Application of Particle Swarm Optimization for Economic Load Dispatch Problems

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Abstract— This paper presents an efficient and reliable Particle Swarm Optimization (PSO) method for the Economic load dispatch (ELD) problems. The PSO method was developed through the simulation of a simplified social system and has been found to be robust in solving continuous nonlinear optimization problems in terms of accuracy of the solution and computation time and it can out perform other algorithms. The proposed algorithm is applied for the ELD of three unit & six unit thermal plant systems and extended to three plant system in which one plant is combined cycle co-generation plant. The performance of the proposed PSO method is compared with the conventional method and Genetic algorithm method and it is observed that this method is reliable and may replace effectively the conventional practices presently performed in different central load dispatch centers. The comparison of results shows that the proposed PSO method was indeed capable of obtaining higher quality solutions efficiently for ELD problems within less computation time.

Keywords-- Economic Dispatch, Genetic Algorithms, Particle swarm optimization.

I. NOMENCLATURE

F_1 - Total fuel cost
N - Number of online generators committed to the operating system
P_i - Power output of i-th generator.
F_i (P_i) - Fuel cost characteristics of the i-th generator.
P_D - Total power demand
P_L - Total transmission loss
C_{1,2} - Co-efficient of Transmission loss formula.
P_i, max - Maximum generation capacity of the i-th generator.
P_i, min - Minimum generation capacity of the i-th generator.
n - Number of particles in a group
m - Number of members in a particle
t - Pointer of iterations (generations)
ω - Inertia weight factor
C_1, C_2 - Acceleration constant
rand ( ) , Rand ( ) - Uniform random value in the range [0, 1]
V_{id} (t) - velocity of particle i at iteration 't',
V_{id}^{min} \leq V_{id}^{max} \leq V_{id}^{max}
X_{id} (t) - current position of particle i at iteration 't'
A_{1}, B_{1}, C_{1} - Fuel cost coefficients

II. INTRODUCTION

The Economic Load Dispatch (ELD) problem is one of the fundamental issues in power system operation. The main objective is to reduce the cost of energy production taking into account the transmission losses. While the problem can be solved easily if the incremental cost curves of the generators are assumed to be monotonically increasing piece-wise linear functions, such an approach will not be workable for non-linear functions in practical systems. In the past decade, conventional optimization techniques such as lambda iterative method, linear programming and quadratic programming have been successfully used to solve power system optimization problems such as Unit commitment, Economic load dispatch, Feeder reconfiguration and Capacitor placement in a distribution system [1,2]. For highly non-linear and combinatorial optimization problems, the conventional methods are facing difficulties to locate the global optimal solution. Recently there is an upsurge in the use of modern evolutionary computing techniques in the field of power system optimization. The Genetic algorithm method, Evolutionary programming, Evolution strategy and simulated annealing are some of the well known evolutionary algorithms [3].

Though the GA method has been employed successfully to solve complex optimization problems, recent research has identified some deficiencies in GA performance. This degradation in efficiency is apparent in applications with highly epistatic objective functions ((i.e.) where the parameters being optimized are highly correlated). The crossover and mutation operations cannot ensure better fitness of offspring because chromosomes in the population have similar structures and their average fitness is high towards the end of the evolutionary process [4,5]. Moreover, the premature convergence of GA degrades its performance and reduces its search capability that leads to a higher probability of obtaining a local optimum[5].

Particle Swarm Optimization (PSO), first introduced by Kennedy and Eberhart, is one of the modern heuristic algorithms. It was developed through simulation of a simplified social system, and has been found to be robust in solving continuous non-linear optimization problems [6,7]. B

The PSO technique can generate high-quality solutions within shorter calculation time and stable convergence characteristics than other stochastic methods [3,6,7]. Unlike in GA method, in PSO the selection operation is not performed [3,8]. All the particles in PSO are kept as members of the population through the course of a run [9] (a run is defined as the total number of generation of the evolutionary algorithms.
prior to termination). It is the velocity of the particle which is updated according to its previous best position of its companions. The particles fly with the updated velocities [6].

This paper proposes the application of PSO method for solving the economic load dispatch of three example problems, that is,

(i) Three unit & six unit thermal plant systems and the results are compared with conventional method and Genetic algorithm method, and
(ii) three unit system in the eastern region of electricity generating authority of Thailand (EGAT) in which one unit is a combined cycle cogeneration plant and the results are compared with Genetic algorithm method.

