Multi Objective Directed Bee Colony Optimization for Economic Load Dispatch With Enhanced Power Demand and Valve Point Loading

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ABSTRACT

Earlier economic emission dispatch methods for optimizing emission level comprising carbon monoxide, nitrous oxide and sulphur dioxide in thermal generation, made use of soft computing techniques like fuzzy, neural network, evolutionary programming, differential evolution and particle swarm optimization etc. The above methods incurred comparatively more transmission loss. So looking into the nonlinear load behavior of unbalanced systems following differential load pattern prevalent in tropical countries like India, Pakistan and Bangladesh etc., the erratic variation of enhanced power demand is of immense importance which is included in this paper vide multi objective directed bee colony optimization with enhanced power demand to optimize transmission losses to a desired level. In the current dissertation making use of multi objective directed bee colony optimization with enhanced power demand technique the emission level versus cost of generation has been displayed vide figure-3 & figure-4 and this result has been compared with other dispatch methods using valve point loading (VPL) and multi objective directed bee colony optimization with & without transmission loss.

Keywords:
Economic load dispatch
Particle swarm optimization
Valve point loading

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INTRODUCTION

Traditional dispatch makes a simplification presuming that power plant efficiency increases quadratically, piece-wise linearly or linearly with the output. However, in real life valves control the steam coming into the turbine through separate nozzle groups. Each nozzle group attains better efficiency when operated at rated output. So, when the output increases, valves are opened in sequence in order to achieve highest possible efficiency for given output. The end result is a rippled efficiency curve. This gives rise to a distorted heat rate input output curve, displaying the impact of VPL. At its favor the cost of generation is updated with a sinusoidal dependence. The hybridization of multi agent system and bee decision making process makes multi objective directed bee colony (MODBC) to generate a fast solution and a better pareto front for economic dispatch. In this paper one of the bees is chosen at random to replace the existing scout bee.

Following two or more dominant bees, a linear combination of objective function is used to decide one of the dominant bees. Making use of user defined weighted combination random search technique for enhanced power demand multi objective directed bee colony optimization with enhanced power demand (MODBCEPD) finds better solution in the specific search area. Earlier methods on evolutionary programming
techniques[1] based on stochastic optimization, were restricted to moderate case systems for which the impact of enhanced power demand associated with MODBC technique was applied for better cost strategy comparatively in larger systems. The basic theme of economic dispatch [7] is to ascertain the optimal combination of power outputs of the generating units in electric power system so as to optimize the total fuel cost for a certain load demand satisfying operational constraints. The economic load dispatch (ELD) [3] problem is analyzed basically through intelligent systems involving VPL[11] and MODBC technique. Since a variable 3 step cost function involves Lagrangian philosophy which is nonlinear by nature, that involves sinusoidal terms demonstrating the valve point effect[11]. The cost of generation versus emission characteristic [4] with and without transmission loss [12] incorporating valve point analysis has been compared with swarm optimization technique[2] involving MODBC[9]. In this dissertation the impact of enhanced power demand involving load frequency control loop(LFC) and automatic voltage regulator loop(AVR) for optimizing oscillations in frequency deviation and improving steady state performance, has been attempted. The MODBCEPD technique using PSO [6] based PID controller pertaining to the Zeigler Nichols method of tuning has been adopted in this dissertation. Cost of generation versus emission level of a thermal power plant with and without transmission loss incorporating VPL, MODBC and MODBCEPD optimization techniques has been analyzed in this dissertation and displayed vide FIG-3 and FIG-4 respectively.

2. VALVE POINT LOADING

Thermal power plants are characterized by multiple steamvalves. In order to analyze the fuel cost function the valve point loading [11] effect is described as follows. Let N be the number of units. The generation cost objective function for the thermal power plant in the proposed method can be represented by the cost function:

\[
p_i^3 = \sum_{i=1}^{N} a_i p_i^2 + b_i p_i + c_i + \sum_{i=1}^{N} \frac{\lambda}{2}(P_{D} - \min(P_{G}))
\]

Where, \(a_i\), \(b_i\) and \(c_i\) are generation cost coefficients for the \(i_{th}\) generating unit of the proposed method with valve point loading subjected to condition:

\[
\sum g_i = P_D + p_i
\]

Where \(i=1,2,3,\ldots,n\).

