

# Hybrid PSO-DE for Solving the Economic Dispatch Problem with Generator Constraints

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**Abstract**— This paper proposes an improved approach based on conventional particle swarm optimization (PSO) for solving an economic dispatch(ED) problem with considering the generator constraints. The mutation operators of the differential evolution (DE) are used for improving diversity exploration of PSO, which called hybrid particle swarm optimization – differential evolution (PSO-DE). The mutation operators are activated if velocity values of PSO nearly to zero or violated from the boundaries. Four scenarios of mutation operators are implemented for PSO-DE. The simulation results of all scenarios of the PSO-DE outperform over the PSO and other existing approaches which appeared in literatures.

**Keywords**— Particle swarm optimization, Economic dispatch problem, Mutation operator, Prohibited operating zones, Differential Evolution.

## I. INTRODUCTION

The main objective of ED problem is to decrease the fuel cost of generators, satisfying many equality and inequality constraints. In the past, classical ED problem is solved using classical mathematical optimization methods, such as lambda method, gradient method and Newton method [1].

Many researchers exert to improve many optimization techniques for solving ED problem such as PSO [2], GA [2], chaotic particle swarm optimization (CPSO) [3], clonal algorithm (AIS) [4] and multiples tabu search (MTS) [5]. PSO was introduced by J. Kennedy and R. Eberhart in 1995 [6]. PSO is a type of modern optimization techniques and a type of swarm intelligence. PSO has been tested and seen to be high efficiency in solving continuous nonlinear optimization problems [6-7].

This paper proposed the techniques are based on particle swarm optimization and mutation operators of the differential evolution algorithm [8-9] for guarantee the global optimal solution and reduced the computational time. Four scenarios of mutation operators are introduced, which can enhance the exploration performance of the PSO.

## II. FORMULATIONS OF ED PROBLEMS

Minimizing the fuel cost function of all generating units in the power system subjected to power system balanced constraint, power losses and generating unit operation is the main purpose of the economic dispatch problem and represented as following.

$$\text{Minimize } F_T = \sum_{i=1}^n a_i + b_i P_i + c_i P_i^2 \quad (1)$$

where  $F_T$  is total fuel cost,  $n$  is number of online generating unit,  $a_i, b_i, c_i$  are cost coefficients of generating unit  $i$ ,  $P_i$  is the real power output of unit  $i$ .

The minimization of the ED problem is subjected to the following constraints

### A. Generator Constraint

$$P_{i(t)} = \begin{cases} P_{i,\min} \leq P_i \leq P_{i,1}^L \\ P_{i,k-1}^U \leq P_i \leq P_{i,k}^L & k = 2,3,\dots,n_i, n_i = 1,\dots,m \\ P_{i,n_i}^U \leq P_i \leq P_{i,\max} \end{cases} \quad (2)$$

where  $k$  is the number of prohibited operating zones of generating unit  $i$ ,  $P_{i,k}^L$  and  $P_{i,k}^U$  are lower and upper limits of the  $k^{\text{th}}$  prohibited zone of generating unit  $i$ , respectively.

According to the operating increases and operating decreases of the generators are ramp rate limit constraints can be described as follow

$$\begin{aligned} \max(P_{i,\min}, P_{i(t-1)} - DR_i) &\leq P_{i(t)} \\ &\leq \min(P_{i,\max}, P_{i(t-1)} - UR_i) \end{aligned} \quad (3)$$

1) as generation increases

$$P_{i(t)} + P_{i(t-1)} \leq UR_i \quad (4)$$

2) as generation decreases

$$P_{i(t-1)} - P_{i(t)} \geq DR_i \quad (5)$$

where  $P_{i(t)}$  is output power of generating unit  $i$  at current and  $P_{i(t-1)}$  is output power at previous.  $UR_i$  is upramp limit of generating unit  $i$  (MW/time–period) and  $DR_i$  is downramp limit of generating unit  $i$  (MW/time–period)

### B. Power balance constraint

$$\sum_{i=1}^n P_i = D + P_L \quad (6)$$

with

$$P_L = \sum_{i=1}^n \sum_{j=1}^n P_i B_{ij} P_j + \sum_{i=1}^n P_i B_{oi} + B_{oo} \quad (7)$$

where  $D$  is total load demand,  $P_L$  is total transmission line loss,  $P_{i,\min}$  and  $P_{i,\max}$  are minimum and maximum power output of unit  $i$  and  $B_{ij}$ ,  $B_{oi}$  and  $B_{oo}$  are transmission line loss coefficients.

