Economic Dispatch with Valve Point Effect using Iteration Particle Swarm Optimization

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***Abstract*- Economic dispatch (ED) is one of the optimization problems in power system operation and planning. The practical ED problems have non-smooth cost functions with equality and inequality constraints. It becomes more complicated problem when valve point effects of generator are considered and results multiple local minima. This makes the ED problems are difficult to find global optimum solution when using any mathematical approach due to non-convex cost function. The Classical particle swarm optimization (PSO) has ability to reach near global optimum solution by tuning some parameters but always stuck at local minima. In this paper, an iteration particle swarm optimization (IPSO) is proposed to solve ED problems with valve point effects. The proposed algorithm is introduced a new parameter in the original velocity equation of PSO in order to enrich searching behaviour, solution quality and avoid being trapped at local minima. The proposed IPSO algorithm has been implemented on two test power systems (consisting 3 and 13 generating units) to validate its effectiveness. The simulation results confirmed that IPSO algorithm has better convergence characteristic and more robust compared to PSO and some published results.**

***Index Terms*-- Economic dispatch, constraints handling, particle swarm optimization, valve point effect.**

I. INTRODUCTION

The operation cost of power system has becomes an important issues due to increase power demand and fuel cost. One of the options is to operate the committed generator units efficiently and economically based on economic dispatch (ED) optimization. The main objective of ED problem is to allocate power demand among scheduled generator at minimum cost while satisfying all the generator and system constraints [1, 2].

Different methods have been developed to solve ED problem in past few decade. Traditional algorithm such as lambda iteration, gradient method, Newton method, linear programming [3] and quadratic programming [4] has been implemented to solve ED problems. However, most of these methods are not capable of solving ED problem with non-convex and highly nonlinear solution space [5]. The practical ED problem with valve point effect, prohibited operating zone, multifuel options and ramp rate limit represent non-smooth or non-convex optimization problem (with equality and inequality constraints). This makes the finding of global optimum difficult and cannot be solve by traditional methods.

Modern heuristic optimization methods are proposed by researcher based on artificial intelligence concepts such as evolutionary programming [6], genetic algorithm [7], simulated annealing, ant colony optimization [8], tabu search [9], artificial immune system [10] and particle swarm optimization [1, 11]. These methods do not always guarantee to find global best solution but they often achieve a fast and near global optimum solution.

Among these methods, PSO is widely implemented in ED problem due to simple implementation, less storage requirement and able to find global optimum solution. PSO is also capable to solve nonlinear and complex problems because it is a free derivative algorithm. However, premature convergence always occurs in classical PSO and results to local solution.

In this paper, an iteration particle swarm optimization (IPSO) is proposed to solve economic dispatch problem considering valve point effects. A new parameter is introduced into velocity equation of IPSO algorithm that can enhance exploration capability, improve solution quality and avoid premature convergence. Two test power systems are employed (3 and 13 unit systems) to verify the performance of IPSO as compared to PSO. Furthermore, results obtained by IPSO and PSO are compared with other methods reported in literature. For the ED problem, simulation results show that the IPSO method has better convergence property with lowest generation cost and more robust compared to PSO method.

The paper organized as follows. Section II presents the mathematical model of economic dispatch problems. Section III briefly reviews the concept of PSO and IPSO methods. Section IV discusses the detailed implementation of IPSO method to solve ED problems. Section V shows the simulation results on two test system and compared with classical PSO and published results. Finally, the conclusions are drawn in section VI.

II. PROBLEM FORMULATION

The economic dispatch problem is about minimizing the total generation cost of thermal generator while satisfying equality and inequality constraints. The objective function corresponding to the fuel cost production can represent as follow:

$$\text{Minimize } F_t = \sum_{i=1}^{Ng} F_i(P_i) \quad i=1,2,\ldots,Ng \tag{1}$$

Where,
F_t = total cost production
F_i = fuel cost for generator i

The generation cost for generator is usually approximated by a second order quadratic function as:

$$F_i(P_i) = \sum_{i=1}^{Ng} a_i P_i^2 + b_i P_i + c_i \quad (2)$$

Where a_i, b_i and c_i are cost function coefficients of i-th generating unit, N_g is Number of committed generators and P_i is the real power output of generator i.