\(p_g\) be the power supplied by the \(i_{th}\) unit and \(P_D\) be the load demand in MW. The transmission loss for a \(n\) unit electric power system is expressed as:

\[
p_t = \sum_{m=1}^{n} p_{m}R_{m}B_{mm}
\]

\[
\sum B_{mm} = \cos(\sigma_m - \sigma_n)M_{m}p_n \times M_{n}p_m \times R_t
\]

Where \(p_{gm}\) = Real power generated by mth power plant, \(p_{gn}\) = Real power generated by nth power plant; \(B_{mn}\) = Transmission loss in per mega watt; \(\sigma_m\) = Bus voltage angle of mth power plant; \(\sigma_n\) = Bus voltage angle of nth power plant; \(M_{m}\) = Current distribution factor of mth plant; \(M_{n}\) = Current distribution factor of nth plant; \(\phi_m\) = Phase angle of mth plant; \(V_m\) = Voltage at the mth bus; \(V_n\) = Voltage at the nth bus; \(R_t\) = Load resistance, and \(\phi_n\) = phase angle of nth plant.

Including valve point loading and incorporating transmission loss[12],[13] using conventional method the cost of thermal generation is expressed as:
\[ F_i^p(p_g) = \sum a_i p_g^i + b_i p_g + c_i + d_i p_g + p_g - \sum p_g_i \] (5)

Subjected to condition \( p_g\) (min) \( \leq p_g \leq p_g\) (max)

2.1. Cost Criteria for Economic Load Dispatch Problem

Using the Lagrangian multiplier method, fuel cost function incorporating transmission loss was expressed in equation (5), by differentiating the equation (5) we get:

\[ \frac{dF(p_g)}{dp_g} = 0 \] (6)

\[ \frac{\partial F(p_g)}{\partial \lambda} = \lambda \sum p_g - p_v \] (7)

\[ \Rightarrow 2a_ip_g + b_i + \lambda \left( \frac{\partial p_g}{\partial p_g} - 1 \right) = 0 \] (8)

Equation (8) satisfies the equality constraint \( \sum p_g = (p_v + p_i) \). Dividing equation (7) by \( 2a_i \)

\[ \frac{b_i}{2a_i} + \frac{\lambda}{2a_i} \left( \frac{\partial p_g}{\partial p_g} - 1 \right) = 0 \] (9)

\[ \Rightarrow \sum p_g + \frac{b_i}{2a_i} = \lambda \sum \frac{1}{2a_i} \left( 1 - \frac{\partial p_g}{\partial p_g} \right) \]

\[ p_g + \frac{b_i}{2a_i} = \lambda \frac{1}{2a_i} \left( 1 - \frac{\partial p_g}{\partial p_g} \right) \] (10)

The emission equation is expressed as,

\[ E_i^p = E_i = \alpha_i p_g^2 + \beta_i p_g + \gamma_i + \eta_i \exp(k_i p_g) \] (11)

Where, \( \alpha_i, \beta_i, \gamma_i, \eta_i \) and \( K_i \) are emission cost coefficients for the \( i \)th generating unit of the proposed method.

3. MODBC

3.1. Description

In this paper, we make use of MODBC [9] for multi objective problems which is a hybrid version of multi agent system (MAS), that mimics its structure and modified Nelder–Mead [5] method to find an optimal solution based on the algorithm used by bees for finding a suitable place for establishing a new colony. The experimental results show the robustness and accuracy of MODBC over genetic algorithm [1] and PSO [2]. Due to its hybrid nature, this algorithm provides only deterministic solutions. Making use of these agent–agent [5] interactions and evolution mechanism of bee swarms in a lattice-like environment, the proposed method can find high-quality solutions reliably with the faster convergence characteristics in a reasonably good computation time.

The starting point and the number of agents are important issues while handling such algorithms. The choice of the number of agents and the starting point of search are also presented and discussed in this paper. The decision making process in the honey bees gives rise to an interesting swarm research area to work. Two different cases with different conditions have been considered in this optimization process. Aforesaid reported techniques were applied to the standard IEEE 30-bus [1] six-generator test case system.
3.2. MODBC Algorithm

1) Set the parameter, \( p \). Set the length of steps, \( R_k \) (k = 0, 1, 2, ..., p).

2) Where \( R_k \) stands for step size for the kth parameter.

3) (2) Set the range for each parameter as \( [T_{i k}, T_{f k}] \) where k = 0, 1, ..., p where \( T_{i k}, T_{f k} \) represent the initial and final value of the parameter.

4) (3) Compute the number of steps in each step \( n_k = \frac{T_{f k} - T_{i k}}{R_k} \).

5) (4) Compute the number of volumes \( N_v = \prod_{k=1}^{p} n_k \).

