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A Traditional Approach to Solve Economic Load Dispatch Problem Considering the Generator Constraints

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Abstract: *Economic load dispatch (ELD) problem is very important part of the power system. The purpose of economic dispatch is to determine the generation of different units in a plant such that the total fuel cost is minimum and at the same time the total demand and losses at any instant must be equal to the total generation. Many traditional methods such as lambda iteration, gradient method, Newton's method etc. are applied to determine the optimal combination of power output of all generating units so as to meet the desired demand without violation of generator constraint. This paper presents lambda iteration method to solve the ELD problem using MATLAB for three and six generating units with and without transmission losses.*

Keywords: *Economic Load Dispatch (ELD), Fuel Cost, Lambda Iteration Method, Matrix Laboratory (MATLAB), Transmission Loss.*

I. Introduction

The sizes of electric power system are increasing rapidly to meet the total demand but the rate of increase of generation is less than the rate of increase of power demand hence it is necessary to operate power system in economic manner. This can be done by ELD techniques. The most common task in power system is to determine and provide an economic condition for generating units without violation of any system constraints, which is known as Economic Load Dispatch (ELD). The parameters must be taken into account for any ELD problem are load demand, transmission power losses and generation cost coefficients. The total operating cost of a power plant depends upon the fuel cost, cost of labour, supplies and maintenance. Generally the costs such as cost of labour, supplies and maintenance being difficult to determine and approximate, are assumed to change as a fixed percentage of the fuel cost. Thus cost function of power plant which is mainly dependent on fuel cost is given as a function of generation. Traditionally the cost function in ELD problem has been approximated as a quadratic function [1]. The generation cost depends upon the system constraint for a particular load demand it means that the generation cost is not fixed for a particular load demand but depends upon the operating constraint of the sources [1], [2].

There are many traditional optimization methods to solve ELD problem. These traditional methods are lambda iteration, gradient method, base point, participation factor method, Newton's method, Linear programming, and quadratic programming [5], [6]. ELD is major topic and many research works have been done in this field. In [7], [11], [12] ELD problem has been solved by using GA. In [13] PSO technique has been used to solve ELD problem.

The economic operation of a thermal unit, input-output modeling characteristic is significant. For this function considers a single unit consisting of a boiler, a turbine, and a generator. Figure 1 shows the simple model of a thermal generation system [3], [8], [9].

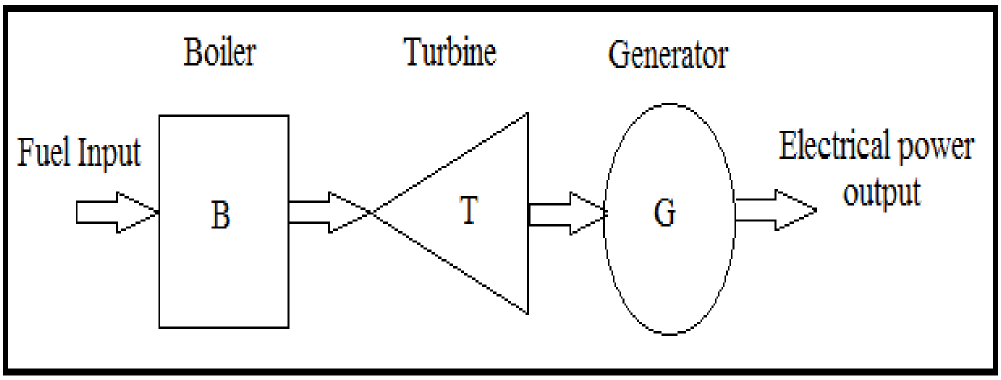

Fig.1 Simple model of thermal generation system

II. Formulation of ELD Problem

The primary goal of ELD problem is to minimize the total fuel cost while fulfilling the operational constraints of the power system. In ELD problem allocation of optimal power generation among the different generating units at minimum possible cost is done in such a way so as to meet demand constraint and generating constraint. The formulation of ELD problem can be done as follows-

1. Objective function

The ELD problem can be formulated by single quadratic function which is given by following equation:-

$$F(P_{gi}) = \sum_{i=0}^{N_g} F_i(P_{gi}) \quad (1)$$

Where,

$F(P_{gi}) =$ Total fuel cost ($/h)

$F_i(P_{gi}) =$ Fuel cost of i^{th} generator ($/h)

N_g = Number of generator

The fuel cost of i^{th} generator can be expressed as,

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

Where,

a_i, b_i, and c_i = Fuel cost coefficients of i^{th} generator.

