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Economic Dispatch of Generated Power Using Modified Lambda-Iteration Method

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Abstract: *In practical situations and under normal operating conditions, the generating capacity of power plants is more than the total losses and load demand. Also, power plants have different fuel costs and are not the same distance from the load centers. Hence the need for developing improved methods of economic dispatch of generated power from mostly remote locations to major load centers in the urban cities. Most methods adopted for optimal dispatch are either cumbersome in their computational approaches. This work proposes a fast and easy to use generic MATLAB syntax to aid in solving economic dispatch problems. The software component proposed in this work will try to estimate the optimal value of real power to be generated with the least possible fuel cost. This will be based on the assumption of equal incremental cost and the result compared to genetic algorithm simulation.*
Keywords: *Economic Dispatch, Equal Incremental Cost, Modified Lambda-Iteration, Genetic Algorithm*

I. Introduction

Economic Dispatch is "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities [1]." The objective of economic dispatch is to determine the power output of each generating unit under the constraints of load demands and transmission losses that will give minimal cost on fuel or operation of the whole system [2].

Over the years, many research works have been published on many and various efforts made to solve Economic Load Dispatch (ELD) problems, employing different kinds of constraints, mathematical programming and optimization techniques. The classical or conventional methods include Lambda-iteration method [2], Gradient Projection Algorithm, Interior Point Method [3], Linear Programming, Lagrangian relaxation [4] and Dynamic Programming. The heuristic methods include Evolutionary Programming (EP) [5], [35], Differential Evolution (DE) [6-10], [29], Particle Swarm Optimization (PSO) [11-24], Genetic Algorithm (GA) [25-27], Simulated Annealing [28-29], Tabu Search (TS) [30-31], Artificial Immune System [32-33] and Artificial Bee Colony Method [34].

II. Problem Formulation

The economic dispatch problem will now be mathematically described. We will be considering the operation of m generating units.

The variation of the fuel cost of each generator (F_i) with real power output (P_i) is given by a Second order smooth fuel cost function [57]. The total fuel cost of the plant is the sum of the costs of the individual units:

$$F = \sum_{i=1}^{m} \alpha_i + \beta_i P_i + \gamma_i P_i^2 \qquad (1)$$

Where, F is the input-output cost function, m is the total number of units, i is the index of dispatchable units, $\alpha_i, \beta_i, \gamma_i$ are coefficients of the quadratic fuel cost function and P_i is the generated power of unit i.

With losses neglected, the fuel cost will be subjected to the power balance equation given as (2);

$$P_D = \sum_{i=1}^{m} (P_i) \qquad (2)$$

This can be rewritten as:

$$P_D - \sum_{i=1}^{m} (P_i) = 0 \qquad (3)$$

Where,
P_D is the sum of all demands at load nodes in the system

Each unit has its maximum and minimum generating limit. This will also serve as a form of constraint.

$$P_{i\,min} \leq P_i \leq P_{i\,max} \quad (4)$$

Where,
$P_{i\,min}$ is the minimum generation limit of unit i
$P_{i\,max}$ is the maximum generation limit of unit i

For optimal dispatch, we assume that the incremental cost of running each unit is equal i.e.:

$$\frac{\partial F_1}{\partial P_1} = \frac{\partial F_2}{\partial P_2} = \cdots = \frac{\partial F_m}{\partial P_m} \quad (5)$$

$$\frac{\partial F_i}{\partial P_i} = \lambda \quad (6)$$

Where,
λ is the incremental cost

The optimality condition from (6) reduces to:

$$\frac{\partial F_i}{\partial P_i} = \beta_i + 2\gamma_i P_i \quad (7)$$

$$\beta_i + 2\gamma_i P_i = \lambda \quad (8)$$

From the (8), the power generated in unit i can be gotten as:

$$P_i = \frac{\lambda - \beta_i}{2\gamma_i} \quad (9)$$

Now accounting for transmission losses, from kron's loss formula:

$$P_{Loss} = \sum_{i=1}^{m}\sum_{j=1}^{m} P_i B_{ij} P_j + \sum_{i=1}^{m} B_{0i} P_i + B_{00} \quad (10)$$

Where,
P_{Loss} is the transmission losses
B_{ij}, B_{0i}, B_{00} are the transmission line coefficients

The power balance constraint, (3), becomes:

$$P_D = \sum_{i=1}^{m}(P_i) - P_{Loss} \quad (11)$$

Also, the optimality condition, (6), becomes

$$\frac{\partial F_i}{\partial P_i} + \lambda \frac{\partial P_{Loss}}{\partial P_i} = \lambda \quad (12)$$

$$\frac{\partial P_{Loss}}{\partial P_i} = 2\sum_{j=1}^{m} B_{ij} P_j + B_{0i} \quad (13)$$

