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Dynamic Economic Dispatch by Equal Embedded Algorithm

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Abstract

In this paper, Equal Embedded Algorithm is used to solve Dynamic Economic Dispatch problem. This problem satisfies the load demand over a certain period of time and some practical operation constraints of generators such as ramp rate limits. The proposed method was tested on a power system having 6 and 15 generating units with ramp rate limits. The results obtained by the proposed method were compared with lambda iterative method and particle swarm optimization method. The simulation results showed that the proposed method achieved qualitative solution with less computational time.

Key wards- dynamic economic dispatch, equal embedded algorithm, ramp rate limits.

Symbols and notations

$F_i(P_i)$ Generator fuel cost of i^{th} generating unit

λ_i Incremental fuel cost of i^{th} generating unit

P_i Real power output of i^{th} generating unit

P_D Demand Power

Ng No.of generating units.

P_i^{min} Minimum real output power of i^{th} generating unit

P_i^{max} Maximum real output power of i^{th} generating unit

$P_i^o =$ Output powers of generators at initial state

UR_i Up ramp rate limit

DR_i Down ramp rate limit.

1. Introduction

Dynamic Economic Dispatch problem is one of the main functions of power system operation and control. The main objective of Dynamic Economic Dispatch problem is to determine the optimal schedule of online generating outputs with the predicted load demands over a certain period of time so as to meet the demand power at the minimum operating cost. It is a dynamic optimization problem that includes generator constraints and ramp rate limits [1]. Moreover, it is the most accurate formulation of the economic load dispatch problem. Generally the dynamic economic dispatch problem solved by dividing the entire dispatch period into a number of small time intervals and then static economic load dispatch is used to solve the problem in each interval.

Earlier efforts of solving dynamic economic dispatch problem were using classical methods such as lambda iterative method [2], Gradient projection algorithm [3], Linear programming [4] and Dynamic programming [5]. These methods were facing lot of problems to give optimal solution due to the non-linear characteristics of generating units. Also conventional methods has oscillatory problem for large scale mixed generating unit.

For getting qualitative solution, irrespective of the non-linear characteristics of generators, Gradient type Hopefield neural network method [6] has been used to solve DED problem. The major problem with the Hopfield neural network is that the unsuitable sigmoid function may increases the computational time to give optimal solution [7].

Recently stochastic optimization techniques such as Genetic algorithm [8],[9], Evolutionary programming [10] and particle swarm optimization [11],[12] methods have been used to solve DED problem by many researchers because they can achieve global optimal solution. Major problem associated with these algorithms is appropriate control parameters are required.

More precisely, hybrid methods combining probabilistic methods and deterministic methods are found to be very effective in solving complex optimization problems [13],[14]. In these methods, initially probabilistic methods are used for search purpose to find near optimal solution then deterministic methods are used for fine tune that region to get the final solution.

In this paper, we proposed an equal embedded algorithm to solve the dynamic economic dispatch problem. The proposed algorithm was implemented in MATLAB on a Pentium III, 550-MHz personal computer with 256-MB RAM.

The paper is organized as follows: Dynamic Economic Dispatch problem formulation is introduced in Section 2. Section 3 addresses the description of an equal embedded algorithm to solve economic load dispatch problem. Implementation of an equal embedded algorithm is given in Section 4. The simulation results of power system with various generator units are presented in Section 5. Conclusions are finally given in the last section.

2. Dynamic Economic Dispatch Problem

Formulation dynamic dispatch problem is as fallows,

$$F_i(P_i) = \alpha_i + \beta_i P_i + \gamma_i P_i^2 \quad (1)$$

The objective function is

$$\text{Minimize } F_t = \sum_{i=1}^{ng} \alpha_i + \beta_i P_i + \gamma_i P_i^2 \quad (2)$$

Subjected to the constraints

i) Power balance equation

$$\sum_{i=1}^{n_g} P_i = P_D, \; i = 1,2,3......n_g \quad (3)$$

(ii) Generator constraints

$$P_i^{\min} \le P_i \le P_i^{\max} \quad (4)$$

iii) Ramp rate limits:

The inequality constraints due to ramp rate limits for unit generation changes are given as

A. when generation increases

$$P_i - P_i^0 \le UR_i \quad (5)$$

B. when generation decreases

$$P_i^0 - P_i \le DR_i \quad (6)$$

Finally generator constraints can be modified as

$$\max(P_i^{\min}, P_{i,t}^o - DR_i) \le P_{i,t} \le \min(P_{i,t}^o + UR_i) \quad (7)$$
$$i = 1,2,.. \; to \; ng \quad t=1,2,...T$$

Expressions of the lambda and the output power are

$$\lambda = b_i + 2 \cdot c_i \cdot P_i \quad (8)$$

$$P_i = \frac{\lambda - b_i}{2 \cdot c_i} \quad (9)$$

3. Equal Embedded Algorithm for Dynamic Economic Dispatch Problem

We proposed a new algorithm based on numerical methods such as interpolation and Muller method and it is known as an equal embedded algorithm.

