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Artificial Bee Colony Optimisation for Economc Load Dispatch of a Modern Power system

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Abstract— This paper deals with optimization of fuel cost of coal fired generators of a modern power sytem. The conventional method of solving economic load dispatch (ELD) uses Newton Raphson, Gauss and Gauss Siedel techniques whose time of computation increases exponentially with the size. Inorder to overcome the dreawbacks of conventional methods, Artificial Intelligent (AI) techniques likes like Genetic Algorithm (GA), Nueral Networks (NN), Artificial Immune systems (AIS) and Fuzzy Logics etc… are used. One such AI technique used is Artificial Bee Colony optimization (ABC) inspired from the foraging behaviour of bees. The ABC is applied for ELD and compared with the other AI techniques. The results show that ABC promises global minimum of the solution while others may land in local minimum.

Index Terms— Artificial bee colony, Artificial intelligent techniques, Economic load dispatch, Genetic Algorithm, Power systems

1 Introduction

Artificial Bee Colony optimization algorithms are formulated on the basis of natural foraging behaviour of honey bees. ABC was first developed by Dr.Korba. Some artificial ideas are added to construct a robust ABC .Very unlike to classical search and optimization methods ABC starts its search with a random set of solutions (Colony size), instead of single solution just like GA. Each population member is then evaluated for the given objective function and is assigned fitness.The best fits are entertained for next generation while the others are discarded and compensated by a new set of random solutions in each generation. The only stopping criterion is the completion of maximum no of cycles or generations. At the end of cycles the solutions with best fit is the desired solution.

Economic Load Dispatch (ELD) is one of the important optimization problems in modern Energy Management Systems (EMS). ELD determines the optimal real power settings of generating units in order to minimize total fuel cost of thermal plants. Various mathematical programming methods and optimization techniques have previously been applied for solution of ELD. These include Lambda iteration method, participation factors method and gradient methods. ELD problems in practice are usually hard for traditional mathematical programming methodologies because of the equality and inequality constraints.

ABC is applied for solution of ELD.A generating unit based encoding scheme is used, however when applied to large size systems, the number of maximum iterations or generations has to be increased proportinally.The solution time grows approximately linearly with problem size rather than geometrically.

2 ECONOMIC LOAD DISPATCH

2.1 Problem Formulation

The objective of Economic Load Dispatch (ELD) for power system consisting of coal fired thermal generating units is to find the optimal combination of power generations that minimizes the total fuel cost for generation while satisfying the specified equality and inequality constraints. The fuel cost function of the generator is modeled as a quadratic function of generator active powers (P). The minimization function 'A' can be obtained as sum of the fuel costs F_i of all the generating units.

$$\text{Min } A = \sum F_i \quad \forall\, i \in (1, 2, 3\ldots, NG) \tag{1}$$

Subjected to

$$\sum P_{Gi} = P_D + P_{loss} \quad \forall\, i \in (1, 2, 3\ldots, NG) \tag{2}$$

$$P_{Gimin} \le P_{Gi} \le P_{Gimax} \quad \forall\, i \in (1, 2, 3\ldots, NG) \tag{3}$$

The fuel cost of generating unit is given by

$$F_i = (a_i + b_i P_i + c_i P_i^2) \tag{4}$$

Where a_i, b_i, c_i are cost coefficients of generating unit i, P_i or P_{Gi} is real power generation of unit 'i'. P_D is the total demand and P_{loss} represents the transmission losses. P_{Gimin} and P_{Gimax} are the minimum and maximum generation limits of i^{th} unit.

This is a constrained optimization problem that may be solved using calculus methods that involve Legrange function. The necessary condition for the minimization of fuel cost is that the incremental cost rates of all the units be equal to some undetermined value Lambda (λ). Along with the above condition, the equality constraint, the sum of the power outputs must be equal to the combined power demand and losses. If transmission system losses are neglected, the equality constraint becomes, the sum of the power outputs must be equal to the total power demand by the load. Also, the power output of each unit must be with in its generation range.

