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COMBINED ECONOMIC EMISSION DISPATCH PROBLEM INCLUDING LINE LOSSES USING QUADRATIC PROGRAMMING

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ABSTRACT

The prime objective in the operation and planning mission of power system is to meet the power load demand at the lowest possible cost. In addition to these objectives, minimizing the environmental impact of power generation is getting to be exceedingly important as a consequence of the increase in the number of power plants. This paper presents an effective quadratic programming (QP) for the combined economic emission dispatch (CEED) problem. The results have been demonstrated for standard 6-generator systems with consideration of transmission losses.

Keywords—Combined Economic Emission Dispatch (CEED), Transmission Losses, Quadratic Programming (QP)

I. INTRODUCTION

Electric power is mostly produced from conventional non-renewable energy sources such as oil, natural gas and coal in addition to nuclear and hydro sources. Thermal plants that burn fossil fuels generate the major share of worldwide electric energy. In such plants heat energy is released and converted to mechanical form of energy which consequently generates electricity. This energy conversion is processed through thermal cycles with conversion efficiencies less than 40% [1].Clearly this increases the fuel consumption and decreases the existing resources. Furthermore, the continuous increase in the global demand on electric energy is accelerating the depletion of the limited and irreplaceable fuel supplies.

The main source of gaseous emissions and pollutants is generation of electric power from conventional non-renewable energy sources such as oil, natural gas and coal. The issue of environmental impacts and air pollution associated with power generation has become important consideration of today's power system operational practice. A significant portion of the total air pollutants and gaseous emissions in the atmosphere is produced from burning fossil-based fuels in power plants. The harmful effects of the various pollutants, such as nitrogen oxides NOx, sulphur dioxide SO_2 and carbon dioxide CO_2, are attracting great public concern so that they cannot be removed

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from any operational and planning strategy. In order to minimize these impacts on human life and the atmosphere at large, strict environmental laws and firm restrictions have been internationally imposed on power generation industry [2]. A prime objective in the operation and planning mission is to meet the power load demand at the lowest possible cost. A more imperative objective is the safety of individuals and equipment. Reliability and continuity of service are among the various essential planning and operational considerations. In addition to these objectives, minimizing the environmental impact of power generation is getting to be exceedingly important as a consequence of the increase in the number of power plants.

II. PROBLEM FORMULATION

a) Economics of Thermal Power Generation

The total annual expenditure of the plant can be classified into several subheadings namely,

i) Fixed Charges   ii) Running Charges

Fixed charges, as the name suggest does not vary either with the capacity of the plant or with plant operation. It consists the civil construction costs, electromechanical equipment cost, engineering and design (E&D) cost, supervision and administration (S&A) cost, inflation cost during construction etc. [3]

ii) **Running Charges of Power Generation**

The running charges or running cost of a power plant is probably one of the most important parameters while considering the economics of power generation as it depends upon the number of hours the plant is operated or upon the number of units of electrical energy generated. It consists fuel cost, operation & maintenance (O & M) cost, replacement & renovation cost etc. [4-6]

The overall cost function for thermal generating units $F_T(P_{gi})$ in \$/h is represented by quadratic equations as (1) [1]

$$F_T(P_{gi}) = \sum_{i=1}^{N_T}\left(a_i P_{gi}^2 + b_i P_{gi} + C_i\right) \quad (1)$$

Where, a_i, b_i, and c_i are the appropriate cost coefficients for individual generating units, Here a_i is the measure of losses in the system. b_i, represents the fuel cost which usually dominates and c_i, includes the salary, wages, interest and depreciation.

The cost is minimized subjected to the following generator capacities and active power balance constraints.

Load balance equation (2)

$$\sum_{i=1}^{N_g} P_{gi} - P_D - P_L = 0 \quad (2)$$

Generation unit capacity limits (3)

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad (3)$$

The lower limit of the output power P_{gi}^{min} is the minimum economical loading limit below which the operation is infeasible technically and/or economically. On the other hand, P_{gi}^{max} represents the upper limit and the maximum output power. In order to obtain a more accurate loss formula, a linear term and a constant is added to the expression of (4) to form what is referred to as Kron's loss formula [4-9]:

$$P_L = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} P_{gi} B_{ij} P_{gj} + \sum_{i=1}^{N_g} B_{i0} P_{gi} + B_{00} \tag{4}$$

