}\ ,\quad i \in [1, N_g] \quad (6)$$

When $\sum_{i=1}^{N_g} P_{i\,min} > P_d$ or $\sum_{i=1}^{N_g} P_{i\,max} = P_d$, there is no feasible solution,

When $\sum_{i=1}^{N_g} P_{i\,min} = P_d$, each seller is contracted amount is at its capacity lower limit.

When $\sum_{i=1}^{N_g} P_{i\,min} < P_d$ and $\sum_{i=1}^{N_g} P_{i\,min} > P_d$ is a non-trivial case.

Here,

$F_i(P_{gi}) -$ cost of generator i

$P_{gi} -$ Power in MW of i^{th} generator

$a_i, b_i, c_i -$ constant co − ordinate

$P_{i\,min}, P_{i\,max} -$ minimum and maximum limits of i^{th} generator

$P_d -$ Power demand in MW

$n, N_g -$ Number of generators

$P_l -$ Power in MW of i^{th} generator

With all the above constraints deregulated power system problem is formulated [6].

3. Solutions Methods Used

3.1 Particle Swarm Optimization (PSO) [12]

The particle swarm optimization is a simple stochastic search method

Inspired from the nature behavior. The algorithm is done with the behavior of insects on its food searching behavior. Steps of the algorithm are given below.

i) The size of the swarm (control variable 'X' (generated power P_g)) is initialized as N.

ii) Initial population of X is given as within the power limit. And initial velocity of the particle (V_j) is taken as zero.

iii) Calculate the fitness (Cost of the fuel (F)) for each population. And find the new velocities. Then increment the iteration count.

iv) The fitness values for each population are assigned to the personal best (P_{best}) of its own X value. Then the X value which is responsible for the lower cost value is taken as global best (G_{best}). Then velocity function is calculated using the following equation,

$$V_j(i) = V_j(i-1) + c_1r_1[P_{bestj} - X_j(i-1)] + c_2r_2[G_{best} - X_j(i-1)] \quad (6)$$

where, $j = 1,2,\ldots,N$ here,
$c1, c2$ are cognitive and social learning rates taken 2
$r1, r2$ are uniformy distributed randoms in range 0 and 1

v) Then the X value is updated with the following equation

$$X_j(i) = X_j(i-1) + V_j(i) \quad (7)$$

vi) Then go to step three and do it until the stop criteria. Here total number of iteration is stopping criteria. The final G_{best} value is the final result.

3.2 Genetic Algorithm (GA)

Genetic algorithm is inspired by the genetic behavior in the human. This is also population-based search method like particle swarm optimization. The solution steps are given below [12].

Total number of populations is fixed (N). And the initial population for X (control variable) is initialized with the limits given.

Each population string is evaluated with its fitness value (bidding cost).

The X value is passed through three cycles.

Reproduction: It is used to select the good strings from the mating pool.

It copies the characteristic of good string and multiples the copies in the mating pool using probabilistic proportion to its fitness. The formula used is

$$p_i = \frac{F_i}{\sum_{j=1}^{n} F_j};\ \text{Where } i = 1,2,\ldots,n. \quad (8)$$

Crossover: This operation creates the new strings based on the data available on the mating pool.

Mutation: It alters the strings locally to get best of it.

Evaluate the fitness values.

Test for convergence. Here it is taken as the final iteration count.

Increment the iteration count and go to step three.

3.3 Deferential Evolution Algorithm (DE)

The DE algorithm has much similarity with the genetic algorithm.

It is also a stochastic search method for solving complex problems [6].

i) The number of populations is initialized and control variable (X) also.

ii) Evaluate the fitness value.

iii) Then mutation operator creates mutant vectors with X variables.

iv) Crossover vector generates trial vector by mixing the parameters of the mutant vector with selected probability distribution.

v) The selection is made with the trial vectors and their predecessors.

vi) Go to step (ii). This is done till the stopping criteria reached.

