ECONOMIC-EMISSION LOAD DISPATCH THROUGH GOAL PROGRAMMING TECHNlqUES

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Abstract - Operating at absolute minimum cost can no longer be the only criterion for dispatching electric pouer due to increasing concern over the environmental considerations. The economic-emission load dispatch (EELD) problem which accounts for minimization of both cost and emission is a multiple, conflicting objective function problem. Goal programming techniques are most suitable for such type of problems. In this paper, the economic-emission load dispatch problem is solved through linear and non-linear goal programming algorithms. The application and validity of the proposed algorithms are demonstrated for a sample system having six generators.

INTRODUCTION

Economic dispatch is a familiar problem pertaining to the allocation of the amount of pouer to be generated by different units in the system on an optimum economy basis. This problem has been tackled by many researchers in the past. Recently the problem uhich has attracted much attention is pollution minimization due to the pressing public demand for clean air. Environmental pollution is a direct consequence of industrial advancement. Technology, uhich has made economic development possible produces enormous quantities of harmful by-products and wastes. Thermal pouer stttions are major causes of atmospheric pollution, because of high concentration of pollutants they cause.

Unfortunetely, not much uork has been done in the area of economic-emission load dispatch. Gent and Lamont [1] were possibly the first to publish a paper on minimum emission dispatch in uhich a computer algorithm was presented to minimize the nitrogen oxide (NO_x) emission. Sullivan [2] achieved minimum pollution dispatch) by applying Kuhn-Tucker conditions. Delson [3] described the method of using monetary conversion factors to achieve controlled emission dispatch. Finnigan and Fousd [4] proposed tuo non-linear programming solution procedures for economic dispatch uith pollution constraints. Zahavi and Lisenberg [5] formulated the economic-environmental pouer dispatch to be solved by an interactive search method but they have not illustrated the effectiveness of the methcri throuyh any suitable example. Kothari et al. [6] presented a computer oriented technique for thermal pouer generation scheduling resulting in the minimization of nitrogen oxide emissions.

All these methods are based on usual programming techniques, uhich, houever, do not consider multiple objectives of conflicting nature. In reality, the ELLO problem is a multiple objective problem uith conflicting objectives because minimum pollution is conflicting to minimum cost of generation. In this paper the EELD problem is solved for the first time, to the best of the authors' knouledge, using a linear goal programming (LGP) technique and also by developing a neu and efficient non-linear goal programming (NLGP) algorithm. Results obtained by both the approaches are duly compared and discussed.

GOAL PñUGFtAHMING_hbDLL

Goal Programming (GP) is extension of linear programming (LP)/non-linear programming (NLP). Though formulating a GP model is similar to formulating LP/iMLP, yet differs in the approach to the solution problem. The first step is to define the decision variables. Then ell the managerial goals must be specified and ranked in order of priority. Even though management may not be aols to relate the various goals on a cardinal scale, it can usually provide an ordinal ranking to each of its goals or objectives. Gl: can resolve infeasiule problems stemming from goal resource constaint interactions. Such interactions occur when goals are conflicting. For example, consider an investor uho desires investments that uill have a r^axim&l return and minimal risk. These goals are generally incompatible and,therefore unachieveable. GP is capable of handling decision proolems uith single or multiple goals even of conflicting netjre. Basically, the n.ethod of goal programming consists of formulating an objective function in uhich optimization comes as close PE possible to the specified goals. In real decision-making situations typicelly, goals established by the decision maker eie achievable only at the expense of other goals [11J.

