Optimal Solution of Combined Economic Emission Load Dispatch using Genetic Algorithm

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ABSTRACT
In this paper, a genetic algorithm (GA) approach is presented for optimal solution of combined economic emission load dispatch (CEELD) problem. Fuel cost and emission are considered to formulate the multi-objective optimization problem. An optimal trade-off between fuel cost and emission is obtained using genetic algorithm. Two test systems are considered to show the effectiveness of the GA approach. An extensive analysis is done by presenting a short term thermal generation scheduling for the Test system-1.

Keywords
Economic load dispatch, Combined economic emission Load dispatch, Genetic algorithm.

1. INTRODUCTION
The main objective of economic load dispatch (ELD) is to schedule the committed generating units output to meet the load demand at minimum operating cost [1] .However, with the increasing public awareness of the environment protection and the passage of the Clean Air Act Amendment of 1990, we need to reduce the pollution and atmospheric emissions of the thermal power plants [2]. Economy in cost is not enough so emission is also considered along with the cost. The most important objectives which are to be satisfied simultaneously are economic operation, minimal impact on environment, reliability and security [3].

Several strategies to reduce the emission have been proposed and discussed [4-6]. These include some pollution cleaning equipments. The emission dispatching option is an attractive short term alternative in which the emission in addition to the fuel cost that is combined economic emission load dispatch (CEELD) is to be minimized [7]. The economic dispatch problem can be handled as a multi-objective optimization problem with non-commensurable and conflicting objectives. In recent years, this option has received much attention since it requires only small modification to ED to include emissions [8].

Various techniques such as direct NR method based on alternative jacobian matrix [8], a recursive approach based on dynamic programming [9], a simplified recursive process, a progressive articulation of preference information based optimization technique[10] and an analytical strategy based on mathematical modeling [11] have been presented to handle combined economic emission dispatch problems.

In recent years evolutionary approaches such as interactive fuzzy satisfying based simulated annealing technique, particle swarm optimization, a multi-objective genetic algorithm and a fuzzified multi-objective particle swarm optimization algorithm [12] have been extensively articulated to obtain the global optimal solution. The problem has been reduced to a single objective problem by treating the emission as a constraint [13]. This formulation has some difficulty in getting the trade off relations between cost and emission. Then minimizing the emission has been handled as another objective in addition to the cost. Recently, the studies on evolutionary algorithms have shows that these methods can be efficiently used to eliminate the most of the difficulty of classical methods [14, 15]. Various solutions of ELD and CEELD have been reported recently in the literature [19-20].

GA has been applied on a three generator test system considering CEELD [16]. Further in this paper GA has been extended on two different standard test systems and extensive analysis is done by presenting a short term thermal generation scheduling for the test system-1.

In this paper genetic algorithm [16] is applied to solve the CEELD. CEELD problem is considered as an optimization problem where the fuel cost and emission are treated as competing objectives. The presented GA is applied on the two standard test systems. Test system-1 comprises a three generator system [17]. Test system-2 comprises a standard six generator (IEEE 30 bus system) [18]. Short term optimal generation scheduling is done on Test system-1.

2. PROBLEM FORMULATION
CEELD Problem is formulated as an optimization problem in which fuel cost and emission are minimized simultaneously for the prescribed schedule of load. Multi-objective optimization problem of Fuel cost and emission are converted into single objective problem using penalty factor [16].