In this paper, valve point effect is considered as practical operation constraint of generators. The valve point effect introduce ripple in the heat rate function and make the fuel cost function highly non-linear, discontinuous and having multiple local optimum [1]. A second order quadratic cost function is added with rectified sinusoidal equation for accurate modeling of generator cost function considering valve point effect as follows:

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left| e_e \sin(f_f (P_i^{\min} - P_i)) \right| \quad (3)$$

Where, e_i and f_i are the coefficient of generator i with valve point effects.

There are two types of constraint involve in ED problems that must be satisfied throughout the optimization process as follows:

i. *Equality constraint:*
In ED problem, equality constraint is the total generated power must be equal to load demand and system losses.

$$\sum_{i=1}^{Ng} P_i = P_D + P_L \quad (4)$$

Where P_D and P_L are total load demand and total system loss. Total system loss can be calculated by using B-coefficient as follow:

$$P_L = \sum_{i=1}^{Ng} \sum_{j=1}^{Ng} P_i B_{ij} P_j + \sum_{i=1}^{Ng} B_{0i} P_i + B_{00} \quad (5)$$

Where, B_{ij}, B_{0i} and B_{00} are transmission loss coefficients. However, transmission loss is not considered in this paper (P_L=0).

ii. *Inequality constraints:*
The real power output of each generating unit must vary between lower and upper limits as given by:

$$P_i^{\min} \le P_i \le P_i^{\max} \quad (6)$$

Where $P_i^{\min}$ and $P_i^{\max}$ are minimum and maximum limit for power output of the i-th generating unit.

III. Review of PSO and IPSO

A. Particle swarm optimization (PSO)

In 1995, Kennedy and Eberhart developed a PSO algorithm based on the social behaviour of organisms such as fish schooling and bird flocking [12]. The PSO algorithm is based on the group of individual to find the optimum solution. An individual in swarm approaches to the optimum through the previous experience, present velocity and experience of its neighbours.

Let X and V are the particle or position and velocity in a d dimension search space. Position represents the objective variable in optimization problem and velocity is the step size particle to move in the next iteration. The i particle is represented as $X_i=(X_{i1}, X_{i2},..., X_{id})$ in the d dimensional searching space. The best position of the i particle is stored and represented as $pbest_i=(pbest_{i1}, pbest_{i2},..., pbest_{id})$. The best particle among all particles in the group is recorded as $gbest_d$. The velocity of the i particle is updated using the following formula:

$$V_{id}^{j+1} = wV_{id}^j + c_1 r_1 (pbest_{id}^j - X_{id}^j) + c_2 r_2 (gbest_d^j - X_{id}^j) \quad (7)$$

And the position is updated as follows:

$$X_{id}^{j+1} = X_{id}^j + V_{id}^{j+1} \quad (8)$$

Where,
V_{id}^{j+1} = the updated velocity of particle i in dimension d
w = inertia weight factor
V_{id}^j = velocity of particle i at iteration j
c_1, c_2 = acceleration coefficients
r_1, r_2 = random number [0,1]
X_{id}^{j+1} = update position of particle i in dimension d
X_{id}^j = position of particle i at iteration j

The inertia weight factor (w) is used to increase the rate of convergence speed of the PSO algorithm based on descending linear function. The best range for w is between 0.9 and 0.4 implemented using following equation [13]:

$$w = w_{\max} - \left(\frac{w_{\max} - w_{\min}}{iter_{\max}} \right) \times iter \quad (9)$$

Where w_{max} and w_{min} are maximum and minimum value of weighting factor respectively, *iter* is the current iteration and $iter_{max}$ is the maximum number of iteration.

B. Iteration particle swarm optimization (IPSO)

In order to improve the solution quality of PSO, a new index named 'iteration best' is incorporated in (7) and employed in this paper. The updated velocity of proposed IPSO method is computed as follows:

$$V_{id}^{j+1} = wV_{id}^{j} + c_2 r_1 (pbest_{id}^{j} - X_{id}^{j}) + c_2 r_2 (gbest_{d}^{j} - X_{id}^{j}) + c_3 r_3 (I_{best,d}^{j} - X_{id}^{j}) \quad (10)$$

Where $I_{best,d}$ is the best value of fitness function that has been obtained by any particle in iteration *j* and c_3 is represents the weighting of the stochastic acceleration term to pull each particle towards I_{best} [14] as follow:

$$c_3 = c_1 \times (1 - \exp(-c_1 \times iter)) \quad (11)$$

To evaluate performance of IPSO comparing with PSO, a mathematical test function has been performed. The main purposed of this analysis is to minimize the function (12) with multiple local points. Where the global minimum value is $f(x,y)$=-18.55 reported in [15].

