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Multi-objective Thermal Power Scheduling by Evolutionary Search Weighted Simulation Techniques

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***Abstract*—In the present paper multi-objective thermal power dispatch problem with three objectives and constrains has been addressed. The multi-objective economic-emission dispatch problem is converted into a scalar optimization problem using weighting method. The criterion is to determine a non-inferior solution using weighting method. The decision maker has been provided to search the best alternative from all the possible non-inferior solutions to decrease the computation time as the numbers of objectives are more than two. Hook- Jeeves and Evolutionary search techniques have been implemented to search the "preferred" weightage pattern in the non-inferior domain which corresponds to the best optimal solution. Subsequently a Fuzzy methodology has been implemented to decide optimal operating point by interacting with the decision maker. The non-inferior solution which attains maximum satisfaction level from the membership function of participation of objectives has been adjusted the best solution. This proposed method requires few search moves to get the optimal operating point in the non-inferior domain.**

***Index Terms*—Evolutionary technique, fuzzy decision making,membership function, multiobjective, weight simulation method.**

I. INTRODUCTION

THE basic objective of economic power dispatch (EPP) of electric power generation is to schedule the generation units output so as to meet the total load demand and satisfying all system equality and inequality constraints with minimum operating cost [1].

With an increase in the power demand the power generation scale is constantly expanding. Issues related to the policies of energy-saving scheduling, which demand to reform the existing power generation scheduling to reduce energy consumption and pollutant emissions in India are taking the centre stage of the energy planners. The generation of electricity from fossil fuel releases several contaminants, such as sulphur dioxide (SO2), nitro-gen oxides (NOx), and carbon dioxide (CO2) into the atmosphere. Atmospheric pollution affects not only humans but also other life forms such as animals, birds, fish and plants. It also causes damage to materials, reducing visibility as well as causing global warming. Due to the increasing concern over the environmental considerations, society demands adequate and secure electricity not only at the cheapest possible price, but also at a minimum level of pollution. In particular, since the passage of the clean air Act amendments of 1990, emission control has become one of the important operational objectives.

Therefore, priority structure of EPP can be formed by considering multi-objective functions Wong et al. [2] have proposed a bi-criterion global optimization approach to determine the most appropriate generation dispatch solution taking in to account fuel costs, environmental costs, and security requirements of power network. Kermanshah et al.[3] presented a decision making methodology to determine the optimal generation dispatch and environmental marginal cost for power system operation with multiple conflicting objective,Dhillon et al.[4] have solved a stochastic economic emission load dispatch in which non-inferior solution has been generated by weighted min-max techniques and the fuzzy set theory have been used for decision making,Dhillon et al.[5] have solved multi-objective thermal power dispatch problem using ε-constraint method. A recursive quadratic programming method to solve the emission constrained dynamic economic dispatch by fuel switching has been presented in ref. [6]. A Hopfield neutral network for finding the optimal economic/ environmental dispatching of thermal generating unit is considered by Kin et al.[7].

The objective of the paper is to solve multi-objective thermal power dispatch problem having three objectives. These are economic index and impact on environment due to SO_2, CO_2 gaseous pollutants. The objectives are of conflicting nature and improvement in one objective can be reached only by the reduction of other. The formulated EED problem is solved using weighting method to generate non-inferior solutions which allow explicit trade-off between the objective levels for each non-inferior solution. Fuzzy set theory has been implemented to decide the optimal operating point by interacting with a decision maker. Since the generation of non-inferior solution requires an enormous amount of time, when there are large numbers of objectives. Hence to reduce the computational time, Hook-Jeeves and, evolutionary search technique are implemented to search the preferred weight pattern in the non-inferior domain.

II. ENVIRONMENTAL/ECONOMIC DISPATCH

The multi-objective thermal power dispatch problem is defined to minimize the operating cost, $SO_2$and CO_2 emission levels of the thermal plant while meeting total real power load plus real power transmission losses [8].

Objective Functions

1. Fuel cost objective

The fuel cost (Rs/h) of a thermal unit is regarded as essential criteria for economic feasibility. The fuel cost curve is approximated by a quadratic function of generator's active power outputP_{G_i}

$$F_i = \sum_{i=1}^{N_G} \left(a_i P_{G_i}^2 + b_i P_{G_i} + c_i\right) \qquad (1)$$

where,a_i, b_i and c_i are the cost coefficients and N_G is the number of the generators.