III. PROBLEM FORMULATION

The Economic Load Dispatch (ELD) is generating adequate electricity to meet the continuously varying consumer load demand at the least possible cost under a number of constraints. Practically, while the scheduled combination of units at each specific period of operation are listed, the ELD planning must perform the optimal generation dispatch among the operating units to satisfy the load demand, spinning reserve capacity, and practical operation constraints of generators.

The objective of the ELD problem is to minimize the total fuel cost. Mathematically it can be represented as [8]

\[ \text{Minimize } F_i = \sum_{i=1}^{n} F_i(P_i) \]  

where

\[ F_r = \sum_{i=1}^{n} A_i P_i^2 + B_i P_i + C_i \]  

The ELD problem is subjected to the following constraints, The power balance equation,

\[ \sum_{i=1}^{NG} P_{gi} = P_D + P_L \]  

The total Transmission loss,

\[ P_L = \sum \sum P_{m}B_{mn}P_n \]  

In addition, power output of each generator has to fall within the operation limits of the generators as shown below,

\[ P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{max}, \text{ for } i=1, 2 \ldots n. \]  

IV. OVERVIEW OF PARTICLE SWARM OPTIMIZATION

PSO, as an optimization tool, provides a population-based search procedure in which individuals called particles change their position (states) with time [6,10]. In a PSO system particles fly around in a multi-dimensional search space. During flight, each particle adjusts its position according to its own experience and the experience of neighboring particles, making use of the best position encountered by it and neighbors. The swarm direction of a particle is defined by the set of particles neighboring the particle and its history experience [7]. Instead of using evolutionary operation to manipulate the individuals, like in other evolutionary computational algorithms, each individual in PSO flies in the search space with a velocity which is dynamically adjusted according to its own flying experience and its companions flying experience.

Let \( x \) and \( v \) denote a particle co-ordinate (position) and its corresponding flight speed (velocity) in a search space respectively. Therefore, each \( i^{th} \) particle is treated as a volume less particle, represented as \( x_i = (x_{i1}, x_{i2} \ldots x_{id}) \) in the \( d \) - dimensional space. The best previous position of the \( i^{th} \) particle is recorded and represented as \( pbest_i = (pbest_{i1}, pbest_{i2} \ldots pbest_{id}) \). The index of the best particle among all the particles is treated as global best particle, is represented as \( gbest \). The rate of velocity for particle ‘i’ is represented as \( v_i = \)
In this paper, an algorithm to solve a constrained ELD problem using PSO was developed to obtain a high quality solution. The PSO algorithm was utilized mainly to determine the optimal allocation of power among the units, which were scheduled to operate at the specific period, thus minimizing the total generation cost. Before applying the PSO method to solve the ELD problem, two definitions must be made as follows.

A. Representation of Individual String

For an efficient evolutionary method, the representation of chromosome strings of the problem parameter set is important. In this paper, we adopted the power output of each unit as a gene, and many genes comprise an individual. Each individual within the population represents a candidate solution for ELD problem. For example, if there are n units that must be operated to meet a load, then the ith individual $P_{gi}$ can be defined as follows,

$$P_{gi} = [P_{i1}, P_{i2} ... P_{id}]$$  

The dimension of a population is $(n \times d)$. The genes in each individual are represented as real values. The matrix representation of a population is as follows,

<table>
<thead>
<tr>
<th>Individual number</th>
<th>$P_{i1}$</th>
<th>$P_{i2}$</th>
<th>...</th>
<th>$P_{i(d-1)}$</th>
<th>$P_{id}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>420.03</td>
<td>150.32</td>
<td>75.12</td>
<td>45.55</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>390.28</td>
<td>165.35</td>
<td>80.23</td>
<td>41.93</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>412.88</td>
<td>156.84</td>
<td>78.11</td>
<td>42.78</td>
<td></td>
</tr>
</tbody>
</table>

B. Evaluation Function

We must define the evaluation function $f$ (it is called fitness in GA) for evaluating the fitness of each individual in the population. The evaluation function $f$ is adopted as follows

$$\text{Minimize } F_T = \sum_{i=1}^{n} F_i(P_i)$$  

C. Calculation process of the proposed method

This paper presents a quick solution to the constrained ELD problem using the PSO algorithm to search optimal or near optimal generation of each unit. The sequential steps of the proposed PSO method are given below.