3.4 Cuckoo Search Algorithm (CSA)

The Cuckoo search algorithm is based on the cuckoo bird on behavior of its breeding. The cuckoo bird can't build the nest. It depends on the host bird nest for laying eggs and hatching it. But host bird nest not allows to do so. It may abandon the nest or it may damage the cuckoo birds' eggs. But cuckoo lays eggs similar to the host bird and if it hatches the cuckoo chicks mimic the sound of the host bird. So finding the best nest to survive the cuckoo birds makes a search that is represented as the mathematical equation steps are following.

i) Generate the initial population with X variable of n host nests.

ii) The cuckoo is selected randomly by levy flights equation, then evaluate the fitness.

iii) Choose the nest among n randomly and compare with the fitness initially calculated. If the new solution fits then replace with the old one.

iv) Remaining fraction of (pa) nests is abandoned and best nest are kept.

v) Rank the current solution and find the best X value.

vi) Increment the iteration count and go to step (ii).

Do it till the last iteration count.

4. Results and Discussion

The results cases are split as two. Case (i) is with 3 seller system [6] and case (ii) is 8 seller system [6].

Case (i)

The three-seller system is taken as test system in these solution algorithms. The loss formula is used for loss calculation to solve F2 equation. PSO, GA, DE and CSA are chosen for getting the optimal cost value. Fig .1 shows the results of 10 runs with respect to fitness value with PSO. The deviation can be seen in the figure clearly. It deviates from $9150 to 9160. Fig.2 shows the same results of GA there are lesser deviations compared to PSO algorithm. Fig. 3 shows the results of DE. Here its deviation is more compared to GA and lesser compared to PSO. Fig.4 shows the results of CSA. Here comparatively it gives lesser deviation with all the other algorithms. Table 1-4 shows the final generation values (B1 to B3), fitness equations (F1, F2) of each algorithm in all the 10 runs.

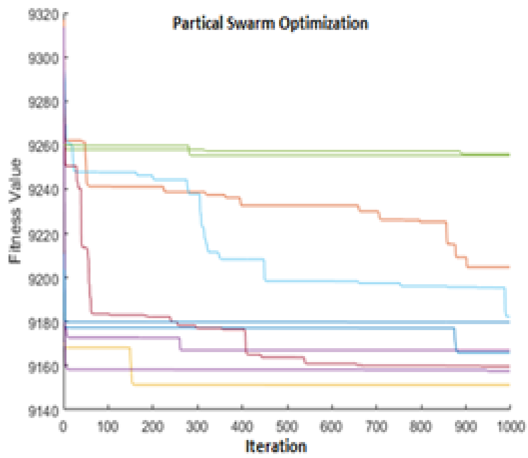

Figure 1: Convergence graph-PSO-3seller

Case (ii)

The eight-seller system is taken as test system in these solution algorithms. PSO, GA, DE and CSA are chosen for getting the optimal cost value. As the control variable increases the deviation increases in the entire algorithms. Fig .5 shows the results of 10 runs with respect to fitness value with PSO. The deviation can be seen in the figure clearly. It deviates from $4730 to 4709. Fig.6 shows the same results of GA there are lesser deviations compared to PSO algorithm. Fig. 7 shows the results of DE. Here its deviation is more compared to GA and PSO. Fig.8 shows the results of CSA. Here comparatively it gives lesser deviation with all the other algorithms. So even though control variables are more it gives better results. Table 5-8 shows the final generation value (B1 to B8), fitness equations(F1,F2) of each algorithm in all the 10 runs.

