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The Pareto Optimal Solution for Multi Objective Electric Power Dispatch Problem

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Abstract—***The economic power dispatch is used to finding an optimal distribution of system load to minimize the total generation cost while meeting all the system constraints without considering the pollution. Due to environmental regulations and social awareness act, the emission is to be minimized. These two major functions are conflicting in nature and both have to be considered simultaneously to evaluate the overall optimal dispatch. The economic and emission dispatch (EED) is a multi-objective optimization problem (MOP) with contradictory objectives. The various conventional methods like Newton's method, Lambda-iteration method and gradient method are used to solve the environmental and economic dispatch problem but results are near to optimal solution and are not exact because more computational time. To overcome this problem, the mathematical solutions for the combined economic and emission dispatch using Pareto optimal front approach are developed and applied to the test system and also verify the results using MATLAB environment.***

Keywords—**Economic and Emission dispatch, Pareto optimal solution, Test System, Simulation and Performance analysis.**

I. INTRODUCTION

Scheduling of power plant generation is gives a great importance in electric power utility systems. One of the prime concerns from social and environment aspects is that both human and non-human life forms are severely affected by the atmospheric pollution caused during generation of electricity from fossil fuels. This may give rise to the problem of global warming. Due to increasing concern over the environmental consideration [1] [2], society demands adequate and secure electricity not only at the cheapest possible price, but also at minimum level of pollution. So the optimal scheduling of generation in a thermal power plant system involves the allocation of generation so as to optimize the fuel cost and emission level simultaneously. The remote location of power plant from the load centre has been identified as one of the reasons which caused high cost. The increase in fuel cost these days has also contributed to this phenomenon. Therefore, economic load dispatch is implemented in order to determine the output (generating) of each generator so that the generation cost will minimized. The generators output has to be varied within limits so as to meet a particular load demand and losses with minimum fuel cost [3]. Thus, economic load dispatch (ELD) is one of the important topics to be considered in power system engineering. In addition, the increasing public awareness of the environmental protection and passage of clean air act Amendments of 1990 have forced the utilities of modify their Design or operational strategies to reduce pollution and atmospheric emission of thermal plants. Apart from heat, power utilities using fossil fuel as primary energy source, produces harmful gasses such as CO_2, SO_2 and NO_2 which cause detrimental effect on human beings. The solution of economic power dispatch or minimum emission problems, when attempted in isolation will be different and conflicting with each other therefore in order to solve these two objectives (economic and emission) simultaneously, the problem is formulated in to multiobjective problem. Thus multiobjective optimization problem minimize these competing objective functions while satisfying equality and inequality power constraints. The equality constraints are the power balance constraint. The inequality constraints are due to the generation limits of thermal power plant. The soft computing techniques literature such as stochastic search algorithm, genetic Algorithm (GA), Evolutionary programming (EP), Particle Swarm Optimization (PSO) and Simulated Annealing (SA) [16-20] may prove to be efficient in solving highly nonlinear ELD problem without any restrictions on the shape of the cost curves. Although these methods do not always guarantee the global optimal solution, they generally provide a fast and reasonable solution (sub optimal or near global optimal). This paper proposes the mathematical model of Pareto optimal solution for the economic and emission dispatch have been developed and applied to the six generating unit test system and also compared the optimization with analytical result and MATLAB programming.

II. MULTIOBJECTIVE OPTIMIZATION GENERATION SCHEDULING

The economy and emission functions are conflicting in nature and both have to be considered simultaneously to find optimal dispatch. The situation is formulated as a multiobjective problem is to minimize not a single objective (economy or emission) but to minimize both the objectives (economy and emission) simultaneously.