2.SO_2 Emission Objective

The amount of emission from a unit such as CO_2, SO_2 etc. depends on the power generated by the unit. Therefore, the amount of SO_2 emission is considered as a quadratic function of generator output$P_{Gi}$and is expressed using eqn. (2).

$$F_2 = \sum_{i=1}^{N_G} (d_{1i} P_{Gi}^2 + e_{1i} P_{Gi} + f_{1i})\; Kg/h \qquad (2)$$

where,d_{1i}, e_{1i} and $f_{1i}$are SO_2emission coefficients.

3.CO_2 Emission Objective

Similarly the amount of CO_2 emission is also represented as quadratic function of generator output eqn. (3).

$$F_3 = \sum_{i=1}^{N_G} (d_{2i} P_{Gi}^2 + e_{2i} P_{Gi} + f_{2i}) \frac{ton}{h} \quad (3)$$

The optimization problem is bounded by the following constraints.

where,d_{2i}, e_{2i} and $f_{2i}$are CO_2emission coefficients.

Power Balance Constraints

The total power generated must supply the total load demand and the transmission losses.

$$\sum_{i=1}^{N_G} P_{Gi} - \sum_{i=1}^{N_B} P_{Di} - P_L = 0 \qquad (4)$$

$$\sum_{i=1}^{NG} Q_{Gi} - \sum_{i=1}^{N_B} Q_{Di} - Q_L = 0 \qquad (5)$$

where,

P_{Di}, Q_{Di} =total real and reactive power demand at ith bus

P_{Gi}, Q_{Gi} =total real and reactive power generation at ith bus

P_L , Q_L=total real and reactive power losses respectively at i^th^ bus

1.Maximum and Minimum Limits of Power Generation

The power generated P_{Gi} ,Q_{Gi} by each generator is constrained between its minimum and maximum limits given by eqn. (6) and (7).

$$P_{Gi\,min} \le P_{Gi} \le P_{Gi\,max} \quad (6)$$

$$Q_{Gi\,min} \le Q_{Gi} \le Q_{Gi\,max} \quad (7)$$

III. SOLUTION PROCEDURE

The EPP problem has been formulated in section II is a multi-objective nonlinear problem. Various solution methods namely Newton-Raphson method, weight simulation method have been proposed in the literature to solve such a problem. However, in the present work, Evolutionary optimization method has been used to get the optimal solution of the multi-objective EEP problem.

To generate the non-inferior solution the multi-objective problem is converted into a scalar optimization problem using weighting method as

Minimize

$$\sum_{j=1}^{L} (w_j F_j) \quad (8)$$

Subjected to

$$\sum_{j=1}^{L} w_i = 1.0 \quad (9)$$

$$\sum_{i=1}^{N_G} P_{Gi} = \sum_{i=1}^{N_b} P_{Di} + P_{Loss} \quad (10)$$

$$\sum_{i=1}^{N_G} Q_{Gi} = \sum_{i=1}^{N_b} Q_{Di} + Q_{Loss} \quad (11)$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \;; \qquad i = 1,2,\ldots\ldots,N_g$$

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max} \;; \qquad i = 1,2,\ldots\ldots,N_g$$

where,$w_i$is the level of the weight coefficients.

L is number of objectives.

To find the solution constrained problem is converted into unconstrained problem.

The generalized augmented function is formed as

$$L(P_{Gi}, Q_{Gi}, \lambda_P, \lambda_q) = \sum_{j=1}^{L} (w_j F_j) - \lambda_p \left(\sum_{i=1}^{N_G} P_{Gi} - \sum_{i=1}^{N_b} P_{Di} - P_{Loss} \right) - \lambda_q \left(\sum_{i=1}^{N_G} Q_{Gi} - \sum_{i=1}^{N_b} Q_{Pi} - Q_{Loss} \right) \quad (12)$$

where λ_p and λ_q are Lagrange multipliers.

Because the equation is non-linear, two steps are required to solve the eqn.(6),eqn.(7)and eqn.(12).

