# Solving Dynamic Economic Dispatch With Modified PSO Algorithm Considering Valve Point Effects And Ramp Rate Limits

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**Abstract: The practical dynamic economic dispatch (DED), with consideration of valve-point effects, and ramp up, ramp down generators constraints considered as a complicated non-linear constrained optimization problem. In this paper, a new variant swarm optimization based time varying acceleration (PSO-TVAC) proposed to solve this problem. This algorithm has been compared and found to be superior compared to the results of classical (PSO) and (GA) method in term of solution quality and convergence characteristic.**

**Key words:** Dynamic economic dispatch, Non-smooth cost function, PSO-TVAC, GA, Valve point effect, Ramp rate limits.

## 1. Introduction

Dynamic economic dispatch (DED) is one of the important power system optimization problems which is a non-linear and complicated dynamic optimization problem. (DED) is a method to dispatch the generating units to the predicted load demands over a certain period of time at minimum operating cost while satisfying equality and inequality constraints[1-2]. There were many methods applied to solve the dynamic economic dispatch, such as dynamic programming [3], linear programming [4], Lagrange relaxation method [5], but the nonlinearity and discontinuity of the search space makes all these methods enable to obtain the optimal solution and these method leads to suboptimal solution [6].

New techniques are being used in the last years to tackle the (DED) problem in a more efficient and quality convergence. A lot of works are studied and reported in literature, recently evolutionary algorithm is applied by G. Ching et al. to solve dynamic economic dispatch with energy saving and emission reduction [7]. Ivatloo et al. proposed time varying acceleration coefficients IPSO for solving dynamic economic dispatch with non-smooth cost function [6.]

A group search optimizer with multiple producers algorithm is treated by C.X. Guo et al. to solve the dynamic economic emission dispatch problem [8].The artificial immune system algorithm is proposed by S. Hemamalini et al. to solve the dynamic economic dispatch for units with valve point effect [2]. A hybrid algorithm approach based on sequential combination of (GA) and active power optimization using Newton's second order approach is presented by T. Nadeem Malik et al to solve economic dispatch problem with valve point effect [9]. The Hopfield neural network method is applied too by A.Y. Abdelaziz et al to solve this problem [10]. Mahdad and Srairi [18] proposed a combined method based GA-DE-PS to solve practical economic dispatch considering power losses and valve point effects.

It can be seen that recently the meta-heuristic optimization methods have been significantly used in (ED) and considered as an alternative to the classical methods, primarily due to theirs nice feature of population-based search. Particle swarm optimization is such a technique. We adopt PSO to handle the complexity and nonlinearity of the problem [11-12]. PSO has several key advantages over other existing optimization techniques in terms of simplicity, convergence speed, and robustness [11-13]. PSO is easy to implement in computer simulations using basic mathematical and logic operations, since its working mechanism only involves two fundamental updating rules. PSO also has fewer operators to adjust in the implementation, and it can be flexibly combined with other optimization techniques to build hybrid algorithms [11-14-15].

The mechanism of PSO facilitates a better convergence performance than some other optimization procedures like genetic algorithms, which have computationally expensive evolutionary operations such as crossover and mutation [11]. Unlike the traditional optimization algorithms, PSO is a derivative-free algorithm and thus it is especially effective in dealing with complex and nonlinear problems. PSO is more robust to deal with such problems, since it is less sensitive to the nature of the objective function in terms of convexity and continuity [16], and the inner working of PSO helps to escape local minima. The robustness of PSO can also be reflected by its less sensitivity to the optimizer parameters as well as the initial solutions to start its iteration process [11].

In this paper, a novel Time Varying Acceleration particle swarm optimization (PSO-TVAC) algorithm is proposed to deal with the dynamic economic dispatch problem without considering losses. The effectiveness of the proposed approach is demonstrated on a practical electrical network test system using 5 and 10 unit test system.