Where $\frac{\partial P_{Loss}}{\partial P_i}$ is the incremental loss of unit i

Putting (7) and (13) into (12), we have:

$$\beta_i + 2\gamma_i P_i + 2\lambda \sum_{j=1}^{m} B_{ij} P_j + B_{0i}\lambda = \lambda \quad (14)$$

From Equation 14, the power generated in unit i can be gotten as:

$$P_i = \frac{\lambda(1 - B_{0i}) - \beta_i - 2\lambda \sum_{j=1}^{m} B_{ij} P_j}{2(\gamma_i + \lambda B_{ii})} \quad (15)$$

This can be simplified as:

$$P_i = \frac{\lambda - \beta_i}{2(\gamma_i + B_{ii})} \quad (16)$$

The net power can then be calculated as:

$$P_{Net} = \sum_{i=1}^{m} P_i - P_D - P_{Loss} \quad (17)$$

III. Implementation

1.1. Algorithm for Economic Dispatch

1. Initialization:

Input data such as; number of plants, total load demand, generator limits, cost curve coefficients, iteration limit and tolerance.

2. Start counter.
3. Calculate power value for each plant using Equation 15.
4. Check if iteration limits is exceeded.

If yes, inform user of non-convergence and stop.
Else, go to step 5.

5. Check if Power value for plant is less then set limit.

If yes, set power value to lower limit, increment counter and go to 4.
Else, go to 6.

6. Check if Power value for plant is more than set limit.

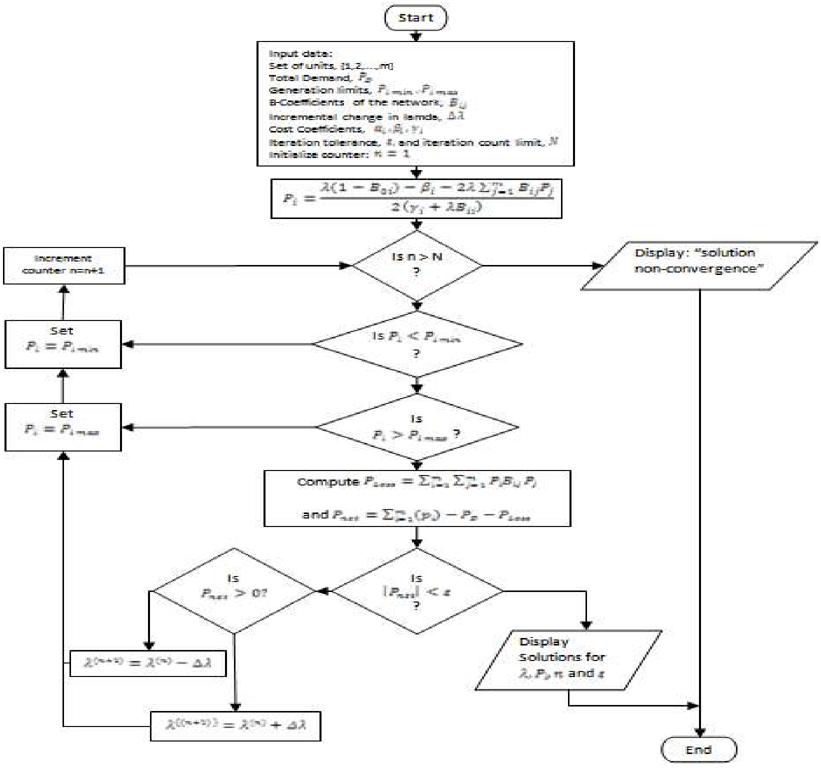
If yes, set power value to upper limit, increment counter and go to 4.
Else go to 7.

7. Sum up Power for all plants and calculate the power loss using Equation 10.
8. Calculate net power from Equation 17.
9. If absolute value for net power is less than set tolerance level,

Display calculated power value, incremental cost value and stop.

10. If net power is greater than zero,

Reduce the value of the incremental cost, increment counter and go to 4.
Else, increase the value of the incremental cost, increment counter and go to 4.
The flow chat of which is shown in Fig. 1.