2.2 Transmission system Losses

Since always transmission losses are involved with a network, in order to achieve exact ELD, transmission system losses must be taken into account.Using B-coefficients method, the network losses are expressed as a quadratic function of unit generations as

$$P_{loss} = \Sigma\Sigma P_i B_{ij} P_j \quad \forall\, i,j \in [1,2,3, \ldots NG] \tag{5}$$

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In (5) B_{ij} are called as B-coefficients or loss coefficients which are constant under certain assumed conditions. The above loss formula is known as the George's formula.

3 Artificial Bee Colony Foraging Behaviour

To find the optimal decision variables, to optimize an objective function and to satisfy the constraints, the variables are bounded to the limits. Eqn. (6) gives a function defined to [1] take care of variable bounds.

3.1) Random solution generation

Food sources which are in their proximity are selected by the employed bees when they move to a new location. Each employed bee associated with a food source responsible for nectar extraction from it.

$$P_i = P_{imin} + \text{rand}(0,1) \times (P_{imax} - P_{imin}) \quad (6)$$
$$\forall\, i,j \in [1,2,3, \ldots NG]$$

P_{imin} and P_{imax} are lower and upper bounds of variable P_i. In (6) 'rand (0, 1)' represents a random number between 0 and 1.

$$\sum P_{Gi} = P_D + \Sigma\Sigma P_i B_{ij} P_j \quad \forall\, i \in (1, 2, 3\ldots, NG) \quad (7)$$

1)

Inorder to satisfy the equality constraint, solve for slack bus power (P_{G1}) from the above quadrtic equation and replace it with the randomly choosen P_{G1}.The solution is represented in matrix form as below

$$X_i = [P_1\ P_2\ P_3\ \ P_4\ \ P_5\ \ \ldots\ldots..\ \ P_{ng}] \quad (8)$$

Similarly the Foodsources $[X_1\ X_2\ X_3\ X_4\ \ldots\ldots X_n]$ is the set of all the randomly choosen solutions which satisfies all the defined constraints.

3.2) Evaluation of Fitness of solutions

The food sources are ranked bases on the quality and quantity of their nectar. Similarly Fitness is assigned to each solution, which represents the goodness of each solution.

$$\text{Fitness}(i) = 1/\left(1+\sum F_i\right) \quad \forall\, i \in (1, 2, 3\ldots, NG) \quad (9)$$

$\sum F_i$ from represents the total fuel cost of generation.

3.3) Employed Bee phase

Each solution is handled by an employed bee and the employed bee searches for the food source in their neighbourhood and if a better food source is found it discards its previous food source and starts exploiting the new food source until it explores a better food source.

Similarly a mutant solution is generated for each solution using its randomly selected neighbour and the parameter to be changed.

$[X_1\ \ X_2\ \ X_3\ \ X_4 \ldots\ldots X_n]$ is the solution set where each solution X is represented as

$$X = [P_1, P_2, P_3, P_4, P_5, \ldots\ldots..\ \ P_{ng}]$$

A random variable of all ng variables is chosen and a neighbour of all n-1 neighbours is chosen randomly and a mutant solution is produced as shown below.

$$X_{1mutant} = X_1(i) + (X_j(i) - X_1(i)) * (2*\text{rand} - 1))$$

Where i,j are randomly chosen parameter and neighbour respectively.

A greedy selection between the mutant and original solutions takes place resulting in the discard of least fit solution. This process of selection is repeated for each solution. The solution whose mutant is less fit increases its trial and may lead to dissertation of the food source if the trial leads a threshold limit.

3.4) Onlooker Bee phase

The onlooker bees in the hive detect a food source by means of the information presented to them by the employed foragers. A food source is chosen with the probability which is proportional to its food quality. Different schemes can be used to calculate the probability values. For example

Probability (i) =Fitness (i)/sum (Fitness)
Probability (i) =a*Fitness(i)/max(Fitness)+b where (a+b=1)

A random number is chosen which represents the expectancy of the onlooker bee is compared with probability of a solution (food) if the solution meets the expectancy of the onlooker then it moves to exploit the food source and becomes an employed bee and corresponding employed bee of food source retires . The new employed bee starts exploring the neighbourhood and repeats the employed bee behaviour.

