Dual objective multiconstraint swarm optimization based advanced economic load dispatch

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ABSTRACT

In electric power system, the vital topic to be mooted is economic load dispatch (ELD). It is a non-linear problem with some unavoidable constraints such as valve point loading and ramp rate constraint. For solving ELD problem distinct methods were devised and tried for different electric supply systems yielding slow convergence rates. To achieve fast convergence, dual objective multi constraint swarm optimization based advanced economic load dispatch (DOMSObAELD) algorithm is proposed making use of simulated values of real power outages of a thermal power plant as initial estimates for PSO technique embedded in it and used for optimizing economic dispatch problem in this article. DOMSOBAELD method was developed in the form of amalgamating fluids. Presence of power line losses, multiple valves in steam turbines, droop constraints and inhibited zones were utilized to optimize the ELD problem as genuinely approximate as possible. The results obtained from DOSOBAELD are compared with particle swarm optimization (PSO), PSOIW and differential particle swarm optimization (DPSO) techniques. It is quite conspicuous that DOMSOBAELD yielded minimum cost values with most favourable values of real unit outputs. Thus the proposed method proves to be advantageous over other heuristic methods and yields best solution for ELD by selecting incremental fuel cost as the decision variable and cost function as fitness function.

Keywords:
Differential evolution
Differential particle swarm optimization
Economic load dispatch
Evolutionary programming
Particle swarm optimization
Particle swarm optimization involving inertia weight

1. INTRODUCTION

Due to growing complexity of the power demand the reliability, transmission loss and clear power free of distortion becomes a challenging problem for economic load dispatch (ELD). Slow convergence rate of Soft computing methods and complex computational burden with complex structural algorithm for conventional method lead to complex ELD problem. To overcome these barriers dual objective multi constraint swarm optimization based advanced economic load dispatch (DOMSObAELD) method is applied in the proposed research work. In this paper, multiple versions of particle swarm optimization techniques are used to ascertain the optimal cost of generation capacity that can be integrated into the existing power system and the results of the proposed algorithm for a 30 bus test case system are reported. A new fictitious code based algorithm is developed, in this paper, for equality constraints [1] other than the penalty function methods that performs better due to its parallel search capability. The effect of multiple valves in steam turbines narrated by Singh and Wang et al., [2-4] yields more perturbation in cost function which can be piece wise linear using conventional economic dispatch techniques. This methodology is so easy that particle
swarm optimization (PSO) utilizes some parameters and definitions of the optimization process and then it starts the process with an initial random population involving parallel search technique, named particles. Each of these particles has a feasible solution for the main problem and is processed as a part in ‘n’ dimensional space. In the variable space, each particle has a position identified by xi and a velocity identified by vi. If a particle has a best position, it is brought over to the next stage. Additionally, best positions are denoted as Pbest and the best position of all particles is denoted as Gbest. The results of generation outages for 6 units obtained through the simulation of aforesaid thermal power plant involving multiple constraints are used as initial estimates for proposed DOMSOBAELD method and final optimal schedules for real power generation, final position of swarm and their velocities are updated using PSO technique involved in DOMSOBAELD approach and are compared with various traditional methods like Lagrange multiplier method [5, 6], PSOIW, DPSO [7, 8] and sequential quadratic programming method referred in [9, 10].

2. RESEARCH METHOD
This section presents and formulates the objective functions viz. cost, emission and combined objective function satisfying multiconstraints involving price penalty factor $F_i$. The basic economic load dispatch problem incorporating valve point loading described by Sharma and Goyal et al., [11] is formulated through (1) and (2) as under;

$$Z_i = a_i PG_i^2 + b_i PG_i + c_i + K_i \sin(l_i(P_i - PG_i)) \quad (1)$$

$$J_i = (h_i PG_i^2 + g_i PG_i + q_i) \quad (2)$$

where, $Z_i$ and $J_i$ are cost and emission objective functions and $a_i, b_i, c_i, K_i, l_i$ and $h_i, g_i, q_i$ are cost and emission objective function coefficients. In this dissertation the emission function involves global warming gases like CO, NO$_2$ and SO$_2$. The final objective function [12, 13] formulated incorporating penalty factor $F_i$ is formulated in (3) as under;

$$S_i = Z_i + F_i \times J_i \quad (3)$$

where,

$$F_i = \frac{Z_{i_{max}}}{J_{i_{max}}} \quad (4)$$

$$Z_i = a_i PG_i^2 + b_i PG_i + c_i + K_i \sin(l_i(P_i - PG_i)) \quad (5)$$

$$J_i = (h_i PG_i^2 + g_i PG_i + q_i) \quad (6)$$

The constraints in incorporated in this work are;

a. Equality constraint

$$\sum_{i=1}^n PG_i = P_D + TL \quad (7)$$

$$TL = \sum_{m=1}^6 \sum_{m-1}^6 PG_m \times PG_n \times B_{mn}$$

where,

$P_D$ = net power demand

TL = transmission loss.

