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SECURE AND EFFICIENT METHOD FOR DYNAMIC ECONOMIC LOAD DISPATCH IN LARGE SCALE POWER SYSTEMS

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ABSTRACT: This paper presents an efficient and secure method of solving dynamic economic load dispatch (DELD) scheduling problems for large-scale power system operation systems. The main objective is to reduce the total operating costs into the lowest possible level while considering system operation constraints. The method uses LaGrangian Relaxation Method, Linear Programming and other techniques. The algorithm used appears to be efficient and secure to meet the required scheduling objectives of the system. After real system individual generators are economically loaded and periodically dispatched, optimized total generation cost and fast computation times have been achieved. DELD with different period intervals has been taken into consideration. Promising results have been achieved using different real data systems.

Keywords
Dynamic economic dispatch, Linear programming, LaGrangian Relaxation, Spinning Reserve Contribution.

1 INTRODUCTION

Since Unit Commitment and Economic Load Dispatch are inseparable from one another because of their interdependent characteristics in their sub-problems, it is considered that economic load dispatch is the one part of unit commitment problem provided that the unit commitment problems has already been solved.
The primary objective of economic dispatch problem is to determine the economic loading of the generators such that the load demand in power systems can be achieved

This paper is to investigate and demonstrate the best way of optimizing large-scale DELD generation units with modest computation time.
The adopted application methodology is to apply suitable technique(s) to both DELD objective function and all major constraints involved in the system. LaGrange Relaxation optimization method (LR) along with other techniques have been used to decompose DELD problem into a master problem and more manageable sub-problems, which can be solved by using iterations until a near-optimal solution is reached. These sub-problems are solved independently. Partition of the real problem into smaller sub-problems simplifies the difficult and multi-constrained problems to manageable sub-problems. The hybrid methods used for the solution of this large-scale problem show better result of the selected DELD solution when proper modeling techniques are formulated and utilized. This algorithm is applied to the constraints for minimizing the operating cost of generators. Fast and optimized ELD solution results have been gained with a very short computation time. The objective function of the problem and its related constraints are illustrated in Fig. 1.

2 ECONOMIC DISPATCH MODELING

Economic dispatch may some times classified into two types [1]. One is static optimization problem in which costs associated with the changing time period of the generation outputs of generating units are not considered as dynamic form. A dynamic dispatch on the other hand is considered as the one in which the operating cost changes with the time periods and power outputs of the generating units in the load dispatching process [2]. The use of the steady state operating costs in the static optimization, poor transient behavior result when these solutions are incorporated in the feedback control of dynamic electric power networks. The dynamic dispatch method uses load forecasts of the system to enable the system operator experts to develop optimal generator output trajectories. Generators are driven along the optimal trajectories by the control performance of the feedback controller [1, 3]. In dynamic economic load dispatch, it is habitual to divide dispatch horizon into different time periods and form a model to meet the power generation and load demand balance at the end of