If the expectancy is not reached then the onlooker chooses other food source (solution) with different expectancy until it becomes employed. The above procedure repeats while all the onlooker bees get employed to food source. The food source with highest probability will be chosen maximum and the one with least probability is discarded more times.

3.5) Scout Bee phase

The scout bee is to explore the search area and it is often represented by a randomly generated solution. It will replace an employed bee if its trials of mutation exceed a threshold limit. The scout will encourage the exploration of unexplored area of the search space.

The best solution and fitness values are memorized for every iteration. The above process is repeated for maximum no of iterations and the result at the end will ensure a global minimum or maximum.

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4) Artificial Bee Colony Algorithm

1) Generate n random solutions with in boundaries of the system
   $P = P_{min} + rand*(P_{max} - P_{min})$
2) Calculate the objective function and fitness of each solution
3) Store the best fit as P_{best} solution
4) A mutant solution is formed using a randomly selected neighbour
   $P_{k\,mutant} = P_k(i) + (P_j(i) - P_k(i))*(2*rand - 1))$
   Where j is the randomly selected neighbour and i is a random parameter
5) Replace $P_{k\,mutant}$ by P_k, if the mutant has higher fitness or lower fuel cost of generation.
6) Repeat the above procedure for all the solutions.
7) Probability of each solution is calculated as
   Probability (i) =a*fitness (i)/max (fitness) + b
   Where { a+b =1 }
8) The solution P is selected if its Probability is greater than a random number
   If (rand<probability (i))
   Solution is accepted for mutation
   Else
   Go for next solution
   Counter is Incremented
   While (Counter = population/2)
9) Again the best P is determined
10) Replace a P by random P if its trial counter exceeds threshold
11) Repeat the above for max no of iterations
12) The P_{best} and F (P_{best}) are the best solution and Global min of the objective function.

5) Results

The results of ELD after the implementation of proposed ABC algorithm are discussed and compared with the GA and classical method (lambda iteration). The algorithms are coded in MATLAB to solve ELD problem.The performance is evaluated with losses for three sets of generator data.

Note: All the values of power generation and demand are presented in the units of MW. The Fuel cost coefficients and fuel cost are mentioned in same units for relative comparision. Otherwise mentioned the fuel cost is assumed in INR.

5.1) Three generator test systems

The specifications of three generator test system are detailed in table 5.1(a) and 5.1(b). The power demand is considered to be 300MW.Transmission loss coefficients are given in Table 5.1(c). The results corresponding to Lambda Iteration method, GA, FCGA and ABC are detailed in section 5.1(d).

Unit no	a_i	b_i	c_i
1	0.00525	8.663	328.13
2	0.00609	10.040	136.91
3	0.00592	9.760	59.16

Table 5.1 (a) Cost coefficients of 3 generator system

Limits	P_{Max}	P_{Min}
P1	250	50
P2	150	5
P3	100	15

Table 5.1(b) Max and Min limits of the generators

0.000136	0.0000175	0.000184
0.0000175	0.000154	0.000283
0.000184	0.000283	0.000161

Table 5.1(c) Loss coefficients (B coefficients)

Simulation parameters
1) Colony size (employed bees + onlooker bees) = 20
2) Foodsources = 10
3) Limit=100
4) Max iterations=100

Algorithm	LIM	GA	FCGA	ABC
P_1	202.49	202.464	202.457	202.4705
P_2	81.0267	80.9787	80.9728	80.9742
P_3	27.0149	27.0799	27.0779	27.0817
P_{losses}	10.5311	10.5354	10.5344	10.5364
Error	0.00065	0.012929	0.026841	0.00000
Fuel cost	3615.11	3614.95	3614.79	3615.100

5.2(c) Power generation and fuel costs of 3 gen system.

5.2) IEEE Six generator thirty bus system

The IEEE data of 6 generator 30 bus system is given in Table 5.2(a).This data is used to solve economic dispatch using ABC, [6] GA and AIS algorithm in the MATLAB platform.