The GP formulation requires the aspiration levels (called as goal valjes) for each of the objective functions end for each of the constraint functions to be converted into objective goals and constraint goals respectively. Constraint goals arn also called as absolute or rigid goals. Goals that are ranked in order of priority are satisfied sequentially by the solution algorithm. Louer priority goals are considered only after higher priority goals have been satisfied. The achievement of a goal is the value by uhich the function value deviates from its aspiration

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lev/el. The deviation represents the degree or over-achievement (postive devistion) or under-achievement (negative deviation). Each achievement function is a linear fjnction of the appropriate deviational variables. The fundamental distinction is that GP minimises these achievement functions in order of priority rather than minimizing or maximizing the objective functions directly. The absolute goals are treated as top priority goals and are assigned to the first achievement function. The deviation of this achievement function should invariably be zero. Otheruise, no solution exists for the problem.

The general goal programming model can be expressed as

Find $X(x_1, x_2, \ldots, x_n)$ (1)

so as to minimize

$$A = \{a_1(d^-, d^+), a_2(d^-, d^+), \ldots, a_t(d^-, d^+)\} \quad (2)$$

subject to

$$g_i(X) + d_i^- - d_i^+ = c_i \quad i = 1,2,\ldots,m$$
$$f_i(X) + d_{m+i}^- - d_{m+i}^+ = b_i \quad i = 1,2,\ldots,k \quad (3)$$

where

X the decision vector

$x_1, x_2, \ldots, x_n$ decision variables

A the achievement function vector

$a_1, a_2, \ldots, a_t$ achievement functions in order of priority

$g_i(X)$ ith constraint goal function

c_i aspiration level for ith constraint goal

$f_i(X)$ ith objective goal function

b_i aspiration level for ith objective goal

n number of decision variables

m number of constraint goals

k number of objective goals

t number of priorities

d^- deviation variable representing degree of under-acheivement

d^+ deviation variable representing degree of over-schievement

Each devistion variable is determined independently from the corresponding constraint equation as follows 2

$$d_i^- = \begin{cases} d_i^- & \text{if } d_i^- \geq 0 \\ 0 & \text{if } d_i^- < 0 \end{cases} \quad (4)$$

uhere

$$d_i^- = c_i - g_i(X)$$

or

$$d_i^- = b_i - f_i(X)$$

Similarly

$$d_i^+ = \begin{cases} 1 & \text{if } d_i^+ \geq 0 \\ 0 & \text{if } d_i^+ < 0 \end{cases} \quad (5)$$

Where

$$d_i^+ = g_i(X) - c_i$$

or

$$d_i^+ = f_i(X) - b_i$$

PROBLEM FORMULATION

Power utilities using fossil fuels as a primary energy source, give rise to psrticulates and gaseous pollutants apart from heat.The psrticulates as also the gsseous pollutants such as carbondioxide (CO_2), oxides of sulphur (SO_x) and oxides of nitrogen (NO_x) cause detrimental effects on human beings. However, in reality, the effect of CO_2 on the environment is not yet precisely knoun. Pollution control agencies (Municipal/Governmental regulatory bodies) restrict the amount of emission of pollutants depending upon their relative harmfulness to human beings and hence a priority structure can be formed for the multiobjective problem. In fact NO_x emission, SO_x emission, thermal emission and particulates all together can be treated as a single minimum emission criterion. Thus, the EELD problem can be defined as :

Find the real power generations $P_1, P_2, \ldots, P_n$ (6)

which will minimize the objectives

(1) Total emission expressed as

$$f_1(P) = \sum_{i=1}^{n} \{ D_i (P_i)^2 + E_i(P_i) + F_i \} \quad (7)$$

where D,E and F are emission coefficients.

(2) Total operating cost expressed as

$$f_2(P) = \sum_{i=1}^{n} \{A_i (P_i)^2 + B_i(P_i) + C_i\} \quad (8)$$

uhere A,B and C are cost coefficients

subject to

(a) the operating constraints i.e.,

$$P_{i\,min} \leq P_i \leq P_{i\,max} \quad (9)$$

where $i = 1,2,\ldots, n$

(b) the power demand constraint i.e.,

$$\sum_{i=1}^{n} P_i = P_D \quad (10)$$

(Losses can be neglected ss we are concerned with environmental rather than only operating cost)

The oojective functions, Lqs. (7) and (8) are considered as continuous quadratic functions relevant to tha proDlem under consideration. Houever, situations having discontinuous objective functions can also be handled *by* the GP moriel.