2.1 Economic Dispatch
Mathematically the objective function or fuel cost function [1] is written as

$$F_i(P_{gi}) = a_i P_{gi}^2 + b_i P_{gi} + c_i \quad \text{Rs/h} \qquad (1)$$

$where,$

$F(P_{gi})$ = total fuel cost

a_i, b_i, c_i = cost coefficients of ith generating units

2.2 Emission dispatch
Harmful pollutants like oxides of nitrogen (NO_x), oxides of sulphur (SO_x) and carbon monoxide (CO) are emitted due to burning of fuel in thermal powers plants [1]. Mathematically emission is defined by quadratic equation [1]. Equation 2

shows the emission function to be minimize while satisfying the constraints as per equation (7) and equation (8).

$$E(P_{gi}) = d_i P_{gi}^2 + e_i P_{gi} + f_i \quad \text{Kg/h} \qquad (2)$$

d_i, e_i, f_i = emission coefficients of i_{th} generating unit

2.3 Combined economic emission dispatch

Fuel cost and emission are two conflicting objectives to be attained. When the fuel cost is minimized, emission increases and cost increases when emission is minimized. So the cost and emission are reduced simultaneously while satisfying the constraints imposed as per equation (7) and equation (8). Both objectives fuel cost and emission are converted into a single objective function [16] with the help of penalty factor using equation as

$$\text{Minimize } F_i(P_{gi}) + P_f E(P_{gi}) \quad \text{Rs/h} \qquad (3)$$

Where,

P_f = Penalty factor

2.3.1 Steps to determine Penalty factor

Penalty factor is determined using following procedure [16].

(1)Fuel cost at maximum power output for every generator is determined

$$F_i(P_{gi(max)}) = a_i P_{gi(max)}^2 + b_i P_{gi(max)} + c_i \qquad (4)$$

(**2**)Emission at maximum power output for every generator is determined as

$$E(P_{gi(\max)}) = d_i P_{gi(\max)}^2 + e_i P_{gi(\max)} + f_i \qquad (5)$$

(3)Penalty factor form each generator is determined

$$P_{fi} = F_i(P_{gi(max)}) / E(P_{gi(\max)}) \qquad (6)$$

(4) Penalty factor are arranged in ascending order.

(5) Maximum capacity of each generator is added one at a time, starting from the lowest penalty factor unit until $\sum P_{gi(\max)} \geq P_d$

(6) Penalty factor with the last unit in this process is the price penalty factor.

2.4 Constraints

Constraints imposed on CEELD problem are given as:

2.4.1) Equality Constraint (Energy balance equation)

Total generated power is equal to the total demand plus the transmission loss. Equality constraint [1] is given in equation (2)

$$\sum_{i=1}^{NG} P_{gi} = P_d + P_L \qquad (7)$$

P_{gi} = real power output of the ith generating unit

P_L = total power transmission losses

P_d = total demand

This equation denotes that the total generation is equal to the total demand when transmission losses are considered.

2.4.2) Inequality constraints (Generating capacity limit constraints):

The generation output of each unit should be between its maximum and minimum limits. Inequality constraints [1] is written as

$$P_{gi}^{min} \leq P_{gi} \leq P_{gi}^{max} \qquad (8)$$

P_{gi}^{min} = minimum power output of the ith generating unit

P_{gi}^{max} = maximum power output of the ith generating unit

To achieve true CEELD transmission loss must be taken into account. Using B-coefficients method, the network losses are expressed using George's formula [1]

$$P_{Loss} = \sum_{i-1}^{NG} P_{gi} \sum_{j=1}^{NG} Pgj\, B_{ij} \qquad (9)$$

B_{ij} are constant called B-coefficients or loss coefficients.

The exact value of the system losses can only be determined by power flow solution. Kron's formula is used to find thelosses and appropriates the losses as a function of the output level of the system generators. Kron's formula [1] is expressed as

$$P_{Loss} = \sum_{i=1}^{NG} P_{gi} \sum_{j=1}^{NG} P_{gj}\; B_{ij} + \sum_{i=1}^{NG} Pgi\, B_{i0} + B_{00} \qquad (10)$$

3. OVERVIEW OF GENETIC ALGORITHM

GA was developed by John Holland and finally popularized by one of his student, David Goldberg [14]. GA is a stochastic searching algorithm. It is a genetics search algorithm based on the principles of natural selection and natural genetics. It is based on the 'Darwinian survival of the fittest' principle [1].