A. Economic Load Dispatch

T he cost function of each generator is approximated by a single quadratic function

$$F(P) = \sum_{i=1}^{n} F_i(P_i) \qquad (1)$$

$$F_i(P_i) = \sum_{i=1}^{n} (a_i + b_i P_i + c_i P_i^2) \ \text{Rs/hr} \qquad (2)$$

Where, F_i (P_i) - Total fuel cost (Rs/hr)
P_i- generation of i th unit (MW)

a_i, b_i, c_i - fuel cost coefficients of i th unit
n- Number of generating units

i) Power balance constraint

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

$$\sum_{i=1}^{n} P_i = P_d + P_l \quad MW \qquad (3)$$

Where, P_d- total load demand (MW)
P_l- total transmission losses (MW)

ii) Unit capacity constraint

The power generated, P_i by each generator is constrained between its minimum and maximum limits, i.e.

$$P_i^{min} \le P_i \le P_i^{max} \qquad (4)$$

Where, P_i min- minimum generation limit
P_i max- maximum generation limit

B. Emission Dispatch

The fuel cost objective function is replaced by an emissions objective function. The constraints are the same but the optimal solution will produce the lowest total emissions as opposed to the lowest total cost. The total (kg/hr) emission can be expressed as

$$E(P) = \sum_{i=1}^{n} E_i(P_i) \qquad (5)$$

$$E_i(P_i) = \sum_{i=1}^{n} (d_i + e_i P_i + f_i P_i^2) \ Kg/hr \qquad (6)$$

Where, E_i (P_i) - Total Emission (Kg/hr)
P_i - generation of unit i (MW)
d_i,e_i,f_i - Emission coefficients of i th unit
n - Number of generating units

C. Multiobjective Problem Formulation

Considering the two conflicting objectives (1), (5) and the two constraints (3), (4), the EED problem can be mathematically formulated as follows:

$$\text{minimize: } [F(P), E(P)]$$
$$\text{subject to: } g(P) = 0$$
$$h(P) \le 0 \qquad (7)$$

Where, g is the equality constraint representing the power balance and h is the inequality constraint representing the unit generation capacity.

III. PARETO OPTIMAL FRONT APPROACH

A. Introduction

The Multiobjective optimization with such conflicting objective functions gives rise to a set of optimal solutions, instead of one optimal solution. The reason for the optimality of many solutions is that no one can be considered to be better than any other with respect to all objective functions. These optimal solutions are known as pareto-optimal solutions.

B. Pareto Optimal Solution

The MOP consists of a number of objectives to be optimized simultaneously and is associated with a number of equality and inequality constraints:

$$\text{minimize}: f_i(x), \quad i = 1, \dots, N_{obj}$$
$$\text{subject to}: g_j(x) = 0, \quad j = 1, \dots, J$$
$$h_k(x) \le 0, \quad k = 1, \dots, K \qquad (8)$$

Where f_i is the i th objective function, x represents a solution and Nobj is the number of objectives.

For a MOP have two solutions x1 and x2 can have one of two possibilities: one dominates the other or neither dominates the other. In a minimization problem, a solution x1 dominates x2 if the following two conditions are satisfied:

$$\forall_i \in \{1, \dots, N_{obj}: f_i(x_1) \le f_i(x_2)\}$$
$$\exists_j \in \{1, \dots, N_{obj}: f_j(x_1) \le f_j(x_2)\} \qquad (9)$$

If any of the above conditions is violated, the solution x1 does not dominate the solution x2. If x1 dominates the solution x2, x1 is called the non-dominated solution within the set {x1, x2}. The solutions that are non-dominated within the entire search space are denoted as Pareto optimal and constitute the Pareto optimal set.

1. Weighted Sum Approach
2. Goal Programming
3. e- constrained method

Among all these methods the weighted sum approach is most efficient and simple method.

i) Weighted Sum Approach

In this method, the different objectives are added with different weights to form a single objective function.

$$\min \sum_{i=1}^{n} w_i \, f_i(x) \qquad (10)$$

Assume

$$\sum_{i=1}^{n} w_i = 1 \qquad (11)$$

The single objective problem using the weighted sum of C_i and E_i

$$\text{minimize}: \ \delta \sum_{i=1}^{n} C_i(P_i) + (1-\delta) \sum_{i=1}^{n} E_i(P_i)$$
$$\text{subject to}: \sum_{i=1}^{n} P_i = P_d + P_l$$
$$P_i^{min} \le P_i \le P_i^{max}, \quad \forall_i = 1, \dots, N \qquad (12)$$

Where δ is a constant in the range of (0, 1).

