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HYBRID GENETIC ALGORITHM FOR OPTIMIZING ENVIRONMENTAL/ECONOMIC POWER DISPATCH

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*The conventional economic power dispatch is a non-linear optimization problem with several constraints. The environmental issues concerning the pollutant emissions produced by fossil based thermal generating units became a matter of concern in recent years. Accordingly, minimization of emissions by dispatch of power generation is very desira*7. Settling chamber*ble. The problem is how to supply all electrical loads at minimum cost taking the environmental issues into account (minimum pollution). Environmental/Economic dispatch is a multi-objective problem treats economic and pollutant emissions. This multi-objective problem is converted into single objective function using a modified price penalty factor approach to calculate environmental /economic power dispatch problem. A commonly used technique to solve this problem is to apply genetic algorithm to a small number of generations to get near optimum economic solution for the power system dispatch. This paper presents an application of hybrid genetic algorithm (HGA) to achieve an optimal solution for the Combined Economic Emission Dispatch problem (CEED). The optimum solution obtained by the proposed technique is faster and more efficient than that obtained by using both the Conventional Optimization methods (CM) and simple Genetic Algorithm (GA). The proposed algorithm is tested on standard IEEE 30-bus model system.*

KEYWORDS: *Optimization, GA, HGA, power Dispatch*

1. INTRODUCTION

The generation of electricity from fossil fuel plays an important rule in atmosphere pollution phenomenon; since it releases several pollutants, such as Sulfur Oxides, Nitrogen Oxides and Carbon Dioxide. Recently, this problem has attracted much attention due to the pressing public demand for clean air. Since the text of the Clean Air Act Amendments of 1990 and similar Acts by European and Japanese governments, environmental constraints have forced the utilities to modify their design or operational strategies to reduce pollution and atmospheric emissions of the thermal power plants. Achieving only the minimum cost can no longer be the only criterion for dispatching electric power due to increasing concern with environmental consideration. Emissions can be reduced by dispatch of power generation to minimize emissions instead of or as a supplement to the usual cost objective of economic dispatch. Environmental /Economic dispatch is a multi-objective problem with conflicting objectives because pollution is conflicting with minimum cost of generation. Traditionally, the cost function and emission for each generator has been approximately represented by a lambda iteration method, first-order gradient method, second-order gradient method, Newton–Raphson method (NR), Linear programming, and dynamic programming. In traditional methods, formulation of Lagrangian function as well as the incremental loss is always the key point in the solution algorithm. All of these methods lead to inaccurate results due to the nonlinear and non-convex characteristics of generating units. These methods also fail to find the optimal solution in case of complex dispatch problems. Thus we are in a bad need for developing a reliable, fast and efficient algorithm to solve the power dispatch problem.

Recently, the economic dispatch problem has been solved using modern heuristic optimization techniques, such as evolutionary algorithms [1], Tabu search [2], Particle Swarm optimization [3], simulated annealing [4], genetic algorithms [5], Hopfield neural networks [6,7], fuzzy [8,9] and Ant colony techniques [10].

GA is probabilistic heuristic procedures or optimizing algorithm, which is based-on the principle of natural selection and genetics. It has demonstrated considerable success in providing good solutions to many nonlinear optimization problems. Recently, GA has been studied to solve the power system optimization problems. It combines solution evaluation with randomized, structured exchanges of genetic information between solutions to obtain optimality. GA contains many computational advantages, such as simplicity and generalization. In addition, it searches multiple solutions simultaneously in contrast to conventional optimal algorithms.

Therefore, the possibility of finding global optimal solution is increased. But due to the premature convergence nature of the simple GA method, there is a possibility for getting stuck at local optimal solution. Therefore, the objectives considered in this study are minimizing both fuel cost and environmental impact of emission by using HGA to improve optimal solution and work more efficiently than simple GA. The main advantage of HGA is that it finds near optimal solution in relatively short time compared with other random searching methods; conventional methods or simple GA. The price penalty factor that combines the emission costs with the normal fuel costs is presented in this paper. This paper is organized as follows. Section 2 gives the mathematical description of the economic power dispatch problem. Section 3 presents a technique for calculating price penalty factor. Section 4 presents the methodology of MatPower and GA and also the improvements implemented for solving the problem. Section 5 presents a case study and simulation results. Section 6 summarizes the conclusions of study.

2. PROBLEM FORMULATION

The Environmental/Economic dispatch problem is multi-objective, since the two conflicting objectives, fuel cost and pollutant emission, should be minimized simultaneously to satisfy the system constraints.