From equation (1) and (2),

$$F(P_{gi}) = \sum_{i=0}^{N_g} (a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad (3)$$

2. System Constraint

There are two types of constraints in ELD problem:

2.1 Equality Constraint (Power balance constraint)

The cost function is not affected by reactive power but it is affected by real power. According to this constraint summation of real power of all the generating unit must be equal to the total real power demand on the system plus power transmission loss. This constraint is also known as power balance constraint.

$$\sum_{i=0}^{N_g} P_{gi} = P_d + P_L \quad (4)$$

Where,

P_{gi} = Real power generation of i^{th} generator

P_d = Total real power demand

P_L = Power transmission loss

2.2 Inequality Constraint

Inequality constraints for the generating unit can be given as follows:

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad (5)$$

Where,

P_{gi}^{min} = minimum limit of power generation of i^{th} generator

P_{gi}^{max} = maximum limit of power generation of i^{th} generator

Transmission loss P_L can be expressed as a function of generator power through B-coefficients. The simplest form of loss equation using B-coefficients is given by

$$P_L = \sum_{i=0}^{N_g} \sum_{j=0}^{N_g} P_{gi} B_{ij} P_{gj} \text{ MW} \quad (6)$$

Where,

P_{gi}, P_{gj} = Real power generation at the i^{th} and j^{th} buses, respectively

$B_{ij} = B_{ji}$ = Loss coefficients

For this constraint based optimization problem we use Lagrangian multiplier. So the augmented cost function is given by

$$L(P_{gi}, \lambda) = F(P_{gi}) + \lambda \left[P_D + P_L - \sum_{i=0}^{N_g} (P_{gi}) \right] \quad (7)$$

Where λ is the Lagrangian multiplier.

The necessary condition for optimization problem is given by equation (8)

$$\frac{\partial L(P_{gi},\lambda)}{\partial P_{gi}} = 0, \quad (i=1, 2\ldots N_g) \tag{8}$$

$$\frac{\partial F(P_{gi})}{\partial P_{gi}} + \lambda\left(\frac{\partial P_L}{\partial P_{gi}} - 1\right) = 0 \tag{9}$$

Equation (9) can be written as

$$\frac{\partial F(P_{gi})}{\partial P_{gi}} = \lambda\left(1 - \frac{\partial P_L}{\partial P_{gi}}\right), \quad (i=1, 2\ldots N_g) \tag{10}$$

Where,

$\frac{\partial F(P_{gi})}{\partial P_{gi}}$ = Incremental cost of the i^{th} generator ($/MWh)

$\frac{\partial P_L}{\partial P_{gi}}$ = Incremental transmission loss (ITL) of i^{th} generator.

The above equation is called as coordination equation.

Furthermore,

$$\frac{\partial L(P_{gi},\lambda)}{\partial \lambda} = P_D + P_L - \sum_{i=0}^{NG}(P_{gi}) = 0 \tag{11}$$

By differentiating equation (6) with respect to P_{gi},

$$\frac{\partial (P_L)}{\partial P_{gi}} = \sum_{j=0}^{N_g}(2B_{ij}P_{gj}) \tag{12}$$

The incremental cost of i^{th} generator can be obtained by differentiating equation (3) with respect to P_{gi},

$$\frac{\partial F(P_{gi})}{\partial P_{gi}} = 2a_iP_{gi} + b_i \tag{13}$$

With the help of equation (12) & (13), equation (10) can be written as

$$2a_iP_{gi} + b_i = \lambda\left[1 - \sum_{j=0}^{N_g}(2B_{ij}P_{gj})\right] \tag{14}$$

By arranging equation (14)

$$2(a_i + \lambda B_{ii})P_{gi} = \lambda\left(1 - \sum_{j=0, j\neq i}^{N_g}(2B_{ij}P_{gj})\right) - b_i \tag{15}$$

The value of P_{gi} can be formulated as

$$P_{gi} = \frac{\lambda\left(1 - \sum_{j=0, j\neq i}^{N_g}(2B_{ij}P_{gj})\right) - b_i}{2(a_i + \lambda B_{ii})}, \quad (i=1, 2\ldots N_g) \tag{16}$$

If λ is known then generator real power can be obtained by equation (16).

III. Lambda Iteration Method

One of the most popular traditional technique to solve ELD problem for minimizing the cost of generating unit is lambda iteration method. Although in lambda iteration technique computational procedure is complex but it converges very fast for this type of optimization problem [4], [13].