C. Analytical Solution for CEED Problem without Transmission Losses

The objective functions are second-order polynomials [21] and imposed natural constraint to the thermal power:

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$$\left.\begin{aligned} minimize: & \sum_{i=1}^{n} C_i(P_i) \\ & = \sum_{i=1}^{n}(\alpha_i + \beta_i P_i + \gamma_i P_i^2) \\ \text{subject to}: & \sum_{i=1}^{n} P_i = P_d \\ & P_i \ge 0, \\ & \forall_i = 1, \dots, n \qquad (13) \end{aligned}\right\}$$

Assume that $\beta_1 \le \beta_2 \le \cdots \le \beta_N$.
If $\delta_k \le P_d < \delta_{k+1}$, then the equivalent minimize is a second-order polynomial with piece-wise constant coefficients:

$$\psi(P_d) \sum_{i=1}^{n} C_i(\psi_i(P_d)) = (\alpha_k + \beta_k P_d + \gamma_k P_d^2)$$

With the coefficients

$$\gamma_k = \frac{1}{\sum_{i=1}^{k} 1/\gamma_i}$$

$$\beta_k = \gamma_k \sum_{i=1}^{k} \frac{\beta_i}{\gamma_i}$$

$$\alpha_k = \sum_{i=1}^{n} \alpha_i + \frac{\beta_k^2}{4\gamma_k} - \sum_{i=1}^{k} \frac{\beta_i^2}{4\gamma_i}$$

and δ_k being

$$\delta_k = \frac{1}{2}\left[\beta_k \sum_{i=1}^{k} \frac{1}{\gamma_i} - \sum_{i=1}^{k} \frac{\beta_i}{\gamma_i}\right]$$

The value of the demanded power P_d below which the k th plant is kept at its minimum value: $P_k=0$

The k th distribution function $\psi_k(P_d)$ is

i) If $P_d \le \delta_k : \psi_k(P_d) = 0$

ii) If $\delta_k \le \delta_j \le P_d < \delta_{j+1} : \psi_k(P_d)$

$$= \frac{\sum_{i=1}^{j} \frac{\beta_i}{2\gamma_i} + P_d}{\gamma_k \sum_{i=1}^{j} \frac{1}{\gamma_i}} - \frac{\beta_k}{2\gamma_k}$$

In [22], we calculated the equivalent minimizer in the cost functions (inequality) model,

$$\left.\begin{aligned} minimize: & \sum_{i=1}^{n} C_i(P_i) \\ \text{subject to}: & \sum_{i=1}^{n} P_i = P_d \\ & P_i \ge 0, \quad \forall_i = 1, \dots, n \qquad (14) \end{aligned}\right\}$$

The kth distribution function $\psi_k(P_d)$ is

1) If $P_d \le \delta_k : \psi_k(P_d) = P_k^{min}$

2) If $\delta_k \le \delta_j \le P_d < \delta_{j+1} : \psi_k(P_d)$

$$= \left(\sum_{i=1}^{j} F_i'^{-1} \circ F_k'\right)_{-1}\left(P_d - \sum_{i=j+1}^{n} P_i^{min}\right)$$

with

$$\delta_k = \sum_{i=1}^{k} (F_i'^{-1} \circ F_k')(P_k^{min}) + \sum_{i=k+1}^{n} P_i^{min}$$

The value of the demanded power, P_d below which the kth plant is kept at its minimum value, P_k^{min}, now generalized MOP is from the equations (13) & (14), so we get

$$C_i(P_i) = \delta C_i + (1-\delta)E_i = \alpha_i + \beta_i P_i + \gamma_i P_i^2 \quad (15)$$

We assume $C_i(P_i^{min}) < C_i'(P_j^{max})$, $\forall_i$, j.

we obtain the values δ_k

$$\delta_k = \sum_{i=1}^{k} (C_i'^{-1} \circ C_k')(P_k^{min}) + \sum_{i=k+1}^{n} P_i^{min} \quad (16)$$

and new value of θ_k

$$\theta_k = \sum_{i=k}^{n} (C_{\sigma(i)}'^{-1} \circ C'_{\sigma(k)})(P^{max}_{\sigma(k)}) + \sum_{i=1}^{k-1} P^{max}_{\sigma(i)} \quad (17)$$