6) (5) For individual volume, take the starting point of the explorations as the mid point of the volume,

\[
\left[ \frac{T_{i 1} + T_{f 1}}{2}, \frac{T_{i 2} + T_{f 2}}{2}, \ldots, \frac{T_{i p} + T_{f p}}{2} \right].
\]

7) (6) Search the volume according to modified Nelder–Mead method.

8) (7) Notice the value of optimal point obtained corresponding to each volume in form of \( Z_1, Z_2, \ldots, Z_{N_v} \).

9) (8) On completion of the search, the global optimized point making use of bee decision approach is as follows:

\[
F(Z_v) = \min \left[ F(Z_1), F(Z_2), \ldots, F(Z_{N_v}) \right].
\]

3.3. Analysis for MODBC Optimization Technique

The cost objective function presuming step wise linearized characteristics for MODBC neglecting transmission loss is expressed as:

\[
F_i = a_i p g_i^2 + b_i p g_i + c_i
\]

One of the ingenious technique proposed for multi-objective directed bee colony optimization[9] is as follows:

\[
E_i = \alpha_i p g_i^2 + \beta_i p g_i + \gamma_i + \eta_i \exp(k_i p g_i)
\]

Incorporating transmission loss the aforesaid cost and emission objective functions for multi-objective directed bee colony optimization is as follows:

\[
F_i = a_i p g_i^2 + b_i p g_i + c_i + \lambda_i p g_i - \sum p g_i
\]

\[
E_i = \alpha_i p g_i^2 - \beta_i p g_i + \gamma_i + \eta_i \exp(k_i p g_i)
\]

3.4. Random Particle Search Methodology

The optimization of the given objective function is carried out vide Nelder-Mead [5] method. In this methodology the function to be minimized is quite similar to food function of the agents i.e. the bees. To commence with we consider three vertices of a triangle as food points. The movement of the agent from initial food position towards the final one is carried out through Figure-1(a) where in a test point \( z_T \) is so considered that it is a reflection of worst food position denoted by \( z_3 \) as depicted in Figure 1(a). The vector \( z_T \) is expressed as:

\[
z_T = 2 \times z_{12} - z_3
\]
Figure 1. Agents(bases) search movements with recent optimization algorithm

The movement of a bee by an additional distance $d$ along the line marked in Figure 1(b) achieves a new position at point $z_e$. Since the function value at $z_e$ is made less than that at $z_T$, so it enables the agent for a better food approximation than $z_T$. The vector $z_e$ shown in Figure 1(b) is expressed as:

$$z_e = 2 \times z_T - z_{12}$$

(17)

A further movement of $d$ along the line of action of $z_e$ yields a point $z_f$ where in the agent has obtained a much better food point than $z_T$. The vector $z_e$ shown in Figure 1(b) is expressed as

$$z_f = 2 \times z_e - z_T$$

(18)

It has been observed that the lattice center of the lattice is a good starting point for optimal solution which is achieved by a group of 50-60 agents in a pool.

4. MODBCEPD

The proposed method MODBCEPD for multi objective generation dispatch incorporating nonlinear behavior of power demand has been emphasized in this paper. The decision making, based on bee colony optimization [9] making use of the Nelder-Mead [5] method for associating a better food option for bees, has been used for optimizing the cost & emission function [4]. In this method a better food position for agents is extrapolated beyond point $z_e$ [6,2] upto point $z_f$ as shown in Figure 1(b) justifying the random power demand behavior. Section 4.1 reflects the formulation of cost objective and emission objective functions vide equation (19) to (22) with & without transmission loss [12] as described below.

4.1. Without loss

$$P_i^c = a_i p g_i + b_i p g_i + c_i$$

(19)

$$E_i^c = \alpha_i p g_i + \beta_i p g_i + \eta_i \exp(k_i p g_i - p_d)$$

(20)

With loss

$$P_i^c = a_i p g_i + b_i p g_i + c_i$$

(21)

$$E_i^c = \alpha_i p g_i + \beta_i p g_i + \gamma_i + \eta_i \exp(k_i p g_i - p_d)$$

(22)

This paper used IEEE 30 bus test case system [1] comprising 6 generating units shown in Figure 2 for MODBCEPD analysis and comparison of results [8] with other soft computing techniques. The various
parameters [8] used for valve point loading. MODBCEPD technique, PID controller, ALFC loop & AVR loop [10] have been tabulated vide table-1 to table-6 respectively.

4.2 Nelder Mead Method
At par with section-3.4 the waggle dance [5] of the bees for better food search options is attained at the point $z_c$ converging to the optimal point [3,7] for the objective function. Section-4.2 realizes the utility of the Nelder Mead method at an extrapolated interval for meeting the nonlinear behavior of enhanced power demand up to point $z_f$ as shown in Figure 1(b).