Step 1

Newton-Raphson method is applied to obtain the non-inferior solution for the simulated weight combination of the objectives to achieve the necessary condition. The necessary conditions to minimize the unconstrained Lagrangian function are:

$$\frac{\partial L}{\partial P_{Gi}} = \sum_{i=1}^{L-1} w_i \left(\frac{\partial F_i}{\partial P_{Gi}}\right) + \lambda_p \left(\frac{\partial P_L}{\partial P_{Gi}} - 1\right) + \lambda_q \left(\frac{\partial Q_L}{\partial P_{Gi}}\right) = 0 \qquad (13)$$

where $i = 1, 2, 3, \dots N$

$$\left(\frac{\partial L}{\partial Q_{Gi}}\right) = w_L \frac{\partial F_L}{\partial Q_{Gi}} + \lambda_p \left(\frac{\partial P_L}{\partial Q_{Gi}}\right) + \lambda_q \left(\frac{\partial Q_L}{\partial Q_{Gi}} - 1\right) = 0 \qquad (16)$$

where $i = 1,2,3, \dots, N$

$$\left(\frac{\partial L}{\partial d_p}\right) = P_D + P_L - \sum_{i=1}^{N} P_{Gi} = 0 \qquad (14)$$

$$\left(\frac{\partial L}{\partial d_Q}\right) = Q_D + Q_L - \sum_{i=1}^{N} Q_{Gi} = 0 \; (15)$$

After solving the equation using the Newton-Raphson method, we will get a large number of non-inferior solution .to get optimal solution we will find the membership function of objective.

Step 2

Upon having the pareo-optimal set of non-dominated solution, the proposed approach presents one solution to the decision maker as the best compromise solution .Due to imprecise nature of the decision makers judgment, the i-th objective function F_i is represented by membership function $\mu(F_i)$ defined as[9].

$$u(F_i) = \begin{cases} 1 & F_i \le F_i^{min} \\ \dfrac{(F_i^{max} - F_i)}{\left(F_i^{max} - F_i^{min}\right)} & F_i^{min} < F_i \\ 0 & F_i > F_i^{max} \\ i = 1,2,3, \dots u \end{cases} \; (15)$$

where F_i^{min} and F_i^{max} are the minimum and maximum values of ith objective function in which the solution is expected. By applying min-max technique, minimum value of membership function is selected for each weight set as follows:

$$Y_j = \left[Min\{\mu(F_i^j);\; i = 1,2,3, \dots L\};\; j = 1,2,3, \dots, M\right]$$

where M=1,2,.....,(2^{L-1}+1)

The decision regarding best solution is made by the solution of mini-max of membership function.

$$Max\{Y_j\}; \quad j = 1,2, \dots, (2^{L-1} + 1)$$

IV. SOLUTION METHODOLOGY

Evolutionary optimization method [12] is proposed to search the optimum weight combination of economic load dispatch problem. In this method (2^{L-1}+1) weight combination is simulated at (2L-1) dimensional hypercube centered on the current best point. Hence (2^{L-1}+1) non-inferior solution are generated. The best non-inferior solution is selected using min-max techniques and the current point is shifted to the best point. To continue the iterations, another hypercube is formed around this best point until some termination criterion is met.

Weights are generated as given below

$$w_i^j = w_i^c + Y_i^j \qquad (16)$$

$$i = 2,3, \dots, L \text{ and } j = 1,2, \dots, 2^{L-1}$$

$$w_1^j = 1 - \sum_{i=2}^{L} w_i^j \quad ; \quad j = 1,2, \dots, 2^{L-1} \qquad (17)$$

where, Y= Distance of the corners of the hypercube from the point around which hypercube is generated.

V. RESULTS AND DISCUSSIONS

The results have been obtained from the developed algorithm

for multi-objective power dispatch based on weight pattern

and fuzzy decision making techniques.The validity of the proposed method is demonstrated on 3 and six generators test system [6-16] whose data is given below:

The system demand is 850MW in all simulations.

The following cases have been studied –

Case Study 1: Multi-objective Fuel Cost and NO_X Emission for three generator.

Case Study 2: Multi-objective Fuel Cost and NO_X Emission for six generator.

