Solving Economic Load Dispatch Problem Using Particle Swarm Optimization Technique

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Abstract: Economic load dispatch (ELD) is one of the important problems of power system operation. Conventional methods like Lambda iteration method are not efficient for complex ELD problems. Particle swarm optimization is preferred in ELD problem due to its high performance. The Inertia Weight PSO and Constriction Factor PSO algorithms are performed on three unite and six unite systems. The analysis of ELD problem is performed by Conventional method and PSO method. In this paper, losses are neglected in the ELD problem. PSO algorithm obtains the best solution for ELD problem.

Keywords: Optimization, Economic load dispatch (ELD), Particle swarm optimization (PSO), IPSO, CPSO

1. Introduction

The economic load dispatch problem is one of the optimization problems. The main aim of this problem is to minimize the total cost of generation. The conventional methods require more computation time in the ELD problem. PSO and Genetic Algorithm methods are mainly used in ELD problems. The conventional method cannot obtain the best solution to the ELD problem. PSO is the most efficient method for economic load dispatch problem. Various PSO algorithms used in this paper are Inertia weight PSO (IPSO) and Constriction factor PSO (CPSO) algorithm[1].

Various optimization problems are not solved by the single optimization. Different optimization methods are available for various optimization problems. The PSO algorithm offers the best solution for optimization problems. Modern optimization methods like PSO are effective for engineering problems. The main aspect of PSO algorithm is its simplicity and a relatively less number of parameters.

2. Problem Formulation

The main focus of the ELD problem is to generate power at the minimum cost while satisfying certain constraints. Economic load dispatch determines the optimum share of the power demand subject to various system constraints. The ELD problem is expressed as (1).

\[
\min F_t = \sum_{i=1}^{n} F_i (P_i)
\]

\[
F_i (P_i) = (a_i + b_i P_i + c_i P_i^2)
\]

Pi - Power generation of ith unit

Ft - Total cost of generation

ai, bi, ci - fuel cost coefficients of ith unit

A. System Constraints

There are two types of constraints.

i) Power balance constraints[2]

In this constraint, power generation is equal to the sum of Power demand and power loss.

\[
\sum_{(i=1)^n} P_i - P_D - P_L = 0
\]
ii) Inequality constraints\[2\\]
The output power of each generator should be between its lower limit and upper limit.
\[\text{Pimin} \leq P_i \leq \text{Pimax} \quad (4)\]

\text{Pimin} - Minimum output power of ith generator
\text{Pimax} - Maximum output power of ith generator

\text{Pi} - Output power of ith generator

3. Particle Swarm Optimization

The concept of PSO was developed by Kennedy and Eberhart. In PSO, a swarm consists of several particles. The PSO technique is based on the representation of social psychology. Each particle in PSO has a random position and random velocity. Each particle searches for a speed-adjusted position based on their flying and neighbourhood flying experience. If one particle first finds the best path to food then other particles will quickly follow the best path. The parameters that affect the performance of PSO are Swarm size, Number of iterations and Acceleration coefficients.

A. Computational Procedure of PSO \[3\]

The various steps of the PSO algorithm are as follows.
1. Parameter selection
   Selection of PSO parameters such as population size, maximum iteration and acceleration constant.
2. Initialization of Population
   In PSO, the particles are initialized with position \( p \) within the generator limits and velocity \( V \).
3. Evaluation of Objective function
   Calculate the fuel cost of the plant for each particle with the help of generated output power.
4. Selection of Previous best and Global best position
   Set the initial output power for every particle to its previous best and set the best of the previous best to the global best.
5. Velocity and Position updation
   Calculate the updated Position and Velocity of the particle.
6. Termination step
   The PSO algorithm stops after a sufficient best fitness or maximum iterations are reached.