Step 1: Initialize randomly the individuals of the population according to the limit of each unit including individual dimensions, searching points, and velocities. These initial individuals must be feasible candidate solutions that satisfy the practical operation constraints.

Step 2: To each chromosome of the population the dependent unit output $P_i$ will be calculated from the power balance equation and $B_{mn}$ coefficient matrix.

Step 3: Calculate the evaluation value of each individual $P_{gi}$, in the population using the evaluation function $f$ given by (10).

Step 4: Compare each individual’s evaluation value with its $pbest$. The best evaluation value among the pbests is denoted as $gbest$. 

(V11, v12,……v1d). The modified velocity and position of each particle can be calculated using the current velocity and the distance from pbesti to gbest as shown in the following formulas,

$$v_i^{(t+1)} = \omega v_i^{(t)} + C_1 r_1 * (pbest_i - P_{gid}^{(t)}) + C_2 r_2 * (gbest - P_{gid}^{(t)})$$

$$P_{gid}^{(t+1)} = P_{gid}^{(t)} + v_i^{(t+1)}$$

The term $r_1$ * $(pbest_i - P_{gid}^{(t)})$ is called particle memory influence

The term $r_2$ * $(gbest - P_{gid}^{(t)})$ is called swarm influence. The term $r_1$ which is the velocity of i th particle at iteration ‘t’ must lie in the range $V_{d_{min}} \leq v_i^{(t)} \leq V_{d_{max}}$. The parameter $V_{d_{max}}$ determines the resolution, or fitness, with which regions are to be searched between the present position and the target position. If $V_{d_{max}}$ is too high, particles may fly past good solutions. If $V_{d_{max}}$ is too small, particles may not explore sufficiently beyond local solutions. In many experiences with PSO, $V_{d_{max}}$ was often set at 10-20% of the dynamic range on each dimension.

The constants $C_1$ and $C_2$ pull each particle towards pbest and gbest positions. Low values allow particles to roam far from the target regions before being tugged back. On the other hand, high values result in abrupt movement towards, or past, from the target regions before being tugged back. On the other hand, high values result in abrupt movement towards, or past, target regions. Hence, the acceleration constants $C_1$ and $C_2$ are often set to be 2.0 according to past experiences. Suitable selection of inertia weight ‘$\omega$’ provides a balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal solution. As originally developed, $\omega$ often decreases linearly from about 0.9 to 0.4 during a run. In general, the inertia weight $w$ is set according to the following equation,

$$\omega = \omega_{max} - \left[ \frac{\omega_{max} - \omega_{min}}{iter_{max}} \right] * iter$$

where $\omega$ - inertia weight factor
$\omega_{max}$ - maximum value of weighting factor
$\omega_{min}$ - minimum value of weighting factor
iter_{max} - maximum number of iterations
iter - current number of iteration
Step 5: Modify the member velocity $v$ of each individual $Pg$, according to (11)

$$V_{id}^{(t+1)} = \omega V_{id}^{(t)} + C_1 \text{rand()} (pbest_{id} - P_{gid}^{(t)}) + C_2 \text{Rand()} (gbest_{id} - P_{gid}^{(t)})$$

(11)

Where $i=1, 2 \ldots n$, $d=1, 2 \ldots m$

Step 6: Check the velocity components constraint occurring in the limits from the following conditions,

- If $V_{id}^{(t+1)} > V_{d}^{max}$, then $V_{id}^{(t+1)} = V_{d}^{max}$
- If $V_{id}^{(t+1)} < V_{d}^{min}$, then $V_{id}^{(t+1)} = V_{d}^{min}$

where $V_{d}^{min} = -0.5 P_{g}^{min}$

$V_{d}^{max} = +0.5 P_{g}^{max}$

Step 7: Modify the member position of each individual $Pg$ according to (12)

$$P_{gid}^{(t+1)} = P_{gid}^{(t)} + V_{id}^{(t+1)}$$

(12)

$P_{gid}^{(t+1)}$ must be modified toward the near margin of the feasible solution.

