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SOLVING THE ECONOMIC DISPATCH PROBLEM OF A TWO-AREA POWER SYSTEM CONSIDERING TRANSMISSION CONSTRAINT USING SEMI-DEFINITE PROGRAMMING

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Abstract
This paper presents a method of semi-definite programming approach to solving the economic load dispatch problem in two areas of an electrical power system where tie transmission line capacity is considered as the constraint. The algorithm was developed with some equality and inequality constraints without difficulty for complex cost functions. The simulation was performed in MATLAB environment at four different loads 800, 950, 1030, and 1130 MW. From the results, it is found that the semi-definite programming approach yields a higher-quality solution with better computation efficiency and stable convergence characteristics when compared with the results obtained when the direct search method and enhanced direct search method are used. In addition, it uses some iterations and converges faster. Thus, the semi-definite programming approach gives the best result in terms of total cost minimization (reduced fuel cost and power loss) when compared with other methods referenced in this work.

1. Introduction

Economic load dispatch (ELD) may be described as the operation of generation facilities to produce energy at the lowest possible cost and reliably serve consumers, with due consideration of any operational limits of generation

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and transmission facilities [1]. One of the substantial operating tasks in power systems is to reduce the total generation cost, which makes load dispatch a fundamental issue in modern power system operation [2]. This is a crucial optimization problem, and its main objective is to divide the required power demand among online generators. It is used to minimize the generation cost of units when equality and inequality constraints are satisfied [3]. Daily generation scheduling is an essential operational problem facing electrical utilizes and has been the subject of intensive research over the past years [4]. With the existence of electrical power systems that are capable of producing sufficient electrical power to meet a range of load demands, power system operators are always concerned with minimizing the cost of products and services.

With many challenges arising in electric networks, the energy crisis in the world, and continuous rises in prices of generation, transmission, and distribution of electric power, it is important for operators to reduce the running costs of the electric energy supply. Consequently, operators continuously strive to achieve economic dispatch (ED), which entails determining the optimal output of generation facilities at the lowest cost that guarantees reliable supply to the overall system load [5]. Thus, ED can be considered as the problem of minimizing only the fuel cost through determination of the allocation of generation among a set of committed units in the same thermal power plant or among a number of committed thermal power plants of different locations subject to the constraint that total generated power equal to the demand or the total generated power equals the demand and transmission losses among power plants [5]. In a related effort, economic dispatch is described as a procedure of simultaneous determination of the electrical power generated by the committed generating units in a power system at a minimal cost while satisfying the load demand [6]. This makes the ED an important tasks in power system planning and operation [7].

The major component of generator operating cost is the fuel input/hour, whereas maintenance contributes only to a small extent. The fuel cost is meaningful in the case of thermal and nuclear stations, but for hydro stations where energy storage is “apparently free”; the operating cost is not meaningful. Hence, this work will concentrate on fuel-fired stations only. One of the main objectives of electric power utilities is to provide high-quality, reliable power supply to the consumer at a lower operating cost while meeting the operating limit and constraints imposed on the generating unit. In addition, economic dispatch problems have become a crucial task in the operation and planning of power systems. The primary objective of ED is to schedule the committed generating unit’s output at a minimum cost that satisfies all units and system operational constraints. Improvements in scheduling unit outputs can lead to significant cost saving.

A genetic algorithm-based approach to adaptive optimal economic load dispatch in electrical power systems was carried out in [1], while the work reported in [8] employed semi-definite programming formulation for the multi-objective economic-emission dispatch problem. The fuel cost and emission functions were represented by high-order polynomial functions as a more accurate representation of the economic-emission dispatch problem. The polynomial functions of both objective functions were aggregated into a single objective function using the weighted sum approach. Thus, the problem was reduced to that of a standard polynomial optimization problem formulated as a hierarchy of semi-definite relaxation problems.

Over the years, a lot of work has been done regarding the problem of economic load dispatch. In [8], the ELD problem was expressed as a multi-objective one where operating costs, emission and transmission losses in thermal power dispatch systems, and uncertainty and inaccuracy of the system data were used as objectives. The validity and effectiveness of the method were demonstrated using a 6-generator system. A review of single- and multi-area economic dispatch problems was presented in [9] with highlights of approaches for solving different

ED problem scenarios. It was submitted that due to its performance and faster processing time, semi-definite programming was adjudged best for solving the EDED problem.