$$f(x,y) = x\sin(4x) + 1.1y\sin(2y) \quad 0 \le x, y \le 10 \quad (12)$$

To make a fair comparison, the number of population is set at 20, value c_1 and c_2 are set to 0.4 and maximum iteration is set to 500 for both methods. After completing 20 runs for each method, the results are presented in Table 1. From the result, IPSO have lowest standard deviation and highest percentage of hits to the global solution compared to conventional PSO. In term of average function value, the IPSO method has lowest value which is near to global value compared to PSO. Fig. 1 shows the best result can be achieved by IPSO and PSO after 20 runs. It can be shown that, the IPSO has ability to give consistent result after different runs compared to the PSO. So it can be concluded that IPSO is more ability to find global optima and less stuck at local minima as compared to PSO.

TABLE 1
PERFORMANCE OF PSO AND IPSO AFTER 20 RUNS

Function Value	Method	
	PSO	IPSO
Minimum	-18.5547	-18.5547
Maximum	-9.03554	-15.1079
Average	-15.3696	-18.0377
Standard Deviation	2.773748	1.262725
Percentage of hits global (%)	30	85

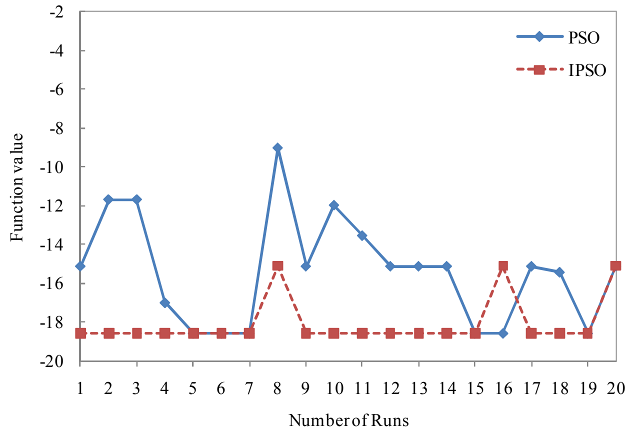

Fig. 1. Best result of PSO and IPSO after 20 runs

IV. IMPLEMENTATION OF IPSO FOR ED PROBLEM WITH VALVE POINT EFFECTS

The implementation steps of the IPSO algorithm for solving ED problem with valve point effect are as follows:

***Step 1**: Initialization*
In ED problem, the number of generating units is the dimension (or variable) in IPSO. The velocity is set to zero initially. The value of c_1 and c_2 are 0.4 respectively. The *i*th particle for *d* generating units (or dimension) is represented as [16]:

$$P_i = (P_{i1}, P_{i2}, \ldots, P_{id}) \quad (13)$$

The particles of each dimension are randomly generated within the maximum and minimum limits of the generator in (6) as given below:

$$P_{id} = r \times (P_d^{\max} - P_d^{\min}) + P_d^{\min} \quad (14)$$

***Step 2:** Evaluation function*
The fitness of each individual is evaluated by the evaluation function. The popular penalty factor method is employed to reduce the fitness function of the particle that proportional to the equality constraints violation in (4). The penalty parameter must be choosing carefully to distinguish between feasible and infeasible solution. The evaluation function is defined as follows [17].

$$f(P_i) = \sum_{i=1}^{Ng} F_i(P_i) + k\left|\sum_{i=1}^{Ng} P_i - P_D - P_L\right| \quad (15)$$

Where *k* is the penalty parameter for the total generated power not satisfying load demand and system loss.

Step 3: Initialization of *pbest* and *gbest*
The initial particles obtained in Step 1 are set as initial *pbest* values of the particles. The best fitness value among the *pbest* is defined as *gbest*.

Step 4: Update the velocity

The velocity is updated using (10). The velocities of the *i*th particle in *d* dimensional space are limited by $-V_{max}$ and V_{max}. In this paper, the maximum velocity was set between 15% and 20% of the dynamic range of each variable (dimension) [1].

Step 5: Update the swarm

The new position of each particle in *d* dimensional search space is computed using (8). If the evaluation function of *i*th particle is better than the previous *pbest*, the current value is set to be *pbest*. If current *gbest* is better than previous *gbest*, the value is set to be *gbest*.

Step 6: Stopping criteria

In this paper, IPSO algorithm will be terminated if the maximum number of iteration is reached ($iter_{max}$=500). Then, choose global best as an optimal solution. Otherwise, go to step 2.

