Comparative Study to Solution of Economic Load Dispatch - Using Evolutionary Algorithms

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Abstract: Economic load dispatch (ELD) problem is meant to load the online-generators optimally, such that they meet the power demand as well as other constraints such as losses etc..., to which the power system is subjected. To solve ELD optimization we have lot of conventional methods, such as Gradient Search, Lambda Iteration etc. These conventional methods are fast but not that efficient techniques, as they assume the cost curves of the generating units to be piece wise linear functions and hence they are not sufficient for real applications in deregulated market. In reality the cost functions of the generating units is a nonlinear function [1, 2]. With the advent of the high speed computing devices evolutionary algorithms have gained there importance to solve such optimization problems. Firstly Genetic Algorithms (GA) where used, later Particle Swarm Optimization (PSO) has gained prominence and currently Nature Inspired Meta-Heuristic methods such as Cuckoo Search seems to beget best results [5]. A comparative study is held in this paper using the evolutionary algorithms to solve an ELD for a 3 unit and IEEE-30 bus (6 unit) system [17] and best results are achieved using Cuckoo Search Optimization (CSO) [7].

Keywords: Economic dispatch, Particle swarm optimization, Genetic Algorithm; Cuckoo search optimization.

I. INTRODUCTION

Economic Load Dispatch (ELD) is an important optimization problem to schedule the generation among generating units in power system. The main aim of ELD problem is to minimize the operation cost by satisfying the various operational constraints in order meet the load demand. Due to the nonlinear nature of modern generating unit's input-output characteristics and other constraints, the topic of ED problem is still becoming the main research interest in order to find for the better solution.

Many traditional algorithms (Wood and Wollenberg, 1996) [1,2] like lambda iteration, Gradient search, Newton method are applied to optimize ELD problems however in these methods it is assumed that the incremental cost curves of the units are monotonically increasing piecewise linear functions, though the practical systems are nonlinear in nature[3,4]. For such non-linear optimization problems, evolutionary algorithms are not only providing local optimal solutions but also a global optimal solution.

Evolutionary, as the name indicates, which means 'is related' or 'derived from nature' itself and also called 'empirical' methods. GA perhaps is the most popular as well as oldest evolutionary algorithm, which forms the basis for the other evolutionary algorithms. Till date, nature-inspired meta-heuristic techniques such as PSO, Firefly, Bat, Harmony Search, Cuckoo Search algorithms seems to be one of a popular choice to solve non-linear problem with complex non-linear constraints [5]. Excellent solutions are obtained using these methods. The new optimization technique called the Cuckoos Search Optimization technique is employed to get a way out to the ELD problem in sort of acquiring minimum operating cost [6]. In this paper a comparative study is conducted with the solutions of ELD problems using GA, PSO and CSO [7].

II. MATHEMATICAL FORMULATION OF ECONOMIC LOAD DISPATCH PROBLEM

A. *Economic Load Dispatch Problem Objective Function*

The main motive behind economic load dispatch (ELD) of electric power generation is to maintain the generating units in such a way that, it should meet the load demand with a minimum operating cost and satisfy all the constraints. Describing mathematically, the ELD can be termed as minimizing the total fuel cost of all the units combined subject to the constraint (1)

$$Minimize \sum_{i=1}^{N} F_i(P_i) \qquad (1)$$

$F_i(P_i)$ is the fuel cost equation of the i_{th} plant and N is the total number of online-generating units. It shows the variation of power generation with fuel cost. It can be expressed in (2)

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \qquad (2)$$

a_i, b_i, c_i are fuel cost coefficients. The units of a_i, b_i, c_i are $/MW2, $/MW and $ respectively.

The objective is to minimize the overall cost subjected to a number of constraints. The assumption is that the total system demand is supplied by all the generators connected to the same bus. The following constraints are included:

(I). Power Balance Constraint

The total generated power and load at corresponding hours must be equal. Taking the load and transmission losses into account, there's equality constraint which satisfies the criteria that the total generation should meet the load demand and transmission loss. The transmission loss has been determined using the loss coefficient (B_{mn}).

Equality Constraint:

$$\sum_{i=1}^{N} P_i = D + P_l \quad (3)$$

$$P_l = \sum_{i=1}^{N}\sum_{j=1}^{N} B_{ij} P_i P_j \quad (4)$$

Thus, the total loss power is calculated using (4) and this loss as it plays a part in the equality constraint has been added to the load side and thus (3) forms out. While calculating the optimal solution a penalty factor is being added when the load demand is more than generation demand.

(II). Power Generation Limits

The generated power of a unit should be within its minimum and maximum power limits.

Inequality Constraint:

$$P_{min} \le P_i \le P_{max} \quad (5)$$

Here P_{min} and P_{max} are the minimum and maximum output power limit of generator in MW.

