Constrained Economic Load Dispatch Using Evolutionary Technique

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Abstract - This paper proposed a new PSO with moderate random search strategy called MRPSO for the solution of economic load dispatch. The property of moderate random search strategy is to increase the convergence rate of particles and it enhances particles ability in such a way to explore in the solution space effectively. PSO is very popular optimization technique and used by various researchers to solve the economic load dispatch problem, but it is seen that, it’s convergence rate very slow at last stage of iteration. The MRPSO can overcome this problem and gives global solution of economic load dispatch. Economic load dispatch is the process of allocation of power generation units such that satisfied load demand at minimal possible cost and also satisfying the various equality as well as inequality constraints. Validation of the proposed optimization algorithm tested by using test case of 3 and 10 generating unit system. The results are compared with other variants of PSO mention in this paper and it is found that the proposed approach outperforms than other PSO Variants.

Keywords - Economic Load Dispatch (ELD), Fuel cost, Valve point loading effect, Particle swarm optimization (PSO), Moderate random search particle swarm optimization (MRPSO).

I. INTRODUCTION

Achieve the benefits of minimum production cost, better operating conditions and maximum reliability is the basic object of the electrical systems. The economic load is the process of on-line allocation of generating units, wherein it is required to distribute the load among the generating units, in such a way as to minimize the total operating cost of generating units and satisfying system equality and inequality constraints [4]. Since the load demands swings continuously hence it is very difficult to satisfy the demands in the minimum cost. The fuel cost curve characteristic is nonlinear due to presence of various equality and inequality constraints. That’s why it is the great challenge to get optimal solution of economic load dispatch problem.

Economic load dispatch is a nonlinear problem due to presence of valve point loading effect and various constraints. Many classical, hybrid and evolutionary technique listed in the literature were used to solve such a nonlinear ELD problem. Classical methods like Quadratic programming, Linear programming [2], Newton based techniques [4], Dynamic programming, interior point methods and Lagrange relaxation methods etc. were used to solve the ELD problem with valve point loading effects. But it is seen that classical methods have very slow convergence rate and also unable to give the global solution of the nonlinear ELD problem.

It is observed that classical methods have its own drawback such as in case of nonlinear programming has algorithmic complexity. Linear programming methods are fast and reliable but require linearization of objective function as well as constraints with non-negative variables. Quadratic programming is a special form of nonlinear programming which has some disadvantages associated with piecewise quadratic cost approximation. Newton-based method has a drawback of the convergence characteristics that are sensitive to initial conditions. The interior point method is computationally efficient but suffers from bad initial termination and optimality criteria.

Since the classical methods are failed to give optimum solution of ELD problem so that in current scenario various modern evolutionary techniques used for solution of economic load dispatch, which is very efficient with promising performance. The heuristic methods provide a fast and reasonable solution Different modern evolutionary technique which used for the solution of nonlinear ELD model reported in literature such as Nidhal Sinha et al. [5] proposed evolutionary programming techniques for economic load dispatch, K.P. Wong et al. [6] gives simulated annealing based economic dispatch algorithm, W.M. Lin et al. [7] proposed an improved Tabu search for economic dispatch with multiple minima, J.S. Al-Sumait et al. [8] used application of pattern search method to power system valve point economic load dispatch, D.C. Walter et al. [9] used genetic algorithm for the solution of economic dispatch with valve point loading, L.L. Lai [10] proposed ANN to economic load dispatch, J.Kennedy et al. [11] proposed Particle Swarm Optimization, C.H. Chen et al. [12] & K.S. Swarup [13] proposed Swarm intelligence Approach to the solution of optimal power flow, K.T. Chaturvedi et al. [14] proposed advance variant of PSO namely called Self Organizing Hierarchical PSO for nonconvex economic load dispatch, Hao Gao et al. [17] proposed a new particle swarm algorithm called MRPSO etc.

Literature shows that evolutionary technique have many advantages but also have their own disadvantages like evolutionary programming techniques rather slow converging near optimum. SA is very time consuming,
and cannot be utilized easily to tune the control parameters. TS is difficult in defining effective memory structures and strategies which are problem dependent. GA lacks a strong capacity of producing better offspring and causes slow convergence near global optimum. DE greedy updating principle and intrinsic differential property usually lead the computing process to be trapped at local optima.

In comparison with among intelligent methods the PSO has superior search performance with faster and more stable convergence rates[12] but its lacks global search ability in the last stage of iterations. This problem of PSO can be solved by using moderate random search technique with PSO. In this study proposed a new approach of PSO with moderate random search strategy (MRPSO) to solve the ELD problem with valve point loading effect. MRPSO gives more opportunity of the particles to explore in the solution space and enhances the global search ability of the particles as compared to classical PSO [17].