The introduction of the equal embedded algorithm is as follows,

3.1 Selection of the lambda values.

3.2 At required power demand, numerator and denominator expressions of the generator output power are determined in terms of the lambda by Newton forward interpolation

3.3 The lambda evaluated from the power balance equation by Muller method.

3.1. Selection of the Lambda values

Calculation of the lambda values for all generators at their maximum and the minimum output power values. Arrange all lambda values in ascending order.

3.2. Interpolation

A polynomial can be estimated from the known input and the known output data by an interpolation [17]. At desired input, the unknown output value is evaluated from the polynomial by interpolation.

In the economic load dispatch problem, the output power expression of generator is a relation with lambda. At required power demand, the expression of output power is obtained in terms of the lambda from RPPD table by Newton forward interpolation method. In the economic load dispatch problem, the application of Newton forward interpolation method to obtain the output power of the generator in terms of lambda is as follows:

(i)The expression of output power in terms of lambda is given in (8). Also expression of the output power is given in (9).

(ii) At desired power demand λ_j, λ_{j+1} and P_i obtained from the PPD table.

Table-01

Reduced PPD Table

λ	P_i	$SOP = \sum_{i=1}^{ng} P_i$
λ_j	A_i	$\sum_{i=1}^{ng} A_i$
λ_{j+1}	E_i	$\sum_{i=1}^{ng} E_i$

$$P_i = A_{i1} + \frac{(E_i - A_i)}{(\lambda_{j+1} - \lambda_j)}(\lambda - \lambda_j) \quad (10)$$

From the interpolation method, all output powers are obtained in terms of the lambda. If the output powers are substituted in the power balance equation, then it contains lambda only. At required power demand, the lambda can be evaluated by Muller method.

3.3 Muller method

In Muller method, higher order polynomial is approximated by a second-degree curve in the surrounding of a root. The roots of the quadratic equation are then assumed approximately the roots of the equation. This method is iterative and converges almost quadratically [17].

Let x_{i-2}, x_{i-1}, x_i are three distinct approximations to a root of $f(x) = 0$ and y_{i-2}, y_{i-1} *and* y_i are the corresponding values of $y = f(x)$. The relation between y and x can be represented by

$$y = A(x - x_i)^2 + B(x - x_i) + y_i \quad (11)$$

Where

$$A = \frac{(x_{i-2} - x_{i-1})(y_{i-1} - y_i) - (x_{i-1} - x_i)(y_{i-2} - y_i)}{(x_{i-1} - x_{i-2})(x_{i-1} - x_i)(x_{i-2} - x_i)}$$

$$B = \frac{(x_{i-2} - x_i)^2(y_{i-1} - y_i) - (x_{i-1} - x_i)^2(y_{i-2} - y_i)}{(x_{i-1} - x_{i-2})(x_{i-1} - x_i)(x_{i-2} - x_i)}$$

$$x_{i-1}^{(1)} = x_{i-1}^{(0)} - \frac{2 . y_i}{B \pm \sqrt{B^2 - 4Ay_i}} \quad (12)$$

Equation (12) gives the next approximation to the root.

The application of Muller method:

$$\mathrm{f}(\lambda) = \sum_{i=1}^{ng} P_i(\lambda) - (P_D + P_L(\lambda)) \quad (13)$$

At the required power demand,

$$x_{i-2} = \lambda_j \ \&\mathrm{y}_{i-2} = SOP_j \quad (14)$$

$$x_i = \lambda_{j+1} \ \&\mathrm{y}_i = SOP_{j+1} \quad (15)$$

$$x_{i-1} = (\lambda_j + \lambda_{j+1})/2 \quad (16)$$

From (12), the lambda value can be evaluated by an iterative approach.