Formulation in LGP format

Taking decision variables $x_1, x_2, \ldots, x_n$ for the real power generations $P_1, P_2, \ldots, P_n$ the problem is formulated in LGP format as described below :

Absolute goals : (i) The operating limits (louer and upper) on the decision variables and (ii) The power demand equality constraint become the absolute goals.

(i) Operating limit goals are expressed as

$$g_1(X) + d_1^- - d_1^+ = c_1$$
$$g_2(X) + d_2^- - d_2^+ = c_2$$
$$\vdots$$
$$g_n(X) + d_n^- - d_n^+ = c_n \quad (11)$$

$$g_{n+1}(X) + d^-_{n+1} - d^+_{n+1} = c_{n+1}$$
$$\vdots \qquad\qquad \vdots$$
$$g_{2n}(X) + d^-_{2n} - d^+_{2n} = c_{2n}$$

uhere

$c_1, c_2, \ldots, c_n$ are the aspiration levels representing the louer bounds on the decision variables and $c_{n+1}, c_{n+2}, \ldots, c_{2n}$ are the aspiration levels representing the upper bounds on the decision variables and

$g_1(X), g_2(X), \ldots, g_n(X)$ as well as $g_{n+1}(X)$, $g_{n+2}(X), \ldots, g_{2n}(X)$ are the decision variables $x_1, x_2, \ldots, x_n$.

(ii) The pouer demand equality goal is expressed as

$$g_{2n+1}(X) + d^-_{2n+1} - d^+_{2n+1} = c_{2n+1} \qquad (12)$$

uhere

c_{2n+1} is the aspiration level of the pouer demand

and $g_{2n+1}(X) = \sum_{i=1}^{n} P_i$

The absolute goals of operating limits and pouer demand together given the top priority and are assigned to the first achievement function (a_1).

Objective goals : (i) The minimum emission level and (ii) the minimum operating cost are the objective goals.

(i) The emission goal is expressed as

$$f_1(X) + d^-_{2n+2} - d^+_{2n+2} = b_1 \qquad (13)$$

uhere

b_1 is the aspiration level of the emission, and

$$f_1(X) = \sum_{i=1}^{n} \{D_i(P_i)^2 + E_i(P_i) + F_i\}$$

(ii) The operating cost goal is expressed as

$$f_2(X) + d^-_{2n+3} - d^+_{2n+3} = b_2 \qquad (14)$$

uhere

b_2 is the aspiration level of the operating cost, and

$$f_2(X) = \sum_{i=1}^{n} \{A_i(P_i)^2 + B_i(P_i) + C_i\}$$

The objective goals of minimum emission and minimum operating cost as per the desired priorities are assigned to the next achievement functions (a_2 and a_3).

It is worth mentioning once again that each achievement function is the sum of the appropriate deviations to be minimized corresponding to the goals. The deviations that are considered in the achievement function depend upon the type of the goal form. Positive deviation in case of a ≤ type goal, negative deviation in case of a ≥ type goal and both positive and negative deviations in case of a = type goal are considered for minimization.

Thus, the first achievement function a_1 is the sum of all the appropriate deviations of the absolute goals. Suppose the order of achievements of objective goals are (i) minimum emission level and (2) minimum operating cost, then the achievement functions are

$$a_1 = d^+_1 + d^+_2 + \ldots + d^+_n + d^-_{n+1} + d^-_{n+2} + \ldots + d^-_{2n} + d^+_{2n+1} + d^-_{2n+1} \qquad (15)$$

$$a_2 = d^+_{2n+2}$$

$$a_3 = d^+_{2n+3}$$

Hence the problem is nou

to minimize the achievement function vector $A = [a_1, a_2, a_3]$ (16)

subject to

$$g_i(X) + d^-_i - d^+_i = c_i \quad i=1,2,\ldots,2n,2n+1 \qquad (17)$$
$$f_i(X) + d^-_{2n+1+i} - d^+_{2n+1+i} = b_i \quad i=1,2$$

and $d^-_i \geq 0$, $d^+_i \geq 0$ and $d^-_i \cdot d^+_i = 0$ for all i (18)