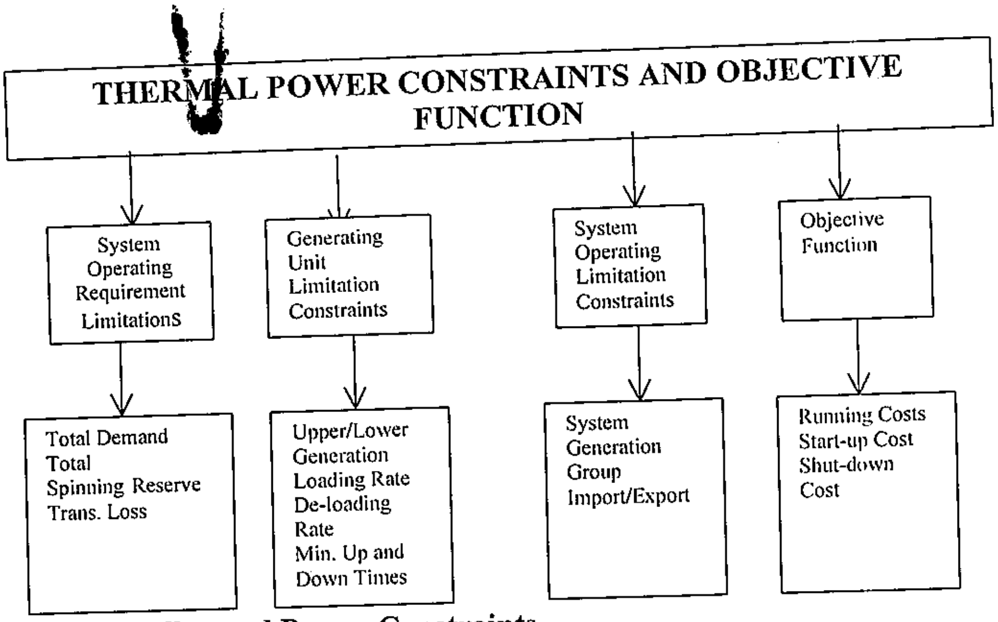

Figure 1: Thermal Power Constraints

each selected period [2]. Since the constraints under consideration are very large scale and complex, it is assumed in this work that the load changes with its related period linearly. There are two types of linear load curves; they are:

a) Step approximation curve
b) Trapezoid approximation curve

According to reference [2] trapezoidal approximation load curve is more accurate than that of step curve approximation particularly when the length of periods are varied. This work is based on formulating the real power demand approximation curve as initial formulation of power generation load balance is carried out by Lambda Multipliers method whereby generation outputs are calculated and balanced with the load demand., objective cost, startup and shutdown costs are also included in this portion(startup and shutdown costs are not included in this paper). DELD problem is solved by Linear programming method for the rest of the constraints while linking constraints are used by dual LaGrange relaxation Technique. This work is partially similar to the work in reference [2] but Standard LaGrange Multipliers are used for the initial stage in order to get initial balanced load dispatch and aimed at LP Method, which will be used later for further optimizing the dispatch system with all undertaken constraints. After getting the first dispatch as initial values, Linear programming problem solution method is applied for the solution to DELD problem. The speed of computation time is not affected by the initial dispatch addition (using Standard Lagrange Multipliers) to the addition of the second solution technique (using Linear Programming

PROBLEM FORMULATION

The problem formulation of ELD problem consists of two portions of solution techniques, which are:

1) Standard LaGrange Multipliers Method is used for solving initial conditions of the load dispatch system such as unit output levels,
Lambda iterations for calculating incremental costs and balancing unit output levels against total load demand.
2) The Linear Programming Technique is used as a second model. It is used for the optimization of total ELD objective function. The main purpose of the adopted mathematical modeling of DELD problem is optimizing total operating cost.

LaGrangian Relaxation Technique

As mentioned above Standard Lagrange Multiplier Method is used for the initial economic dispatch.
The following solution method has been adopted. First of all an initial Standard Lagrange Method is formulated and used for the preliminary run of the dispatch system. The solution method adopted is based on the following equations:

1) Power produced by the units must at least equal to the power demand, P_D plus the network losses, P_L as:

$$\sum P_I \geq P_D + P_{LOSS} \qquad (1)$$

2) The following relation determines LaGrange multiplier, λ which is:

$$\lambda = (2 * P_D + \sum^{m}_{i=1}(\beta_i/\gamma_i))/ \sum^{m}_{i=1} \gamma^{-1} \qquad (2)$$

Where
β_i, γ_i are cost coefficient of unit i

Since the aim is to find a solution to the constrained values of power demand and power generated by the units, Lambda is in effect a conversion factor that accounts for the dimensional in compatibility of the cost function ($/h) and constraints (MW) and resulting problem is unconstrained one [4].