Case Study 3: Multi-objective Fuel Cost and SO_X Emission for three generator.

Case Study 4: Multi-objective Fuel Cost and SO_X Emission for six generator.

Case Study 5: Multi-objective Fuel Cost, NO_X and SO_X Emission for three generator

Case Study 6: Multi-objective Fuel Cost, NO_X and SO_X Emission for six generator.

Table I

FUEL COST COEFFICIENTS FOR THREE GENERATOR SYSTEM

Units	c_i	b_i	a_i	P_{min}	P_{max}
1	0.001562	7.92561	561	150	600
2	0.001940	7.85310	310	100	400
3	0.004820	7.9778	78	50	200

Table II

SO_x Cost Coefficients For Three Generator System

Units	c_{si}	b_{si}	a_{si}
1	1.6103e-6	0.00816466	0.5783298
2	2.1999e-6	0.00891174	0.3515338
3	5.4658e-6	0.00903782	0.0884504

Table III

NO_x Cost Coefficients For Three Generator System

Units	c_{Ni}	b_{Ni}	a_{Ni}
1	1.4721848e-7	-9.4868099e-5	0.04373254
2	3.0207577e-7	-9.7252878e-5	0.055821713
3	1.9338531e-6	- 9.5373734e-4	0.027731524

Table IV

B- Coefficients For Three Generator System

0.000030	0.000000	0.000000
0.000010	0.000090	0.000000
0.000000	0.000000	0.000120

Case Study 1: Multi-objective Fuel Cost and NO_X Emission

A. Three generator system

The results for minimizing fuel cost and NO_X are summarized in Table

Table V

Comparison Of Results For Fuel Cost And NO_X Minimization For Three Generator System

Units (MW)	Best fuel cost ($/h)	Best NO_X emission	Using proposed method	Solution using NSGA (Ref 17)
PG1	430.000	501.213	467.653	470.957
PG2	296.828	253.294	279.100	280.663
PG3	129.730	107.450	112.341	113.675
Fuel cost	8343.561	8371.14	8347.12	8349.7
NO_X emission	0.0982	0.0954	0.0965	0.09563

B. Six generator system

A six generator system [6] is considered and the fuel cost, NO_X emission are taken as an objective and power demand is consider as 1800 mw.

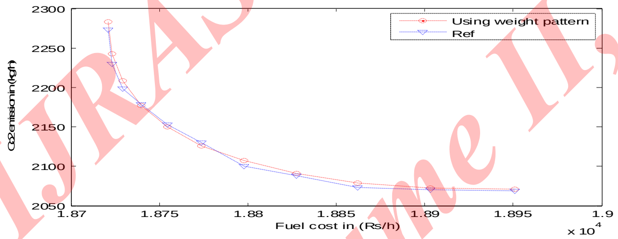

Fig 1 Conflicting nature of objectives (economy and emission) for 6-generator system.

Table VI

Comparison Of Results For Fuel Cost And NO_X Minimization For Six Generator System

Units (MW)	Best fuel cost ($/h)	Best NO_X emission	Using proposed method	Solution using NSGA (Ref 17)
PG1	214.3522	163.6289	220.101	223.401
PG2	232.0000	190.6549	262.091	264.192
PG3	434.4356	479.6228	523.982	521.481
PG4	265.9999	263.9770	345.961	343.562
PG5	437.7819	481.8149	383.101	385.141
PG6	204.5636	201.0322	197.452	199.352
Fuel cost	17379.67	17437.610	18773.86	18771.74
NO_X emission	1816.70	1778.331	2126.864	2127.41

Case Study 2: Multi-objective Fuel Cost and SO_X Emission

In this case study, developed algorithm has been applied for multi-objective real (fuel cost) and emission dispatch (SO_X). The simulation results obtained are given in Table VII and Table VIII for a system of three generators and six generators respectively.

A. Three generator system

The results for minimizing fuel cost and SO_X losses are summarized in Table VII.