b. Inequality constraint

$$P_i < PG_i < P_j \quad (8)$$

where, $PG$ represents the output power of $i^{th}$ generating unit, $P_i$ and $P_j$ are minimum and maximum output Power of $i^{th}$ generating unit respectively.
3. OVERVIEW OF DUAL OBJECTIVE MULTI-CONSTRAINT SWARM OPTIMIZATION BASED ADVANCED ECONOMIC LOAD DISPATCH

Particle swarm optimization [14, 15] formed the behavior of evolutionary techniques for ELD optimization. So in order to obtain optimistic results of nonlinear optimization technique, we incorporate here a ramp rate limit that outsmarts the conventional constraints through improved constriction factor based well defined ramp rate particle swarm optimization technique. This method involves differential particles [14, 15] in search space that randomly update their position using their velocity heuristically following their neighbors so as to obtain position and velocity vectors viz. \( P_{\text{best}}, \ g_{\text{best}} \), i.e. \( (P_{\text{best}}, P_{2\text{best}}, P_{3\text{best}}) \) and \( (g_{1\text{best}}, g_{2\text{best}}, \ g_{\text{best}}) \) respectively. The new values of position and velocity are estimated using (9) and (10).

\[
Y_{n2}^{(k+1)} = [wY_{n2}^k + A_1 \times \text{Rand}_1(T_0 - S_i^k) + A_2 \times \text{Rand}_2(g_{\text{best}} - S_i^k)]
\]

(9)

\[
S_{n1}^{(k+1)} = S_i^k + V_{i}^{k+1}
\]

(10)

Where, \( A_1, A_2 \) are acceleration coefficients

\( w \) = Inertia weight

\( Y_{n2}^{(k+1)} \) = Updated velocity of the k+1 iteration

\( S_{n1}^{(k+1)} \) = Updated displacement of the k+1 iteration

\( T_0 \) = \( P_{\text{best}} \) function

\( S_i^k \) = Initial \( i^{th} \) particle after \( k^{th} \) iteration

\( A_1 \times \text{Rand}_1(P_{\text{best}} - S_i^k) \) = Particle’s Private thinking

\( A_2 \times \text{Rand}_2(g_{\text{best}} - S_i^k) \) = Collaboration among particles

\[
w = w_{\text{max}} - \frac{w_{\text{max}} - w_{\text{min}}}{k} \times n
\]

(11)

\( k \) = Maximum number of iterations

\( n \) = Iteration number

\( w_{\text{max}} \) = Initial Weight in per unit = 0.85

\( w_{\text{min}} \) = Final Weight in per unit = 0.35

To obtain most favourable multivalving effect the ramp rate constraints are applied upon the inequality constraints as under:

\[
\text{Max}(P_{G_i\min}, P_{i0} - DR_i) \leq P_{G_i\text{new}} \leq \text{Min}(P_{G_i\max}, P_{il} + UR_i)
\]

(12)

Subject to condition

\[
P_{Gi} - P_{i0} \leq UR_i \ (\text{Generation increases})
\]

\[
P_{i0} - P_{il} \leq DR_i \ (\text{Generation decreases})
\]

(13)

where,

\( P_{il} \) = Power generation of \( i^{th} \) unit in the current interval.

DOMSOBAELD Algorithm

Step 1. Initialize parameters like,

\( P_{G_1}, P_{G_2}, P_{G_3}, P_{G_4}, P_{G_5}, P_{G_6} \)

Step 2. If \( \Gamma_i \) is better than \( \Gamma_0 \), then

\( \Gamma_i = \Gamma_{\text{new}} \)

Else \( \Gamma_i = \Gamma_{\text{old}} \)

Step 3. Initialize \( g_{\text{best}} \) values for generating units \( P_{G_1} \) to \( P_{G_6} \)

Step 4. Assign best of \( \Gamma_{\text{inew}} \) and \( \Gamma_{\text{old}} \) to \( g_{\text{best}} \)
Step 5. Current position \( S_i = Z_i + F_i \times J_i \) and current velocity \( Y_i = U_{\text{min}} + \text{Rand}(U_{\text{max}} - U_{\text{min}}) \).

Step 6. Update position for each particle where \( Y_{i}^{k+1} \) is the update velocity for each particle.

Step 7. If Particle position is greater than or equal to bounds in (12) then stop otherwise go to step 2.

### 4. RESULTS AND DISCUSSION

This section illustrates implementation of DOMSOBAELD algorithm on 6 unit, 30 bus IEEE test case shown in Figure 1 for forming the combined objective function involving cost and emission level function through a price penalty factor for mitigating the transmission losses and multi constraints through valve point loading (VPL) effect shown in Figure 2 and prohibited operating zones (POZ) marked in Figure 3. Table 1 shows cost coefficient, emission coefficient, minimum and maximum capacity of generating units for cost and emission function. Flow chart for DOMSOBAELD algorithm is presented in Figure 4.