### III. PARTICLE SWARM OPTIMIZATION (PSO)

Kenedy and Eberhart proposed a particle swarm optimization in 1955. The basic idea of PSO based on food searching of a swarm of animals, such as fish flocking or bird swarm. Calculating the new velocity and new position of particles can use equations (8)-(11).

$$V_i^{(t+1)} = K \times \begin{pmatrix} \omega \times V_i^{(t)} + c_1 \times r_1 \times (pbest_i - x_i^{(t)}) \\ + c_2 \times r_2 \times (gbest - x_i^{(t)}) \end{pmatrix} \quad (8)$$

where

$$K = \left| \frac{2}{2 - c - \sqrt{c^2 - 4 \times c}} \right| \quad (9)$$

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \times t \quad (10)$$

$$x_i^{(t+1)} = x_i^{(t)} + V_i^{(t+1)}, \quad i = 1, 2, \dots, n \quad (11)$$

where  $V_i^t$  is velocity of particle  $i$  at iteration  $t$ ,  $K$  is constriction factor,  $\omega$  is inertia factor,  $c_1$  and  $c_2$  are accelerating factor,  $r_1$  and  $r_2$  are positive random number between 0 and 1,  $pbest_i$  is the best position of particle  $i$ ,  $gbest$  is the best position of the group,  $\omega_{\max}$  and  $\omega_{\min}$  are minimum and maximum of inertia factor,  $iter_{\max}$  is maximum iteration,  $n$  is number of particles.

This paper proposed four scenarios of mutation operators for improving diversity exploration of the standard PSO. The mutant operators are the distance between the difference populations that multiplied by the constant factor. The scenarios of mutation operators are expressed as following

#### 1) Scenario 1 (PSO-DE1)

$$V_i^{(t+1)} = SC \times \left( (x_k^{(t)} - x_i^{(t)}) - (x_q^{(t)} - x_i^{(t)}) \right) \quad (12)$$

#### 2) Scenario 2 (PSO-DE2)

$$V_i^{(t+1)} = SC \times \begin{pmatrix} (x_k^{(t-\beta)} - x_i^{(t)}) - \\ (x_q^{(t-\beta)} - x_i^{(t)}) \end{pmatrix} \quad (13)$$

#### 3) Scenario 3 (PSO-DE3)

$$V_i^{(t+1)} = SC \times \begin{pmatrix} (x_k^{(t)} - x_i^{(t)}) - \\ (x_q^{(t)} - x_i^{(t)}) - (x_r^{(t)} - x_i^{(t)}) \end{pmatrix} \quad (14)$$

#### 4) Scenario 4 (PSO-DE4)

$$V_i^{(t+1)} = SC \times \begin{pmatrix} (x_k^{(t-\beta)} - x_i^{(t)}) - \\ (x_q^{(t-\beta)} - x_i^{(t)}) - (x_r^{(t-\beta)} - x_i^{(t)}) \end{pmatrix} \quad (15)$$

where  $SC$  is a real number between 0.1 and 2 that called scaling factor, which controls the amplification of differences populations for escape the local solutions,  $\beta$  is previous iteration that user defined,  $k, q$  and  $r$  are random index of particles, randomly chose from population set and  $k \neq q \neq r$ .

### IV. SIMULATION RESULTS AND COMPARISONS

In this section, to demonstrate the effectiveness of the proposed method, the PSO-DEs are applied to solve the six thermal units. The simulation results are compared with

various methods reported in literatures, such as the PSO [2], GA [2], CPSO [3], AIS [4], MTS [5] and the bees algorithm (BA) [10].

The PSO-DE, PSO, TSA, GA and BA are implemented in MATLAB language and executed on an Intel(R) Core2

Duo 3.0 GHz personal computer with a 4.0 GB of RAM. The best results are obtained from the PSO-DEs' and others method compared in Table I. The results show that the proposed approaches have high solution quality than others method as depicted.