## 2. Problem Formulations

*2.1 Objective Function*

The objective function of (DED) problem is to minimize the total production cost over the operation period, which can be written as :

$$minTC = \sum_{t=1}^{T}\sum_{i=1}^{ng} C_{it}(P_{it}) \qquad (1)$$

Where $C_{it}$ is the unit i production cost at time t; $ng$ is the number of generation units and $P_{it}$ is the power output of $it$ unit at time t. T is the total number of hours in the operation period. The cost function is nonlinear characteristic which represented by the following formula:

$$F(p_{it}) = \sum_{i=1}^{ng} a_i + b_i p_{it} + c_i p_{it}^2 + \left| e_i + sin( f_i( p_{it}^{min} - p_{it} )) \right| \qquad (2)$$

$a_i, b_i, c_i, e_i,$ and $f$ Cost generators coefficients. The objective function of the (DED) problem should be minimized subject to following equality and inequality constraints:

A. *The equality constraints are*

$$\sum_{i=1}^{ng} p_{it} = p_d(t) \qquad t = 1.2.3.......T \qquad (3)$$

,

B. *Inequality constraints:*

$$p^{min}_{i,t} \le p_{i,t} \le p^{max}_{i,t} \quad \text{Which: i=1:ng ,} \qquad (4)$$

$p_i^{min}, p_i^{max}$ are the maximum and the minimum of unit's production.

## 3. Particle swarm optimization with time varying acceleration coefficients PSO-TVAC

In this new algorithm based (PSO) the cognitive and social factors are not constant but they are function of generation (time) to explore most all the positions space research due eliminate the local minima , overcome the non linearity of the equation (2), so it represent then an challenge advantage. The position and velocity of the ith particle are modeled by the following equations

$$\begin{cases} v(t+1) = w*v(t) + \alpha_1 * rand_1 * (P_i - x(t)) \\ \qquad + \alpha_2 * rand_2 * (P_b - X(t)) \\ x(t+1) = x(t) + v(t+1) \end{cases} \quad (5)$$

$$\begin{cases} \alpha_1 = ((c_{1f} - c_{1i}).iter / iter_{max}) + c_{1i} \\ \alpha_2 = ((c_{2f} - c_{2i}).iter / iter_{max}) + c_{2i} \end{cases} \quad (6)$$

Where: $x(t)$ is the Particle initial position, $v(t)$ is Particle initial velocity, $v(t+1)$ is new particle velocity, $x(t+1)$ : A new particle position, $P_i$ : Best local solution, $P_b$ : Best global solution, $w$ : Inertia factor, $iter$ Iteration number, $iter_{max}$ : Maximum iteration number, and $0.4 \le w \le 0.9$, $\alpha_1, \alpha_2, w$ are respectively cognitive, Social, and inertia factors. $C_{1i}, C_{1f}, C_{2i}, C_{2f}$ initial and final values of cognitive and social factors [17].

### *5.1 Algorithms parameters*

1. GA: binary genetic algorithm, the population size; selection and the maximum of iteration are set respectively 16; 50%, 100.The crossover and the mutation set respectively 0.5; 0.15.
2. PSO: standard (PSO), the population size; and the maximum of iteration are set respectively 16; 100. The coefficients of the equation (5) are constants $\alpha_1 = \alpha_2 = w = 1$
3. PSO-TVAC: the population size; and the maximum of iteration are set respectively 16; 100.

The algorithm of optimization is based on the following steps:

Step 1: Initialized of the Population.

Step 2: Evaluation of the mechanism search of PSO-TVAC:

1-Velocity equation

2-Position equation

Step 3: if iter< itermax return to the Step 2.

Step 4: stock the best cost and their optimal unit generation.

## 5. Simulation results:

*Test system 1*

First we are applied the proposed approach at 5 unit test system, the cost coefficients, generators limits and load demand in each hour are taken from [6] and depicted in appendix. Table. 1 shows the optimal power generation obtained without considering ramp rate limits. Table. 3 shows the optimal power generation obtained considering ramp rate limits. Table. 2, table.4 represent a comparison between GA, PSO and the proposed algorithm in each case respectively.

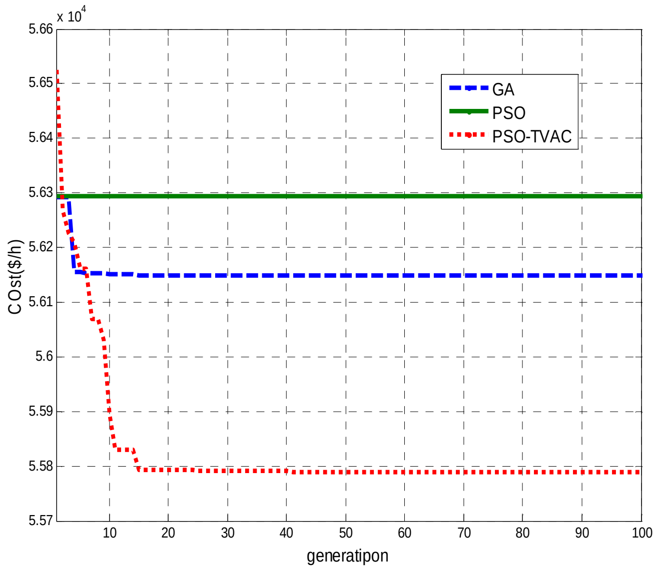


**Fig.1 Convergence characteristic of GA; PSO and PSO-TVAC for 5 unit test system without considering ramp rate limits.**