Step 8: If the evaluation value of each individual is better than previous $pbest$, the current value is set to be $pbest$. If the best $pbest$ is better than $gbest$, the value is set to be $gbest$.

Step 9: If the number of iterations reaches the maximum, then go to step 10. Otherwise, go to step 2.

Step 10: The individual that generates the latest $gbest$ is the optimal generation power of each unit with the minimum total generation cost.

VI. EXAMPLE PROBLEM AND SIMULATION RESULTS

To verify the feasibility of the proposed PSO method, three different power systems were tested. At each sample system, under the same evaluation function and individual definition, we performed 50 trials to observe the evolutionary process and to compare their solution quality, convergence characteristic, and computation efficiency.

A reasonable $B_{mn}$ loss coefficients matrix of power system network was employed to draw the transmission line loss and satisfy the transmission capacity constraints. The software is developed in MATLAB and executed on a Pentium IV personal computer with 512-MB RAM. Although the PSO method seems to be sensitive to the tuning of some weights or parameters, according to the experiences of many experiments, the following PSO parameters can be used [3, 6 and 7].

PSO Method Parameters:
- Population size = 10

Inertia weight factor $w$ is set by (8), where $\omega_{max} = 0.9$ and $\omega_{min} = 0.4$.

The limit of change in velocity of each member in an individual was as $V_{d}^{max} = 0.5 P_{D}^{max}$, $V_{d}^{min} = -0.5 P_{D}^{min}$.

Acceleration constant $C_1 = 2$ and $C_2 = 2$.

Case study:

EXAMPLE 1: THREE-UNIT THERMAL SYSTEM:

The cost characteristics of the three units are given as

$$F_1 = 0.00156 P_1^2 + 7.92 P_1 + 561 \text{ Rs/Hr}$$

$$F_2 = 0.00194 P_2^2 + 7.85 P_2 + 310 \text{ Rs/Hr}$$

$$F_3 = 0.00482 P_3^2 + 7.97 P_3 + 78 \text{ Rs/Hr}$$

The unit operating ranges are:

- 100 MW $\leq P_1 \leq 600$ MW
- 100 MW $\leq P_2 \leq 400$ MW
- 50 MW $\leq P_3 \leq 200$ MW

$B_{mn}$ Coefficient matrix:

$$B_{mn} = \begin{bmatrix}
0.000075 & 0.000005 & 0.000075 \\
0.001940 & 0.000100 & 0.000045 \\
0.004820 & 0.000100 & 0.000045
\end{bmatrix}$$

For the system loads of 585 MW, 700 MW and 800 MW, the proposed PSO method is applied and the results obtained for loss neglected case are shown in Table 1. The results obtained by the proposed method is compared with the solution obtained from conventional method and Genetic algorithm method and is shown in Table 2. The comparison of results shows that the proposed algorithm is very reliable in the aspect of solution quality.

Table 1: Optimal Scheduling of Generators of a Three-unit system by PSO Method (Loss neglected case)

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Power Demand (MW)</th>
<th>P1 (MW)</th>
<th>P2 (MW)</th>
<th>P3 (MW)</th>
<th>F1 (Rs/Hr)</th>
<th>Execution Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>585</td>
<td>268.85</td>
<td>234.2756</td>
<td>81.8141</td>
<td>5821.4</td>
<td>0.1410</td>
</tr>
<tr>
<td>2.</td>
<td>700</td>
<td>322.9244</td>
<td>277.7232</td>
<td>99.3084</td>
<td>6868.4</td>
<td>0.1410</td>
</tr>
<tr>
<td>3.</td>
<td>800</td>
<td>369.9323</td>
<td>315.5234</td>
<td>114.5465</td>
<td>7738.5</td>
<td>0.1560</td>
</tr>
</tbody>
</table>

Table 2: Comparison of results between Conventional method, GA Method and PSO method for Three-unit system (Loss Neglected Case).