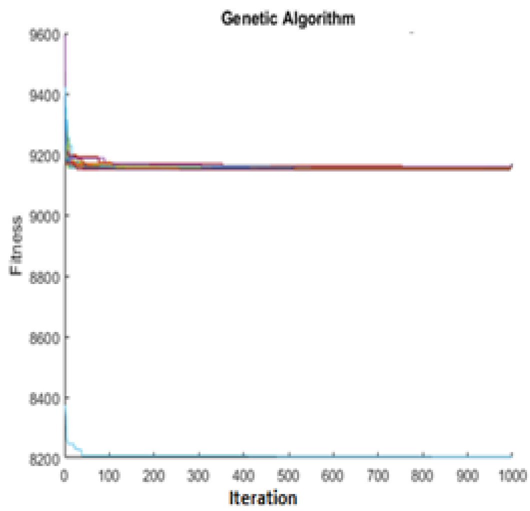

Figure 2: Convergence graph-GA-3seller

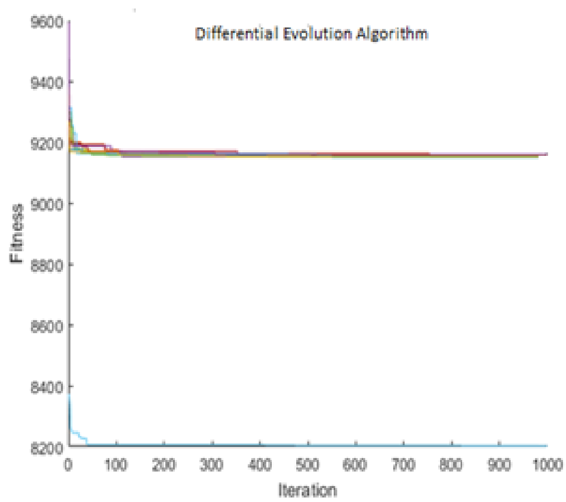

Figure 3: Convergence graph-DE-3seller

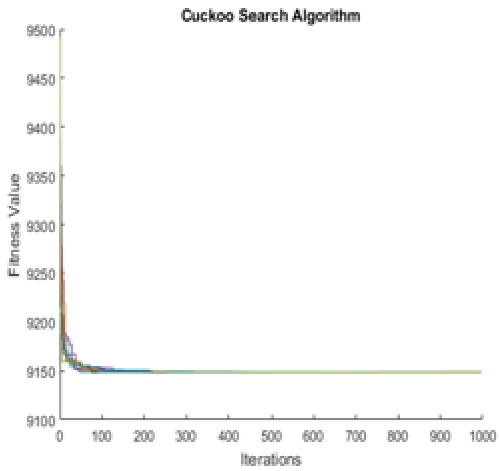

Figure 4: Convergence graph-CSA-3seller

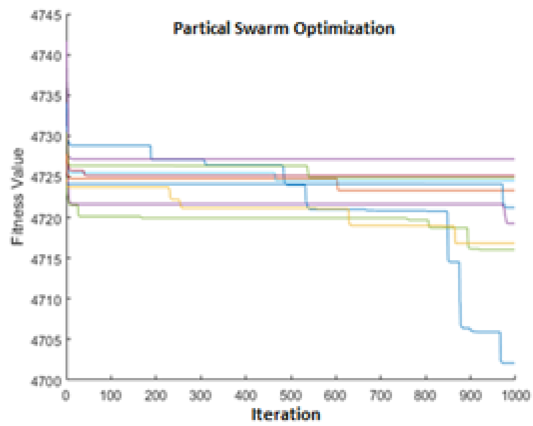

Figure 5: Convergence graph-PSO 8 seller

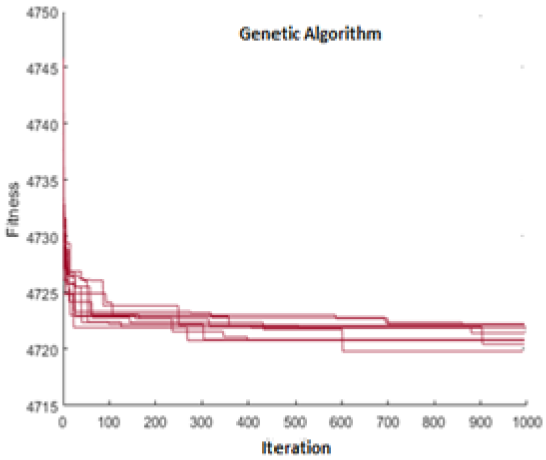

Figure 6: Convergence graph-GA 8 seller

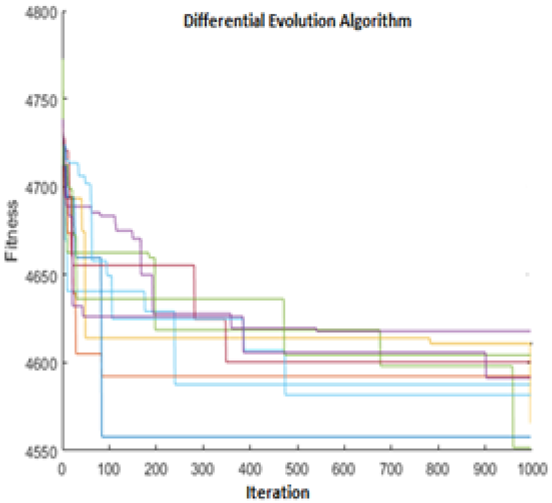

Figure 7 : Convergence graph-DE 8 seller

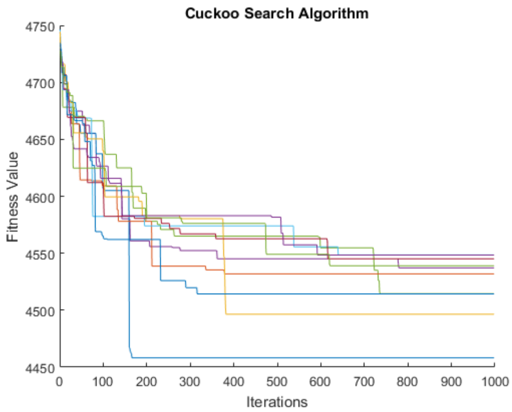

Figure 8: Convergence graph-CSA 8 seller

Table 1: 3 seller system comparisons for 10 runs -PSO algorithm

PSO algorithm					
Run	Power in MW			F1	F2
	B1	B2	B3		
1	373.9976	368.7681	209.2608	9167.071	0
2	305.0119	366.161	271.7205	9165.961	0
3	228.5528	382.6872	327.4867	9255.941	0
4	361.9966	410.0769	184.9247	9204.72	2.90E-07
5	438.0801	261.9145	248.179	9182.34	3.48E-08
6	345.4727	330.4532	267.2072	9151.262	0
7	319.2636	346.9465	275.9017	9159.676	1.54E-07
8	324.3642	367.6697	253.1732	9157.5	0
9	409.4653	350.109	195.2429	9179.83	0
10	299.6858	467.2248	191.3166	9255.227	0

Table 2: 3 seller system comparisons for 10 runs -GA algorithm

GA algorithm					
Run	Power in MW			F1	F2
	B1	B2	B3		
2	366.5414	320.7389	257.3013	9149.262	0.002266
3	361.6295	336.6921	247.5097	9149.585	0.013219
4	350.4475	338.0459	256.1053	9149.54	0.005047
5	352.2328	333.0721	258.913	9150.253	0.012909
6	355.3011	327.8851	260.8224	9149.599	0.003134
7	364.8776	323.851	256.0178	9150.688	0.018136
8	352.908	335.0107	256.6283	9149.211	0.003137
9	360.3907	335.1883	249.9214	9148.443	0.001506
10	355.2878	330.8503	258.2153	9149.615	0.006839