*Test system 2*

To verify the robustness of the proposed approach the algorithm has been applied on a large scale network 10 unit test system. All generators data are taken from [6].

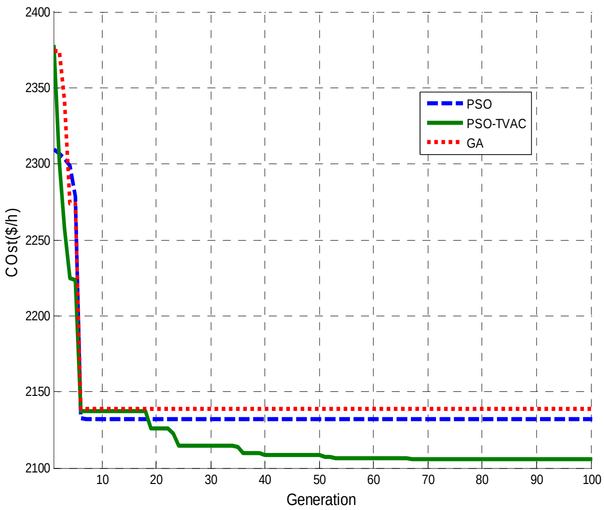


**Fig.2 Convergence characteristic of GA, PSO and PSO-TVAC for 10 units test system considering ramp rate limits**

Table. 5 shows the optimal power generation obtained in ten execution solution of dynamic economic dispatch without considering ramp rate limits. Table.7 shows the optimal power generation obtained considering ramp rate limits. Table. 6 and Table. 8 illustrate a comparison between GA, PSO and the proposed algorithm in each case respectively.

Fig. 1 show the characteristic convergence of the three algorithms for solving the dynamic economic dispatch of 5 units test system without considering ramp rate limits for active power demand equal 710 MW. Fig 2 shows the optimal solution calculated by the three algorithms for 10 unit test system considering ramp rate limits when the active power demand set 2131MW. The best cost found by the proposed new variant (PSO-TVAC) is better in

**Table 1. Optimal solution of 5 unit considering valve point effect without Ramp rate limits based PSO-TVAC**

two cases (5 and 10 units) than the optimum value found using PSO and GA in term of solution quality and execution time.

| *Time* | *Pg1* | *Pg2* | *Pg3* | *Pg4* | *Pg5* | *Cost($)* |
|---|---|---|---|---|---|---|
| 1 | 10 | 20 | 30 | 120.48 | 229.52 | 1244.1 |
| 2 | 30.571 | 20.002 | 30 | 124.91 | 229.52 | 1348.5 |
| 3 | 10 | 87.66 | 112.67 | 124.91 | 139.76 | 1403.8 |
| 4 | 40.665 | 20 | 30 | 209.82 | 229.52 | 1592.7 |
| 5 | 10 | 81.118 | 112.68 | 124.79 | 229.41 | 1632 |
| 6 | 35.991 | 20 | 112.67 | 209.82 | 229.52 | 1760.9 |
| 7 | 60.359 | 98.54 | 112.67 | 124.91 | 229.52 | 1796.3 |
| 8 | 10 | 91.993 | 112.67 | 209.82 | 229.52 | 1800.7 |
| 9 | 39.451 | 98.54 | 112.67 | 209.82 | 229.52 | 1945 |
| 10 | 53.452 | 98.539 | 112.67 | 209.82 | 229.52 | 1985.7 |
| 11 | 10 | 95.794 | 174.87 | 209.82 | 229.52 | 2053.2 |
| 12 | 75 | 112.99 | 112.67 | 209.82 | 229.52 | 2105.8 |
| 13 | 53.45 | 98.54 | 112.67 | 209.82 | 229.52 | 1985.7 |
| 14 | 12.991 | 125 | 112.67 | 209.82 | 229.52 | 1986.4 |
| 15 | 10 | 91.992 | 112.67 | 209.82 | 229.52 | 1800.7 |
| 16 | 10 | 20 | 110.66 | 209.82 | 229.52 | 1618.1 |
| 17 | 10 | 85.752 | 112.67 | 209.81 | 139.76 | 1607.1 |
| 18 | 35.991 | 20 | 112.67 | 209.82 | 229.52 | 1760.9 |
| 19 | 10 | 91.993 | 112.67 | 209.82 | 229.52 | 1800.7 |
| 20 | 53.452 | 98.54 | 112.67 | 209.82 | 229.52 | 1985.7 |
| 21 | 29.45 | 98.541 | 112.67 | 209.81 | 229.52 | 1897.9 |
| 22 | 44.211 | 98.54 | 112.67 | 209.82 | 139.76 | 1751 |
| 23 | 37.665 | 20 | 30 | 209.82 | 229.52 | 1580.5 |
| 24 | 58.572 | 20 | 30 | 124.91 | 229.52 | 1437.6 |