The attractive property of GA is that it searches for many optimum points in parallel. GA searches through many points in the solution space at one time which is other important advantage of GA as compared to other techniques.

The GA begins with a collection of chromosome known as the population. The population has L chromosomes called population size.

3.1 Genetic operator

A simple genetic algorithm consists of three basic operators: Elitism, Crossover and Mutation. The copying of best population to the next population is called "Elitism". If the probability is high, then the convergence rate increases. But it will not be too high to get good result

For carrying out the crossover, there is need to identify the parents. The parent selection is done by using the roulette wheel selection. The parent selection is to be repeated two times to get the two parents for crossover. Then a random number is generated between 0 and 1, and compared with the crossover probability. If it is less than crossover probability then crossover is performed otherwise as it is passed. The crossover probability is defined before solving the problem. Mutation is the process of random modification of the value of a string position with a small probability .It is taken as very small.

3.2 Fitness function and parent selection

Implementation of power dispatch problem in GA is realized with the fitness function. Since the proposed approach uses the equal incremental cost criterion as its basic the constraint equation (2) can be written as

$$\varepsilon^j = \left| \sum_{i=1}^{NG} P_{gi} - (P_d + P_L) \right| \quad (11)$$

Then the convergence rule is when error (ε) decreases with in a particular value. For the purpose of emphasizing the best chromosome and speed up convergence of the iteration procedure, fitness is normalized between 0 and 1[13]. The fitness function used is:

$$f^j = 1/1+\alpha(\varepsilon^j/P_d) \qquad (j=1,2.......L) \quad (12)$$

L= Population size

α = scaling constant

The equivalent decimal integer of binary string λ is obtained as

$$y^j = \sum_{i=1}^{l} 2^{i-1} b_i^j \ (j=1,2,........L) \quad (13)$$

b_i^j is ith binary digit of the jth string

l is the length of the string

L is the population size.

The continuous variable λ can be obtained to represent a point in the search space according to a fixed mapping rule, i.e

$$\lambda^j = \lambda^{min} + (\lambda^{max} - \lambda^{min}) * y^j/2^l-1 \quad (14)$$

y^j is the binary coded value of the string

λ^{min} is the minimum value of variable, λ

λ^{max} is the maximum value of the string

4. COMBINED ECONOMIC EMISSION DISPATCH USING GENETIC ALGORITHM

The step-wise procedure [1, 19] is outlined below for a quick reference.

1. Read data, namely cost coefficients, emission coefficients, B-coefficients, maximum allowed iterations, ITMAX, L population size, probability of crossover and mutation,λ^{min} and λ^{max} .

2. Compute the price penalty factorP_f from equation (8).

3. Convert the multi-objective problem into singleobjective.

4. Generate an array of random numbers. Generate the population λ^j (j=1,2....L)

by flipping the coin .The bit is set according to the coin flip as

b_{ij} = 1 if p=1or random 0≤p

= 0 Otherwise

Where p is the probability (0.5)

5. Set generation counter, k=0, f^{min} =1and f^{min} =0.

6. Increment the generation counter, k=k+1 and set the population counter, j=0.

7. Increment population counter, j=j+1

8. Decode the string.

9. Using Gauss elimination method, find P_l^J

10. Calculate transmission losses.

11. Find ε^j and check if ε^j <BIG, then set BIG = ε^j

12. Find fitness from eq. (7)

If ($f^j > f^j$) then $f^j = f^j$ and if $f^j < f^j$ then set $f^j = f^j$

13. If (j<L) then go to step 5 and repeated

14. If (BIG<error) then go to step 17.

15. Find population with maximum and average fitness of the population.

16. Select the parents for crossover and perform crossover

17. Perform mutations

18. If (k<ITMAX) then go to step 4 and repeat.

19. Calculate fuel cost, emission release and emission cost etc. print the results

20 stop

5. RESULTS AND DISCUSSION

Genetic algorithm is applied on two different test systems. A short term optimal generation scheduling is done on Test system-1[17]. Test system-2 [18] is a standard IEEE 30-bus (six generator system).. Genetic algorithm parameter used are

Population size = 50

Generation = 500

Crossover probability = 0 .9

Mutation probability =0.01

5.1 Results of Test system-1

Best trade-off solution between fuel cost and emission is shown in Table-3 The total cost is 39436.46 Rs/hour and transmission losses are 11.6956 MW. A short term optimal generation scheduling for Test system-1 is shown in Table-4 for corresponding load demands as shown in figure-1.