Formulation in NLGP format

In the proposed NLGP algorithm Box complex method [7] is used to minimize the achievement functions. The advantage of this method is that the operating limits on the decision variables (real pouer generations in this case) uill be taken care uhile generating the feasible points. Hence the boundary constraints can no more needed to be included in absolute goals. Hence, for the proposed NLGP algorithm pouer demand equality constraint is the only constraint goal (absolute goal). Sox complex method cannot handle equality constraints. Hence, the pouer demand equality constraint is converted into an inequality constraint as :

$\sum_{i=1}^{n} P_i = P_D$ can be replaced by

$$\sum_{i=1}^{n} P_i \geq P_D - \delta \qquad (i)$$

and

$$\sum_{i=1}^{n} P_i \leq P_D + \delta \qquad (ii)$$

The constraints of the nature (ii) are needed only for getting a feasible starting point. This type of constraints are never violated during the process of searching for the optimum point. This is due to the fact that as the complex shrinks the objective moves touards the constraints of the nature (i). In fact cost of generation uill be minimum, uhile meeting load requirements uhen (i) is satisfied as equality constraint uith $\delta = 0$. Hence, constraints of the nature (ii) can be ignored. Thus, the pouer demand constraint can be uritten as

$$\sum_{i=1}^{n} P_i \geq P_D - \delta \qquad (19)$$

Taking decision variables $x_1, x_2, \ldots, x_n$ for the real pouer generations $P_1, P_2, \ldots, P_n$ the NLGP format can nou be uritten as

absolute goal : $g_i(x) + d^-_i - d^+_i = c_1$

objective goals: $f_2(X) + d_2^- - d_2^+ = b_2$ (20)

$$f_3(X) + d_3^- - d_3^+ = b_3$$

where

$$g_1(X) = \sum_{i=1}^{n} P_i$$

$$f_1(X) = \sum_{i=1}^{n} \{ D_i(P_i)^2 + E_i(P_i) + F_i \} \quad (21)$$

$$f_2(X) = \sum_{i=1}^{n} \{ A_i(P_i)^2 + B_i(P_i) + C_i \}$$

and c_1, b_1 and b_2 are the aspiration levels of the power demand goal, emission goal and operating cost goal, respectively.

The achievement functions for the power demand goal, emission goal, and operating cost goal, respectively, are

$$a_1 = d_1^- , \quad a_2 = d_2^+ \text{ and } a_3 = d_3^+ \quad (22)$$

Thus the problem is to minimize the achievement function vector

$$A = [\ a_1,\ a_2,\ a_3\ ] \quad (23)$$

subject to

$$g_1(X) + d_1^- - d_1^+ = c_1$$

$$f_i(X) + d_i^- - d_i^+ = b_i \quad i=1,2 \quad (24)$$

and

$d_i^- \geq 0$, $d_i^+ \geq 0$ and $d_i^- . d_i^+ = 0$ for all i (25)

SOLUTION ALGORITHMS

The solution algorithms of both LGP and NLGP are discussed belou:

Linear goal programming

Basically tuo LGP algorithms are existing in literature, viz. (i) sequential linear goal programming and (ii) multiphase linear goal progremming. Sequential linear goal programming is, the earliest method, based on sequential solutions to a series of conventional linear programming problems according to the priority level. Multiphase linear goal programming is more straightforward and generally requires fewer computations. It is bssed on multiphase simplex method uhich is simply a refinement of the well known tuo-phas3 method. In the present paper the EELD problem is solved using the multiphase simplex method [8].