The optimum distribution function is

1) If $P_d \le \delta_k : \psi_k(P_d) = P_k^{min}$

2) If $\delta_k \le \delta_j \le P_d < \delta_{j+1} : \psi_k(P_d)$
$= \left(\sum_{i=1}^{j} C_i'^{-1} \circ C_k'\right)_{-1}\left(P_d - \sum_{i=j+1}^{n} P_i^{min}\right)$

3) If $\delta_N \le P_d < \theta_1 : \psi_k(P_d)$
$= \left(\sum_{i=1}^{j} C_i'^{-1} \circ C_k'\right)(P_d)$

4) If $\theta_j \le P_d < \theta_{j+1} : \psi_k(P_d)$
$= \left(\sum_{i=j+1}^{j} C_i'^{-1} \circ C_k'\right)$
$\left(P_d - \sum_{i=1}^{j} P^{max}_{\sigma(i)}\right)$ (18)

5) If $\delta_{\sigma-1} \le P_d : \psi_k(P_d) = P_k^{max}$

With

$$\delta_k = \frac{1}{2} \sum_{i=1}^{k} \frac{\beta_k + 2\gamma_k P_k^{min} - \beta_i}{\gamma_i} + \sum_{i=k+1}^{n} P_i^{min}$$

$$\theta_k = \frac{1}{2} \sum_{i=k}^{n} \frac{\beta_{\sigma(k)} + 2\gamma_{\sigma(k)} P^{max}_{\sigma(k)} - \beta_{\sigma(i)}}{\gamma_{\sigma(i)}} + \sum_{i=1}^{k-1} P_{\sigma}^{r}$$

With the coefficients

$$\gamma_k = \frac{1}{\sum_{i=1}^{k} 1/\gamma_i}, \quad \beta_k = \gamma_k \sum_{i=1}^{k} \frac{\beta_i}{\gamma_i}$$

$$\alpha_k = \sum_{i=1}^{n} \alpha_i + \frac{\beta_k^2}{4\gamma_k} - \sum_{i=1}^{k} \frac{\beta_i^2}{4\gamma_i} + \sum_{i=k+1}^{n} (\beta_i P_i^{min} + \gamma_i P$$

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and

$$\gamma_k = \frac{1}{\sum_{i=k+1}^{n} 1/\gamma_{\sigma(i)}}, \quad \beta_k = \gamma_k \sum_{i=k+1}^{n} \frac{\beta_{\sigma(i)}}{\gamma_{\sigma(i)}}$$

$$\alpha_k = \sum_{i=1}^{n} \alpha_i + \frac{\beta_k^2}{4\gamma_k} - \sum_{i=k+1}^{k} \frac{\beta_{\sigma(i)}^2}{4\gamma_{\sigma(i)}} + \sum_{i=1}^{k} (\beta_{\sigma(i)} P_{\sigma(i)}^{max} + \gamma_{\sigma(i)} P_{\sigma(i)}^{max2}) \quad (19)$$

We have obtained the exact formulae for the MOP without losses.

D.Analytical Solution for CEED Problem with Losses

The transmission losses are represented in terms of demand. To calculate the initial distribution of optimal power values (neglecting transmission losses) and use power values to calculate the losses, subsequently incorporating the losses in the demand. A new solution is obtained with this new demand. The transmission losses represent by means of classic B-coefficients

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_j \quad (20)$$

Where, B_{ij} represents the transmission loss coefficients, P_i the generation of unit i (MW), and P_j the generation of unit j (MW).

For transmission losses P_l in terms of demand P_d,

$P_l = A + BP_d + CP_d^2$ (21)

The total power generated P_g must be equal to total load demand and transmission losses, so

$$P_g = \sum_{i=1}^{n} P_i = P_d + P_l$$

$$= A + (B+1)P_d + CP_d^2 \quad (22)$$

Introducing P_g as a new demand in (18), we obtain a new solution.

IV. IMPLEMENTATION OF PROPOSED SYSTEM

A. Test System

The gradient method and the multiobjective Pareto optimal front approach have applied to the test systems at different load conditions. To get the optimum condition, one has to solve a complex quadratic equation, which is a function of fuel cost and transmission loss coefficients and incremental cost of received power.