TABLE I  
COMPARISON OF THE BEST RESULTS

Methods	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	Total cost (\$/h)
GA [2]	474.81	178.64	262.21	134.28	151.90	74.18	15 459.0
PSO [2]	447.50	173.32	263.47	139.06	165.48	87.13	15 450.0
CPSO [3]	434.43	173.32	274.47	128.06	179.48	85.93	15 446.0
AIS [4]	458.29	168.05	262.52	139.06	178.39	69.34	15 448.0
MTS [5]	449.37	182.25	254.29	143.45	161.97	86.02	15 451.6
TSA	451.73	185.23	260.93	133.10	171.08	73.51	15 449.2
BA	438.65	167.90	262.82	136.77	171.76	97.67	15 445.9
PSO	444.24	170.83	254.68	141.32	173.04	91.36	15 446.1
GA	438.42	178.99	270.88	131.59	166.55	89.20	15 446.6
PSO-DE1	451.36	174.21	257.36	137.05	165.15	90.36	15 444.8
PSO-DE2	444.72	172.37	260.50	144.86	167.71	85.23	15 444.5
PSO-DE3	450.08	170.83	270.00	129.01	166.99	88.76	15 444.9
PSO-DE4	447.77	178.19	256.46	134.75	171.63	86.80	15 444.9

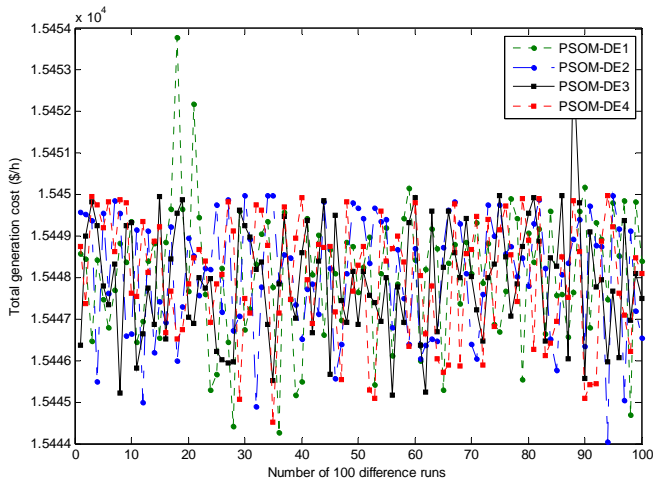


Fig.1 100 solutions profile of PSO-DEs.

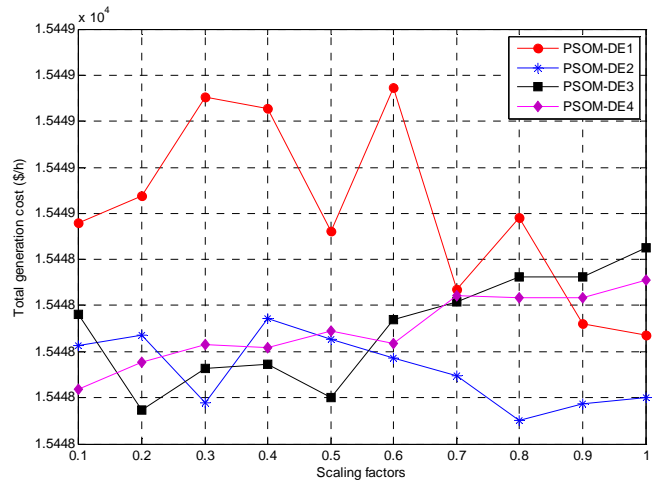


Fig.2 variation of scaling factors versus generation cost.

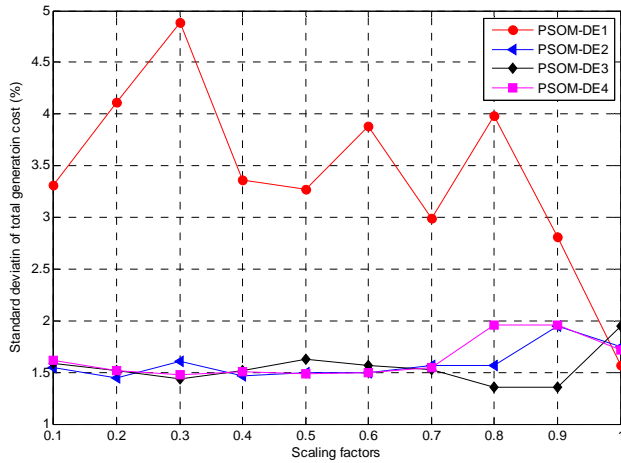


Fig.3 variation of scaling factors versus standard deviation.