A. Objective Functions

Objective 1: Minimization of fuel costs

The classical economic power dispatch problem is to find the real power generation for each unit, which minimizes the total fuel cost while satisfying the total required demand. The generator cost curves are represented by quadratic functions to represent the loading effects. The objective function is the total production cost measured in dollars per hour can be mathematically defined by the following equation [5,10]

$$F_t = \sum_{i=1}^{n_g} F_i = \sum_{i=1}^{n_g} (a_i.P_{gi}^2 + b_i.P_{gi} + c_i) \tag{1}$$

Where

F_t : Total production cost, \$/h,

F_i : Production cost of i[th] generator, \$/h,

a_i, b_i, c_i : The fuel cost coefficients of the i[th] generator,

P_{gi} :The power generated by i[th] generator,

ng :The number of power generators.

Objective 2: Minimization of Emission

The total emission can be reduced by minimizing the three major pollutants: oxides of nitrogen (NO_x), oxides of sculpture (SO_x) and carbon dioxide (CO_2). The total emission of atmospheric pollutants can be expressed in a quadratic equation as the sum of all the three pollutants resulting from generator real power P_{gi}. Measured in tons per hour. The objective function can be expressed as follows [1,3] :-

$$E_{Nox} = \sum_{i=1}^{n_g} E_{noxi} = \sum_{i=1}^{n_g} (d_i.P_{gi}^2 + e_i.P_{gi} + f_i) \tag{2}$$

Where;

d_i, e_i, and f_i are the coefficients of generator emission characteristic.

The pollution control cost (in \$/ton) can be obtained by assigning a penalty factor.

The previous two equations are combined together giving the total objective function which represents both the fuel cost and the total emission. In addition, price penalty factor (h) is used in the objective function to combine both fuel cost, \$/h and pollutant emissions, ton/h. The combined economic and emission dispatch problem can be formulated as follows:

$$\min T_c = \sum_{i=1}^{n_g} (a_i.P_{gi}^2 + b_i.P_{gi} + c_i) + h\,.\sum_{i=1}^{n_g} (d_i.P_{gi}^2 + e_i.P_{gi} + f_i) \tag{3}$$

Once price penalty factor (h) is calculated, equation (3) can be rewritten as follows:

$$\min T_c = \sum_{i=1}^{n_g} (a_i + h.d_i).P_{gi}^2 + (b_i + h.e_i).P_{gi} + (c_i + h.f_i) \tag{4}$$

B. Constraints

The economic/environmental dispatch problem is subject to two types of constraints, the real power balance equality constraint and generation capacity inequality constraint

Constraint 1: Real power balance

The total power generated must supply the total load demand plus the transmission losses as the following equation:

$$\sum_{i=1}^{n_g} P_{gi} = P_d + P_{Loss} \qquad \text{(Equality Constrained)} \tag{5}$$

Where; P_d : Total load demand,

P_L : Transmission losses.

The transmission loss can be determined form B-coefficient method. It can be expressed as follows:

$$P_{Loss} = \sum_{i=1}^{n_g} \sum_{j=1}^{n_g} P_{gi}.B_{ij}.P_{gj} + \sum_{i=1}^{n_g} P_{gi}.B_{i0} + B_{00} \quad \text{MW} \tag{6}$$

Where

P_{gi}, P_{gj} : The real power generation at the i^{th}, j^{th} generator,

B_{ij} : The transmission loss coefficients,

B_{io} : The dimensionless vector of linear loss coefficients,

B_{00} : The constant of loss coefficients, MW.

All B-coefficients can be calculated based on load flow solutions. A Newton-Raphson load flow, losses calculation as well as B loss coefficients are implemented in "line flow", which is written using MATLAB. The loss is used as an evaluation function in the Genetic Algorithm Optimization Toolbox to search the optimal CEED problem.

Constraint 2: Generation capacity

For a stable operation, the real power generated, P_{gi} by each generator is constrained by lower and upper power limits as follows:-

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad \text{(Inequality Constrained)} \tag{7}$$

where $P_{gi}^{\min}$ and $P_{gi}^{\max}$ are the minimum and the maximum real power outputs of i^{th} generator.