III. OPTIMIZATION TECHNIQUES

A. Cuckoo Search Optimization

CSO is one of the recent nature-inspired meta-heuristics techniques proposed by [8] in 2009. The parasitic behaviour of Cuckoo birds in reproduction strategy has been used as a basic idea in this algorithm. The implementation with Levy flight behaviour in CSO algorithm make this algorithm superior compared to other swarm intelligence techniques such as PSO, GA and others.

The structure of CSO consists of two main operations viz. a) a direct search based on Levy flights, b) a random search based on the probability for a host bird to discover an alien egg in its nest. In this algorithm, each nest represents a solution and a population of nest is utilized to search the best solution of the optimization problem. The steps of the proposed CSO are as follows:

Steps:

1. Initialize the population size 'N' as number of sets for the number of units and probability of alien egg discovery asP_a.
2. Initialize the minimum and maximum bound L_b and U_b as the minimum and maximum values of generation for every unit respectively in the algorithm.
3. The population is initialized using the random function.

$$nest(i,j) = Lb + (Ub - Lb) * rand(size(Lb))$$

4. The population is initialized using the random function. Calculate the fitness function according to the number of Cuckoos. Run the loop for the condition such that the new fitness value is just below the fitness value of the optimal trial values.
5. Determine the sigma value using

$$\sigma_u = \left\{\frac{\gamma(1+\beta)\sin(\pi\beta/2))}{\gamma[(1+\beta)/2]\beta * 2^{(\beta-1)/2}}\right\}^{1/\beta}$$

6. Find new nest using step size between *Lb* and *Ub* limits.
7. Check if, *new fitness value < fitness value*. If yes, update it to the fitness value. Also, update the corresponding nest values to the *new nest*. If no, the fitness value retains its value. The fitness function here comprises of the cost function. And the objective is to minimize it. A penalty factor has been added in the end to satisfy the various constraints used in the load dispatch problem.
8. Check for new solution using random value >$P_a$to obtain a new step size *new_stepsize* and thus obtain new nest by *newnest = nest + new_stepsize*. If the condition violates, go to Step 4.

CSO Parameters:

Population, *N = 25*

Alien egg discovery probability, P_a = 0.25

Levy Flight Parameter, $\beta = 3/2$.

B. Genetic Algorithm

Genetic Algorithm, invented by John Holland in 1970, follows the concept behind natural evolution. It is also an evolutionary population based optimization algorithm. The concept of natural selection, which provides a link between chromosomes and the decoded values obtained from it, has been inculcated in this algorithm. Evolution is another aspect it envisages. Then, out of reproduction, new off springs come into existence. By the principle of elitism, there are other steps involved later to transfer the best parent to next generation.

Selection, Crossover and mutation take place to bring in the new generation values for the algorithm. Crossover operation involves exchanging two equal counterparts of the binary coded parents of their corresponding chromosomes. It is often denoted by crossover rate P_c which is also called crossover probability. Mutation, in the other hand diversifies the population. Selection process chooses the best solution out of the parent domain and sorts them out accordingly. The reason of the success behind the algorithm is their wide applicability and ease of use. The details of GA, is described in [9-12] and the parameters used are described after the steps:

Steps:

1. Start by initializing the population.
2. Randomize the population, *n = 1, 2, 3, 4… N*. By the principle of elitism, the best value is always restored.
3. Decode the binary values using

$$x_i = x_1^{min} + \left[\frac{x_i^{max} - x_i^{min}}{2^l - 1}\right] DC$$

4. Define the number of iterations, *iter*. Set iteration count, *iter = 1.*
5. Use the parent generation for further crossover &

mutation. This step reproduces the new child generation. Add the child chromosomes in the same parent matrix.

6. The cost function has to be the objective matrix with its parameters as population size, number of iteration, loss so as to satisfy the inequality constraint.
7. Roulette wheel selection sorts out the best four values of the matrix. These four values are further inherited to the next generation.
8. In the next generation, further crossover and mutation reproduce new children.
9. Update the iteration count, *iter = iter + 1.*
10. Repeat Step 6-9.

GA Parameters

Population Size, *pop = 10*

Crossover probability, *pcross= 0.8*

Mutation probability, *pmute* = 0.01

C. Particle Swarm Optimization

Particle swarm optimization has gained much more popularity as it involves lesser time constraints as well as a memory. Birds flocking for food are what follow the process for this optimization. Every bird is considered a particle here, and their group is particularly known by swarm. Every position attained by a particle here is crucial, which defines the *Pbest* for every particle, and the consecutive best position attained by the one of those birds for time *t* counts in *Gbest.* These positions, then varies as they converge towards a better solution and so as *Pbest* varies for every time interval. It is more or less similar to cuckoo search algorithm, the execution time varies. Genetic algorithm has a significant advantage over the cuckoo search and particle swarm optimization; it deals way more efficiently and easy when it's a binary coded logic. Since initially, the chromosomes are initialized using binary coded, which later on supports a binary to decimal conversion. The main parameters of this algorithm are the number of particles, particle dimension, particle velocity interval (V_{min}, V_{max}), c_1 and c_2, w_{max} and w_{min}, particle position interval(X_{min}, X_{max}). The details of PSO, is described in [13-16] and the parameters used are described after the steps