Non-linear goal programming

The NLGP algorithms existing in the literature are (i) by Ignizio [9] and (ii) by Huang and Masud [10] . These NLGP algorithms have certain drawbacks such as selection of step sizes rnd/or starting feasible point. In order to overcome these drawbacks a neu MLGP algorithm is developed which utilizes the Sox method efficiently for minimizing the achievement functions. The following are the steps to be followed to solve the ELLQ problem by the proposed NLGP algorithm.

Step 1 : Set the complex size K. Set the achievement function count, IACH = 0.

Step 2 : Increment the achievement function count, IACH = IACH + 1.

Step 3 : If IACH is 1, the starting feasible point is generated. Otherwise, previous best point is treated as the starting feasible point.

Step 4 : Set the sequential search count, ISEQ = 1 .

Step 5 : Set the iteration count, ITR = 1. The remaining (K-1) complex points are generated by the use of random numbers such that

$$X_j = L_j + R(U_j - L_j), \quad j=2,3,\ldots,K$$

uhere R is a random number generated in the range 0 to 1 and L_j and U_j are the louer and upper bounds for X_j. This relation uill ensure that the (K-1) points so generated uill satisfy the lower and upper bounds of the jth decision variable. Check uhether these points satisfy the previous achievement function values.If satisfied go to next step. Otherwise, the trial point is moved half way towards the centroid X_c of the remaining already accepted points as

$$X_j = \frac{1}{2} [X_c + X_j]$$

uhere $X_c = \frac{1}{j-1} \sum_{\ell=1}^{j-1} X_\ell$

The process of moving half way towards the centroid X_c is continued until a feasible point X_j is found.

step 6 : Evaluate the objective function value at each of the K points. Estimate the point X_w at which the function value assumes the worst value $f(X_w)$ and the point X_b at which the function value is the best $f(X_b)$.

Step 7 : Check uhether $| f(X_w) - f(X_b) | \leq \epsilon_1$ (a prespecified tolerance). If yes, go to the next step. Otherwise go to step 11 .

Step 8 : If ISEQ = 1, go to step 10. Otheruise, check whether ISEQ ≥ ISTMAX (a prespecified maximum number of sequential searches. Experience shows that generally 2 to 3 sequential searches are sufficient to find the global optimum). If yes, go to step14, Otherwise, go to the next step.

Step 9 : Check uhether $| f(X_{old}) - f(X_b) | \leq \epsilon_2$ (a prespecified tolerance). If yes, go to step 14. Otherwise, go to next step.

Step 10 : Set $f(X_{old}) = f(X_b)$, increment ISEQ= ISEQ+1 and go to step 5.

Step 11 : The worst point X_w is replaced by its reflection point X_r such that $X_r = (1+\alpha)X_c - \alpha X_w$, where α is called the reflection coefficient and its recommended value is 1.3 and X_c is the centroid of ell the points except X_w.

Step 12: Check uhether the point X_r is feasible and its function value $f(X_r)$ is better than $f(X_w)$. If satisfied go to next step. Otherwise, reduce a anci go to step 11. The process of reducing is continued ti^l its value becomes as small as 10~J and then go to step 5.

Step 13: Check whether the iteration count ITR has reached the prespecified maximum number of iterations. If yes, go to step 10. Otherwise, increment ITR=ITR +1 and go to step 6.

Step 14: Check whether IACH <NACH (number of achievements). If yes, go to step 2. Otherwise search is terminated.

RESULTS AND ANALYSIS

The proposed LGP and NLGP algorithms have been applied to a six generator system [43 for two specific cases :

I. Generators running with natural gas.

II. Generators running with fuel oil.

It is worth mentioning once again that the pouer demand and the operating limits on generators become the absolute goals in case of LGP algorithm, but the pouer demand is the only absolute goal while using NLGP algorithm. Also, that the absolute goals should be given the first priority.