Two methods were proposed in [10] to address the optimal generation dispatch problem particle swarm optimization (PSO)-based and lambda iterative-based methods. The Indian 62-bus, IEEE 30-bus, and standard IEEE 14-bus networks were used as case studies to illustrate the approaches. Simulation results revealed that the PSO-based method exhibited excellent convergence characteristics because it charged consumers per unit. The lambda iteration approach provided information on the next incremental cost of generation for each power demand. This information is particularly helpful to utility firms because the outcomes show that the two approaches are appropriate for offering effective fixes for issues with economic dispatch in large power networks. Mathematically based models and linear programming were used to solve the ED problem in [11]. The ED problem was formulated using a linear piecewise function, and Turing Bot software was employed to optimize the collected data. This enabled the construction of a mathematical model for optimal power generation as a function of the load values. The proposed model provides a simple and easy means of developing mathematical equations that represent the feasible operating conditions for the selected system. Fast execution time, accuracy in reading, accessibility, and simplicity are the major characteristics of the developed model [11]. The multi-area economic dispatch problem was solved for a single area with three-generation units, a two-area system with four generating units, and four areas with a 40-unit system using, dynamic particle swarm optimization (DPSO) and gray wolf optimizer (GWO) techniques [13]. Results from the simulation showed that GWO techniques generate quality, cost-effective solutions without constraint violations, unlike DPSO. In addition, the GWO based technique exhibited noticeable improvement in cost results compared with the method adopting conventional optimization techniques [12].

A method for economic and emission dispatch using the Cuckoo search algorithm (CSA) was presented in [13]. Three power generators were used to test the algorithm and compare it with other approaches, such as PSO and Conventional Method (CM). The best power loads were found using CSA with superior performance in managing the nonlinearity associated with the ED problem at reduced fuel and pollution costs. The outcome of the campaign showed that CSA provides optimal ways of minimizing cost and maximizing energy. Economic load dispatch problems involving 3-, 5- and 6-unit test systems were solved using the gravitational search algorithm (GSA) in [14]. The GSA method was shown to outperform conventional optimization techniques in terms of its efficacy, resilience, consistent convergence properties, high-quality solution, practicality, and high computing efficiency. The GSA approach provides an effective means of optimizing energy compared with conventional methods.

2. Formulation

ELD is one of the most serious problems from the viewpoint of power system to derive an optimal economy. The task of finding the optimum combination of the generation level of all generating units that satisfies a given level of loads can be described as an optimization problem with the objective of minimizing the fuel cost function. The cost function is expressed as a quadratic function of the ELD problem and can be expressed;

$$F_i(P_i) = \sum_{i=1}^{N} a_i + b_i P_{Gi} + c_i P_{Gi}^2 \quad (1)$$

The total fuel cost of the generation system is given by

$$F_i(P_i) = \sum_{i=1}^{N} F_i(P_{Gi}) \quad (2)$$

subject to

$$\sum_{i=1}^{N} P_i = P_D \quad (3)$$

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max}, i = 1, \ldots, N$$

where i is a unit index number, N is the total number of units in the power system, F_i is the fuel cost function of the units, P_{Gi} is the power generated by unit i, P_D is the total system load while P_{Gi}^{min} and P_{Gi}^{max} are the lower and upper limits of the unit i, respectively.

Thus, it follows for the two areas depicted in Fig. 1 and identified as areas 1 and 2, respectively, that

$$\sum_{i=1}^{N} P_{Gi}^{1} = P_D^1 + P_{12} \quad (4)$$

$$\sum_{i=1}^{N} P_{Gi}^{2} = P_D^1 - P_{12} \quad (5)$$

with this constraint

$$-P_{12}^{max} \leq P_{12} \leq P_i^{min}$$

where P_D^1 and P_D^2 are the load demand of each of areas 1 and 2 while P_{12} and P_{12}^{max} are the power transfer from area 1 to area 2 and its upper limit.