Steps:

1. Initialize the population of particles P_j and other variables. Each particle is usually generated randomly with in allowable range

$$P_{jmin} \leq P_j \leq P_{jmax}$$

Where P_j represents random solution i.e. for ELD problem in power system, it is the power generated by jth unit.

2. Initialize the parameters such as number of particles, the size of population, inertia weight, velocity of particle, number of iterations and cost coefficients data etc.
3. Evaluate the fitness function for the population using the objective function for a system. Compare each individual's fitness value with its P_{best}. The best fitness value among P_{best} is denoted as G_{best}.
4. Modify the individual's velocity *Vi* of each individual using the equation

$$V_j^{t+1} = WV_j^t + c_1 r_1^t\left(P_{bestj}^t - x_j^t\right) + c_2 r_2^t(G_{best}^t - x_j^t)$$

5. Modify the individual's position *xj* using

$$x_j^{t+1} = x_j^t + V_j^{t+1}$$

6. If the evaluation value of each individual is better than the previous P_{best}, the current value is set to be P_{best}. If the best P_{best} is better than G_{best} the value is set to be G_{best}.
7. If the number of iterations reaches the maximum then go to step 8. Otherwise go to step 3.
8. Evaluate the total cost, power distribution between the units, number of units committed.
9. The individual that generates the latest *Gbest* is the optimal set of control variables with the global minimum value of the objective function i.e., it is the optimal generation power of each unit with the minimum total generation cost.

PSO Parameters Population,

Population, *N = 10*

$$w_{max} = 0.9, w_{min} = 0.4$$

$$V_{max} = 0.5P_{max}, V_{min} = -0.5P_{max}$$

a) For 3-bus system

$$c_1 = 1.99, c_2 = 1.99$$

b) For 6-bus system

$$c_1 = 2.01, c_2 = 2.01$$

IV. SEARCH RESULTS

The proposed Cuckoo Search algorithm has been used to calculate the economic load dispatch and compare the values using genetic algorithm and particle swarm optimization. It looks into all the constraints satisfied for the dispatch. All the programs were performed on a HP personal computer equipped with AMD A8-4500M APU with Radeon(tm) HD Graphics, 1.90 GHz and 4 GB RAM, under Windows 8.1 Single Language, 64 bit OS. The implementation of all programs was done in MATLAB® Version 2013b.

A. 3-UNIT SYSTEM

Economic load dispatch by cuckoo search algorithm, particle swarm optimization as well as genetic algorithm has been performed on this data for different loads. Below are the generators data and the B-coefficient or loss coefficient matrix respectively.

THREE UNIT DATA:

Unit	a_n	b_n	c_n	P_{min}	P_{max}
1	0.001562	7.92	561	150	600
2	0.001940	7.85	310	100	400
3	0.005784	9.564	93.6	50	200

The B-coefficient matrix for 3 unit data is here as follows:

$$\boldsymbol{B_{ij}} = \begin{bmatrix} 0.000075 & 0.000005 & 0.0000075 \\ 0.001940 & 0.000015 & 0.0000100 \\ 0.004820 & 0.000100 & 0.0000450 \end{bmatrix}$$

Taking 3-unit data and B_{ij} coefficient matrix in to account,

following are the results for three different loads taken $P_d = 450MW, 585MW, 700MW, 800MW, 900MW$.
It provides a detailed comparative analysis of the cost function for every load data profile.

COMPARISON OF RESULTS FOR 3 UNIT DATA:

1. $P_d = 450MW$

LOAD	CSO	PSO	GA
P1(MW)	204.51	204.71	203.1
P2(MW)	188.66	188.59	189.8
P3(MW)	58.09	58.06	57.7
Ploss(MW)	1.26	1.37	1.36
Cost($/Hr)	**4662.15**	**4664.1**	**4664.2**

2. $P_d = 585MW$

LOAD	CSO	PSO	GA
P1(MW)	267.94	268.19	268.19
P2(MW)	241.70	241.6	241.6
P3(MW)	77.59	77.54	77.54
Ploss(MW)	2.23	2.35	2.35
Cost($/Hr)	**5841.30**	**5842.7**	**5842.7**

3. $P_d = 700MW$

LOAD	CSO	PSO	GA
P1(MW)	322.06	322.35	321.45
P2(MW)	287.02	286.90	287.63
P3(MW)	94.19	94.13	94.29
Ploss(MW)	3.27	3.38	3.38
Cost($/Hr)	**6868.07**	**6868.9**	**6868.82**