4. Methods For Eld Problem

A. Inertia weight Particle Swarm Optimization

Shi and Eberhart \[4\] developed Inertia weight PSO to enhance the performance of PSO. This algorithm is known as Inertia weight PSO (IPSO). The inertia weight \( w \) is used to limit the velocity below its maximum value. This method enables the faster convergence of the swarm. The equations used in this algorithm are (5) and (6) respectively.

\[\begin{align*}
V_{i}^{t+1} &= w \cdot V_{i}^{t} + c1 \cdot r1 \cdot (p_{best_{i}} - x_{i}^{t}) + c2 \cdot r2 \cdot (g_{best} - x_{i}^{t}) \\
x_{i}^{t+1} &= x_{i}^{t} + V_{i}^{t+1} \quad (6)
\end{align*}\]

\[w = w_{max} - \frac{(w_{max} - w_{min}) \cdot t}{t_{max}} \quad (7)\]

Acceleration constants \( c1 = c2 = 2 \), weight factor \( w_{max} = 0.9 \) and \( w_{min} = 0.4 \), \( w_{max} \) and \( w_{min} \) are maximum and minimum weight factor, \( t \) and \( t_{max} \) are current iteration and maximum iteration, \( x_{i}^{t} \) and \( x_{i}^{t+1} \) are current velocity and position of particle respectively.

B. Constriction factor Particle swarm optimization

After the standard PSO algorithm, various PSO algorithms were introduced. Clerc \[5\] developed a Constriction factor PSO (CPSO) algorithm to improve the PSO performance. Constriction factor \( k \) is included to increase the convergence rate of PSO. The equations used in this algorithm are (8) and (9) respectively.

\[\begin{align*}
V_{i}^{t+1} &= K \cdot [V_{i}^{t} + c1 \cdot r1 \cdot (p_{best_{i}} - x_{i}^{t}) + c2 \cdot r2 \cdot (g_{best} - x_{i}^{t})] \\
x_{i}^{t+1} &= x_{i}^{t} + V_{i}^{t+1} \quad (9)
\end{align*}\]

\[K = \frac{2}{[2-\alpha-\sqrt{\alpha^2-4\alpha}]} \quad (10)\]
Acceleration constants \( c_1 = c_2 = 2.05 \) and Constriction factor \( K = 0.729 \). \( V_{i}^{(t+1)} \) and \( x_{i}^{(t+1)} \) are current velocity and position of particle respectively.

**5 Results**

**A. Case Study 1: 3 UNIT SYSTEM**

In this case study three unit thermal system is considered. All units have the minimum and maximum generation limits. The generation data of three unit thermal system without loss is given in Table I[6].

**TABLE I - GENERATION DATA FOR 3 UNIT SYSTEM**

| UNIT | a | b | c | \( p_{mi} \) | \( p_{ma} \) |
|------|---|---|---|-------------|-------------|
| 1    | 56 | 7.92 | 0.0156 | 10 | 60 |
| 2    | 31 | 7.85 | 0.0194 | 10 | 40 |
| 3    | 76 | 7.97 | 0.0482 | 50 | 20 |

**PARAMETERS OF PSO FOR 3 UNIT SYSTEM**

- Population size = 200
- Maximum iteration = 100
- \( w_{max} = 0.9, w_{min} = 0.4 \) for IPSOALGORITHM
- Acceleration constant \( c_1 = c_2 = 2 \) for IPSO ALGORITHM
- \( c_1 = c_2 = 2.05 \) for CPSO ALGORITHM

**TABLE II - CONVENTIONAL METHOD FOR 3 UNIT SYSTEM**

| S NO | DEMAND (MW) | P1 (MW) | P2 (MW) | P3 (MW) | TOTAL COST (RS./HR) |
|------|-------------|---------|---------|---------|---------------------|
| 1    | 600         | 275.94  | 239.93  | 84.122  | 5953               |
| 2    | 700         | 322.94  | 277.725 | 99.333  | 6838.4             |
| 3    | 800         | 369.93  | 315.51  | 114.54  | 7738.5             |
| 4    | 850         | 393.43  | 334.41  | 122.14  | 8194               |
| 5    | 1050        | 487.43  | 409.996 | 152.57  | 10053              |