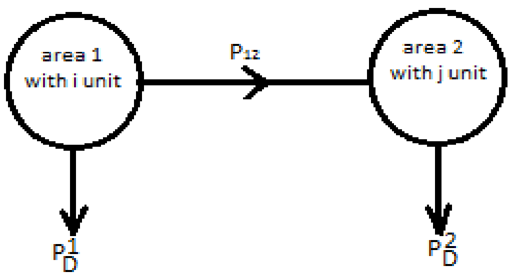

Fig. 1: Two-area power system

Consider the two-area system shown in Fig. 1 as having four generating units and that the percentage of the total load demands in area 1 is 70%, whereas that in area 2 is 30%. The unit data of area 1 are given as follows:

$$F_1(P_1) = 533 + 7.524P_1 + 0.00148P_1^2 \quad (6)$$

where $150\ MW \leq P_1 \leq 600\ MW$

$$F_3(P_3) = 74.1 + 7.57P_3 + 0.004579P_3^2 \quad (7)$$

where $50\ MW \leq P_3 \leq 200\ MW$

The load demand in area 2 is 30% of the total load demand, and the unit data are given as follows:

$$F_2(P_2) = 294.5 + 7.524P_2 + 0.001845P_2^2 \quad (8)$$

where $100\ MW \leq P_2 \leq 400MW$

$$F_4(P_4) = 237.5 + 7.125P_4 + 0.00172P_4^2 \quad (9)$$

where $50\ MW \leq P_4 \leq 350MW$

For simplicity, network losses are neglected so that only the effect of transmission capacity limits in the studied cases is considered. The system transfers power from area 2 (cheap) to area 1(expensive area) because units in area 2 generates power cheaply.

3. Proposed Method: Semi Definite Programming

In semi-definite programming (SDP), one minimizes or maximizes a linear function subject to the constraint that a combination of symmetric matrices is positive semi-definite [15]. Such a constraint is nonlinear and non-smooth, but convex, so semi-definite programs are convex optimization problems. SDP is diverse in various fields, as it is used in modeling operational and research combinatorial optimization problems in various fields like control theory and power generation optimization [15]. Because SDP is solvable via interior point methods, which form a linear matrix inequality, most of these applications can usually be solved very efficiently in practice as well as in theory [16].

Equation (2) gives the objective function to be minimized when the ELD problem is expressed as the minimization problem of the total fuel cost of the generation system. Representing the non-convex optimization problem of Eq. (1) in SDP format, one obtains:

$$minimize\{trace\ (P_{Gi}^T c_i P_{Gi} + b_i^T P_{Gi} + a_i)\} \qquad (10)$$
$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}$$
$$y = P_{Gi}$$
$$Y = y^T y$$

It is difficult to solve the non-convex optimization problem with the polynomial constraint in Eq. (10), as the matrix c_i are indefinite. To reduce the difficulties encountered in the non-convex optimization problem, it is desirable to relax Eq. (11) into a convex optimization problem to achieve optimal values for the problem with less computational time. The relaxed version of Eq. (10) is given by:

$$minimize\{trace(c_i Y + b_i^T y + a_i)\} \qquad (11)$$
$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}$$
$$\begin{pmatrix} 1 & y^T \\ y & Y \end{pmatrix} \geq 0$$

According to [9][16], the quadratic expression in Eq. (11) can be represented in SDP matrix form as:

$$minimize\left(\begin{bmatrix} c_i & b_i \\ b_i & a_i \end{bmatrix}\begin{bmatrix} 1 & y^T \\ y & Y \end{bmatrix}\right) \qquad (12)$$
$$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}$$
$$\begin{pmatrix} 1 & y^T \\ y & Y \end{pmatrix} \geq 0$$

Solving the economic load dispatch problem for the convex optimization problem, the SDP approach requires less computational time, converges faster, and gives the best results in terms of reduced total fuel cost for the ELD problem.

4. Results and Discussion

Table 1 shows the cost coefficients and power constraints for the ELDP [1].

Table 1: Cost coefficients and power constraints for the ELD problem

C	B	a	P^{min}	P^{max}
533	7.52	0.001484	150	600
294.5	7.46	0.001845	100	400
74.1	7.57	0.004579	50	200
237.5	7.125	0.00172	50	350

Table 2 shows the values of the result for P_D of 950 MW without considering the transmission limit and the total cost for the SDP compared to DSM and EDSM based on the results presented in [1].

Table 2: Values of the total cost when the total load P_D is 950 MW for different methods

Methods	Total Cost ($/h)
SDP	8646.30
DSM	8664.83
EDSM	8651.70

It can be inferred from the entries Table 2 that SDP has the lowest total cost though marginal. It has values of 18.53 and 6.4 lower than those obtained in DSM and EDSM, respectively.