![Figure 1. IEEE 30 bus test case systems for DOMSOBAELD approach](image1)

![Figure 2. Multi-valve effect of turbine generator units](image2)

![Figure 3. Input output characteristic of generating units with prohibited operating zones](image3)

### Table 1. Cost coefficients, unit capacity and emission coefficients for IEEE 30 bus test case system with 6 generating units

| Unit | \( a_i \) | \( b_i \) | \( c_i \) | \( P_{i,\text{max}} = P_i \) | \( P_{i,\text{min}} = P_i \) | \( h_i \) | \( g_i \) | \( q_i \) |
|------|------|------|------|-------------------|-------------------|------|------|------|
| 1    | 0.1424 | 37.439 | 755.80 | 125               | 15                | 0.0039 | 0.3266 | 13.84932 |
| 2    | 0.0958 | 45.144 | 455.325 | 170               | 10                | 0.0040 | 0.32667 | 13.84932 |
| 3    | 0.0180 | 39.385 | 1048.88 | 225               | 30                | 0.00673 | 0.54771 | 40.2709 |
| 4    | 0.0025 | 37.304 | 1235.55 | 235               | 30                | 0.00103 | 0.54.651 | 40.2709 |
| 5    | 0.0111 | 35.326 | 1656.56 | 320               | 135               | 0.00501 | 0.5119 | 42.88553 |
| 6    | 0.0169 | 37.250 | 1355.65 | 390               | 130               | 0.00501 | 0.5119 | 42.88553 |

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Optimal parameters for the thermal power plant and the loss coefficients for 6 unit system for inclusion of transmission loss are presented vide Tables 2 and 3 respectively. In this method initial values of real powers for 6 generating units are obtained by simulating the thermal power plant outages involving all the constraints in form an integro differential equation involving automatic load frequency parameters and automatic voltage regulator loop parameters shown in Table 4. These values of real power generations are considered as the initial fitness variables for PSO and using them the final best values are obtained and updated particle position and velocities are obtained to estimate the final values of cost, emission and combined objective functions shown in Figures 6-8. The results shown in Figures 6-8 suggest that beyond 200 MW, cost, emission level referred through [16] as well as total objective function yield better performance over the classical methods like lambda iteration, mixed integer with linear programming (MILP) method and quadratic method because of updation of swarm position i.e. $S_{n1}(k+1) = S_{n1}^k + Y_{n2}^{(k+1)}$. It also outperforms heuristic methods like PSO [17-21] PSOIW [22, 23], constriction factor based particle swarm optimization (CPSO) [24] and DPSO [25], and the results are tabulated in Table 5. Valve point loading effects of turbines [26] and prohibited operating zones analysis [27] are effectively dealt in this dissertation. The ramp rate constraints and multi-valve effects [28, 29] are of paramount importance in realizing the DOMSOBAELD approach.
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5. ANALYSIS OF VARIOUS OBJECTIVE FUNCTIONS

Various objectives targeted through DOMSOBAELD optimization approach were found to satisfy various nonlinear constraints like prohibited operating zones, valve point loading and ramp rate constraints along with equality and inequality constraints. The results obtained through a P5 machine employing Matlab 2016 yields better result in comparison to other heuristic methods for optimum operating cost, emission level and total objective function with respect to real power variation of various generating units.

6. CONCLUSION

The DOMSOBAELD technique illustrated an advanced PSO technique involving multi valve effects, droop constraints and power system swarm optimization tool box for analysing the economic dispatch problem and the results were verified with other heuristic methods using matlab simulation for multi-objective problem involving particle swarm optimization technique, PSOIW technique and differential particle swarm optimization technique. The simulink model is used for comparing the results of various heuristic methods described earlier. The optimal values of generating units give rise to cost of generation, emission level and combined objective response in DOMSOBAELD analysis. This method proved to be efficient and beneficial over lambda iteration method, mixed integer linear programming method (MILP), quadratic programming method and soft computing methods like particle swarm optimization, constriction factor based particle swarm optimization (CPSO) and differential particle swarm optimization (DPSO), in terms of convergence time for most favourable solution. The DOMSOBAELD technique would be applied to electromagnetic based particle swarm optimization dispatch problems in upcoming paper involving formidable prohibited operating zones. The recent work has basic constraints like valve point loading resulted out of multi-valve effect, ramp rate constraints, less formidable prohibited operating zones, equality and inequality constraints. However, this method in conjunction with electromagnetic based dispatch can be utilized to handle constraints coming out of tie line in multi area economic dispatch, multi fuel option constraint, penalty factor constraint and different tie line capacity constraints resulted out of varying load behaviour. The correlation of particle position and particle velocity with aforesaid multiple constraints decides and P best values which are not being used by any other heuristic methods. As a result of this, fast convergence is obtained in this method resulting thereby better simulation results so as to reduce simulation time required for obtaining response characteristic of system model involving multiple heuristic subsystems.
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