**TABLE III - INERTIA PSO ALGORITHM FOR 3 UNIT SYSTEM**

| S NO | DEMAND (MW) | P1 (MW) | P2 (MW) | P3 (MW) | TOTAL COST (RS./HR) |
|------|-------------|---------|---------|---------|---------------------|
| 1    | 600         | 273.976 | 241.193 | 84.738  | 5952.1             |
| 2    | 700         | 321.160 | 277.502 | 101.251 | 6837.6             |
| 3    | 800         | 368.985 | 317.457 | 113.467 | 7737.6             |
| 4    | 850         | 395.333 | 333.121 | 121.8193| 8193.2             |
TABLE IV - CONSTRICTION PSO ALGORITHM FOR 3 UNIT SYSTEM

| S NO | DEMAND (MW) | P1 (MW) | P2 (MW) | P3 (MW) | TOTAL COST (RS./HR) |
|------|-------------|---------|---------|---------|---------------------|
| 1    | 600         | 277.127 | 238.773 | 84.0    | 5952.2             |
| 2    | 700         | 323.521 | 277.172 | 99.2    | 6837.6             |
| 3    | 800         | 370.354 | 315.464 | 114.085 | 7737.6             |
| 4    | 850         | 393.626 | 333.985 | 122.298 | 8193.2             |
| 5    | 1050        | 495.005 | 0       | 154.900 | 10052.3            |

TABLE V - COMPARISON OF COST FOR 3 UNIT SYSTEM

| S NO | DEMAND (MW) | CONVENTIONAL (RS./HR) | INERTIAL PSO (RS./HR) | CONSTRICTION PSO (RS./HR) |
|------|-------------|------------------------|-----------------------|---------------------------|
| 1    | 600         | 5953                   | 5952.1                | 93                        |
| 2    | 700         | 6838.4                 | 6837.6                | 71                        |
| 3    | 800         | 7738.5                 | 7737.6                | 96                        |
| 4    | 850         | 8194                   | 8193.2                | 97                        |
| 5    | 1050        | 10053                  | 10052.3               | 337                       |

B. Case Study 2: 6 UNIT SYSTEM

In this case study six unit thermal system is considered. All units have the minimum and maximum generation limits. The generation data of six unit thermal system without loss is given in Table II[7].

TABLE VI - GENERATION DATA FOR 6 UNIT SYSTEM

| UNIT | a   | b   | c   | P_min | P_max |
|------|-----|-----|-----|-------|-------|
| 1    | 240 | 7   | 0.0070 | 100   | 500   |
| 2    | 200 | 10  | 0.0095 | 50    | 200   |
| 3    | 220 | 8.5 | 0.0090 | 80    | 300   |
| 4    | 200 | 11  | 0.0090 | 50    | 150   |
| 5    | 220 | 10.5| 0.0080 | 50    | 200   |
PARAMETERS OF PSO FOR 6 UNIT SYSTEM

Population size = 150
Maximum iteration = 200
Inertia factor \( w_{\text{max}} = 0.9, w_{\text{min}} = 0.4 \) for IPSO ALGORITHM

Acceleration constant \( c_1 = c_2 = 2 \) for IPSO ALGORITHM

\( c_1 = c_2 = 2.05 \) for CPSO ALGORITHM

### TABLE VII - CONVENTIONAL METHOD FOR 6 UNIT SYSTEM

| NO | DEMAND (MW) | P1 (MW) | P2 (MW) | P3 (MW) | P4 (MW) | P5 (MW) | P6 (MW) | TOTAL COST (RS./HR) |
|----|-------------|---------|---------|---------|---------|---------|---------|---------------------|
| 1  | 1080        | 410.8   | 30      | 144.822 | 236.2   | 97.31   | 140.01  | 50.10 8             | 12896               |
| 2  | 1150        | 424.5   | 53      | 154.934 | 246.8   | 107.9   | 152.734 | 62.91 6             | 13796               |
| 3  | 1240        | 442.1   | 98      | 167.935 | 260.5   | 121.7   | 168.173 | 79.38 4             | 14972               |
| 4  | 1300        | 453.9   | 61      | 176.602 | 269.7   | 130.8   | 178.466 | 90.36 3             | 15768               |
| 5  | 1400        | 473.5   | 66      | 191.048 | 284.9   | 146.1   | 195.620 | 108.6 61            | 17117               |