1.2. Matlab Program

```
%N = iteration count limit
%e = iteration tolerance
%lamda = Lagrange multiplier (Lambda)
%del_lamda = change in lambda
%PD = Power Demand
%Pmin & Pmax = minimum and maximum power limits
n=1; lamda=0; del_lamda=0; e=0.01; P=0;
Psum=0;
```

```
m=input('Input total number of thermal unit:')
for k=1:m
   disp('plant')
   disp(k)
   Pmin(k)=input('insert minimum power:')
   Pmax(k)=input('insert maximum power:')
end
disp('Input cost coefficients per plant in the form below:')
disp('[alpha1 beta1 gamma1;alpha2 beta2 gamma2;...]')
C=input('Insert Cost Coefficients:')

for k=1:m
      P(k)=(lamda-C(k,2))/(2*C(k,3));
      if P(k)<Pmin(k)
         P(k)=Pmin(k);
      elseif P(k)>Pmax(k)
         P(k)=Pmax(k);
      end
      Psum=Psum+P(k);
end
if n>N
   disp('Solution non-convergence');
   disp('Number of Iterations:')
   disp(n-1)
else
   Pnet=Psum-PD;
   del_lamda=abs(Pnet)/P(k);
   if abs(Pnet)<e
      disp('final value for lamda:')
      disp(lamda)
      disp('Power for plants 1 to m:')
      disp(P)
      disp('number of iterations:')
      disp(n)
      disp('iteration tolerance:')
      disp(e)
   elseif Pnet>0
      lamda=lamda-del_lamda;
   else
      lamda=lamda+del_lamda;
   end
end
Psum=0;
%n=n+1;
```

1.3. Implementation Data

Table 1: Fuel Cost Coefficients

Generator No.	γ	β	α
1	0.0070	7.0	240
2	0.0095	10.0	200
3	0.0090	8.5	220
4	0.0090	11.0	200
5	0.0080	10.5	220
6	0.0075	12.0	190

Table 2: Real Power Limits for the Generators

Generator No.	Generator Limits (MW)	
1	100	500
2	50	200
3	80	300
4	50	150
5	50	200
6	50	120

IV. RESULTS AND DISCUSSION

An economic load dispatch is performed on a 26 bus system with six generators. The six generators are connected to bus1, bus2, bus3, bus4, bus5, and bus26 respectively. The operating costs of the generators are in \$/h. The optimal scheduling of the generators has to be within the maximum and minimum limits of each of the generators. The total load demand of the system is 1263MW. The fuel cost coefficients are shown in TABLE 1.

Table 3: Result

Generator No.	Power Generated (MW)	
	Proposed Method	Genetic Algorithm [25]
1	446.7087	454.7141
2	171.2591	147.5434
3	264.1068	269.7175
4	125.2179	144.7849
5	172.1201	170.7478
6	83.5948	92.0970

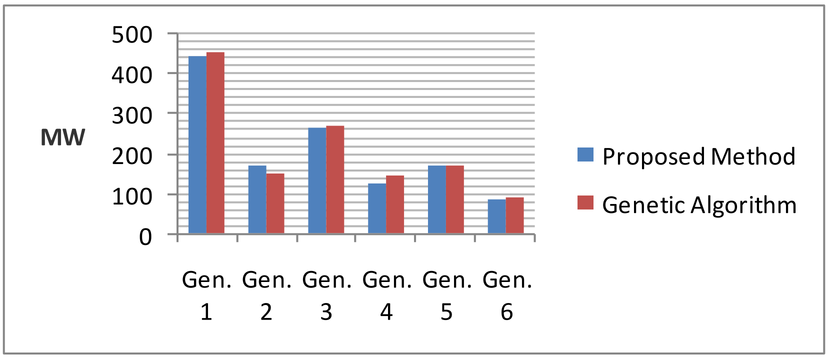


Figure 1: bar chart showing result

The proposed method gave a total power value of 1263.0074MW with incremental cost of 13.2539\$/MWh, while the genetic algorithm gave an incremental cost of 13.6445\$/MWh with total power value of 1263.8809 and transmission loss of 15.7238MW. Successive Approximation is used to calculate the incremental costs of the generators, based on equal incremental cost principle. This is done with the help of the proposed MATLAB syntax. The following results are gotten from a 3GB RAM, 2.1GHz, and Pentium Dual-Core CPU.

V. Conclusion

A new approach to solving Economic Dispatch Problem (EDP) s using modified lambda-iteration is proposed. This paper demonstrates the feasibility of the proposed technique for efficient solving of EDPs with generator constraints. The technique was implemented with the help of MATLAB programming.

The loss formula and loss coefficients were not fully employed in the examples used in the paper. However, there is no problem in implementing the changes, because it has been incorporated in the flow chart.

Computational results reveal that the proposed method gave fairly improved results when compared with that obtained from Genetic algorithm Method, in most of the geneators.

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