4. Implementation of Equal Embedded Algorithm

Solution of dynamic economic dispatch problem by the proposed algorithm is as follows

Step-1 Calculate the lambda values by (8) for all the generators at their maximum and minimum output powers and arrange them in ascending order.

Step-2 Compute the output powers for all values of lambda by using (9). All the lambda values, output powers are formulated as a table is called as a PPD table.

Step-3 Enter the predicted power demand in each interval.

Step-4 Two rows of PPD table selected such that the predicted power demand in each interval lies within the SOP limits and these two rows are formulated in a table is known as a Reduced PPD table.

Step-5 Obtain the expressions of generator output power denominator and numerator in terms of the lambda by Newton forward interpolation from RPPD table.

Step-6 The lambda is evaluated by Muller method from the power balance equation

Set the generator constraints and ramp rate limits.

Step-7 Obtain the optimal solution

5. Case studies and Simulation Results

The equal embedded algorithm presented above was applied to solve the dynamic economic load dispatch problem with prohibited zones and ramp rate limits. The computer program was implemented in MATLAB and executed on a Pentium III, 550-MHz personal computer with 256-MB RAM. The proposed algorithm was tested on a power system having 6 and 15 generating units. The simulation results obtained by the proposed method were compared with Lambda iterative method and particle swarm optimization.

5.1 Numerical Examples and Simulation Results

5.1.1 Example 1

The system contains six thermal units, 26 buses, and 46 transmission line that are given in [16]. Ramp rate limit data was also obtained from [15].

Table-2

Daily Load demand

Hour	1	2	3	4	5	6
Load (MW)	955	942	935	930	935	963
Hour	7	8	9	10	11	12
Load (MW)	989	1023	1126	1150	1201	1235
Hour	13	14	15	16	17	18
Load (MW)	1190	1251	1263	1250	1221	1202
Hour	19	20	21	22	23	24
Load (MW)	1159	1092	1023	984	975	960

In this example, initially the lambda values are computed for all generators at their maximum and minimum output power and arranged in ascending order. The output powers are evaluated for all lambda values and PPD is formulated. Here the dimension of the PPD table is 12×5. At required power demand, optimal solution is evaluated by interpolation and Muller method. Table-3 listed the statistical results that involved generation cost and computational time.

Table-3

Simulation Results of Iterative method, PSO method and the proposed method

Methods	Iterative	PSO	Proposed
Fuel cost ($)	310481	310481	310481
Computational Time (Sec)	2.674	95.75	2.34

5.1.2 Example-2

In this example, the system contains 15 generating units whose characteristics are given in[15]. Ramp rate limits data also given in [12].

Table-4

Daily Load Demand

Hour	1	2	3	4	5	6
Load(MW)	2236	2215	2226	2236	2298	2316
Hour	7	8	9	10	11	12
Load(MW)	2331	2443	2651	2728	2783	2785
Hour	13	14	15	16	17	18
Load(MW)	2780	2830	2953	2950	2902	2803
Hour	19	20	21	22	23	24
Load(MW)	2651	2584	2432	2312	2261	2254

Table-5
Simulation Results of Lambda iterative method, Particle Swarm Optimization method and proposed method

Methods	Iterative	PSO	Proposed
Fuel cost ($)	75 2129	752128	752128
Computational Time (Sec)	67.85	136.11	5.36

5.2. Comparison of methods

5.2.1. **Solution quality**: Tables-3 and 5 demonstrate the effectiveness of the proposed method for getting the qualitative solution compare to Lambda iterative method and particle swarm optimization method.

5.2.2. **Computational time**: Due to the less iterations, the proposed method has better computation performance than the iterative method and particle swarm optimization method. The evaluation process involved in the proposed method is that the output power expressions in terms of lambda by interpolation and the lambda evaluation from the power balance equation by Muller method. So the computational time is very less. Lambda iterative method takes more iterations when the system has mixed generating unit data. So computational time increases and some cases it may not converge. Similarly the evolution process involves in PSO is that the fitness function evaluation, velocity modification by random process and identification of best particle.

6. Conclusions

In this paper, the equal embedded algorithm is used to solve the dynamic economic load dispatch problem. The proposed method gives minimum fuel cost with less computational time compare to the Lambda iterative method and particle swarm optimization method. The chief advantages of the proposed method are that the algorithm formulated based on the numerical methods such as interpolation and Muller method, the quality of solution got in less iterations and the initial guess value of lambda is not required. Also the proposed algorithm can be implemented for solving the dynamic economic load dispatch problem with real time losses.

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