**Table 2. Comparison of optimization results: 5 units with valve point effect.**

| *Total cost* | *GA* | *PSO* | *PSOTVAC* |
|---|---|---|---|
| Min | 42905 | 43640 | 41881 |
| Mean | 43027 | 43962 | 42054 |
| Max | 43256 | 44478 | 42190 |
| Time (s) | 2.494 | 2.191 | 2.120 |

**Table 3. Optimal solution of 5 unit considering valve point effect with Ramp rate limits based PSO-TVAC**

| *Time* | *Pg1* | *Pg2* | *Pg3* | *Pg4* | *Pg5* | *Cost($)* |
|---|---|---|---|---|---|---|
| *1* | *10* | *20* | *30* | *120.48* | *229.52* | *1244.1* |
| 2 | 30.573 | 20 | 30 | 124.91 | 229.52 | 1348.5 |
| 3 | 20.573 | 20 | 30 | 174.91 | 229.52 | 1579.4 |
| 4 | 10.665 | 50 | 30 | 209.82 | 229.52 | 1617.9 |
| 5 | 10 | 78.665 | 30 | 209.82 | 229.52 | 1645.8 |
| 6 | 40 | 98.665 | 30 | 209.82 | 229.52 | 1760.4 |
| 7 | 18.125 | 98.54 | 70 | 209.82 | 229.52 | 1892.3 |
| 8 | 10 | 94.665 | 110 | 209.82 | 229.52 | 1802.3 |
| 9 | 39.451 | 98.54 | 112.67 | 209.82 | 229.52 | 1945 |
| 10 | 53.451 | 98.54 | 112.67 | 209.82 | 229.52 | 1985.7 |
| 11 | 69.452 | 98.54 | 112.67 | 209.82 | 229.52 | 1996.7 |
| 12 | 75 | 112.99 | 112.67 | 209.82 | 229.52 | 2105.8 |
| 13 | 53.451 | 98.54 | 112.67 | 209.82 | 229.52 | 1985.7 |
| 14 | 39.451 | 98.54 | 112.67 | 209.82 | 229.52 | 1945 |
| 15 | 10 | 91.991 | 112.67 | 209.82 | 229.52 | 1800.7 |
| 16 | 10 | 61.991 | 72.673 | 205.82 | 229.52 | 1919.5 |
| 17 | 10 | 75.991 | 32.673 | 209.82 | 229.52 | 1671.7 |
| 18 | 10 | 98.54 | 60.125 | 209.82 | 229.52 | 1804.4 |
| 19 | 16 | 98.54 | 100.12 | 209.82 | 229.52 | 1862 |
| 20 | 46 | 105.99 | 112.67 | 209.82 | 229.52 | 2027 |
| 21 | 29.45 | 98.541 | 112.67 | 209.82 | 229.52 | 1897.9 |
| 22 | 10 | 82.991 | 72.674 | 209.82 | 229.52 | 1892 |
| 23 | 10 | 52.991 | 32.674 | 201.82 | 229.52 | 1680.4 |
| 24 | 10 | 22.991 | 30 | 170.49 | 229.52 | 1530.6 |

**Table 4. Comparison of optimization results: 5 units with valve point effect and ramp rate limits**

| *Total cost* | *GA* | *PSO* | *PSOTVAC* |
|---|---|---|---|
| Min | 43708 | 44525 | 42941 |
| Mean | 44207 | 44960 | 44260 |
| Max | 44693 | 45296 | 44821 |
| Time (s) | 24.555 | 21.467 | 19.725 |