4.3. Simulation Results
Section-4.3 deals with simulation results for frequency deviation obtained out of ALFC and AVR loop [10] vide Figure 5 incorporating PID controller subjected to MODBCEPD optimization for optimizing cost of generation and emission level with and without transmission loss.

Section-2 deals with conventional optimization method using Lagrange multiplier with & without transmission loss incorporating valve point loading [11]. Finally the optimization result obtained for emission level versus cost of generation using VPL & MODBC technique is compared with MODBCEPD incorporating and neglecting transmission loss. It has been found from simulation result and conventional optimization method with valve point [14] loading that the MODBCEPD approach yields least cost of generation against variation of emission level [4] with and without transmission loss. This result has been displayed in Figure 3 and Figure 4. The simulation result illustrating the frequency deviation [10] is shown vide Figure 6 to Figure 8 with and without transmission loss.
4.4. Performance Characteristics & Results

Various results pertaining to performance characteristics in Figure 3 and Figure 4 were tabulated vide table 1 to table 6.

Table 1. Fuel cost and emission cost function parameters for valve point loading (vpl)

<table>
<thead>
<tr>
<th>ai</th>
<th>bi</th>
<th>ci</th>
<th>ei</th>
<th>pgi in pu</th>
<th>pd in pu</th>
<th>ca</th>
<th>fi</th>
<th>gi</th>
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<tr>
<td>0.059</td>
<td>1.18</td>
<td>0.59</td>
<td>0.46</td>
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<td>0.55</td>
<td>0.0252</td>
<td>0.04</td>
<td>0.055</td>
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<tr>
<td>0.011</td>
<td>0.16</td>
<td>0.13</td>
<td>0.53</td>
<td>0.64</td>
<td>0.63</td>
<td>0.027</td>
<td>0.06</td>
<td>0.050</td>
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<tr>
<td>0.011</td>
<td>0.09</td>
<td>0.02</td>
<td>0.53</td>
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<td>0.64</td>
<td>0.015</td>
<td>-0.05</td>
<td>0.045</td>
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<tr>
<td>0.015</td>
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<td>0.09</td>
<td>0.54</td>
<td>0.65</td>
<td>0.65</td>
<td>0.017</td>
<td>-0.04</td>
<td>0.040</td>
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<tr>
<td>0.011</td>
<td>0.09</td>
<td>0.022</td>
<td>0.55</td>
<td>0.67</td>
<td>0.67</td>
<td>0.007</td>
<td>-0.05</td>
<td>0.045</td>
</tr>
<tr>
<td>0.016</td>
<td>0.24</td>
<td>0.16</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.009</td>
<td>-0.07</td>
<td>0.060</td>
</tr>
</tbody>
</table>

Table 2. Fuel cost and emission cost function parameters for modbcepD technique

<table>
<thead>
<tr>
<th>ki</th>
<th>n_i</th>
<th>pl in pu</th>
<th>P_gi in pu</th>
<th>P_g max in pu</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>1.007</td>
<td>0.09</td>
<td>3.01</td>
<td>0.04</td>
</tr>
<tr>
<td>2.4</td>
<td>1.15</td>
<td>0.31</td>
<td>4.05</td>
<td>0.04</td>
</tr>
<tr>
<td>2.2</td>
<td>0.99</td>
<td>0.58</td>
<td>6.0</td>
<td>0.04</td>
</tr>
<tr>
<td>3.0</td>
<td>1.12</td>
<td>0.39</td>
<td>3.0</td>
<td>0.04</td>
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<tr>
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<td>0.04</td>
</tr>
<tr>
<td>3.3</td>
<td>1.19</td>
<td>1</td>
<td>6.5</td>
<td>0.04</td>
</tr>
</tbody>
</table>

Table 3. PID controller parameters (without loss)

<table>
<thead>
<tr>
<th>Optimization technique</th>
<th>PID controller parameters (without loss)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>k_p</td>
</tr>
<tr>
<td>VPL</td>
<td>65.6</td>
</tr>
<tr>
<td>MODBC</td>
<td>75.78</td>
</tr>
<tr>
<td>MODBCEPD</td>
<td>85.8</td>
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</table>
Table 4. PID controller parameters (with loss)

<table>
<thead>
<tr>
<th>Optimization technique</th>
<th>$T_H$ in sec</th>
<th>$T_T$ in sec</th>
<th>$T_p$ in sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>vpl</td>
<td>0.055</td>
<td>0.30</td>
<td>19</td>
</tr>
<tr>
<td>modbc</td>
<td>0.045</td>
<td>0.28</td>
<td>18</td>
</tr>
<tr>
<td>modbcepd</td>
<td>0.08</td>
<td>0.35</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 5. ALFC parameters in per unit