The detailed algorithm of lambda iteration method for ELD problem is given below:

1. Read given data, for example cost coefficients (a_i, b_i, c_i), B-coefficients, power limits and power demand.
2. Assume the starting value of λ and Δλ.
3. Calculate generated power P_{gi} from each unit.
4. Check generation limit for each unit.
   If $P_{gi} > P_{gi}^{max}$, set $P_{gi} = P_{gi}^{max}$
   If $P_{gi} < P_{gi}^{min}$, set $P_{gi} = P_{gi}^{min}$
5. Calculate total generated power.
6. Calculate mismatch in power which is given by following equation
   $$\Delta P = \sum_{i=0}^{N_g} P_{gi} - P_d$$
7. If $\Delta P < \varepsilon$, then stop calculation and calculate the generation cost. Otherwise go next step.
8. If $\Delta P > 0$, then $\lambda = \lambda - \Delta\lambda$.
   If $\Delta P < 0$, then $\lambda = \lambda + \Delta\lambda$.
9. Repeat the procedure from step 3.

The above steps can be summarized in the flowchart of figure 2.

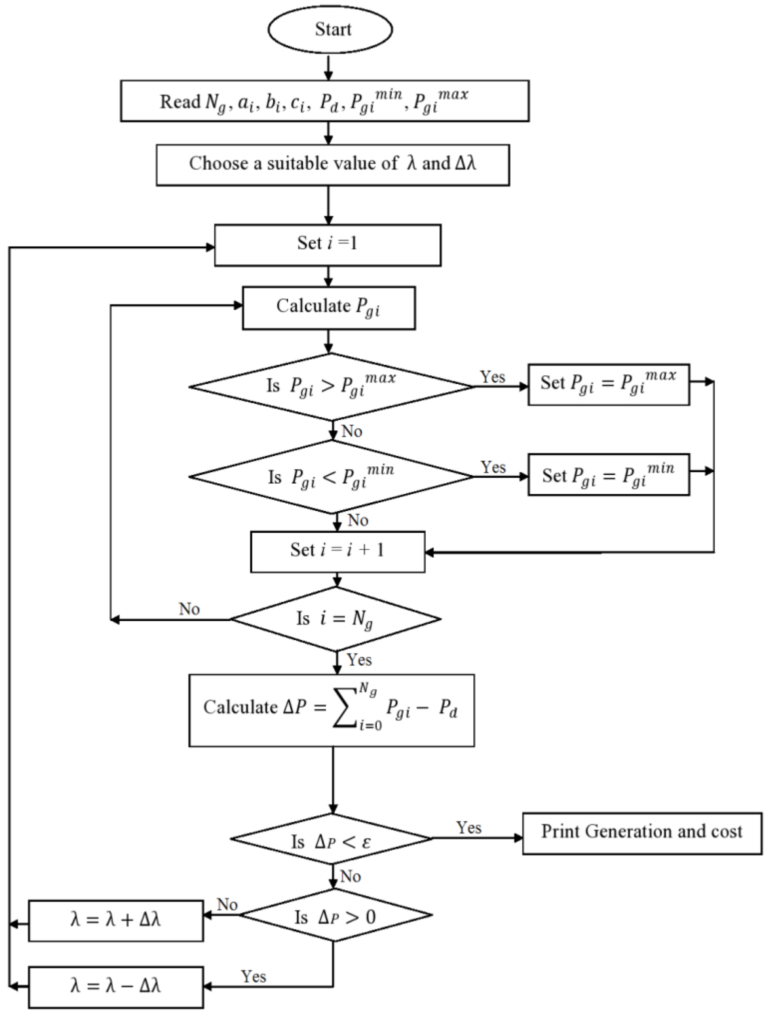

Fig. 2 Flow chart of lambda iteration method for ELD

IV. Result And Discussions

The Lambda iteration method is implemented in three and six generating units. The results are compared for two different cases with and without losses. In first case generator constraints are considered along with the lossless system and in second case generator constraints are considered with the losses. All the programming has been done in MATLAB environment.

Case Study-1: 3-units system

In this case, three unit thermal power plant is considered which is solved for two different cases with and without losses. The cost coefficients and generator power limits are shown by table 1 [13].