3. CALCULATION OF PRICE PENALTY FACTOR, H [9,11]

The price penalty factor, h can be calculated as follows:

1. Evaluate the maximum cost of each generator at its maximum output as follows:

$$F_i(P_{gi}^{\max}) = (a_i.(P_{gi}^{\max})^2 + b_i.(P_{gi}^{\max}) + C_i) \tag{8}$$

2. Evaluate the maximum NOx emission of each generator at its maximum output as follow:-

$$E_i(P_{gi}^{\max}) = (d_i.(P_{gi}^{\max})^2 + e_i.(P_{gi}^{\max}) + f_i) \quad \text{Ton/h} \tag{9}$$

3. Divide the maximum cost of each generator by its maximum NOx emission.

$$\frac{F_i(P_{gi}^{\max})}{E_i(P_{gi}^{\max})} = \frac{a_i.(P_{gi}^{\max})^2 + b_i.(P_{gi}^{\max}) + C_i}{d_i.(P_{gi}^{\max})^2 + e_i.(P_{gi}^{\max}) + f_i} \tag{10}$$

Recalling that

$$h_i = \frac{F_i(P_{gi}^{\max})}{E_i(P_{gi}^{\max})} \tag{11}$$

4. Sort the obtained values of h_i's in ascending order
5. Add the maximum capacity of each unit, ($P_{gi}^{\max}$), repeatedly starting from the smallest hi until total demand is met according to the inequality shown below.

$$\sum_{i=1}^{n_g} P_{gi}^{\max} \geq P_d \tag{12}$$

6. At this stage, h_i associated with the last unit in the process is the price penalty factor h ($/ton) for a given load Pd, and equation (4) can be solved to obtain environmental economic dispatch using GA and HGA.

4. METHODOLOGY

Our technique uses Matlab package MATPOWER and hybrid genetic algorithm to optimize the environmental economic dispatch problem.

A. MATPOWER

MATPOWER is a package of Matlab m-files for solving the power flow and optimal power flow problems. The data files used by MATPOWER are simply Matlab m-files which define and return the variables base MVA, bus, branch, gen, and gencost. The bus, branch, and gen variables are matrices. MATPOWER has three power flow solvers. MATPOWER uses two approaches for solving the optimal power flow problem. The first one is based on the constr function included in Matlab's optimization Toolbox, which uses a successive quadratic programming technique with a quasi-Newton approximation for the Hessian matrix. The second one is based on linear programming [12].

B. Genetic Algorithm [13]

A genetic algorithm GA is a search technique used to find exact or approximate solutions to optimization and search problems. GA's are categorized as global search heuristics. These algorithms are a particular class of evolutionary algorithms that use techniques inspired by evolutionary biology such as inheritance, mutation, and crossover. The basic terminology of the GA is fitness function. The fitness function is the objective function. The GA tries to find the minimum of the fitness function. The fitness function of the CEED is written as an M-file which is treated as a function handle input argument to the main genetic algorithm function. The fitness function can be expressed as follows:-

$$Fit(P_{gi}) = \sum_{i=1}^{n_g} (a_i + h.d_i).P_{gi}^2 + (b_i + h.e_i).P_{gi} + (c_i + h.f_i) \tag{13}$$

A Hybrid GA is an optimization function to improve the value of the fitness function. The hybrid GA uses the final point from the genetic algorithm as its initial point. HGA is a robust approach because no restrictions on the solution space are made during the search process. Although the binary representation is usually applied to power optimization problems, in this paper, we use the real valued representation scheme for solution. The use of real valued representation in the HGA is used in this paper.

5. CASE STUDY AND SIMULATION RESULTS

To assess the feasibility of the HGA method, it has been applied to solve the emission, economic and CEED problem on power systems with 6 units. Every test case was solved for approximately more than 40 individual trials by Intel® Core(TM)2 Duo CPU, T8300@ 2.4 GHz, With 4GB RAM under Windows Vista Ultimate.

A. CASE STUDY

The proposed method has been applied on the power system IEEE 30-bus system. The 30-bus system contains six generators with total generation capacity 335MW, 24 load buses and 41 transmission lines with 4 tap changing transformers.

The cost and emission coefficients are given in Appendix A. In normal operation of the system, the loss coefficients B matrices with the 100 MVA base capacity are given in Appendix B. The computed values of proposed price penalty factor for power generation of IEEE-30 bus are shown in Table I and Fig. 1.

According to the results of many experiments, Table II shows the control parameters for HGA algorithm after running a number of simulations.

