A NOVEL WEIGHT-IMPROVED PARTICLE SWARM OPTIMIZATION FOR COMBINED ECONOMIC AND EMISSION DISPATCH PROBLEMS

BHUVNESH KHOKHAR

Department of Electrical Engineering, DCRUST, Murthal,
Sonipat, Haryana 131039, India
bhunnikhokhar@gmail.com

K. P. SINGH PARMAR

Assistant Director (Technical), National Power Training Institute,
Faridabad, Sector-33, Haryana 121003, India
kpsingh_jss@rediffmail.com

Abstract:

This paper presents a weight improved particle swarm optimization (WIPSO) strategy for solving the combined economic and emission dispatch (CEED) problems. From point of view of the safety of the environment, it has become necessary to reduce the emission of harmful pollutants from power plants. This leads to an increased operating cost of the plant. So a compromise has to be made between the emission and the cost. In this paper, the presented WIPSO strategy has been applied to two generating systems, one comprising a three generator system and the other being IEEE 30-bus six generator system and its performance has been compared to the standard particle swarm optimization (PSO) strategy. The results show that the WIPSO strategy provides better solution as compared to the PSO in terms of reduced fuel cost and reduced emission.

Keywords: Economic Dispatch, Emission Dispatch, Particle Swarm Optimization, Weight Improved Particle Swarm Optimization, Combined Economic & Emission Dispatch

1. Introduction

Economic Dispatch (ED) is one of the most fundamental issues in power system operation. The main aim of ED is to minimize the operating cost of units, while satisfying the load demand and certain other constraints [1]. However, due to the increasing level of environmental concerns this single objective may no longer be considered adequate. A large number of fossil-fuelled power plants have been set up for fulfilling the ever increasing load demand which has resulted in the increased emission of pollutants such as sulphur oxides, nitrogen oxides and carbon dioxide. These pollutants cause harmful effects on the human beings as well as on the environment. So, during the load allocation process, the cost economy should not be the only objective but the reduction of emissions should also be taken into account [4-6].

Many works are there in literature for solving the economic/emission dispatch problems. Several methods have been developed to reduce the emissions from units. A solution procedure based on the LaGrange multiplier technique for the economic/emission problem has been proposed in [2]. Gent and Lamont [3] introduced the minimum-emission dispatch concept where they developed a program for online steam unit dispatch that resulted in minimizing the NO_x emission. They introduced the mathematical representation of NO_x emission of steam generating units and used a Newton-Raphson convergence technique to obtain base points and participation factors. Zahavi and Eisenberg [4] proposed a dispatch strategy considering both cost and emissions economy. Srikrishna and Palachinamy [5] proposed a method for Combined Economic and Emission Dispatch (CEED) using price penalty factor. Abido [7-8] developed a multi-objective evolutionary algorithm that determined the pareto optimal set simultaneously using the strength pareto evolutionary algorithm.

In this paper a novel weight-improved particle swarm optimization (WIPSO) [9] method based on the improved function of weight parameter has been presented for minimizing cost, NO_x emissions and for finding optimal solution to the CEED problem. In [9] WIPSO is applied for optimizing the fuel cost only. In [13], PSO is applied to the CEED problem. In order to show the effectiveness of the presented method it has been compared with the particle swarm optimization (PSO) [10-11] technique. Feasibility of the proposed WIPSO method has been demonstrated on two systems, one comprising a three generator system and the other one comprising IEEE 30-bus, six generator test system.