Case I : Generators running with natural gas

The constraint goel (absolute goal) is treated as the first priority goal, NO_x emission as the second priority goal and the operating cost as the third priority goal. The total pouer demand becomes the aspiration lavel for the first priority goal (operating limits on generators also as the first priority in case of LGP), an emission of 2600 lbs/hr (as restricted by the pollution control agency) is the aspiration lavel for the second priority goal. An infeasible aspiration level, say ,.10C0/hr, is assigned to the third priority goal to ensure the minimum operating cost.

The problem is solved again by changing the priorities i.s. absolute goals as the first priority, operating cost as the second priority and NO_x emission as thu third priority. The aspiration levels for the first priority remain the same. The aspiration level for the second priority is taken as i.4000/hr and an infeasible aspiration level, say 1000 lbs/hr, is given to the third priority goal to achisve minimum emission dispatch.

The resjlts of these studies using LGP technique are presented in Tables I 4 II and the corresponding results using the NLGP technique are presented in Tables V & VI.

Case II : Generators running with fuel oil

This case also is solved with absolute goals, NO_x emission and operating cost as the order of priorities. The total pouer demand (and also operating limits on the generators in case of LGP algorithm) becomes the aspiration level for the first priority goal. An emission of 3100 lbs/hr is the aspiration levsl for the; sucond priority goal. An infeasible aspiration lsvel, say ;»1000/hr,is given to the third priority goal.

This problem is also resolved by interchanging the objective goal priorities i.s. absolute goals, operating cost and Nu_x emission as the neu order of priorities.

The results of these studies using the LGP algorithm are presented in Tables III & IV and those obtained with the proposed NLGP algorithm in TablBs VII & VIII. The solution vector (Real pouer outputs in NLJ) is also presented in all the studies.

The results obtained in both the cases I and II clearly reveal that better optimum values ere achieved uith the NLGP as compared to those obtained using LGP. Houever.the solution time will be more with NLGP as compared to LGP. Further, examinining the algorithms of LGP and NLGP and comparing them with the corresponding algorithms of LP and NLP,it can ba seid.in general, that the GP based algorithms will be faster.

In order to validate the proposed LGP and NLGP algorithms, these are applied to a 6 generator system [4^ considering a single objective at a time and duly compering the results with those of Fief.4. It can be observed(Tabls IX) that the optimum resjlts obtained by the proposed LGP end NLGP algorithms are in very close agreement to those of Ref.4, wherein the problems ere solved using NLP.

In the present paper least square minimization princi;- lc ,which yields adequete accuracy, is employed to linearize the nonlinear (quadratic) cost and emission functions.

Table I

Optimum results with LGP-generators running on natural gas

Priority level	Achievement goal	Aspiration level	Achievement function value	Optimum value
1	Power demand & operating limits	As specified	0.0	-
2	NO_x emission	2600 lbs/hr	0.0	2561.85 lbs/hr
3	Operating cost	1000 i/hr	2368.50	3368.60 ^/hr

Solution vector	80.0	80.0	220.0	232.0	344.0	344.0

Table II

Optimum results with LGP-generators running on natural gas (priorities changed)

Priority level	Achievement goal	Aspiration level	Achievement function value	Optimum value
1	Pouer demand & operating limits	As specified	0.0	-
2	Operating cost	4000 „/hr	0.0	3330.69 t/hr
3	NO_x emission	1000 lbs/hr	1736.60	2736.60 lbs/hr

Solution vector	91.0	27.0	236.0	72.0	344.0	330.0

Table III

Optimum results uith LGP-generators running on fuel oil

Prio- rity level	Achieve- ment goal	Aspira- tion level	Achieve- ment func- tion value	Optimum value
1	Pouer demand & operating limits	As speci- fied	0.0	-
2	NO_x emission	3100 lbs/ hr	0.0	3072.55 lbs/ hr
3	Operating cost	1000 t/hr	2952.17	3952.17 fc/hr
Solution vector	g5>Q 95>Q 220.0 232.0 314.0 144.0			