Table 1: Generating Unit Capacity and Cost-Coefficients for Three Unit System

Unit	P_{gi}^{min}	P_{gi}^{max}	a_i	b_i	c_i
1	10	85	0.008	7	200
2	10	80	0.009	6.3	180
3	10	70	0.007	6.8	140

The loss coefficient matrix is given by

$$B_{ij} = \begin{bmatrix} 0.000218 & 0.000093 & 0.000028 \\ 0.000093 & 0.000228 & 0.000017 \\ 0.000028 & 0.000017 & 0.000179 \end{bmatrix}$$

Table 2 and Table 3 presents the results of ELD problem for 3-unit system using lambda iteration method. Table 2 shows the result of 3-unit system for different loading condition without considering transmission losses. Table 3 shows the fuel cost, active power output of generating units and transmission losses for different loading condition.

Table 2: Results of Three Unit System (Without Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	Fuel Cost ($/hr)
1.	120	22.0625	58.5	39.5	1357.2
2.	150	31.9375	67.2778	50.7857	1579.71
3.	170	38.5625	73.1667	58.3571	1731.63

Table 3: Results of Three Unit System (With Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_L (MW)	Fuel Cost ($/hr)
1.	120	22.9577	55.7822	42.8176	1.52698	1368.35
2.	150	32.8204	64.6008	54.9443	2.34274	1597.66
3.	170	39.4269	70.5116	63.0889	2.99255	1754.26

Case Study-2: 6-units system

In this case, six unit thermal power plant is considered which is solved for two different cases with and without losses. The cost coefficients and generator power limits are shown by table 4 [13].

Table 4: Generating Unit Capacity and Cost-Coefficients for Six Unit System

Unit	P_{gi}^{min}	P_{gi}^{max}	a_i	b_i	c_i
1	100	500	240	7.00	0.0070
2	50	200	200	10.0	0.0095
3	80	300	220	8.50	0.0090
4	50	150	200	11.0	0.0090
5	50	200	220	10.5	0.0080
6	50	120	190	12.0	0.0075

The B-coefficient for six unit system is given as

$$B_{ij} = \begin{bmatrix} 0.000017 & 0.000012 & 0.000007 & -0.000001 & -0.000005 & -0.000002 \\ 0.000012 & 0.000014 & 0.000009 & 0.000001 & -0.000006 & -0.000001 \\ 0.000007 & 0.000009 & 0.000031 & 0.000000 & -0.000010 & -0.000006 \\ -0.000001 & 0.000001 & 0.000000 & 0.000024 & -0.000006 & -0.000008 \\ -0.000005 & -0.000006 & -0.000010 & -0.000006 & 0.000129 & -0.000002 \\ -0.000002 & -0.000001 & -0.000006 & -0.000008 & -0.000002 & 0.000150 \end{bmatrix}$$

Table 5 and Table 6 presents the results of ELD problem for 6-unit system using lambda iteration method. Table 5 shows the result of 6-unit system for different loading condition without considering transmission losses. Table 6 shows the fuel cost, active power output of generating unit and transmission losses for different loading condition.

Table 5: Results of Six Unit System (Without Loss)

S. No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	Fuel Cost ($/hr)
1.	600	271.879	50	128.128	50	50	50	7187.41
2.	800	342.221	94.2684	182.839	50	80.6937	50	9458.09
3.	1000	391.664	130.7	221.294	82.4056	123.956	50	11887.3
4.	1263	446.707	171.258	264.106	125.217	172.119	83.5933	15275.9
5.	1450	485.664	199.963	294.406	150	200	119.953	17802.6

Table 6: Results of Six Unit System (With Loss)

S.No.	Load Demand (MW)	P_{g1} (MW)	P_{g2} (MW)	P_{g3} (MW)	P_{g4} (MW)	P_{g5} (MW)	P_{g6} (MW)	P_L (MW)	Fuel Cost ($/hr)
1.	600	273.492	50	129.595	50	50	50	2.98958	7220.73
2.	800	341.757	95.2846	182.325	53.5857	82.5827	50	5.43591	9523.64
3.	1000	391.011	131.737	220.404	93.3534	121.621	50	8.0945	11989.60
4.	1263	447.122	173.22	263.962	139.093	165.617	86.6583	12.4204	15446.1
5.	1450	496.776	200	300	150	200	120	16.7313	18035.4

V. Conclusion

In this paper, the economic load dispatch problem is solved by most popular traditional technique lambda iteration method. Two test units three unit system and six unit system are solved lambda iteration method for two different cases. In first case ELD problem has been solved by considering generator constraints without transmission loss and in second case ELD problem has been solved by considering generator constraints with transmission loss. After comparison of the above cases we have concluded that first case (ELD without transmission loss and with generator constraint) give the better result in comparison to other case. The above comparison shows that transmission loss plays very important role in ELD problem. Thus lambda iteration method is simple and gives the better result for ELD problem.

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