4. $P_d = 800MW$

LOAD	CSO	PSO	GA
P1(MW)	369.18	369.5	369.5
P2(MW)	326.53	326.29	326.07
P3(MW)	108.61	108.5	108.6
Ploss(MW)	4.32	4.44	4.44
Cost($/Hr)	**7778.41**	**7779.37**	**7779.37**

5. $P_d = 900MW$

LOAD	CSO	PSO	GA
P1(MW)	416.35	416.7	416.04
P2(MW)	366.14	365.9	366.9
P3(MW)	123.02	122.9	122.61
Ploss(MW)	5.52	5.64	5.63
Cost($/Hr)	**8705.08**	**8705.81**	**8705.53**

B. IEEE 30 BUS/6 –UNIT SYSTEM:

Economic load dispatch results have been shown below by all the optimization algorithms performed on the IEEE-30 bus system/six unit data for different loads. Below are the generators data and the B-coefficient or loss coefficient matrix respectively:

SIX-UNIT DATA:

No	a_n	b_n	c_n	P_{min}	P_{max}
1	0.15240	38.53	756.79886	10	125
2	0.10587	46.15916	451.3251	10	150
3	0.02803	40.39655	1049.9977	35	225
4	0.03546	38.30553	1243.5311	35	210
5	0.02111	36.32782	1658.5596	130	325
6	0.01799	38.27041	1356.6592	125	315

$$B_{ij} = \begin{bmatrix} 0.000140 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix}$$

Taking 6-unit data and B_{ij} coefficient matrix in to account, following are the results for five different loads taken $P_d = 600MW, 700MW, 800MW, 850MW, 950M$. It provides a detailed comparative analysis of the cost function for every load data profile.

COMPARISON OF RESULTS FOR 6 UNIT DATA:

1. $P_d = 600MW$

LOAD	CSO	PSO	GA
P1(MW)	23.90	23.8	22.8
P2(MW)	10	10	10
P3(MW)	95.60	95.7	100.3
P4(MW)	100.67	100	98.9
P5(MW)	202.78	202.6	194.23
P6(MW)	181.16	181.2	187.5
Ploss(MW)	14.11	14.24	14.2
Cost($/Hr)	**32088.77**	**32091.68**	**32098.6**

2. $P_d = 700MW$

LOAD	CSO	PSO	GA
P1(MW)	28.32	28.2	29.09
P2(MW)	10	10	10
P3(MW)	118.90	118.53	116.64
P4(MW)	118.64	118.53	123.43
P5(MW)	230.70	230.2	226.4
P6(MW)	212.73	214.16	213.7
Ploss(MW)	19.30	19.4	19.4
Cost($/Hr)	**36905.99**	**36912.2**	**36913.7**

3. $P_d = 800MW$

LOAD	CSO	PSO	GA
P1(MW)	32.62	31.95	32.5
P2(MW)	14.47	10.8	12.4
P3(MW)	141.51	153.2	140.51
P4(MW)	136.01	151.8	136.2
P5(MW)	257.61	247.3	258.28
P6(MW)	242.96	229.69	245.3
Ploss(MW)	25.20	24.95	25.44

Cost($/Hr)	**41890.23**	**41896.2**	**41925.6**

4. $P_d = 850MW$

LOAD	CSO	PSO	GA
P1(MW)	34.74	30.18	35.06
P2(MW)	17.76	10	19.3
P3(MW)	152.67	143.82	152.94
P4(MW)	144.59	147.7	146.53
P5(MW)	270.85	324.9	269.14
P6(MW)	257.81	222.5	255.3
Ploss(MW)	28.42	29.24	28.42
Cost($/Hr)	**44443.68**	**44452.08**	**44456.28**

5. $P_d = 950MW$

LOAD	CSO	PSO	GA
P1(MW)	39.04	39.05	39.7
P2(MW)	24.39	24.4	24.9
P3(MW)	175.16	191.8	179.17
P4(MW)	161.85	172.56	163.13
P5(MW)	297.44	294.5	288.4
P6(MW)	287.60	262.4	290.1
Ploss(MW)	35.5	34.9	35.4
Cost($/Hr)	**49675.21**	**49681.38**	**49682.7**

V. CONCLUSION

This paper proposed a detailed comparative analysis in between three optimisation techniques named GA, PSO and Cuckoo Search. Here in this case a three and six unit bus system is taken and the load for which the cost minimum is calculated. Here the accuracy is calculated up to two digits. It clearly shows that the cuckoo search is converging to a better quality near-optimal solution. The simulation results obtained by cuckoo search clearly reveal that, it can be used as an excellent optimizer for the solution of economic load dispatch problems of power systems.

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