The B-coefficients mainly depend on the operating condition of the system. They are usually assumed to be constant parameters, unless the system operating state of a new generation scheduling is significantly different from the base case [10-17].

b) Emission in Thermal Power Plant

Coal fired thermal power plants are one of the main contributors for atmospheric pollution and greenhouse gases. Emissions that come from these plants could be categorized into three different categories:

- Gaseous emissions Carbon Dioxide, Carbon Monoxide, Sulphur Dioxide and Nitrogen Dioxide which lead to global warming and acid rain.
- Particulate emissions - this fine dust that is emanated from the stacks of power plants is a health hazard.
- Trace elements like Mercury, Cadmium and Lead which are also health hazards.

These emissions are formed due to the Combustion process when coal is burned to produce heat. Some are avoidable, some can be controlled or reduced, and some cannot be avoided.

Total emission is given by-

$$E_c = \sum_{i=1}^{N_T}\left(d_i P_{gi}^2 + e_i P_{gi} + f_i\right) \tag{5}$$

Where E_c =Total emission

di, ei, fi = emission coefficient of i_{th} unit

c) Combined Economic and Emission Dispatch (CEED)

These Economic Load Dispatch (ELD) and Economic Emission dispatch (EED) are different to each other. The Economic Load Dispatch reduces the fuel cost by increasing the pollutants. Whereas the EED reduces the emission of pollutant gasses by increasing the fuel costs. So, we have to find out an operating point to make a balance between operating cost and emission rate and this can be achieved by CEED. The main objective function in CEED can be developed by combining ELD with EED with the help of price penalty factor h_i (Venkatesh et al., 2003) as follows [7-10]:

$$F_T = \sum_{i=1}^{N_T}\left(a_i P_{gi}^2 + b_i P_{gi} + c_i\right) + h_i\left(d_i P_{gi}^2 + e_i P_{gi} + f_i\right) \tag{6}$$

The price penalty factor can be calculated by the formula:

$$h_i = \frac{a_i P_{gi}^2 + b_i P_{gi} + c_i}{d_i P_{gi}^2 + e_i P_{gi} + f_i} \tag{7}$$

III. QUADRATIC PROGRAMMING (QP)

A linearly constrained optimization problem with a quadratic objective function is called a Quadratic programming (QP). Due to its numerous applications; quadratic programming is often viewed as a discipline in and of itself. Quadratic programing is an efficient optimization technique to trace the global minimum if the objective function is quadratic and the constraints are linear. Quadratic programming is used recursively from the lowest incremental cost regions to highest incremental cost region to find the optimum allocation. Once the limits are obtained and the data are rearranged in such a manner that the incremental cost limits of all the plants are in ascending order.

The general quadratic programming can be written as:

$$\text{Minimize } f(x) = cx + \frac{1}{2} x^T Q x \tag{8}$$

Subjected to $Ax \leq b$ and $x \geq 0$

Where c is an n-dimensional row vector describing the coefficients of the linear terms in the objective function, and Q is an $(n \times n)$ symmetric matrix describing the coefficients of the quadratic terms. If a constant term exists it is dropped from the model. As in linear programming, the decision variables are denoted by the n-dimensional column vector x, and the constraints are defined by an $(m \times n)$ A matrix and an m-dimensional column vector b of right-hand-side coefficients. We assume that a feasible solution exists and that the constraint region is bounded. When the objective function f(x) is strictly convex for all feasible points the problem has a unique local minimum which is also the global minimum. A sufficient condition to guarantee strictly convexity is for Q to be positive definite.

If there are only equality constraints, then the QP can be solved by a linear system. Otherwise, a variety of methods for solving the QP are commonly used, namely; interior point, active set, conjugate gradient, extensions of the simplex algorithm etc. The direct ion search algorithm is minor variation of quadratic programming for discontinuous search space. For every demand the following search mechanism is followed between lower and upper limits of those particular plants.

For meeting any demand the algorithm is explained in the following steps:

1) Assume all the plants are operating at lowest incremental cost limits.

2) Substitute $P_i = L_i + (U_i - L_i)\, X_i$, where $0 < X_i < 1$ and make the objective function quadratic and make the constraints linear by omitting the higher order terms.

3) Solve the CEED using quadratic programming recursively to find the allocation and incremental cost for each plant within limits of that plant.

4) If there is no limit violation for any plant for that particular piece, then it is a local solution.