3). Quadratic equation can be stated as:

$$F_i(P_i) = \alpha_i + \beta_l P_i + \gamma_i^2 P_i \tag{3}$$

4) The above equation is changed to linear one by differentiating it for optimality condition and is reduced to:

$$d F_i(P_i) / d P_i = \beta_i + 2\gamma_l P_i - \lambda = 0 \tag{4}$$

$$\text{and } \lambda = \beta_i + 2\gamma_l P_i$$

$$P_i = (\lambda - \beta_i) / 2\gamma_l P_i \tag{5}$$

By reaching the optimum solution of operating cost "Equation (4)", output power, Lambda cost, and achieving the generation load balance are aimed for their solutions. Different prototype examples have been used and the same data have also been applied to the second portion of the basic model.

Linear Programming Technique

By assuming that, the generation levels of each unit Changes linearly with the related periods sequentially until it reaches the last generation level. The dispatch system is dynamic one in that sense.

Energy cost of a unit with respect to its periods is expressed as:

$$Z_{ij} = b_i P_{ij} T_j \tag{6}$$

Where

Z_{ij} = energy cost produced by unit i

b_l = incremental cost of unit i

P_{ij} = power generated by unit I in interval j

T_j = time interval of period j

Since overall goal of economic dispatch is to reduce the total objective function with reasonable computation, "Equation (6)" is formulated.

$$\text{Minimize } Zt = \sum\sum \propto_{ij} P_{ij} \tag{7}$$

Where

Zt = total objective function

$\propto_{ij} = 1/2 b_l (Tj + T_l)$

and $P_{ij} = 1/2(P_{ij} + P_{il})$ (average of two output powers of two different periods j and l

Since spinning reserve of the system is important here, the following equality condition must be met, whereby output power of unit I must maintain that constraint in "Equation (7)".

$$P_i \geq PD + SR \tag{8}$$

P_i = output power of unit i

St = total system spinning reserve

Power generated by the units must be within the minimum and maximum capacity limits of the units themselves.

$$Pi^{min} <= Pi <= Pi^{max} \tag{9}$$

Pi^{min} = minimum generation limit of unit i

Pi^{max} = maximum generation limit of unit i. Units must be loaded within a specific hour and can be changed in the next hour, the following condition must be found:

$$P_{ij} - P_{il} <= \delta P_l^{+} T_j \tag{10}$$

δP_i^{+} = maximum loading rate of unit i

$$P_{ij} - P_{il} <= \delta P_i^{-} T_j \tag{11}$$

δP_i^{-} = minimum deloading rate of i

Spinning reserve contribution of any steam thermal unit can be modeled as:

If the unit is operating in the lower region, then its reserve contribution can be written as:

$S_{ij} = k_l P_{ij}$ If not, then it can expressed as: $S_{ij} = P_l^{max} - P_{ij}$

Convexity permits the overall contribution to be stated as:

$$\sum S_{ij} <= k_i P_{ij} \tag{12}$$

$$S_{ij} <= P_i^{max} - P_{ij} \tag{13}$$

The Total Spinning reserve constraint can be stated as

$$\sum S_{ij} \geq ST_j \tag{14}$$

The above Equations are used for modeling of linear based programming techniques and because of this reason, some accuracy must be lost but according to this work, the model is based on the potential application of LP programming techniques. As any other method solved by linear based programming technique is concerned whereby the original problem is not linear, changing a non-linear system to a linear one is the demand for the LP technique. The Basic Model of the solution is based on the compromise of seeking better solution and sacrificing some accuracy [5]. This application technique has achieved the near optimal solution with fast computation time that facilitate for online DELD for large-scale power systems. These Equations represent the objective function and constraints undertaken using the formulations in this research, as the objective function is a subject to each constraint while the objective function is a minimization type problem. To simplify the dispatch problem used in this work, figure 3 shows a decomposition flow chart about DELD objective function and the constraints under consideration.