The feasibility of the proposed method was demonstrated for 3 and 10 generator system. The results obtained through the proposed approach compared with other variants of PSO.

II. FORMULATION OF ECONOMIC LOAD DISPATCH PROBLEM

Economic load dispatch is the important task in power system. The main objective of an ELD problem is the minimization the total generation cost of generating units in such a way to meets the demand and satisfies constraints selected as the objective function.

Objective function of the ELD problem is formulated mathematically as shown in Eq. (1) and (2).

\[ F_{\text{objective}} = \text{Min} \ f(FC(P_i)) \]  
\[ f(FC(P_i)) = \sum_{i=1}^{N} a_i P_i^2 + b_i P_i + c_i \]  

Where, \( FC(P_i) \) is the total fuel cost, \( a_i \), \( b_i \) and \( c_i \) are the cost coefficients and \( N \) =number of generating units.

A. PROBLEM FORMULATION WITH VALVE POINT LOADING EFFECT

Due to presence of valve point loading effect nonlinearity and discontinuity of the ELD is increases, that why Eq.(2) can be modified as Eq.(3).

\[ f'(FC(P_i)) = f(FC(P_i)) + \text{abs}(e_i \sin(f_i(P_i^{\text{min}} - P_i))) \]  

Where, \( e_i \) and \( f_i \) are constants of the valve point effect of generators.

Hence, the total fuel cost that must be minimized, according to (1), is modified to (4)

\[ F_{\text{obj,new}} = \text{Min} \ f'(FC(P_i)) \]  

Where, \( f' \) (FC) is the cost function of \( i^{th} \) generator in ($/h).

B. CONSTRAINTS CONSIDERED

A. POWER BALANCE EQUATION

For power balance, an equality constraint should be satisfied in such a way that the total generated power should be equal to total load demand plus the total losses [7].

\[ \sum_{i=1}^{n} P_i = P_D + P_L \]  

Where, \( P_D \) is the total system demand. In this case study we disregarded the transmission losses, so that, \( P_L = 0 \).

B. GENERATING UNIT OPERATING LIMITS

The power output of any unit should not exceed its rating nor should it be below that necessary for stable operation. Generation output of each unit should lie between maximum and minimum limits [5].

\[ P_i^{\text{min}} \leq P_i \leq P_i^{\text{max}} \]  

Where, \( P_i \) is the output power of \( i^{th} \) generator and \( P_i^{\text{min}} \) & \( P_i^{\text{max}} \) are the minimum and maximum power outputs of \( i^{th} \) generator respectively.

III. EVOLUTIONARY TECHNIQUE

A. STANDARED PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is a very popular optimization technique used by many researchers to solve the ELD problem. It was first introduced by Kennedy and Eberhart in the year 1995. It is a modern evolutionary approach based on the population. PSO is motivated from the behavior of social systems such as fish schooling and birds locking[12]. In the multidimensional space where the optimal solution is sought, each particle in the swarm is moved toward the optimal point by adding a velocity with its position.

The position and velocity vectors of the ith particle of a n-dimensional search space can be represented as eq.(7) & (8).

\[ P_i = (P_{i1}, P_{i2}, \ldots \ldots , P_{iN}) \]  
\[ V_i = (v_{i1}, v_{i2}, \ldots \ldots , v_{iN}) \]

On the basis of the value of the evaluation function, the best previous position of a particle is recorded and represented as Eq.(9).

\[ P_{\text{best}} = (P_{11}, P_{12}, \ldots \ldots , P_{1N}) \]

If the gth particle is the best among all particles in the group so far, it is represented as
The particle updates its velocity and position using Eq. (11) and (12).

\[ V_i^{(K+1)} = W V_i^K + c_1 \text{Rand}_1 (P_{\text{best}_i} - S_i^K) + c_2 \text{Rand}_2 (g_{\text{best}} - S_i^K) \]  

\[ S_i^{(K+1)} = S_i^K + V_i^{(K+1)} \]  

Where, \( V_i^K \) is velocity of individual i at iteration k, k is pointer of iteration, W is the weighing factor, \( c_1 \) & \( c_2 \) are the acceleration coefficients, Rand\(_1\) & Rand\(_2\) are the random numbers between 0 & 1, \( S_i^K \) is the current position of particle at iteration k, P\( _{\text{best}_i} \) is the best position of individual and g\( _{\text{best}} \) is the best position of the group.

The term \( c_1 \text{Rand}_1 (P_{\text{best}_i} - S_i^K) \) is called particle memory influence or cognition part which represents the private thinking of the itself and the term \( c_2 \text{Rand}_2 (g_{\text{best}} - S_i^K) \) is called swarm influence which represents the collaboration among the particles.