Table 3 shows the comparison of two area systems with several line capacities and loads of 800, 950, 1030, and 1120 MW.

Table 3: Comparison results of the ELD problem for the two-area system solved via EDSM and SDP at different line capacities and loads

Load (MW)	Flow Limit (MW)	Total Cost (EDSM) ($/h)	Total Cost (SDP) ($/h)
800	90	7444.9	7363.00
	120	7422.2	7358.96
	200	7389.6	7358.32
950	90	8741.8	8606.03
	120	8714.8	8600.18
	200	8651.7	8598.08
1030	90	9449.7	9278.46
	120	9419.7	9271.65
	200	9338.7	9270.02
1120	90	10209.0	10042.84
	120	10206.0	10036.72
	200	10125.0	10036.62

Figure 2 depicts variations of total fuel cost with flow limit when the flow limit is varied between 0 and 600 MW while displayed Fig. Figure 3illustrates variations in the total generated power of area 1(blue colour) and area 2 (green colour) with the flow limit within 0-600MW.

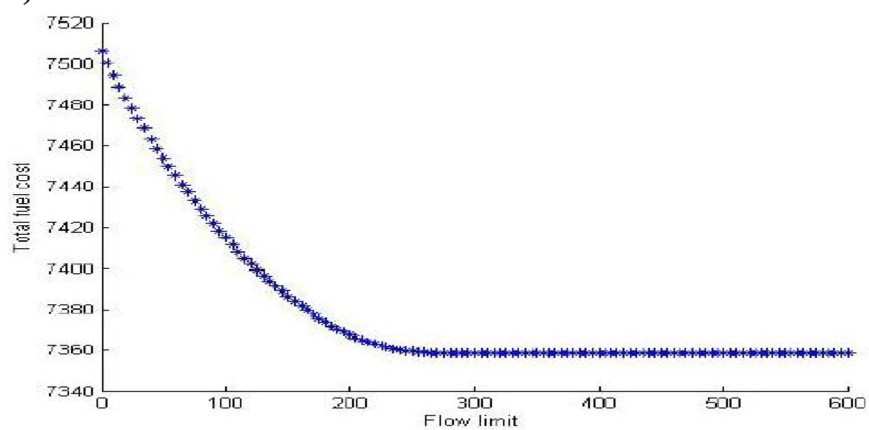

Fig. 2: Total generation cost variation with respect to the line limit

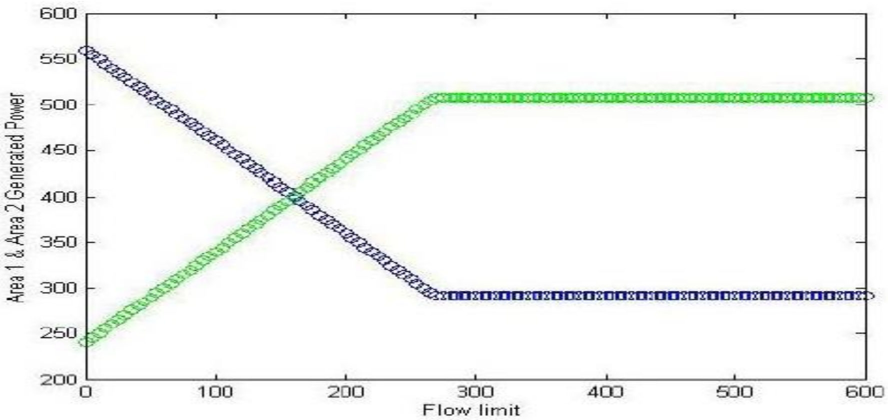

Fig. 3: Total generated power at areas 1 and 2 with respect to the line flow limit

5. CONCLUSION

The proposed semi-definite programming method to solve the economic load dispatch problem of generation for a two-area power system is presented in this paper. The feasibility of the proposed method for solving the economic load dispatch problem was demonstrated and compared with the direct search method and the enhanced direct search method in the literature. The semi-definite programming method algorithm for economic load dispatch was developed in the MATLAB environment. The obtained results showed that outputs using SDP were comparatively superior to those of the DSM and EDSM. We can reasonably conclude that semi-definite programming is capable of obtaining higher-quality solutions with better computation efficiency and stable convergence characteristics than DSM and EDSM.

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