<table>
<thead>
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<th>$K_1$</th>
<th>$K_P$</th>
<th>$T_P$ in sec</th>
<th>$T_G$ in sec</th>
<th>$T_T$ in sec</th>
<th>$R$ in Hz/pu MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>102</td>
<td>20</td>
<td>0.06</td>
<td>0.32</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Table 6. AVR parameters in per unit

<table>
<thead>
<tr>
<th>$K_1$</th>
<th>$K_2$</th>
<th>$K_3$</th>
<th>$K_4$</th>
<th>$K_5$</th>
<th>$K_F$</th>
<th>$K_A$</th>
<th>$K_E$</th>
<th>$T_F$ in sec</th>
<th>$T_A$ in sec</th>
<th>$T_F$ in sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.853</td>
<td>0.1632</td>
<td>0.3457</td>
<td>1.0304</td>
<td>0.0674</td>
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<td>20</td>
<td>0.05</td>
<td>0.05</td>
<td>2.9441</td>
<td></td>
</tr>
</tbody>
</table>

Figure 6(a). Frequency deviation for economic load dispatch involving valve point loading incorporating without transmission loss

Figure 6(b) Frequency deviation for economic load dispatch involving valve point loading incorporating transmission loss

Figure 7(a) Frequency deviation for economic load dispatch involving MODBC without transmission loss

Figure 7(b) Frequency deviation for economic load dispatch involving MODBC incorporating transmission loss

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6. CONCLUSION

Electric power systems are highly complex interconnected networks. They transfer large amount of electric power over wide geographical areas. Scheduling of available generating resources to meet the load demand is a vital job of a power system operator. This generation-load balance should be achieved at minimum operating cost to receive the maximum benefits. The generation scheduling problem consists of determining the optimal operation strategy for the next scheduling period, subject to a variety of constraints. Economic operation is very important for any power system to achieve the profits on the capital investment. The importance of conservation of fossil fuels puts pressure on power companies to achieve maximum possible fuel efficiency by which the cost of kilo watt hour to the consumers can be minimized as the fuel prices are continuously rising.

Economic dispatch is an important optimization task in power system operations for allocating generation amongst the committed units such that all the constraints imposed are satisfied with minimum operating fuel cost. Improvements in the scheduling of unit outputs can lead to significant cost saving. Previous efforts at economic dispatch have applied various mathematical programming methods and optimization techniques. These methods represent the dispatch problem with quadratic fuel cost function and solve it by deterministic optimization techniques such as lambda iteration method, the gradient method and the dynamic programming method. These methods require continuously increasing fuel cost curves to find the global optimal solution. Gradient techniques perform well in their narrow class of problems, but it works inefficiently elsewhere. Later, Lagrangian methods have been increasingly used since they have the capability of including inequality constraints. These methods are based on the equal incremental cost criterion. It is desirable that the solution of power system problems should be globally optimal, but solutions searched for mathematical optimization is normally locally optimal. These facts make it difficult to deal effectively with many power system problems through strict mathematical formulation alone. Despite remarkable advancement in mathematical optimization techniques, conventional mathematical methods have yet to achieve fast and reliable real time applications in power systems.

Considerable efforts are required to avoid mathematical traps such as ill-conditioning and convergence difficulties. Since most classical methods used the point by point approach where one solution gets updated to a new solution in one iteration, parallel programming techniques cannot be exploited in solving the problem. This paper focuses on improvements in MODBC approach. Earlier studies using MODBC technique optimize the cost and emission function individually neglecting transmission losses [12]. Incorporating transmission losses and enhanced power demand in a random manner MODBCEPD technique yields more optimization results for cost of generation and emission level as well. Pareto-optimal curves [8] utilizing VPL, MODBC and MODBCEPD with and without transmission loss shown in FIG-3 & FIG-4 justify the efficacy of MODBCEPD technique over MODBC, VPL, PSO [6] and other soft computing techniques.

The simulated frequency deviation results following the variation of simulation time with and without transmission loss yield a better option to optimize real time and online optimization problems. Comparing the simulated result and MODBCEPD approach [8], it is found that the proposed scheme is more efficient and more effective than other soft computing techniques. The results obtained in this dissertation for
MODBCEPD can be utilized to realize complex industrial processes for obtaining optimum losses. This is however reasonably approximated for huge power plants encompassing a large number of units dealing with multi fuel options leading to convex optimization problems.

REFERENCES