V. Simulation Results

The proposed IPSO for solving ED problem with valve point effect has been tested on two case studies with different sizes (3 and 13 generating unit). The simulation has been done in MATLAB 7.6 on core 2 quad processor 2.66GHz with 3GB RAM. For each test system, 20 independent runs were performed to investigate the solution quality and robustness of proposed method. The performance of IPSO is compared with classical PSO and other methods from the literatures.

A. Case study 1: 3 unit system

This case study consists of 3 generators with the valve point effects. The total load demand of the system is 850 MW. The fuel cost coefficients of the generator are taken from [18] and transmission losses are neglected. The population size for this case study is set to 30. Table 2 show best results obtained by PSO and IPSO after 20 runs with different initial population. We can see that both algorithms can find the global solution at 8234.07 $/h. However, IPSO has lower average cost compared to PSO. Fig. 2 shows the convergence characteristic of the best result obtained by both algorithms in finding the minimum cost for this system.

TABLE 2
Best Results of PSO and IPSO after 20 Runs

Generating Units	PSO	IPSO
P1 (MW)	300.2669	300.2655
P2 (MW)	400	400
P3 (MW)	149.7331	149.7345
Total Power Output (MW)	850	850
Total generation cost ($/h)	8234.07	**8234.07**
Average cost	8425.45	8346.51

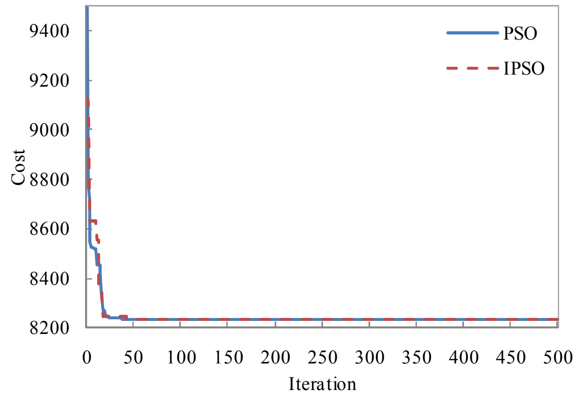

Fig. 2. Convergence characteristics for 3 generating units

The results obtained from the proposed IPSO method has been compared with GA [18], EP [19], and MPSO [20] in Table 3. It can be seen IPSO can achieved the global optimum solution same as others method except better than GA method.

The performance of heuristic methods such as PSO cannot be evaluate by single trial due to the random number involve during optimization process. In order to investigate the robustness the IPSO, 20 independent runs are tested for the both IPSO and PSO methods that illustrated in Fig. 3. It clearly shows that, IPSO can give the lowest cost in the most number of runs result compared to PSO. For this case, IPSO method is more robust compares to PSO in finding the global solution.

TABLE 3
Comparison of Best Results for 3 Unit System

Method	Minimum cost ($/h)
GA [19]	8234.60
EP [20]	8234.07
MPSO [21]	8234.07
PSO	8234.07
IPSO	8234.07

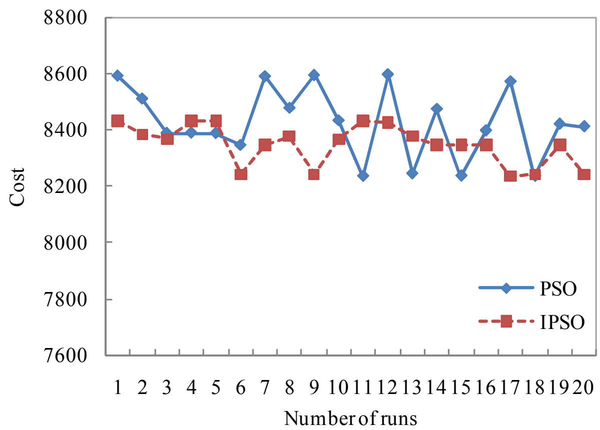

Fig. 3. Best result of PSO and IPSO for 20 runs

B. Case study 2: 13 unit system

This case study consists of 13 generators with valve point effect. The total load demand of the system is 1800 MW. In this system, the number of population for both IPSO and PSO methods are set to 200 due to high dimension or complex problem compared to 3 unit system. The fuel cost coefficient of the generator has been taken from [21] and transmission losses are neglected. Table 4 shows the best result obtained by proposed IPSO and PSO method after 20 runs. As seen in Table 4, the IPSO method can obtain a good solution compared to PSO. Its can reach to near optimum solution faster than PSO as illustrated in Fig. 4. The new parameter in the IPSO method can enhance searching capability of proposed method that result to near global solution. However, the classical PSO stuck at local solution after certain iteration.