**Table 5. Optimal solution of 10 units considering valve point effect without ramp rate limits based PSO-TVAC**

| time | Pg1 | Pg2 | Pg3 | Pg4 | Pg5 | Pg6 | Pg7 | Pg8 | Pg9 | Pg10 | Cost($) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 150 | 135 | 206 | 60 | 73 | 160 | 130 | 47 | 20 | 55 | 28120 |
| 2 | 150 | 135 | 280.15 | 60 | 73 | 160 | 129.85 | 47 | 20 | 55 | 29602 |
| 3 | 150 | 135 | 337.91 | 60 | 163.48 | 159.61 | 130 | 47 | 20 | 55 | 32794 |
| 4 | 216.99 | 135 | 340 | 60 | 243 | 160 | 129.01 | 47 | 20 | 55 | 36100 |
| 5 | 150 | 285.4 | 340 | 60 | 232.6 | 160 | 130 | 47 | 20 | 55 | 37621 |
| 6 | 150.39 | 433.41 | 340 | 60 | 232.59 | 159.6 | 130 | 47 | 20 | 55 | 40767 |
| 7 | 266.12 | 456.07 | 340 | 60 | 167.81 | 160 | 130 | 47 | 20 | 55 | 42406 |
| 8 | 315.95 | 460 | 340 | 60 | 188.05 | 160 | 130 | 47 | 20 | 55 | 44025 |
| 9 | 420.73 | 460 | 340 | 60 | 231.28 | 160 | 130 | 47 | 20 | 55 | 47257 |
| 10 | 464.94 | 460 | 340 | 152.68 | 242.52 | 159.86 | 130 | 47 | 20 | 55 | 50695 |
| 11 | 469.7 | 460 | 340 | 151.23 | 240.07 | 160 | 130 | 120 | 20 | 55 | 52512 |
| 12 | 465.26 | 460 | 340 | 300 | 243 | 160 | 129.74 | 47 | 20 | 55 | 54358 |
| 13 | 466 | 460 | 340 | 137.6 | 243 | 160 | 130 | 60.399 | 20 | 55 | 50742 |
| 14 | 454.34 | 460 | 340 | 60 | 197.66 | 160 | 130 | 47 | 20 | 55 | 47271 |
| 15 | 436.98 | 460 | 333.83 | 60 | 73.185 | 160 | 130 | 47 | 20 | 55 | 44026 |
| 16 | 150 | 352.32 | 340 | 60 | 240.14 | 159.54 | 130 | 47 | 20 | 55 | 39181 |
| 17 | 150 | 411.34 | 340 | 60 | 109 | 157.66 | 130 | 47 | 20 | 55 | 37537 |
| 18 | 158.91 | 460 | 338.11 | 60 | 198.98 | 160 | 130 | 47 | 20 | 55 | 40788 |
| 19 | 430.94 | 460 | 340 | 60 | 73.063 | 160 | 130 | 47 | 20 | 55 | 44036 |
| 20 | 469.07 | 460 | 340 | 147.09 | 243 | 159.92 | 129.96 | 47.962 | 20 | 55 | 50712 |
| 21 | 432.35 | 460 | 340 | 60 | 219.65 | 160 | 130 | 47 | 20 | 55 | 47270 |
| 22 | 150 | 423.95 | 339.72 | 60 | 242.33 | 160 | 130 | 47 | 20 | 55 | 40780 |
| 23 | 150 | 298.09 | 340 | 60 | 73 | 158.91 | 130 | 47 | 20 | 55 | 34339 |
| 24 | 165.83 | 135 | 340 | 60 | 73 | 158.54 | 129.64 | 47 | 20 | 55 | 31165 |

**Table 6. Comparison of optimization results: 10 units with valve point effect**

| *Total cost* | *GA* | *PSO* | *PSOTVAC* |
|---|---|---|---|
| Min | 1006400 | 1005500 | 1004100 |
| Mean | 1006600 | 1006000 | 1004400 |
| Max | 1006800 | 1006300 | 1004900 |
| Time (s) | 2.6622 | 1.9937 | 2.0423 |