RESULTS

A number of case studies have been carried out using SUN WORKSTATIONS, SPARC10 for an ongoing research. In this research, different case studies have been performed in using the aforesaid techniques. Many different data types have been tested for both experimental and verification purposes but due to the space constraints they cannot be shown in this paper fully, however the most significant parts of the results are presented in this paper [5]. The following two tables show some results taken from those cases studies. The results achieved from 53 generators are presented in this paper. All important parameters formulated in DELD equations have been determined and described in this paper. A sample data taken from reference [6] is used incremental cost of the generation system in every period, total power demand against total output level in very period and total cost of the dynamic dispatch are shown in table 1 and table2 respectively. Initially, the problems are solved by standard Lagrange multipliers method. The equations involve in Lagrange multipliers are changed into linear equations by differentiating them. The major problems are solved by the first method, when the required results are achieved then the second method is used for the solution of optimization problems. Both original parameters and new ones are then used for the linear programming technique. All the data shown in these tables are taken from reference [6]. As said in the above, output levels of generation units are considered as dynamic with the time interval that the units are on-line. Table 1 shows the total output levels vs. total power demand. The table shows that balance between unit output levels and total power demand, which demonstrate very close margin where there is a small surplus in the output level which satisfied with the relationship of $P_i \geq PD + SR$ in equation (8) [7].

Table 1: The Dynamic Values of DELD Results

*******For Period 1*******	
Incremental Cost	63.878689
DEMAND	6804.000000
Total output power	6804.004395
TOTAL COST	434631.000000
*******For Period 2*******	
Incremental Cost	63.144590
DEMAND	6574.000000
Total output power	6574.003906
TOTAL COST	415112.687500
*******For Period 3*******	
Incremental Cost	62.713705
DEMAND	6439.000000
Total output power	6439.005371
TOTAL COST	403813.781250
*******For Period 4*******	
Incremental Cost	62.410490
DEMAND	6344.000000
Total output power	6344.003906
TOTAL COST	395932.187500
*******For Period 5*******	
Incremental Cost	62.136001
DEMAND	6258.000000
Total output power	6258.001465
TOTAL COST	388847.375000
*****For Period 6*****	
Incremental Cost	62.937127
DEMAND	6509.000000
Total output power	6509.004395
TOTAL COST	409657.843750
TOTAL COST RM	**2,447,994.875**