Table VII

Comparison Of Results For Fuel Cost And SO_X Minimization For Three Generator System

Units (MW)	Best fuel cost ($/h)	Best SO_X emission	Using proposed method	Solution using NSGA (Ref 17)
PG1	391.4647	534.5313	464.2510	466.2578
PG2	332.6088	228.7482	275.3810	279.481
PG3	120.4265	74.0407	96.3304	95.6314
Fuel cost	8113.6422	8178.7937	8133.521	8134.421
SO_X emission	8.8549	8.75115	8.6602	8.432

B. Six generator system

The results for minimizing fuel cost and SO_X are summarized in Table VIII).

Table VIII

Comparison Of Results For Fuel Cost And SO_X Minimization For Six Generator System

Units (MW)	Best fuel cost ($/h)	Best SO_X emission	Using proposed method	Solution using NSGA (Ref 17)
PG1	214.5226	217.5747	209.2341	210.6618
PG2	230.8900	232.0200	227.7234	230.0000
PG3	432.3604	499.8974	437.6421	436.6352
PG4	263.9879	263.7851	262.0000	264.9999
PG5	437.0877	440.8856	438.7339	439.9999
PG6	202.0201	202.7252	202.1909	200.0000
Fuel cost	17368.21	17364.69	17368.163	17369.36
SO_X emission	10417.501	10418.569	10418.459	10419.53

Case Study 3: Multi-objective Fuel Cost, NO_X and SO_X Emission

In this case study, developed algorithm has been applied for multi-objective fuel cost NO_X and SO_X emission. The simulation results obtained are given in Table IX and Table X for a system of three generators and six generators respectively.

A. Three generator system

The results for minimizing fuel cost, NO_X and SO_X emission are summarized in Table IX.

Table IX

Comparison Of Results For Fuel Cost, NO_X And SO_XMinimization For Three Generator System

Units (MW)	Best fuel cost ($/h)	Best NO_X emission	Best SO_X solution	Using proposed method	Solution using NSGA (Ref 17)
PG1	391.04	491.794	543.36	468.54	467.34
PG2	331.76	243.234	223.22	267.75	266.65
PG3	121.68	105.362	73.70	102.32	104.12
Fuel cost	8115.45	8148.35	8183.87	8134.75	8133.65
NO_X Emission	0.0947	0.0946	0.0965	0.0948	0.0947
SO_X Emission	8.7135	8.7403	8.6432	8.6574	8.5563

B. Six generator system

The results for minimizing fuel cost, NO_X and SO_X emission are summarized in Table X.

Table X

Comparison Of Results For Fuel Cost, NO_X And SO_X Minimization For Six Generator System

Units (MW)	Best fuel cost ($/h)	Best NO_X emission	Best SO_X solution	Using proposed method	Solution using NSGA (Ref 17)
PG1	213.7064	164.615	205.89	165.2305	163.492
PG2	226.8969	192.524	227.98	227.3171	228.932
PG3	435.6449	481.938	437.82	464.5025	462.7034
PG4	267.6924	263.898	261.96	265.090	266.682
PG5	434.4372	481.733	442.13	463.012	462.594
PG6	201.3049	201.308	200.35	200.4580	200.000
Fuel cost	17365.24	17443.47	17361.47	17374.345	17375.48
NO_X Emission	1815.354	1773.516	1807.5613	1784.6041	1788.582
SO_X Emission	10418.80	10453.91	10418.590	10424.45	10423.56

VI. CONCLUSIONS

In power system operation planning, there exist multiple objectives to be attained, which conflict with each other .It means that any one objective can be improved only at the expense of one or more of the other objective. Generally the weight is simulated with suitable variations. The number of non-inferior solutions of the problem increases exponentially with the number of objectives; e.g. if normalized weight are varied by 0.1 then there is need of 12 non-inferior solutions in case of two objectives, 60 non-inferior solutions in the case of three objectives. So generation of complete non-inferior surface is time consuming. To reduce the computational burden and to reduce the complexity and to select the best solution the multi-objective problem has been solved by searching the optimal Weightage Pattern of objectives with evolutionary optimization technique. It can be observed that the proposed method required few search moves to get the optimal operating point in the non-inferior domain for any number of goals. The proposed solution procedure is simple with less time consuming and suitable for any number of objectives. Because of the tremendous annual fuel cost, NOx emission, SO_2 emission and CO_2 emission in thermal plants, a small percentage saving can be considered significant in proposed method.

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