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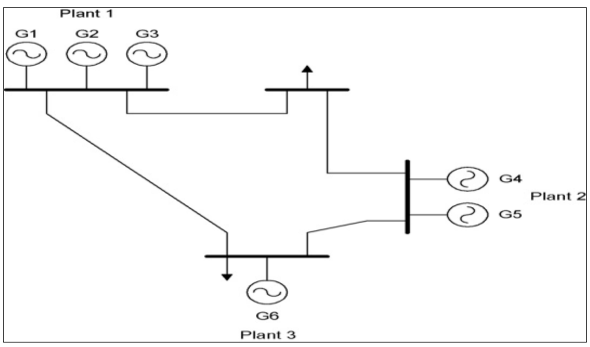

Fig.1 Test System

Fig. shows the 4- bus Test system for the study. The test system has three plants and six generating units. The plant 1 consists of three generating units, plant 2 consists of two generators and plant 3 consists of one unit.

B. Input Data for the Test System

Power Demand P_d=900 MW & 1170 MW

Table I. Input Data for Fuel Cost Coefficients

Plant	Unit	Fuel Cost Coefficients a_i	b_i	c_i	P_i (min) MW	P_i (max) MW
	G1	756.79886	38.53973	0.15247	10	125
1	G2	451.32513	46.15916	0.10587	10	150
	G3	1049.32513	40.39655	0.02803	40	250
2	G4	1243.5311	38.30553	0.03546	35	210
	G5	1658.5696	36.32782	0.02111	130	325
3	G6	1356.65920	38.27041	0.01799	125	315

TABLE II. INPUT DATA FOR TRANSMISSION LOSS COEFFICIENTS

B_{ij}	Transmission Loss Coefficients 1	2	3	4	5	6
1	0.000091	0.000031	0.000029	0.000028	0.000031	0.000029
2	0.000031	0.000091	0.000028	0.000031	0.000029	0.000029
3	0.000029	0.000028	0.000091	0.000028	0.000031	0.000029
4	0.000028	0.000031	0.000028	0.000062	0.000029	0.000031
5	0.000031	0.000029	0.000031	0.000029	0.000062	0.000028
6	0.000029	0.000029	0.000029	0.000031	0.000028	0.000072

Table III. Input Data for Emission Coefficients

Plant	Unit	Emission Coefficients d_i	e_i	f_i	P_i (min) MW	P_i (max) MW
	G1	13.85932	0.32767	0.00419	10	125
1	G2	13.85932	0.32767	0.00419	10	150
	G3	40.2669	-0.54551	0.00683	40	250
2	G4	40.2669	-0.54551	0.00683	35	210
	G5	42.89553	-0.51116	0.00461	130	325
3	G6	42.89553	-0.51116	0.00461	125	315

C. Analytical Output for Economic/Emission Dispatch Problem

Table IV. Analytical Output For Economic/Emission Dispatch Without and With Losses

Plant	Unit	Pareto Output (without loss)		Pareto Output (with loss)	
		P_d=900 MW	P_d=1170 MW	P_d=900 MW	P_d=1170 MW
1	G1	32.4969	49.3809	33.8724	71.2939
	G2	10.8160	35.1316	12.7969	66.6899
2	G3	143.6467	235.4875	151.1287	250.0000
	G4	143.0317	210.0000	148.9459	210.0000
	G5	287.1036	325.0000	297.0382	325.0000
3	G6	282.9051	315.0000	294.5627	315.0000
Total fuel cost (Rs/hr)		45464	59096	47330	62924
Total emission (Kg/h)		795.0169	1291.3	862.9949	1373.5
Transmission loss (MW)				38.3448	67.9838

V. CONCLUSIONS

In this research work the multi objective problems had applied to the test systems having six generating units. The NO_2 Emission is considered and also the various load demand strategy is applied to the test system. The fuel costs as well as the emission characteristics of various generating units are represented by their respective characteristic form in terms of power plant total generations. The total generation is represented by a quadratic equation in terms of total load demand and transmission losses. The Numerical results were obtained using gradient method and Pareto optimal front approach. Both results are verified by using MATLAB program. So that the Pareto optimal solution is best compatible results for the EED problem. This problem can be applied to practical systems and also applied to IEEE standard bus systems. To extend the problem by incorporating more than two objectives.

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