Table 3: 3 seller system comparisons for 10 runs -DE algorithm

DE algorithm					
Run	Power in MW			F1	F2
	B1	B2	B3		
1	363.6634	330.8113	250.9216	9148.751	0.004654
2	354.2163	347.0402	244.9531	9151.086	0.013108
3	377.2818	321.3223	247.4726	9152.835	0.031976
4	371.4942	336.3416	239.2784	9149.774	0.002122
5	375.1628	322.0265	248.6274	9150.959	0.02222
6	377.7573	322.7951	245.6529	9155.116	0.06578
7	361.239	331.2802	252.6088	9149.042	0.008778

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8	387.1935	314.779	244.6618	9153.657	0.021918
9	331.1529	361.3728	252.707	9159.064	0.040345
10	347.8248	343.8474	253.2878	9151.76	0.025147

Table 4: 3 seller system comparisons for 10 runs -CSA algorithm

Cuckoo Search algorithm					
Run	Power in MW			F1	F2
	B1	B2	B3		
1	364.65	326.82	253.57	9148.4	0.00038
2	367.06	328.21	250.25	9148.3	0.000202
3	366.4	332.8	246.79	9148.4	0.000561
4	357.63	334.48	252.96	9148.4	0.000272
5	365.95	332.89	247.11	9148.4	0.000568
6	359.5	332.03	253.48	9148.5	0.001242
7	356.39	332.29	255.97	9148.6	0.000668
8	366.04	329.04	250.41	9148.4	0.001393
9	360.05	331.98	253.04	9148.5	0.001815
10	361.2	334.87	249.5	9148.4	0.001034

Table 5: 8 seller system comparisons for 10 runs -GA algorithm

Geneticalgorithm										
Run	Power in MW								F1	F2
	B1	B2	B3	B4	B5	B6	B7	B8		
1	35.7278	57.9613	63.3283	27.9388	22.2834	98.1808	98.9346	98.323	4720.78	0.00513
2	91.8826	31.9825	24.5734	23.1356	79.6336	99.408	95.2248	56.8498	4720.81	0.00625
3	38.1889	86.4277	97.7732	52.5483	95.8646	22.119	85.6423	24.1354	4722.23	0.01526
4	94.1452	27.0077	97.4841	39.3527	97.4952	54.7394	21.8384	70.6012	4721.88	0.01008
5	99.8694	46.5469	59.5531	39.913	98.3363	20.5956	95.755	41.1166	4721.43	0.00083
6	55.0575	24.9121	97.4872	97.7233	92.3837	26.0608	21.6743	87.3658	4720.44	0.01838
7	28.3846	21.7704	99.1845	45.1068	34.9021	77.5194	97.6881	98.141	4720.85	0.01273
8	59.1697	97.2385	58.3822	22.8756	99.6902	29.9274	38.947	96.4642	4722.2	0.01064
9	87.8803	96.5209	98.7775	44.9007	21.4838	25.1866	95.0179	32.9262	4719.81	0.0099
10	59.9378	61.07	90.3093	24.7023	97.7559	99.3317	49.1272	20.4416	4722.13	0.00825

Table 6: 8 seller system comparisons for 10 runs -PSO algorithm

PSO algorithm										
Run	Power in MW								F1	F2
	B1	B2	B3	B4	B5	B6	B7	B8		
1	69.2203	25.6723	103.485	88.7888	92.0499	78.3456	22.7505	22.3721	4719.29	0
2	31.2401	38.0554	46.8044	136.364	26.6162	146.076	3.95934	73.5687	4702.09	0
3	60.0537	104.998	88.258	25.2807	77.5359	109.3	23.4584	13.7996	4716.03	0
4	88.2364	91.1828	67.9707	42.1575	96.5958	29.5394	61.4018	25.5997	4723.27	0
5	30.0546	78.1237	94.5122	26.4334	82.305	74.68	75.1388	41.4365	4724.48	0
6	111.992	76.9711	92.7778	71.4838	17.9786	51.2789	78.1524	2.05	4716.83	0
7	75.2855	97.848	78.2767	37.8402	56.9512	73.7716	17.9461	64.7644	4725.04	0.00022
8	57.5792	21.9233	49.1984	55.8823	79.2821	81.6041	77.62	79.5948	4727.14	0
9	91.5522	96.2731	24.0321	76.8806	49.2427	50.5674	19.7269	94.409	4721.24	0
10	51.9795	102.186	63.1334	54.8204	43.0455	65.9199	26.2404	95.3593	4724.85	0