Table I Price penalty factor for each power generated

Pg	0-80	81-135	136-165	166-215	216-255	256-335
h	1.734	1.8019	2.2198	2.2296	2.3378	18.4344

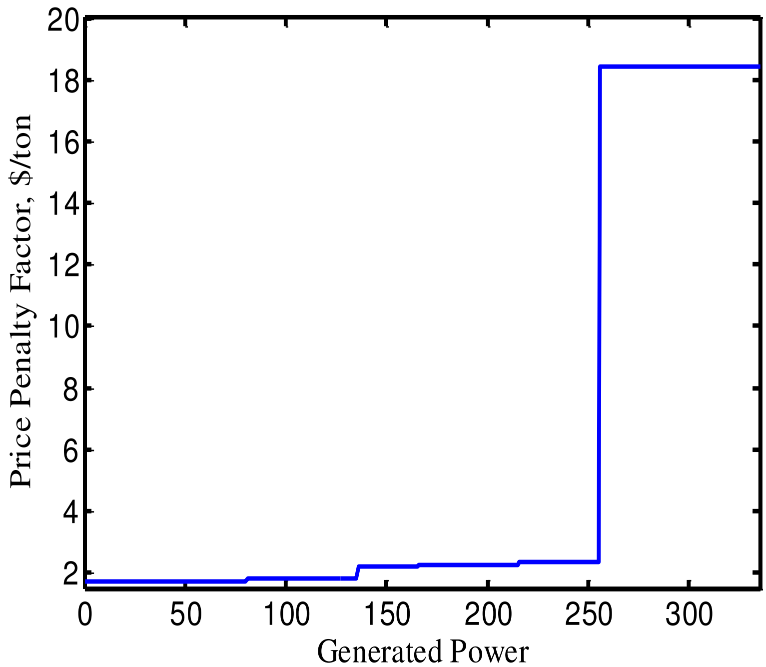

Figure 1. Relation between Price Penalty factor and Generated power

Table II Parameter Values for HGA

Population Type	Double Vector
Population Size	60
Elite Count	1
Crossover Fraction	0.9
Migration Interval	20
Generations	100
Time Limit	60
Stall Generation Limit	50
Stall Time Limit	400
Tolerance Function	1.0000e-006
Initial Penalty	10
Fitness Scaling Function	@fitscalingrank
Selection Function	@selectionstochunif
Crossover Function	@crossoverscattered
Mutation Function	@mutationgaussian
Hybrid Function	@patternsearch

A. SIMULATION RESULTS

Four methods (MatPower, NR, GA and HGA algorithms) were employed to test the system under study. In the case study, each individual P_g contains six generator power outputs: P_{g1}, P_{g2}, P_{g3}, P_{g4}, P_{g5} and P_{g6}, which are generated randomly under constraints as shown in Appendix A. The fitness function for 189.2 MW load demand with h=2.2296 is defined as follows:-

$$T_c = \min\left(\sum_{i=1}^{n_g} F_i\right) = \min(F_1 + F_2 + F_3 + F_4 + F_5 + F_6) \qquad (14)$$

Where,

$F_1 = 0.0481.P_{g1}^2 - 0.4526.P_{g1} + 51.2431$ \$/h

$F_2 = 0.0621.P_{g2}^2 + 1.5270.P_{g2} + 56.4381$ \$/h

$F_3 = 0.1227.P_{g3}^2 + 0.9777.P_{g3} + 56.8662$ \$/h

$F_4 = 0.0732.P_{g4}^2 + 3.2611.P_{g4} + 55.5173$ \$/h

$F_5 = 0.0897.P_{g5}^2 + 2.9911.P_{g5} + 55.0713$ \$/h

$F_6 = 0.0854.P_{g6}^2 + 2.9877.P_{g6} + 56.4091$ \$/h

The economic, emission and CEED problems are solved by using CM, GA and HGA. The control parameters for the HGA are shown in Table II. The following power loads and their corresponding percentages at each maximum generation capacity are considered in the simulation, 89.2 MW (56.48%), 239 MW (71.40%), 255 (76.12%), 256 (76.42%) and 283.4 MW (84.60%). Fig. 2 shows the resulting best fitness plot after 55 generations using HGA for 189.2MW load demand. Fig. 2-a shows the best and mean values of the population in every generation. Fig. 2-b shows the current best individual for each variable. From this Figure, it can be shown that, the results of using HGA can improve the accuracy of the solution efficiently. Fig. 3 shows a comparison of fuel cost obtained from conventional method, simple GA and HGA for various power demands. On the other hand, Fig. 4 shows a comparison of emission generation (ton/h) from generators for each implemented methods under various power demands. Figure 5 shows a comparison of losses in transmission lines for each implemented methods under various power demands. Figure 6 shows the best generator setting obtained from conventional method, simple GA and HGA for various power demands. For accurate results, Table III shows the results of the proposed method and the results of the classical method and GA when the load values are 189.2 MW, 239 MW, 255MW, 256 MW and 283.4 MW. It can be seen ,from figures and Table III, that HGA algorithm gives global or near global optimal solution, hence it provides better solutions than those provided by the conventional technique and simple GA. Also, we can observe, from Table III and Figs 3-5, that the solution obtained by the conventional method is not an optimal one. Fig. 7 shows total fuel and emission cost for each implemented method under various power demands. It can be seen also from Fig. 1 and Fig. 7 that, if the load increases from 255 MW (76.12%) to 256 MW (76.42%) the generation cost will be very high. So, it is not economic to operate the power system above 76.12% of its capacity.