**Table 7. Optimal solution of 10 units considering valve point effect with ramp rate limits based PSO-TVAC**

| *time* | *Pg1* | *Pg2* | *Pg3* | *Pg4* | *Pg5* | *Pg6* | *Pg7* | *Pg8* | *Pg9* | *Pg10* | *Cost($)* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 150 | 135 | 205.24 | 60 | 73 | 122.45 | 130 | 85.312 | 20 | 55 | 28410 |
| 2 | 150 | 135 | 229.37 | 60 | 122.87 | 122.45 | 130 | 85.312 | 20 | 55 | 30134 |
| 3 | 226.63 | 215 | 190.77 | 60 | 122.87 | 122.45 | 129.96 | 115.31 | 20 | 55 | 33535 |
| 4 | 303.25 | 295 | 185.2 | 110 | 73 | 149.65 | 129.59 | 85.312 | 20 | 55 | 36977 |
| 5 | 379.87 | 375 | 179.78 | 60 | 73 | 122.45 | 129.59 | 85.312 | 20 | 55 | 38307 |
| 6 | 456.5 | 396.8 | 179.01 | 60 | 122.93 | 122.45 | 130 | 85.313 | 20 | 55 | 41132 |
| 7 | 456.49 | 396.8 | 200.64 | 110 | 122.87 | 125 | 129.88 | 85.313 | 20 | 55 | 43076 |
| 8 | 456.5 | 396.8 | 186.83 | 120.52 | 172.87 | 122.46 | 130 | 85.311 | 49.706 | 55 | 44673 |
| 9 | 456.49 | 460 | 251.58 | 120.29 | 222.87 | 122.45 | 130 | 85.312 | 20 | 55 | 48370 |
| 10 | 456.5 | 460 | 331.58 | 121.01 | 222.6 | 160 | 130 | 115.31 | 20 | 55 | 51939 |
| 11 | 456.5 | 460 | 340 | 171.01 | 233.9 | 160 | 129.59 | 120 | 20 | 55 | 53890 |
| 12 | 470 | 460 | 340 | 221.01 | 243 | 160 | 130 | 120 | 20.992 | 55 | 56084 |
| 13 | 456.5 | 396.8 | 329.28 | 180.83 | 222.6 | 160 | 130 | 90 | 50.992 | 55 | 51666 |
| 14 | 456.5 | 396.8 | 303.18 | 130.83 | 222.6 | 122.79 | 130 | 85.314 | 20.992 | 55 | 47814 |
| 15 | 379.87 | 396.8 | 300.9 | 80.83 | 172.73 | 123.57 | 130 | 85.312 | 50.992 | 55 | 44713 |
| 16 | 303.25 | 316.8 | 297.4 | 60 | 172.73 | 142.52 | 130 | 55.312 | 20.992 | 55 | 39888 |
| 17 | 226.62 | 309.53 | 317.15 | 60 | 122.94 | 122.45 | 130 | 85.312 | 50.992 | 55 | 38113 |
| 18 | 303.25 | 389.53 | 288.52 | 60 | 172.94 | 122.45 | 130 | 85.312 | 20.992 | 55 | 41238 |
| 19 | 379.88 | 396.81 | 302.11 | 60 | 222.94 | 123.95 | 130 | 85.316 | 20 | 55 | 44266 |
| 20 | 459.88 | 460 | 340 | 110 | 243 | 160 | 130 | 85.312 | 28.812 | 55 | 52352 |
| 21 | 456.5 | 396.81 | 337.82 | 60 | 222.56 | 160 | 130 | 85.312 | 20.002 | 55 | 47863 |
| 22 | 379.87 | 316.81 | 257.82 | 60 | 172.73 | 150.46 | 130 | 85.312 | 20 | 55 | 41664 |
| 23 | 303.25 | 236.82 | 196.29 | 60 | 122.88 | 122.45 | 130 | 85.312 | 20 | 55 | 35043 |
| 24 | 226.62 | 222.27 | 182.21 | 60 | 73 | 160 | 129.59 | 55.312 | 20 | 55 | 31766 |

**Table 8. Comparison of optimization results: 10 units with valve point effect and ramp rate limits**

| *Total cost* | *GA* | *PSO* | *PSOTVAC* |
|---|---|---|---|
| Min | 1029100 | 1027900 | 1022900 |
| Mean | 1030100 | 1030700 | 1025400 |
| Max | 1031600 | 1032800 | 1027600 |
| Time (s) | 4.0966 | 2.691 | 2.632 |

## 6. Conclusion

In this paper, the non-convex dynamic ED problem with valve-point effects and ramp rate limits was solved using new variant based PSO called (PSO-TVAC). To validate the proposed new variant, 5 units and 10 units with practical generator units were considered. Compared with the standard previous approaches such as: GA and PSO, the results showed the effectiveness of the PSO-TVAC algorithm in terms of high-quality solution convergence and good computation efficiency.