5) If for any allocation for a plant, it is violating the limit, it should be fixed to that limit and the remaining plants only should be considered for next iteration.

6) Repeat steps 2, 3, and 4 till a solution is achieved within a specified tolerance.

IV. CASE STUDY

In this case, a simple power system consists of six-unit thermal power plant is used to demonstrate. Characteristics of thermal units are given in Table 1, the following coefficient matrix Bij losses [2].

Characteristics of Thermal units [2]:

$$F1 = 0.15240P_1^2+38.53P_1+756.79886 \quad Rs/Hr$$

$$F2 = 0.10587P_2^2+46.15916P_2+451.32513 \quad Rs/Hr$$

$$F3 = 0.02803P_3^2+40.39655P_3+1049.9977 \quad Rs/Hr$$

$$F4 = 0.03546P_4^2+38.30553P_4+1243.5311 \quad Rs/Hr$$

$$F5 = 0.02111P_5^2+36.32782P_5+1658.5596 \quad Rs/Hr$$

$$F6 = 0.01799P_6^2+38.27041P_6+1356.6592 \quad Rs/Hr$$

Generation Limit of Units

$10 \text{ MW} \leq P1 \leq 125 \text{ MW}$

$10 \text{ MW} \leq P2 \leq 150 \text{ MW}$

$35 \text{ MW} \leq P3 \leq 225 \text{ MW}$

$35 \text{ MW} \leq P4 \leq 210 \text{ MW}$

$130 \text{ MW} \leq P5 \leq 325 \text{ MW}$

$125 \text{ MW} \leq P6 \leq 315 \text{ MW}$

Table: 1 Emission Coefficients

Units	d_i	e_i	f_i
1	0.00419	0.32767	13.85932
2	0.00419	0.32767	13.85932
3	0.00683	-0.54551	40.2669
4	0.00683	-0.54551	40.2669
5	0.00461	-0.51116	42.89553
6	0.00461	-0.51116	42.8955

Loss coefficient matrix Bmn:

$$B_{mn} = \begin{bmatrix} 0.000140 & 0.000017 & 0.000015 & 0.000019 & 0.000026 & 0.000022 \\ 0.000017 & 0.000060 & 0.000013 & 0.000016 & 0.000015 & 0.000020 \\ 0.000015 & 0.000013 & 0.000065 & 0.000017 & 0.000024 & 0.000019 \\ 0.000019 & 0.000016 & 0.000017 & 0.000071 & 0.000030 & 0.000025 \\ 0.000026 & 0.000015 & 0.000024 & 0.000030 & 0.000069 & 0.000032 \\ 0.000022 & 0.000020 & 0.000019 & 0.000025 & 0.000032 & 0.000085 \end{bmatrix}$$

V. SIMILATION RESULTS AND DISCUSSION

The applicability of the quadratic programming (QP) for practical applications have been tested on six unit thermal power plant for Combined Economic and Emission Dispatch (CEED) problem. All the programs are developed using MATLAB 7.8.0 (2009a) and the system configuration is core i3 processor with 2.30 GHz speed and 3 GB

RAM. Table: 2 show the summarized result of the quadratic programming (QP) for test case. Form Table: 2, it is clear that quadratic programming (QP) gives optimum result in term of combined economic emission dispatch (CEED) for power demands of 800 MW and 1000 MW.

Table: 2 Results for test case (PD=800 MW, PD=1000 MW)

Out Put	Load Demand (P_D=800 MW)	Load Demand (P_D=1000 MW)
Pg1(MW)	76.57	105.70
Pg2(MW)	79.26	115.01
Pg3(MW)	135.23	166.21
Pg4(MW)	134.15	163.87
Pg5(MW)	199.71	243.09
Pg6(MW)	197.26	240.78
Total System Loss (MW)	22.19	34.66
Emission (Kg/hr)	557.20	852.98
Total Cost ($/hr)	42784	54057

VI. CONCLUSION

Optimization algorithms are observed to provide significant results for CEED. By controlling the cost, the pollution causing emissions rises. Therefore, the cost reduction must be controlled by means of a technique called emission dispatch. But, the controlling of emission will increase the cost required for power generation. So, a combined technique called Combined Economic and Emission Dispatch emerges. The simulation result shows the performance of the proposed technique and it can be suggested that the proposed technique reduces the fuel cost as well as the emission output. Further, it takes lesser time and number of iterations for optimization.

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