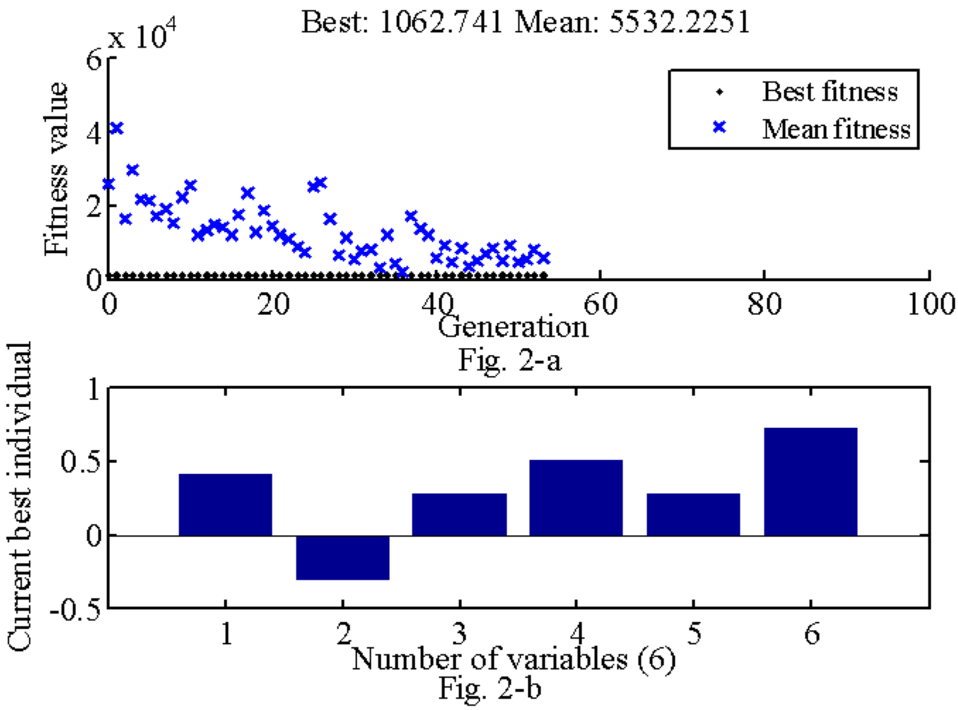

Figure 2. HGA Simulation under 189.2 MW load demand

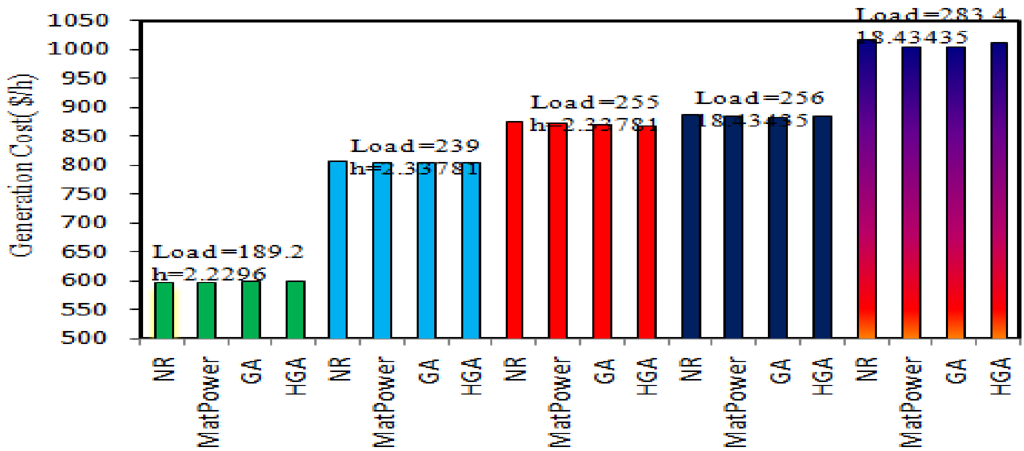

Figure 3. Comparison of fuel cost for each methodology under various loading condition