## . Appendix

***Data of generators coefficients for 5 units test system***

| *ng* | *a* | *b* | *c* | *e* |
|---|---|---|---|---|
| 1 | 0.0080 | 2.0000 | 25.0000 | 100.0000 |
| 2 | 0.0030 | 1.8000 | 60.0000 | 140.0000 |
| 3 | 0.0012 | 2.1000 | 100.0000 | 160.0000 |
| 4 | 0.0010 | 2.0000 | 120.0000 | 180.0000 |
| 5 | 0.0015 | 1.8000 | 40.0000 | 200.0000 |

| *ng* | *f* | $p^{min}$ | $p^{max}$ | *UR* | *DR* |
|---|---|---|---|---|---|
| 1 | 0.0420 | 10 | 75 | 30 | 30 |
| 2 | 0.0400 | 20 | 125 | 30 | 30 |
| 3 | 0.0380 | 30 | 175 | 40 | 40 |
| 4 | 0.0370 | 40 | 250 | 50 | 50 |
| 5 | 0.0350 | 50 | 300 | 50 | 50 |

***Hourly demand for 5 unit test system***

| *hour* | *load* | *Hour* | *load* |
|---|---|---|---|
| 1 | 410 | 13 | 704 |
| 2 | 435 | 14 | 690 |
| 3 | 475 | 15 | 654 |
| 4 | 530 | 16 | 580 |
| 5 | 558 | 17 | 558 |
| 6 | 608 | 18 | 608 |
| 7 | 626 | 19 | 654 |
| 8 | 654 | 20 | 704 |
| 9 | 690 | 21 | 680 |
| 10 | 704 | 22 | 605 |
| 11 | 720 | 23 | 527 |
| 12 | 740 | 24 | 463 |

***Data of generators coefficients for 10 unit test system***

| *ng* | *a* | *b* | *c* | *e* |
|---|---|---|---|---|
| 1 | 0.00043 | 21.6 | 958.2 | 450 |
| 2 | 0.00063 | 21.05 | 1313.6 | 600 |
| 3 | 0.00039 | 20.81 | 604.97 | 320 |
| 4 | 0.0007 | 23.9 | 471.6 | 260 |
| 5 | 0.00079 | 21.62 | 480.29 | 280 |
| 6 | 0.00056 | 17.87 | 601.75 | 310 |
| 7 | 0.00211 | 16.51 | 502.7 | 300 |
| 8 | 0.0048 | 23.23 | 639.4 | 340 |
| 9 | 0.10908 | 19.58 | 455.6 | 270 |
| 10 | 0.00951 | 22.54 | 692.4 | 380 |

| *ng* | *f* | $p^{min}$ | $p^{max}$ | *UR* | *DR* |
|---|---|---|---|---|---|
| 1 | 0.041 | 150 | 470 | 80 | 80 |
| 2 | 0.036 | 135 | 460 | 80 | 80 |
| 3 | 0.028 | 73 | 340 | 80 | 80 |
| 4 | 0.052 | 60 | 300 | 50 | 50 |
| 5 | 0.063 | 73 | 243 | 50 | 50 |
| 6 | 0.048 | 57 | 160 | 50 | 50 |
| 7 | 0.086 | 20 | 130 | 30 | 30 |
| 8 | 0.082 | 47 | 120 | 30 | 30 |
| 9 | 0.098 | 20 | 80 | 30 | 30 |
| 10 | 0.094 | 55 | 55 | 30 | 30 |

***Hourly demand for 10 unit test system***

| *hour* | *load* | *hour* | *load* |
|---|---|---|---|
| 1 | 1036 | 13 | 2072 |
| 2 | 1110 | 14 | 1924 |
| 3 | 1258 | 15 | 1776 |
| 4 | 1406 | 16 | 1554 |
| 5 | 1480 | 17 | 1480 |
| 6 | 1628 | 18 | 1628 |
| 7 | 1702 | 19 | 1776 |
| 8 | 1776 | 20 | 2072 |
| 9 | 1924 | 21 | 1924 |
| 10 | 2072 | 22 | 1628 |
| 11 | 2146 | 23 | 1332 |
| 12 | 2220 | 24 | 1184 |

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