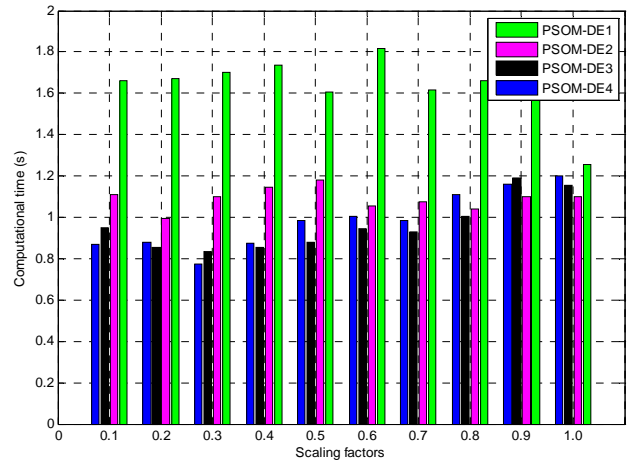


Fig.4 variation of scaling factors versus computational time.

TABLE II  
PERFORMANCE PARAMETERS COMPARISON

Methods	Cost (\$/h)			Average CPU time (s)	Standard deviation
	Min.	Average.	Max.		
GA [2]	15 459.00	15 469.00	15 469.00	41.58	-
PSO [2]	15 450.00	15 454.00	15 492.00	14.86	-
CPSO [3]	15 446.00	15 449.00	15 490.00	8.13	-
AIS [4]	15 448.00	15 459.70	15 472.00	NA	-
MTS [5]	15 450.06	15 451.17	15 453.64	5.98	0.93
TSA	15 449.20	15 495.82	15 632.14	18.97	35.10
BA	15 445.87	15 448.83	15 452.92	5.64	1.56
PSO	15 446.06	15 450.35	15 463.19	2.06	2.88
GA	15 446.55	15 451.55	15 480.94	25.31	5.47
PSO-DE1	15 444.79	15 448.07	15 453.78	1.26	1.57
PSO-DE2	15 444.45	15 448.07	15 449.98	0.99	1.45
PSO-DE3	15 444.93	15 447.93	15 453.32	0.84	1.43
PSO-DE4	15 444.88	15 448.03	15 449.94	0.78	1.47

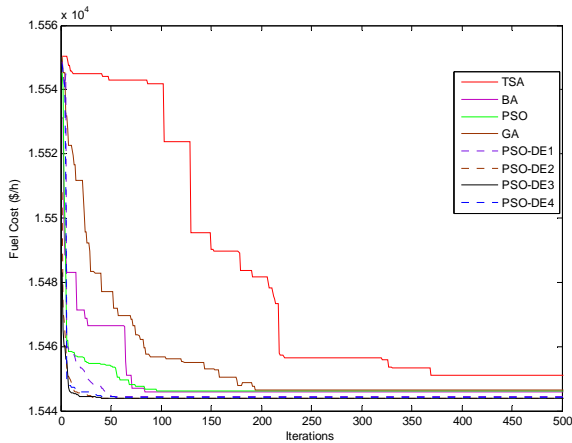


Fig.5 convergences characteristic of each method.

Table II shows the effectiveness in term of the solution quality among 100 trials of proposed methods. The solutions of the proposed methods higher quality than the rest methods in term of minimum cost, average cost, maximum cost, computational time and solution deviation. Fig. 1 shows the profiles of the solutions obtained from running of 100 different trials of the proposed approaches. This paper demonstrates the tuning of scaling factors. Fig. 2 shows the variation of scaling factors from 0.1 to 1.0 versus generation cost. Fig. 3 shows the effect of scaling factor to standard deviation of generation cost. Fig. 4 demonstrates the computation time depend on the scaling factors. Fig. 5 demonstrates the convergences of each proposed methods compared with TSA, BA, PSO and GA.

## V. CONCLUSIONS

The developments of the original PSO for solving the ED problem with the generator constraints by using mutation operators are presented. Ones scenario will have been

activated if particle's velocity slides out of boundary or nearly to zero. The effectiveness of the proposed approaches

is compared with other approaches such as PSO, TSA, GA, BA and methods reported in literatures. The results show that PSO-DEs' had the best solutions quality in term of minimum generation cost and mean generation cost. The proposed approaches can converge to the minimum generation cost faster than the rest approaches.

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