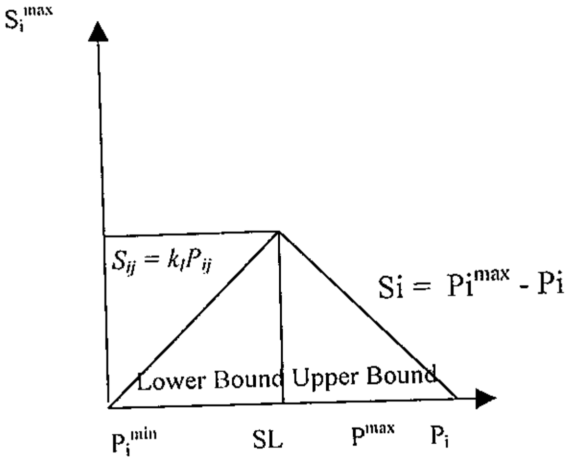

Figure 2: Spinning reserve contribution of a unit

Table 2: The Optimized DELD Solution

GENERATION OUTPUT LEVELS

PERIODS						
	1	2	3	4	5	6
UNIT						
1	179.383	169.159	163.157	158.934	155.111	166.269
2	179.383	169.159	163.157	158.934	155.111	166.269
3	172.970	164.974	160.280	156.977	153.987	162.714
4	172.970	164.974	160.280	156.977	153.987	162.714
5	62.362	61.528	61.038	60.694	60.382	61.292
6	62.362	61.528	61.038	60.694	60.382	61.292
7	251.493	246.637	243.788	241.782	239.967	245.265
8	67.235	65.078	63.812	62.922	62.115	64.469
9	67.235	65.078	63.812	62.922	62.115	64.469
10	67.235	65.078	63.812	62.922	62.115	64.469
11	67.235	65.078	63.812	62.922	62.115	64.469
12	209.230	200.299	195.057	191.368	188.029	197.775
13	209.230	200.299	195.057	191.368	188.029	197.775
14	209.230	200.299	195.057	191.368	188.029	197.775
15	185.695	183.415	182.077	181.135	180.283	182.771
16	32.099	31.414	31.012	30.729	30.473	31.220
17	32.099	31.414	31.012	30.729	30.473	31.220
18	32.099	31.414	31.012	30.729	30.473	31.220
19	32.099	31.414	31.012	30.729	30.473	31.220
20	94.860	93.496	92.695	92.131	91.621	93.110
21	94.860	93.496	92.695	92.131	91.621	93.110
22	94.860	93.496	92.695	92.131	91.621	93.110
23	73.218	72.223	71.639	71.228	70.856	71.942
24	73.218	72.223	71.639	71.228	70.856	71.942
25	192.049	189.769	188.431	187.489	186.637	189.125
26	79.102	78.076	77.474	77.051	76.668	77.786
27	79.102	78.076	77.474	77.051	76.668	77.786
28	85.630	84.174	83.319	82.717	82.173	83.762
29	85.630	84.174	83.319	82.717	82.173	83.762
30	85.630	84.174	83.319	82.717	82.173	83.762
31	91.408	90.246	89.564	89.085	88.650	89.918
32	0.0	0.0	0.0	0.0	0.0	0.0
33	0.0	0.0	0.0	0.0	0.0	0.0
34	84.784	83.666	83.009	82.548	82.130	83.349
35	84.784	83.666	83.009	82.548	82.130	83.349
36	106.947	104.709	103.395	102.471	101.634	104.077
37	106.947	104.709	103.395	102.471	101.634	104.077
38	106.947	104.709	103.395	102.471	101.634	104.077
39	283.198	279.464	277.272	275.730	274.334	278.409
40	450.963	435.142	425.856	419.321	413.405	430.671
41	62.010	61.261	60.821	60.512	60.232	61.049
42	62.010	61.261	60.821	60.512	60.232	61.049
43	62.010	61.261	60.821	60.512	60.232	61.049
44	62.010	61.261	60.821	60.512	60.232	61.049
45	62.010	61.261	60.821	60.512	60.232	61.049
46	62.010	61.261	60.821	60.512	60.232	61.049
47	62.010	61.261	60.821	60.512	60.232	61.049
48	62.010	61.261	60.821	60.512	60.232	61.049
49	441.387	429.772	422.954	418.156	413.813	426.489
50	441.387	429.772	422.954	418.156	413.813	426.489
51	259.791	235.483	221.215	211.175	202.086	228.613
52	259.791	235.483	221.215	211.175	202.086	228.613
53	259.791	235.483	221.215	211.175	202.086	228.613

5 CONCLUSION

Two steps of modeling have been made for the solution of DELD problem; they are:
1) Standard LaGrange Multipliers Method
2) Linear Programming Method

1) Standard LaGrange Multipliers Method is used for solving initial conditions of dispatch system. In this work, initial economic load dispatch which contains as output levels of generating units, balancing them with total power demand forecasted and others have been formulated using Standard LaGrange Multipliers, which are intended to be optimized for the next stage by using linear programming solution technique. Initial balance of power generation outputs and load demand have been achieved.

3) The second model of solving DELD problem is carried out by linear programming technique. To seek both feasible and optimum solutions of The DELD problem, Linear Programming is used these purposes while linking constraints are applied and solved by LaGrange Dual Function. All selected constraints shown in Figure 1 are considered in this stage. The algorithm appears to be fast and meets the deserved near optimum solution.

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