Table IV

Optimum results uith LGP-generators running on fuel oil (Priorities changed)

Prio- rity level	Achieve- ment goal	Aspira- tion level	Achieve- ment func- tion value	Optimum value
1	Power demand * operating limits	fis speci- ied	0.0	-
2	Operat- ing cost	4000 ;/ hr	0.0	3838.06 $/ hr
3	MO_x emission	1000 lbs/ hr	2023.0	3666.10 lbs/hr
Solution vector	35.0 35.0 113.Q 232.0 344.0 344.0			

Table \J

Optimum results uith NLGP-generators running on natural gas

Prio- rity level	Achieve- msnt goal	Aspira- tion level	Achievement function value	Optimum value
1	Pouer demand	1100 Flu	0.0	-
2	NO_x emission	2600 lbs/ hr	0.0	2399.98 lbs/hr
3	Operat- ing cost	1000 i/hr	2297.54	3297.54 Sf/hr
Solution vector	62#73 60.27 1B5.09 184.44 299.0 308.5			

Table VI

Optimum results uith NLGP-generators running on natural gas (Priorities changed)

Prio- rity level	Achieve- ment goal	Aspira- tion level	Achievement function value	Optimum value
1	Pouer demand	1100 F)U	0.0	-
2	Operat- ing cost	4000 |/hr	0.0	3362.07 fc/hr
3	NO_x emission	1000 lbs/ hr	1211.38	2211.88 lbs/ hr
Solution vector	gg g_gg n.185-26 181.06 267.84 267.84			

Table VII

Optimum results uith MLGP-generators running on fuel oil

Pri- ority level	Achieve- ment goal	Aspira- tion level	Achievement function value	Optimum value
1	Pouer demand	1100 MW	0.0	-
2	NO_x emission	3100 lbs/ hr	0.0	3099.99 lbs/ hr
3	Operat- ing cost	1000 i/hr	2850.38	3850.38 $/hr
Solution vector	66#95 60,94 206-«84 201.25 283.34 280.9			

Table VIII

Optimum results uith NLGP-generators running on fuel oil (Priorities changed)

Pri- ority level	Achieve- ment goal	Aspira- tion level	Achievement function value	Optimum value
1	Pouer demand	1100 MW	0.0	-
2	Operat- ing cost	4000 t/hr	0.0	3939.76 $/hr
3	NO_x emission	1000 lbs/ hr	1255.03	2855.03 lbs/ hr
Solution vector	101.0 101.0 212.7 212.7 236.25 236.31			

Table IX

Comparison of minimum operating cost and minimum NO_x emission

Type of fuel	Operating condition	Using LGP Cost	Using LGP NO_x emission lbs/hr	Using NLGP Cost $/hr	Using NLGP NO_x emission lbs/hr	Using MLP (Ref. 4) Cost $/hr	Using MLP (Ref. 4) NO_x emission lbs/hr
Natural gas	Economic Load Dispatch	3289.32	2744.63	3279.79	2633.72	3279.65	2641.29
	Minimum Emission Dispatch	3404.18	2446.12	3362.07	2211.88	3362.17	2211.74
Fuel oil	Economic Load Dispatch	3834.48	3677.66	3819.86	3472.41	3818.85	3542.39
	Minimum Emission Dispatch	3967.30	3023.00	3939.74	2855.03	3932.25	2855.03

CONCLUSIONS

The problem of economic-emission load dispatch to provide optimum operating cost and minimum emission dispatch is formulated as a multiobjective problem. A maiden attempt is made to solve this conflicting, multiobjective problem uith the use of LGP technique as well as uith NLGP technique. A new and efficient NLGP algorithm, uhich utilizes Box complex method for minimizing the achievement functions, is presented uhich overcomes certain drawbacks of existing NLGP algorithms. The effectiveness of the gosl programming techniques is fully demonstrated by solving a sample system. Investigations reveal that the proposed techniques, are quite attractive for practical applications.

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