### TABLE VIII - INERTIA PSO ALGORITHM FOR 6 UNIT SYSTEM

| NO | DEMAND (MW) | P1 (MW) | P2 (MW) | P3 (MW) | P4 (MW) | P5 (MW) | P6 (MW) | TOTAL COST (RS./HR) |
|----|-------------|---------|---------|---------|---------|---------|---------|---------------------|
| 1  | 1080        | 413.6   | 10      | 145.237 | 233.2   | 96.12   | 141.606 | 50 12894.5 59      |
| 2  | 1150        | 421.1   | 45      | 155.534 | 250.8   | 108.1   | 155.882 | 58.28 4             | 13794.2 68          |
| 3  | 1240        | 450.5   | 95      | 171.664 | 263.5   | 114.2   | 161.163 | 78.52 4             | 14970.9 39          |
| 4  | 1300        | 448.3   | 89      | 175.016 | 270.9   | 131     | 181.598 | 92.89 8             | 15766.1 99          |
| 5  | 1400        | 474.1   | 81      | 189.808 | 287.7   | 142.8   | 200     | 105.2 66            | 17115.7 92          |

### TABLE IX - CONSTRICITION PSO ALGORITHM FOR 6 UNIT SYSTEM

| NO | DEMAND (MW) | P1 (MW) | P2 (MW) | P3 (MW) | P4 (MW) | P5 (MW) | P6 (MW) | TOTAL COST (RS./HR) |
|----|-------------|---------|---------|---------|---------|---------|---------|---------------------|
| 1  | 1080        | 410.8   | 30      | 144.822 | 236.2   | 97.31   | 140.01  | 50.10 8             | 12896               |
| 2  | 1150        | 424.5   | 53      | 154.934 | 246.8   | 107.9   | 152.734 | 62.91 6             | 13796               |
| 3  | 1240        | 442.1   | 98      | 167.935 | 260.5   | 121.7   | 168.173 | 79.38 4             | 14972               |
| 4  | 1300        | 453.9   | 61      | 176.602 | 269.7   | 130.8   | 178.466 | 90.36 3             | 15768               |
| 5  | 1400        | 473.5   | 66      | 191.048 | 284.9   | 146.1   | 195.620 | 108.6 61            | 17117               |
TABLE X - COMPARISON OF TOTAL COST FOR 6 UNIT SYSTEM

| S NO | DEMAND (MW) | CONVENTIONAL (RS./HR) | INERTIA PSO (RS./HR) | CONSTRICTION PSO (RS./HR) |
|------|-------------|-----------------------|----------------------|--------------------------|
| 1    | 1080        | 12896                 | 12894.559            | 12894.451                |
| 2    | 1150        | 13796                 | 13794.268            | 13793.755                |
| 3    | 1240        | 14972                 | 14970.939            | 14969.620                |
| 4    | 1300        | 15768                 | 15766.199            | 15766.237                |
| 5    | 1400        | 17117                 | 17115.792            | 17114.617                |

6 CONCLUSION

In this paper, the ELD problem is solved using the conventional method and various PSO algorithms. The two test systems taken for the ELD problem are three unit system and the six unit system. The total cost is minimum in the PSO algorithm as compared to Conventional lambda iteration method. CPSO algorithm provides a faster convergence rate compared to the IPSO algorithm. It is concluded that both IPSO and CPSO algorithm gives the best solution for ELD problem. The total cost reduction is more in the six unit system than the three-unit system.

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