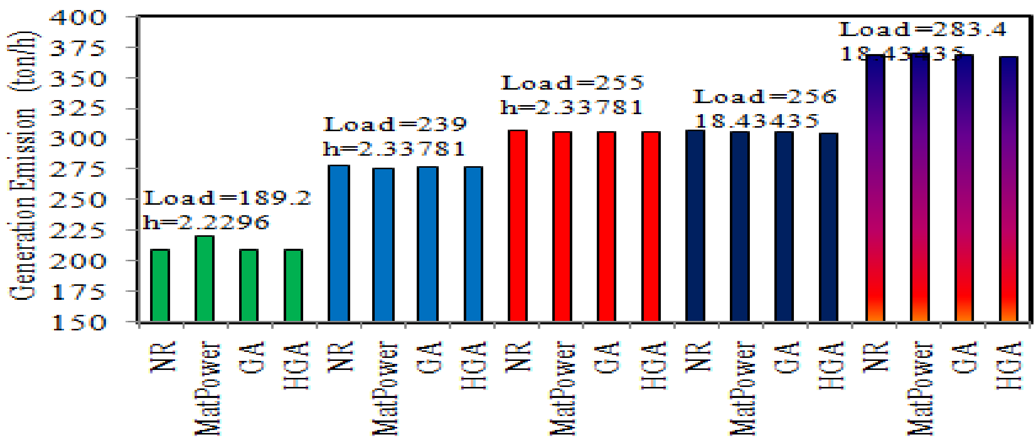

Figure 4. Comparison of emission for each methodology under various loading condition

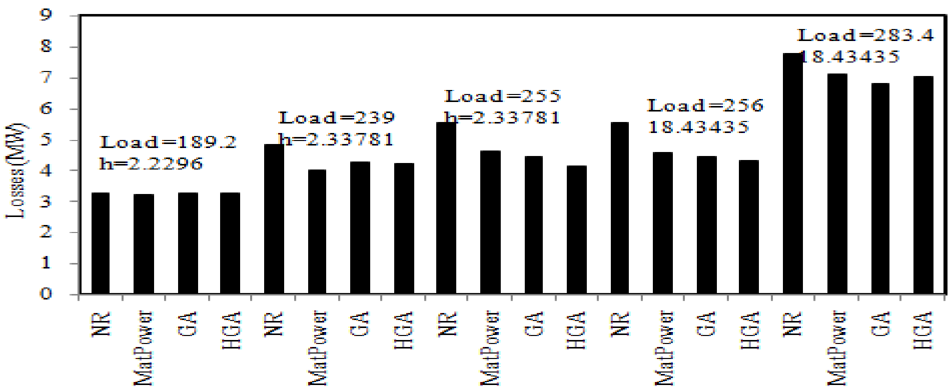

Figure 5. Comparison of Losses for each methodology under various loading condition

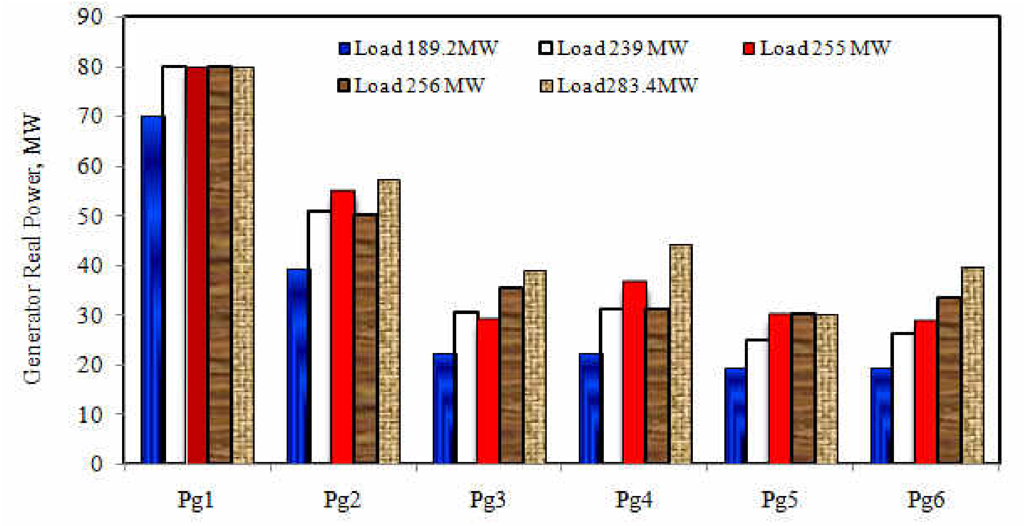

Fig. 6 Comparison of best generator setting for HGA under various loading condition