The inertia weight parameter \( 'W' \) provides a balance between global and local explorations. The following weighing function is used in (13)

\[ W = W_{\text{max}} - \frac{W_{\text{max}}-W_{\text{min}}}{\text{Iter}_{\text{max}}} \times \text{iter} \]  

Where, \( W_{\text{max}} \) is the initial weight, \( W_{\text{min}} \) is the final weight, Iter\(_{\text{max}}\) is the maximum iteration number and iter is the current iteration position.

IV. ALGORITHM FOR ELD WITH VALVE POINT LOADING EFFECT PROBLEM USING MRPSO

The algorithm for ELD problem with valve point loading effect employing MRPSO for practical power system operation is given in following steps.

1. Select suitable constants.
2. Initialization of the swarm: for a population size the particles are randomly generated in the range \([0,1]\) and located between the maximum and the minimum operating limits of the generators.
3. Initialize velocity and position for all particles by randomly set to within their legal range.
4. Set generation counter \( t = 1 \).
5. Evaluate the fitness for each particle according to the objective function.
6. Compare particles fitness evaluation with its \( P_{\text{best}_i} \) and \( g_{\text{best}} \).
7. Update position by using (14).
8. Apply stopping criteria.

V. CASE STUDY

A. TEST CASE 1

The first test results are obtained for 3-generator Systems with their valve point loading effect. The unit characteristics data with valve point effect are given in Table 1. The load demand in this study expected to be 850 MW.

Optimal results obtained by PSO, CPSO, WIPSO and MRPSO is shown in Table 2. Results shown in table 2 is obtain for 100 trial. Since the results are repeted for more than 100 trial so those results not considered.
TABLE I
COST COEFFICIENT, VALVE POINT LODING COEFFICIENTS AND CAPACITY LIMIT OF 3 GENERATING UNITS, DEMAND=850MW.

<table>
<thead>
<tr>
<th>Unit</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>a_i</td>
<td>0.00482</td>
<td>0.00194</td>
<td>0.00156</td>
</tr>
<tr>
<td>b_i</td>
<td>7.97</td>
<td>7.85</td>
<td>7.92</td>
</tr>
<tr>
<td>c_i</td>
<td>78</td>
<td>310</td>
<td>561</td>
</tr>
<tr>
<td>e_i</td>
<td>150</td>
<td>200</td>
<td>300</td>
</tr>
<tr>
<td>f_i</td>
<td>0.063</td>
<td>0.042</td>
<td>0.031</td>
</tr>
<tr>
<td>$p^\text{min}$</td>
<td>50</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>$p^\text{max}$</td>
<td>200</td>
<td>400</td>
<td>600</td>
</tr>
</tbody>
</table>

TABLE II
RESULTS OF 3 GENERATOR SYSTEMS (100 TRAILS)

<table>
<thead>
<tr>
<th>Unit Power Output</th>
<th>PSO</th>
<th>CPSO</th>
<th>WIPSO</th>
<th>MRPSO</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1(MW)</td>
<td>415.2137</td>
<td>327.2974</td>
<td>387.502</td>
<td>387.6287</td>
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<tr>
<td>P2(MW)</td>
<td>209.9597</td>
<td>400</td>
<td>327.401</td>
<td>324.6853</td>
</tr>
<tr>
<td>P3(MW)</td>
<td>143.8266</td>
<td>122.7026</td>
<td>137.601</td>
<td>137.38</td>
</tr>
<tr>
<td>Total Power Output(MW)</td>
<td>850</td>
<td>850</td>
<td>850</td>
<td>850</td>
</tr>
<tr>
<td>Total Cost without valve point effect($/h)</td>
<td>8200.713</td>
<td>8197.16</td>
<td>8200.215</td>
<td>8196.149</td>
</tr>
<tr>
<td>Total Cost with valve point effect ($/h)</td>
<td>8780.762</td>
<td>8802.624</td>
<td>8814.486</td>
<td>8372.777</td>
</tr>
<tr>
<td>Computation Time (sec.)</td>
<td>0.368939</td>
<td>0.356130</td>
<td>0.479264</td>
<td>0.350648</td>
</tr>
</tbody>
</table>

Convergence characteristic of PSO and MRPSO of 3 generating units are shown in fig.1 and fig2 respectively.

TABLE III
COST COEFFICIENTS, CAPACITY, AND VALVE POINT LIMITS OF 10 GENERATOR SYSTEMS. DEMAND=1036MW.