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Power Demand (MW)</th>
<th>Conventional Method (Rs/Hr)</th>
<th>GA Method (Rs/Hr)</th>
<th>PSO Method (Rs/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>585</td>
<td>5821.4</td>
<td>5827.5</td>
<td>5821.4</td>
</tr>
<tr>
<td>2.</td>
<td>700</td>
<td>6838.4056</td>
<td>6877.2</td>
<td>6838.4</td>
</tr>
<tr>
<td>3.</td>
<td>800</td>
<td>7738.5189</td>
<td>7756.8</td>
<td>7738.5</td>
</tr>
</tbody>
</table>

By using the loss formula coefficients the transmission loss has been calculated and the above problem is solved for power demands of 585.33 MW and 812.57 MW. The optimal scheduling of generators obtained by the proposed PSO algorithm for three unit system is shown in Table 3. The comparisons of results obtained by various evolutionary computing techniques have been shown in Table-4. From Table 4, it was found that the proposed method is capable of giving improved solution for the above problem compared with other methods.
Table 3: Optimal Scheduling of Generators of a Three-unit system by PSO Method (Loss included case)

<table>
<thead>
<tr>
<th>SI. No</th>
<th>Power Demand (MW)</th>
<th>P1 (MW)</th>
<th>P2 (MW)</th>
<th>P3 (MW)</th>
<th>Ft Rs/Hr</th>
<th>Loss, P (MW)</th>
<th>Execution Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>585.33</td>
<td>233.2</td>
<td>267.9</td>
<td>90.84</td>
<td>5886</td>
<td>6.95</td>
<td>0.25</td>
</tr>
<tr>
<td>2.</td>
<td>812.57</td>
<td>304.9</td>
<td>400</td>
<td>120.7</td>
<td>7993</td>
<td>12.77</td>
<td>0.25</td>
</tr>
</tbody>
</table>

Table 4: Comparison of results between Classical Method, GA Method and PSO method of a Three-unit system (Loss included Case)

<table>
<thead>
<tr>
<th>SI. No</th>
<th>Power Demand (MW)</th>
<th>Conventional Method (Rs/Hr)</th>
<th>GA Method (Rs/Hr)</th>
<th>PSO Method (Rs/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>585.33</td>
<td>5890.06</td>
<td>5890.09</td>
<td>5886.9</td>
</tr>
<tr>
<td>2.</td>
<td>812.57</td>
<td>7986.09</td>
<td>7986.07</td>
<td>7993</td>
</tr>
</tbody>
</table>

EXAMPLE 2: SIX-UNIT THERMAL SYSTEM:

The cost characteristics of the six units are given as follows

\[
\begin{align*}
F_1 &= 0.15240P_1^2 + 38.53973 P_1 + 756.79886 \text{ Rs/Hr} \\
F_2 &= 0.10587P_2^2 + 46.15916 P_2 + 451.32513 \text{ Rs/Hr} \\
F_3 &= 0.02803P_3^2 + 40.39655 P_3 + 1049.9977 \text{ Rs/Hr} \\
F_4 &= 0.03546P_4^2 + 38.30553 P_4 + 1243.5311 \text{ Rs/Hr} \\
F_5 &= 0.02111P_5^2 + 36.32782 P_5 + 1658.5596 \text{ Rs/Hr} \\
F_6 &= 0.01799P_6^2 + 38.27041 P_6 + 1356.6592 \text{ Rs/Hr}
\end{align*}
\]

The unit operating ranges are

\[
\begin{align*}
10 \text{ MW} & \leq P_1 \leq 125 \text{ MW}; \\
35 \text{ MW} & \leq P_2 \leq 225 \text{ MW}; \\
130 \text{ MW} & \leq P_3 \leq 325 \text{ MW};
\end{align*}
\]

The above test case was solved by the proposed PSO method and the optimal scheduling of generators for the power demands of 700 MW & 800 MW is tabulated in Table 5. The results obtained by the proposed algorithm are compared with other evolutionary computing techniques as shown in Table 6. From the above comparison it is found that the results obtained by the proposed algorithm is less and the computation time also reasonable.

Table 5 Optimal Scheduling of Generators of a Six-unit system by PSO Method (Loss included case)

<table>
<thead>
<tr>
<th>SI. No</th>
<th>Pd (MW)</th>
<th>P1 (MW)</th>
<th>P2 (MW)</th>
<th>P3 (MW)</th>
<th>Ft (Rs/Hr)</th>
<th>PL time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>700</td>
<td>16</td>
<td>24</td>
<td>138</td>
<td>116</td>
<td>208</td>
</tr>
<tr>
<td>2.</td>
<td>800</td>
<td>25</td>
<td>12</td>
<td>116</td>
<td>182</td>
<td>287</td>
</tr>
</tbody>
</table>

In the three plant system, first two units are conventional thermal units and the third plant is a combined cycle cogeneration plant (CCCP) which has two 75 MW gas turbines and one 50 MW steam turbine [8]. The fuel cost characteristics of this plant is shown in figure 1. The optimal dispatch of load among the available generating units is shown in Table 7. The results obtained by the PSO method is compared with the Genetic algorithm method in Table 8 and it is proved that the proposed method is capable of giving improved solution with less computation time.