Table III Comparison of test results for different algorithms under some Loading Conditions

Units / Methods		Pg_1	Pg_2	Pg_3	Pg_4	Pg_5	Pg_6	Fuel Cost,$/hr	Emission ton/hr	Total Cost, $/hr	Losses. MW
Total Load 189.2 MW h=2.2296 $/ton	NR	69.980	39.16	22.4114	22.2428	19.4	19.2763	598.2171	208.8275	1063.821	3.2706
	MatPower	63.057	33.589	21.5907	36.8938	18.9924	18.3175	595.4818	220.185	1086.408	3.2406
	GA	69.993	39.7191	22.4189	21.5248	19.6236	19.2051	598.0692	208.9318	1063.904	3.2846
	HGA	70	39.1232	22.3728	22.1748	19.3568	19.2769	597.6354	208.6048	1062.741	3.1045
Total Load 239 MW h=2.33781 $/ton	NR	80	51.27	28.0506	31.1315	26.3165	27.079	806.0433	277.8104	1455.512	4.8475
	MatPower	80	49.692	28.1945	30.5687	26.1839	28.3495	804.0273	275.6868	1448.532	3.9892
	GA	79.944	51.5013	26.5971	29.8388	30	25.3699	804.167	277.363	1452.589	4.2515
	HGA	80	51.239	28.3679	31.2373	25.3982	25.8901	803.9541	274.9134	1447.721	3.89234
Total Load 255MW h= 2.3378 $/ton	NR	80	55.84	30.3553	34.8465	29.1617	30.3513	874.4389	307.5465	1593.424	5.5545
	MatPower	80	54.571	30.549	34.3086	28.0662	32.1148	871.8308	305.2653	1585.484	4.6097
	GA	79.989	53.1194	31.3048	36.5415	28.4744	30.0257	871.0416	305.3045	1584.786	4.4551
	HGA	80	54.9609	29.083	36.4283	30	28.6856	867.5785	305.7256	1582.307	4.1578
Total Load 256 MW h=18.43435 $/ton	NR	80	51.145	34.2575	32.7765	30	33.387	886.8964	307.3163	6552.076	5.5655
	MatPower	80	50.464	34.048	32.1931	28.7239	35.1637	883.851	305.6331	6518.001	4.5922
	GA	79.963	49.7466	32.0888	32.4967	30	36.1752	882.7794	305.446	6513.478	4.4702
	HGA	80	50.1786	35.5521	31.2934	30	33.3075	884.4521	304.9666	6506.314	4.3315
Total Load 283.4 MW h=18.43435 $/ton	NR	80	60.908	40.8464	39.4222	30	40	1018.218	368.6271	7813.622	7.7768
	MatPower	80	64.566	36.0257	41.9322	27.9786	40	1005.536	370.0476	7827.126	7.1026
	GA	79.88	65.2155	38.1708	41.6615	29.4006	35.8978	1004.761	369.1198	7809.244	6.8259
	HGA	80	57.4414	39.0195	44.1503	30	39.7931	1011.653	367.9225	7794.066	7.0042

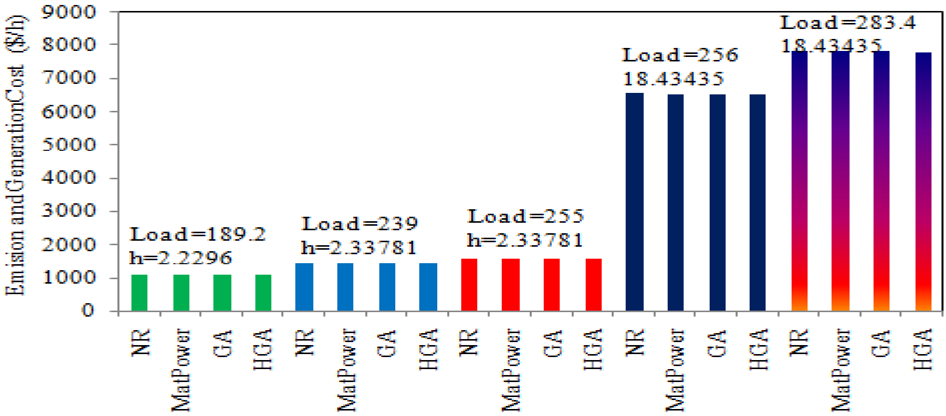

Figure 7. Comparison of total generation cost for each methodology under various loading condition