Table-1 : Best fuel cost (Test system-1)

Power Output	GA
P1(MW)	105.9407
P2(MW)	212.9017
P3(MW)	193.0709
Best Fuel Cost(Rs/hour)	25465.47
NOx Emission(Kg/hour)	318.0288
Losses(MW)	11.9133

Table-2: Best emission (Test system-1)

Power Output	GA
P1(MW)	130.6004
P2(MW)	190.6617
P3(MW)	190.4190
Best NOx Emission(Kg/hour)	311.0869
Fuel Cost(Rs/hour)	25504.2
Losses(MW)	11.6811

Table-3: Compromised solution (Test system-1)

Power Output	GA
P1(MW)	128.5918
P2(MW)	192.7516
P3(MW)	190.3522
Best Fuel Cost(Rs/hour)	25494
Best NOx Emission(Kg/hour)	311.1685
Losses(MW)	11.6956
Price Penalty Factor(Rs/Kg)	44.8063
Total Cost(Rs/hour)	39436.46

Table-4: Short term Thermal generation scheduling (Test system-1)

Time	Demand (MW)	Unit-1 (MW)	Unit-2 (MW)	Unit-3 (MW)	Losses (MW)	Fuel cost Rs/h	Emission Kg/h	Total cost Rs/h
1	380	97.5077	146.1807	142.9868	6.6752	19932	182.62	28115.41
2	395	101.000	151.7180	149.5081	7.2269	20611	195.68	29378.80
3	370	94.3870	142.4961	139.4428	6.3259	19482	174.40	27296.95
4	403	103.3091	155.1700	152.0466	7.5258	20975	202.99	30070.16
5	430	110.2913	165.7503	162.5490	8.5906	2.2212	229.47	32494.20
6	445	114.2675	171.2681	168.6785	9.2141	22907	245.37	33901.52
7	470	120.8725	180.8775	178.5531	10.3031	24075	273.81	36344.15
8	490	126.1556	188.3054	186.7601	11.2211	25020	298.31	38386.12
9	497	128.1558	191.0704	189.3239	11.5501	25352	307.25	39119.29
10	505	129.8189	194.6369	192.4818	11.9376	25732	317.73	39969.05
11	530	136.7399	204.5793	201.8573	13.1766	26933	352.01	42706.00
12	545	140.8438	209.9666	208.1429	13.9534	27661	373.76	44407.71
13	590	152.8168	227.7237	225.2837	16.4242	29871	444.41	49783.13

14	600	155.4948	231.6052	229.9023	17.0023	30368	461.21	51033.11
15	614	159.1757	237.0117	235.6432	17.8306	31068	485.41	52817.20
16	628	162.9241	242.9021	240.8510	18.6772	31772	510.40	54641.14
17	640	166.0570	248.0730	245.2902	19.4201	32378	532.47	56236.56
18	730	190.7282	283.2039	281.5558	25.4879	37037	716.73	71313.10
19	628	162.9241	242.9021	240.8510	18.6772	31772	510.40	54641.14
20	590	152.8168	227.7237	225.2837	16.4242	29871	444.41	49783.13
21	505	129.8189	194.6369	192.4818	11.9376	25732	317.73	39969.05
22	470	120.8725	180.8775	178.5531	10.3031	24075	273.81	36344.15
23	400	102.4874	153.5402	151.3857	7.4133	20838	200.21	29809.45
24	395	101.000	151.7180	149.5081	7.2269	20611	195.68	29378.80