Table 7: 8 seller system comparisons for 10 runs -DE algorithm

DEalgorithm										
Run	Power in MW								F1	F2
	B1	B2	B3	B4	B5	B6	B7	B8		
1	14.1286	368.763	27.2444	33.3407	1.42464	18.1918	38.727	1.06239	4587.57	0.23226
2	19.9373	6.43639	34.4301	13.2166	384.364	17.2118	23.5399	3.5643	4551.56	0.05089
3	15.7748	0.82698	35.5161	18.3832	65.034	2.33742	27.9066	336.604	4617.87	0.26694
4	1.47202	7.50812	19.9187	24.4393	20.8069	21.1751	377.552	29.6527	4565.48	0.12539
5	1.73736	338.428	52.0271	3.86902	70.8474	17.8721	9.78851	8.10917	4592.28	0.02819
6	12.3197	11.7518	6.98318	21.9096	30.5352	24.2615	381.134	13.6725	4557.72	0.08231
7	5.23742	53.4661	8.30599	26.524	40.2285	10.8965	334.596	23.4289	4600.4	0.03306
8	356.05	13.8195	22.6671	13.7686	18.6463	8.36153	45.4342	23.8511	4581.56	0.05159
9	24.5685	13.2822	13.2689	7.58312	4.70024	24.6366	329.293	85.2455	4604.28	0.07152
10	356.402	20.8308	6.80646	3.53413	8.08645	20.7325	29.5994	56.4774	4591.35	0.18103

Table 8: 8 seller system comparisons for 10 runs -CSA algorithm

Cuckoo Search algorithm										
Run	Power in MW								F1	F2
	B1	B2	B3	B4	B5	B6	B7	B8		
1	1.52284	15.4783	1.23965	23.6321	51.3796	7.5507	391.482	10.4041	4537.16	0.00886
2	11.2434	0.01171	454.788	2.31193	5.8467	4.61882	0.38421	23.4861	4458.17	0.01081
3	6.68034	4.39492	5.92427	7.90208	411.618	40.7719	8.28048	17.0949	4514.47	0.01413
4	0.42714	14.8472	14.1676	38.5631	2.74473	1.56685	395.612	34.7512	4531.92	0.00047
5	387.439	23.246	3.47597	12.1416	1.45296	15.2646	37.5805	22.137	4548.48	0.05698
6	19.7343	20.5094	426.848	7.155	1.46383	6.84695	2.32234	17.8163	4496.43	0.01596
7	6.24561	4.385	17.1144	0.88103	384.127	1.11948	54.5273	34.2933	4545.1	0.01282
8	13.1495	19.1925	32.9751	21.2767	7.34888	384.373	23.1293	1.25535	4548.41	0.01971
9	3.96065	9.45482	4.81303	17.2649	0.57154	19.6214	35.2689	411.735	4514.28	0.00983
10	12.8876	0.16394	3.79984	46.288	3.97898	11.5891	23.2935	400.537	4539.04	0.14243

5. Conclusion

The economic load dispatch with deregulated power system with multi-objective is solved for four different algorithms to identify the best algorithm. For this 3-seller and 8-seller test systems are taken. The 3-seller system has three-control variable and 8-seller has 8-control variable. Here many meta-heuristic algorithms like PSO, GA, DE and CSA algorithms are used and for different run the final solution varied by some percent. Here CSA algorithm gives always-same results while running 10 times. But other algorithms give deviation in each run. When it is applied to 8-seller system CSA also deviates but it gives minimum value compared to other three algorithms.

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