![Fig.1 Fuel Cost Characteristics of Combined Cycle Cogeneration Plant (CCCP)](image-url)

Table 6 Optimal scheduling of Generators in Two thermal plant & one CCCP system

<table>
<thead>
<tr>
<th>SI. No</th>
<th>Power Demand (MW)</th>
<th>P1 (MW)</th>
<th>P2 (MW)</th>
<th>P3 (MW)</th>
<th>Loss, P (MW)</th>
<th>Ft (Rs/Hr)</th>
<th>Execution Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>680</td>
<td>283.6643</td>
<td>323.1737</td>
<td>82.8777</td>
<td>9.7157</td>
<td>6588.3</td>
<td>0.1560</td>
</tr>
<tr>
<td>2.</td>
<td>750</td>
<td>273.0729</td>
<td>311.4274</td>
<td>176.6250</td>
<td>11.1253</td>
<td>7235.1</td>
<td>0.1410</td>
</tr>
<tr>
<td>3.</td>
<td>869</td>
<td>328.6344</td>
<td>378.8490</td>
<td>176.6274</td>
<td>15.1108</td>
<td>8346.8</td>
<td>0.1570</td>
</tr>
</tbody>
</table>

Table 7 Comparison of results between various algorithms for Pd=700 MW:

<table>
<thead>
<tr>
<th>SI. No</th>
<th>P2</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
<th>P4</th>
<th>P5</th>
<th>P6</th>
<th>Ft</th>
<th>Loss, P (MW)</th>
<th>Execution Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>700</td>
<td>16</td>
<td>24</td>
<td>138</td>
<td>116</td>
<td>208</td>
<td>214</td>
<td>36987</td>
<td>18</td>
<td>1.2</td>
</tr>
<tr>
<td>2.</td>
<td>800</td>
<td>25</td>
<td>12</td>
<td>116</td>
<td>182</td>
<td>287</td>
<td>203</td>
<td>42114</td>
<td>26</td>
<td>1.6</td>
</tr>
</tbody>
</table>
Table 8. Comparison of Results between PSO and GA method

<table>
<thead>
<tr>
<th>SI.No.</th>
<th>Power Demand (MW)</th>
<th>GA Method (Rs/Hr)</th>
<th>PSO Method (Rs/Hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>680</td>
<td>6639.47</td>
<td>6588.3</td>
</tr>
<tr>
<td>2.</td>
<td>750</td>
<td>7267.93</td>
<td>7235.1</td>
</tr>
<tr>
<td>3.</td>
<td>869</td>
<td>8398.07</td>
<td>8346.8</td>
</tr>
</tbody>
</table>

Fig.2 Convergence Characteristics for Three unit System

Fig.3 Reliability Evaluation

VII. CONCLUSION

In this paper, the PSO method was successfully employed to solve the ELD problem with all the constraints. The PSO algorithm has been demonstrated to have superior features including high quality solution, stable convergence characteristics, and less computation time. Many non-linear characteristics of the generators can be handled efficiently by the proposed method. The comparison of results for the test cases clearly shows that the proposed method was indeed capable of obtaining higher quality solution efficiently for ELD problems. Figure 2 shows the convergence characteristics of the proposed algorithm for the three unit system. Figure 3 shows the reliability of the proposed algorithm for different runs of the program, which shows that irrespective of the run of the program it is capable of obtaining a same result for the example problem.

In addition, in order to verify it being superior to conventional method and GA method, many performance estimation schemes are performed, such as
- solution quality and convergence characteristics;
- dynamic convergence behavior of all individuals in population during the evolutionary processing;
- Computation efficiency.

It is clear from the results that the proposed PSO method can avoid the disadvantage of premature convergence of GA method and can obtain higher quality solution with better computation efficiency and convergence property.

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IX. REFERENCES


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