TABLE 4
BEST RESULTS OF PSO AND IPSO AFTER 20 RUNS

Generating Units	PSO	IPSO
P1 (MW)	359.0779	538.556
P2 (MW)	224.3986	299.1995
P3 (MW)	224.4269	74.70948
P4 (MW)	109.8446	109.1681
P5 (MW)	109.5532	109.8504
P6 (MW)	109.8666	109.8809
P7 (MW)	109.8671	109.8663
P8 (MW)	110.085	111.514
P9 (MW)	109.8736	109.856
P10 (MW)	77.39935	77.36804
P11 (MW)	77.34862	40
P12 (MW)	92.58571	55
P13 (MW)	85.67243	55.03134
Total Power Output (MW)	1800	1800
Total generation cost ($/h)	18087.02	**17998.44**
Average cost	18250.28	18176.95

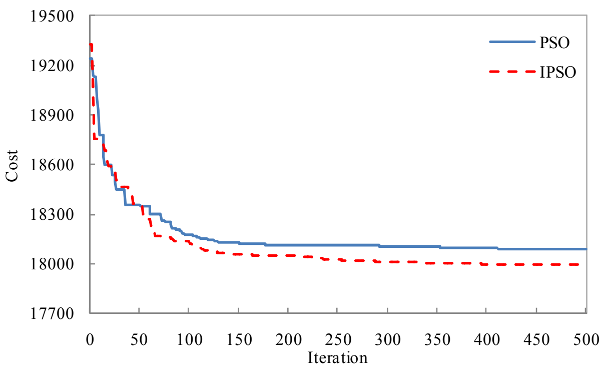

Fig. 4. Convergence characteristics for 13 generating units

The results obtained by the IPSO method has been compared with the published results: GA [22], IGA [23], PSO [21], SAPSO [21], CPSO [21] and NPSO [21] given in Table 5. It is clearly shows that the proposed IPSO has less generation cost compared to other methods.

In order to investigate the robustness the IPSO, similar approach as case study 1 is carried out for both IPSO and PSO methods. From Fig. 5, it clearly shows that the IPSO method can give the lowest generation cost in the most number of runs compared to PSO. Furthermore, the average cost of IPSO is better than PSO given in Table 2. For this case, IPSO method is more robust compared to PSO in finding the global solution because it can provide the consistent result with minimum cost as compared to original PSO. It can be concluded that, IPSO approach can improve the performance of classical PSO for solving ED problem with valve point effect.

TABLE 5
COMPARISON OF BEST RESULT FOR 13 UNIT SYSTEM

Method	Minimum cost ($/h)	Method	Minimum cost ($/h)
GA [23]	18671	NPSO [22]	18124
PSO [22]	18105	IGA [24]	18063.58
SAPSO [22]	18076	PSO	18087.02
CPSO [22]	18090	IPSO	17998.44

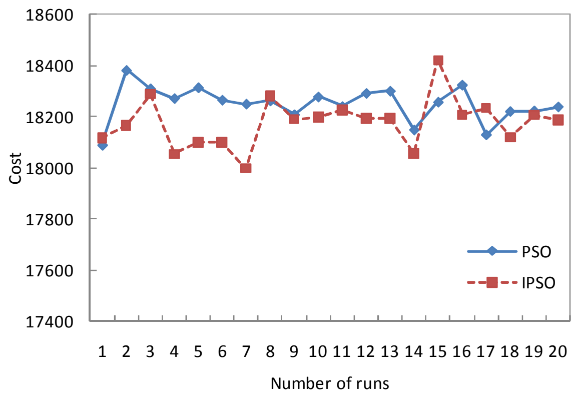

Fig. 5. Best result of PSO and IPSO for 20 runs

VI. CONCLUSION

In this paper, an iteration particle swarm optimization (IPSO) method has been successfully applied to solve the ED problem taking into account the valve point effects. A new iteration best parameter is employed to update the velocity in order to enhance searching behaviour and find the global optimum solution. Simulation results show that the proposed algorithm can achieves the global optimum solution for 3 units system. For 13 units system, the proposed algorithm give better cost compared to other methods from the literature. From the two case studies, it can be concluded that IPSO has ability to reach near to global optimum solution and more robust in comparison with PSO and other published results.

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