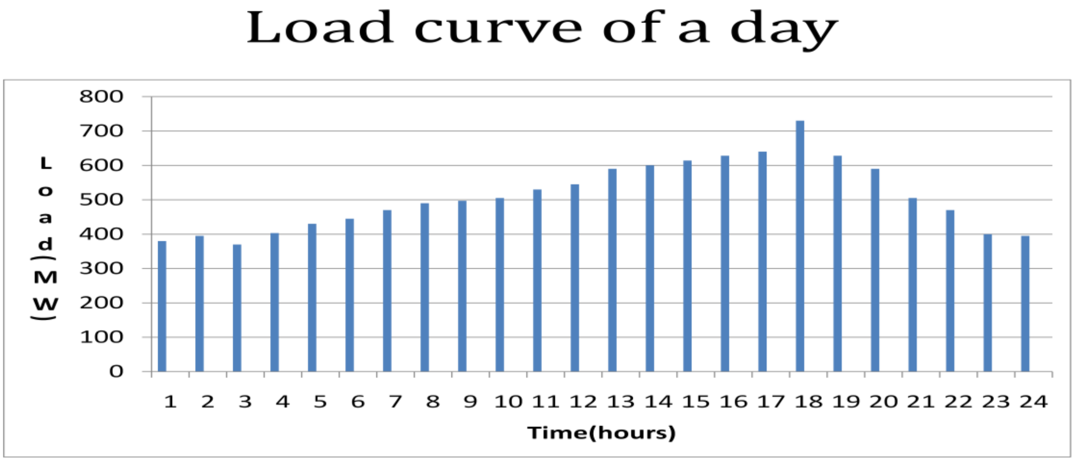

Figure 1: Load profile of a day

5.2 Results of Test system-2

Results of Test system-2 are shown in Tables 5-7. The results for best fuel cost are shown in Table 5 and the results for best emission are shown in Table 6. Best compromised solution between fuel cost and emission is shown in Table 7. Power demand is taken as 2.834 pu at a base load of 100 MVA. The best combined cost is 627.4119 \$/h and transmission losses are 0.0279pu MW.

Table-5: Best fuel cost (Test system-2)

P1(pu MW)	0.1100
P2(pu MW)	0.3104
P3(pu MW)	0.6373
P4(pu MW)	0.9517
P5(pu MW)	0.5177
P6(pu MW)	0.3413
Demand(pu MW)	2.834
Power losses(pu MW)	0.0287
Fuel Cost($/hour)	608.48
NOx Emission(puKg/hour)	0.2258

Table-6: Best NO_X emission (Test system-2)

P1(pu MW)	0.3073
P2(pu MW)	0.4986
P3(pu MW)	0.4619
P4(pu MW)	0.4410
P5(puMW)	0.6067
P6(puMW)	0.5526
Demand(pu MW)	2.834
Power losses(pu MW)	0.0281
NO_X Emission(puKg/hour)	0.2014
Fuel Cost($/hour)	638.96

Table-7: Best Compromised Solution (Test system-2)

P1(pu MW)	0.1278
P2(pu MW)	0.3199
P3(pu MW)	0.6254
P4(pu MW)	0.9289
P5(puMW)	0.5067
P6(puMW)	0.3548
Demand(pu MW)	2.834
Power losses(pu MW)	0.0279
NO_X Emission(puKg/hour)	0.2164
Fuel Cost($/hour)	613.5433
Combined cost($/hour)	627.4119

6. CONCLUSION

An extensive study of GA based CEELD is presented in this paper. The proposed genetic algorithm (GA) applied on two standard test systems. A short term thermal generation scheduling is presented for Test system-1. Compromised solution is obtained for both test systems. Improved version or the hybrid GA may be used in future to solve CEELD problems. In this paper the oxides of nitrogen is used as an emission objective. Oxides of sulphur, Oxides of carbon or their combination may be used in future as an emission objective.

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