<table>
<thead>
<tr>
<th>Unit</th>
<th>1</th>
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<th>3</th>
<th>4</th>
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<th>7</th>
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<tbody>
<tr>
<td>a_i</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b_i</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>c_i</td>
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<tr>
<td>e_i</td>
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<td></td>
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</tr>
<tr>
<td>f_i</td>
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<tr>
<td>$p^\text{min}$</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$p^\text{max}$</td>
<td></td>
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</tbody>
</table>

TABLE IV
CONVERGENCE RESULTS OF 10 THERMAL UNITS WITH VALVE POINT LOADING EFFECT

<table>
<thead>
<tr>
<th>Unit Power Output</th>
<th>PSO</th>
<th>CPSO</th>
<th>WIPSO</th>
<th>MRPSO</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1(MW)</td>
<td>203.0951</td>
<td>215.034</td>
<td>203.095</td>
<td>225.016</td>
</tr>
<tr>
<td>P2(MW)</td>
<td>171.213</td>
<td>165.032</td>
<td>171.213</td>
<td>157.09</td>
</tr>
<tr>
<td>P3(MW)</td>
<td>126.9716</td>
<td>136.0432</td>
<td>126.971</td>
<td>126.971</td>
</tr>
<tr>
<td>P4(MW)</td>
<td>60</td>
<td>75.032</td>
<td>59.034</td>
<td>71.02</td>
</tr>
<tr>
<td>P5(MW)</td>
<td>89.7482</td>
<td>112.012</td>
<td>89.7482</td>
<td>119.76</td>
</tr>
<tr>
<td>P6(MW)</td>
<td>89.0969</td>
<td>82.2217</td>
<td>89.0969</td>
<td>89.0969</td>
</tr>
<tr>
<td>P7(MW)</td>
<td>130</td>
<td>123.02</td>
<td>131.241</td>
<td>121.01</td>
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<tr>
<td>P8(MW)</td>
<td>101.7198</td>
<td>66.8902</td>
<td>101.719</td>
<td>68.032</td>
</tr>
<tr>
<td>P9(MW)</td>
<td>50.0356</td>
<td>44.8734</td>
<td>50.0356</td>
<td>39.023</td>
</tr>
<tr>
<td>P10(MW)</td>
<td>13.9524</td>
<td>16.032</td>
<td>13.9021</td>
<td>19.03</td>
</tr>
<tr>
<td>Total Power Output (MW)</td>
<td>1035.833</td>
<td>1036.191</td>
<td>1036.05</td>
<td>1036.05</td>
</tr>
<tr>
<td>Total Cost without valve point effect($/h)</td>
<td>28295.02</td>
<td>28297.46</td>
<td>28291.8</td>
<td>28245.5</td>
</tr>
<tr>
<td>Total Cost with valve point effect ($/h)</td>
<td>29093.96</td>
<td>29153.2</td>
<td>29100.2</td>
<td>29047.4</td>
</tr>
<tr>
<td>Computation time (sec.)</td>
<td>0.476176</td>
<td>0.539649</td>
<td>1.11758</td>
<td>0.35536</td>
</tr>
</tbody>
</table>

Convergence result of 10 generating units obtained by various PSO variants such as PSO, CPSO, WIPSO and MRPSO is shown in table 4.
Convergence characteristic of PSO and MRPSO for 10 generating units with valve point loading effect is shown in fig.3 and fig 4 respectively.

VI. RESULTS AND ANALYSIS

The Economic load dispatch problem solved by using various variants of PSO such as PSO CPSO WIPSO and MRPSO. Result shows that performance of MRPSO is better than other variants of PSO. Optimal result obtained by different PSO variants is shown in Table 2 for 3 generating units and Table 4 for 10 generating units were obtain for 100 rtials. Fuel cost obtained by MRPSO for 3 generating units without including valve point loading effect is 8196.149 $/h and fuel cost with valve point loading effect is obtained 8372.77 $/h. Convergence time taken by MRPSO for 3 generating units is 0.350648 sec.

Similarly MRPSO results for 10 generating units without including valve point effect is 28245.5 $/h and total fuel cost obtained with including valve point loading effect is 29047.4 $/h. Convergence time taken by MRPSO for 10 generating units is 0.35536 sec.

All PSO algorithm were tested on 1.4-GHz, core-2 solo processor with 2GB DDR of RAM for such ELD problem. The constants used in this study was, acceleration coefficient $c_1 = c_2 = 2$, $W_{max} = 0.9$ and $W_{min} = 0.4$. The performance of MRPSO is tested in this study for the value of $\alpha$ taken 3.84.

VII. CONCLUSION

Economic load dispatch is a challenging task in power system. ELD model characteristic should be nonlinear due to presence of valve point loading effect and presence of various constraints. In the proposed work two case study are considered, the ELD problem with valve point loading effects is solve by using various variants of PSO. The test results obtained by MRPSO shown table 2 and table 4, the results demonstrated that the proposed MRPSO algorithm is capable of achieving global solution, it is computationally efficient and give better optimal results than other PSO methods. Overall, the MRPSO algorithms have been shown to be very helpful in studying optimization problems in economic load dispatch problem.

REFERENCES