Generator	$2*a_i$	b_i	c_i	P_{min}	P_{max}
G1	0.0037	2. 0000	0	50	200
G2	0.0175	1.7500	0	20	80
G3	0.0625	1.0000	0	15	50
G4	0.0083	3.2500	0	10	35
G5	0.0250	3.0000	0	10	30
G6	0.0250	3.0000	0	12	40

Table 5.2(a)) IEEE 30 Bus 6 Generator system data

0.000218	0.000102	0.000010	0.000010	0.000001	0.000027
0.000102	0.000187	0.000004	0.000015	0.000003	0.000031

0.000010	0.000004	0.000430	0.000134	0.000160	0.000108
0.000010	0.000015	0.000134	0.000097	0.000097	0.000051
0.000001	0.000003	0.000160	0.000256	0.000256	0.000000
0.000027	0.000031	0.000108	0.000000	0.000000	0.000359

Table 5.2 (b) Loss Coefficients for IEEE 30 Bus System

Simulation parameters

1) Colony size (employed bees + onlooker bees) = 20
2) Foodsources = 10
3) Limit=100
4) Max iterations=200

P_{demand}	AIS		GA		ABC	
	283.4	350	283.4	350	283.4	350
G1	186.816	195.864	200.000	200.00	174.019	199.95
G2	49.583	40.536	40.860	80.000	51.078	76.0
G3	15.000	15.000	27.168	21.243	26.033	31.79
G4	10.000	10.000	35.000	18.193	10.000	11.84
G5	10.000	10.000	25.235	13.567	10.000	10.00
G6	12.000	12.000	21.735	16.995	12.000	19.697
Cost/hr	767.052	1014.66	767.856	1014.660	726.16441	957.2568

Table 5.2(c) Optimized Fuel cost of a 6 generator system with losses.

From the table 5.2 (c), it is clear that ABC is more robust and ensures a global minimum while AIS and GA ends up in a local minima.

5.3) Thirty eight generator test data

The ABC is applied for a 38 generator system test data with out considering the losses.The generator data is shown below in table 5.3 (a). The results compared with [8] FCGA in table 5.3 (b) shows that ABC ensures global minimum compared to FCGA but at the cost of relatively high compuatational time.

Unit	a_i	b_i	c_i	P_{min}	P_{max}
1	0.3133	796.9	64782	220	550
2	0.3133	796.9	64782	220	550
3	0.3127	795.5	64670	200	500
4	0.3127	795.5	64670	200	500
5	0.3127	795.5	64670	200	500
6	0.3127	795.5	64670	200	500
7	0.3127	795.5	64670	200	500
8	0.3127	795.5	64670	200	500
9	0.7075	915.7	172832	114	500
10	0.7075	915.7	172832	114	500
11	0.7515	884.2	176003	114	500
12	0.7083	884.2	173028	114	500
13	0.4211	1250.1	91340	110	500
14	0.5145	1298.6	63440	90	365
15	0.5691	1298.6	65468	82	365
16	0.5691	12908	77288	120	325
17	2.5881	238.1	190928	65	315
18	3.8734	149.5	285372	65	315
19	3.6842	1269.1	271676	65	315
20	0.4921	696.1	39197	120	272
21	0.5728	660.2	45576	120	272
22	0.3572	803.2	28770	110	260
23	0.9415	818.2	36902	80	190
24	52.123	33.5	105510	10	150
25	1.1421	805.4	22233	60	125
26	2.0275	707.1	30953	55	110
27	3.0744	833.6	17044	35	75
28	16.765	2188.7	81079	20	70
29	26.355	1024.4	124767	20	70
30	30.575	837.1	121915	20	70
31	25.098	1305.2	120780	20	70
32	33.722	716.6	104441	20	60
33	23.915	1633.9	83224	25	60
34	32.562	969.6	111281	18	60
35	18.362	2625.8	64142	8	60
36	23.915	1633.9	103519	25	60
37	8.482	694.7	13547	20	38
38	9.693	655.9	13518	20	38