6. CONCLUSION

Economic load dispatch alone is not sufficient to reduce the pollutant emissions caused by fossil burning for power generation. So, this paper has been investigated CEED problem. The CEED problem is considered as a multiobjective optimization problem that is can be transformed into a single objective one by using a modified price penalty factor technique. A deterministic model of CEED which minimizes both fuel cost and emission simultaneously has been formulated and implemented on IEEE-30 bus power system as a case study. The following conclusions can be drawn from the study:

1- The fuel costs as well as the emission characteristics of generating units are represented by their respective equivalent characteristic in terms of power generations.
2- Transmission losses are expressed in terms of B-coefficients and then the total generation is also represented by total load demand and transmission losses.
3- NR, Matpower, GA and HGA algorithm as a solution to the CEED problem of the IEEE-30 bus test system have been presented.
4- The paper explores loadability and its impacts on economic analysis.
5- Cost and Emission for each load and losses have been calculated for different load conditions.
6- The NR, Matpower and simple GA produced the highest operation cost.
7- The main advantages of HGA over NR, Matpower,and GA methods are: modeling flexibility, more stable convergence characteristics and the solution quality.
8- The validation of the HGA algorithm was demonstrated by comparing the CEED results of IEEE 30 bus system with NR, MatPower and GA. The optimal solutions were obtained for each loading condition within approximately 60 iterations.
9- The results show that the HGA is applicable and effective in the solution of any economic/emission power dispatch problems that consider nonlinear characteristics of power systems with different objective functions.
10- The proposed HGA algorithm can be easily extended to solve any CEED problem.

11- The results show that the cost highly increases if the load is 75% of maximum generation.

Appendixes

Appendix (A) Cost and emission coefficients of six units system [11]

Bus No.	P_{gmin} MW	P_{gmax} MW	a_i	b_i	c_i	d_i	e_i	f_i
1	50	200	0.00375	2.00	0	0.012	-1.100	22.983
2	20	80	0.0175	1.75	0	0.020	-0.100	25.313
5	15	50	0.0625	1.00	0	0.027	-0.010	25.505
8	10	35	0.0083	3.25	0	0.0291	-0.005	24.900
11	10	40	0.0250	3.00	0	0.029	-0.004	24.700
13	12	40	0.0250	3.00	0	0.027	-0.005	25.300

Appendix (B) Loss coefficients B matrices of six generating units

B =[
0.028704 0.014399 0.0015213 -0.002228 -0.003837 0.000264
0.014399 0.018302 0.0014494 -0.002944 -0.005019 0.000066
0.001521 0.001449 0.0692560 -0.015614 0.002464 -0.034273
-0.00222 0.002946- 0.0156139 0.04685 -0.001289 -0.023054
-0.00383 0.005019 0.0024643 -0.00128 0.0907567 -0.01033
0.00026 0.000066 -0.034273 -0.02305 -0.010332 0.343063]
B0 = [-0.001511 -0.000509 0.002057 -0.0006779 -0.0014469 0.0034321];
B00 =[5.224032196360447e-004];

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الملخص العربي

من أهم القضايا التي تهم العاملين في مجال البيئه في هذه الآونه هي قضيه تقليل الأنبعثات الملوثه من كافه المصادر. يقدم هذا البحث طريقه جديده لتغذيه الأحمال وتوزيعها بين وحدات التوليد الكهربائيه المختلفه بطريقه إقتصاديه أخذين في الأعتبار تقليل الأنبعاثات الملوثه الصادره من وحدات التوليد التي تعمل بالوقود الأحفوري. مسأله أخذ تأثير الأنبعاثات الملوثه وإقتصاديات التشغيل علي توزيع الأحمال عبارة عن مساله مثاليه غير خطيه متعددة القيود والأهداف تم تحويلها إلي داله ذات هدف واحد عن طريق معامل العقوبه (Penalty factor) .

يقدم هذا البحث طريقه للحل تعتمد علي نموذج رياضي باستخدام طريقة الحساب الجيني المختلط (Hybrid Genetic Algorithm). الطريقه المقترحه طبقت علي الشبكه الكهربائيه القياسيه IEEE 30 bus وأوضحت النتائج مدي فاعليه الطريقه المقترحه بعد ان تم مقارنتها مع نتائج الطرق التقليديه.