5.3 (a) 38 Generator system test data

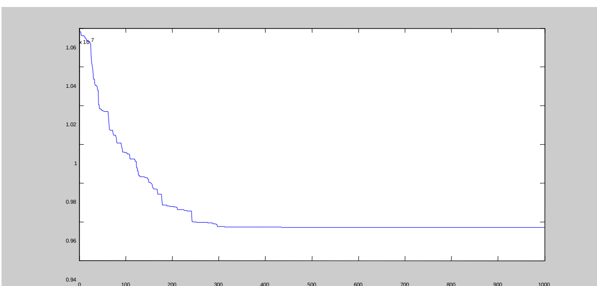
Simulation parameters

1) Colony size (employed bees + onlooker bees) = 20
2) Foodsources = 10
3) Limit=100
4) Max iterations=1000

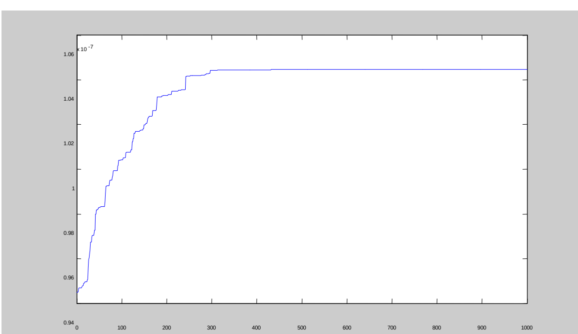
Unit	FCGA	ABC	FCGA	ABC
P_{dem}	7500	7500	8600	8600
1	550	538.0274	550	549.9518
2	550	550.0000	550	550.0000
3	500	550.0000	500	500.0000
4	500	500.0000	500	500.0000
5	500	496.9276	500	499.8397
6	500	498.2321	500	500.0000
7	500	500.0000	500	500.0000
8	500	500.0000	500	00.0000
9	222.9809	500.0000	398.5425	483.8524
10	222.9809	180.5743	398.5425	438.2939
11	230.8836	283.6411	396.1661	490.1684
12	244.9654	110.0000	420.3287	499.9059
13	110	287.2396	272.5453	110.0000
14	90	110.0000	175.9355	90.0000
15	82	90.0000	165.909	80.0000
16	325	80.0000	325	320.0000
17	191.8624	320.0000	239.85	320.0000
18	65	320.0000	65	60.0000
19	65	60.0000	65	60.0891
20	272	60.0000	272	270.0000
21	272	270.0000	272	270.0000
22	260	270.0000	260	259.8940
23	190	259.9791	190	188.8598
24	11.48934	182.4382	13.87236	10.0000
25	125	10.0000	125	130.0000
26	110	102.9404	110	110.0000
27	64.66595	110.0000	70	79.1449

28	20	80.0000	20	20.0000
29	20	20.0001	20	20.0000
30	20	20.0000	20	20.0000
31	20	20.0000	20	20.0000
32	20	20.0000	20	20.0000
33	25	30.0000	25	30.0000
34	18	20.0000	18	20.0000
35	8	10.0000	8	10.0000
36	25	30.0000	25	30.0000
37	31.74845	20.0000	38	20.0000
38	29.78338	20.0000	38	20.0000
Fuel cost (Rs/hr)	10809797.200123	9568643.38898210	12320766.90023	10551436.91004
Time (secs)	0.452	7.213496	0.109	6.420418

5.3 (b) Optimum Fuel cost of 38 generator systems for FGA and ABC



5.3 (c) Plot of Fuel cost Vs number of iterations (P_d= 7500)



5.3 (d) Plot showing Fitness Vs no of iterations (P_d= 7500)

The above plots show the build up of the solution with number of iterations. Once the near global minimum is reached the fitness growth is saturated. The solution for a 38 variable system is obtained in less than 400 iterations where the maximum no of iterations is 1000.

Conclusion

Economic Load dispatch problem being attempted using ABC algorithm for various generator test system evaluates the performance of the proposed approach. Among all Evolutionary Algorithms, ABC is the best method to reach the near Global optimal solution but at the cost of high computational time.. However good choice of the number of iterations, population size, Employed and unemployed bees results in fast computation. ABC can be modified using operators of fast compuational alogrithms to get a hybrid fast computational ABC.

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