2. Problem Description

2.1 Economic Dispatch

The objective of the ED problem is to determine the optimal active power output P_{gi} (MW) of each of the generator for a total load demand of P_D (MW). Total fuel cost C_{fuel} ($/hr) for NG generators is minimized subject to the equality and the inequality constraints. The fuel cost curve is approximated as a quadratic function of the active power output from the generators and is represented as [1]:

$$C\left(P_{gi}\right) = a_i P_{gi}^2 + b_i P_{gi} + c_i \quad (1)$$

Where,
a_i, b_i, c_i are the fuel cost coefficients of the i_{th} generator.
The ED problem can be defined by the following equation:

$$\text{minimize } C_{fuel} = \sum_{i=1}^{NG} C(P_{gi}) \quad (2)$$

subject to the constraints given as:

a) the equality constraint –

$$\sum_{i=1}^{NG} C(P_{gi}) = P_D + P_L \quad (3.1)$$

b) the inequality constraint –

$$P_{gimin} \leq P_{gi} \leq P_{gimax} \quad (3.2)$$

Where,
P_{gimin} - minimum power output limit of the i_{th} generator (MW)
P_{gimax} - maximum power output limit of the i_{th} generator (MW)
The total transmission losses, P_L (MW) is a function of unit power outputs that can be expressed using B-coefficients as [1]:

$$P_L = \sum_{i=1}^{NG} P_i \sum_{j=1}^{NG} B_{ij} P_j + \sum_{i=1}^{NG} P_i B_{0i} + B_{00} \quad (4)$$

2.2 *Emission Dispatch*

The objective of the emission dispatch is to minimize the harmful pollutants emitted from power plants due to burning of the fossil fuels. Pollutants include sulphur oxides, nitrogen oxides and carbon mono-oxides. In this paper only NO_x emissions have been considered. The NO_x emission can be approximated as a quadratic function of the active power output from the generators and is represented as:

$$E\left(P_{gi}\right) = \alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i + \delta_i \exp(\epsilon_i P_{gi}) \quad (5)$$

For a total NO_x emission of $C_{emission}$ (Kg/hr), the emission dispatch problem can be defined as the following optimization problem,

$$\text{minimize } C_{emission} = \sum_{i=1}^{NG} E(P_{gi}) \quad (6)$$

subject to the equality constraint (3.1) and the inequality constraint (3.2).

2.3 Combined Economic and Emission Dispatch (CEED)

The economic dispatch and the emission dispatch are two different objectives. The former reduces the fuel cost of the generators without considering the emission economy and the latter reduces the emissions without considering the cost economy. Therefore, need is there to strike a proper balance between the two objectives. This can be achieved through the concept of combined economic and emission dispatch (CEED) [5].
The CEED problem can be formulated as [5],

$$\text{minimize } F(C_{fuel}, C_{emission}) \tag{7}$$

subject to the constraints given by equation (3).
The multi-objective problem defined by equation (7) can be converted into a single objective problem by introducing a price penalty factor ρ_f [5] as follows,

$$\text{minimize } \psi = C_{fuel} + \rho_f C_{emission} \qquad (\$/\text{hr}) \tag{8}$$

The above equation blends the emission cost with the fuel cost. The introduction of ρ_f avoids the use of two classes of dispatching. The value of ρ_f can be determined by the following procedure given below [5].

1. The fuel cost of each generator is evaluated at its maximum power output,

$$C(P_{gimax}) = a_i P_{gimax}^2 + b_i P_{gimax} + c_i$$

2. The emission release of each generator is evaluated at its maximum power output,

$$E(P_{gimax}) = \alpha_i P_{gimax}^2 + \beta_i P_{gimax} + \gamma_i + \delta_i \exp(\epsilon_i P_{gi})$$

3. ρ_{fi} for each generator is calculated as:

$$\rho_{fi} = C(P_{gimax}) \,/\, E(P_{gimax}) \qquad i = 1, 2, \ldots\ldots, NG \tag{9}$$

4. ρ_{fi} (i = 1, 2, ……, NG) are arranged in ascending order.
5. The maximum capacity of each generator (P_{gimax}) is added one at a time, starting from the smallest ρ_{fi} unit until $\sum P_{gimax} \geq P_D$.
6. At this stage ρ_{fi} associated with the last unit in the process is the price penalty factor ρ_f for the given load demand P_D.

Once the value of ρ_f is known, the optimal generation schedule can be obtained by minimizing equation (8) subject to the constraints given by the equation (3).

3. Weight Improved Particle Swarm Optimization (WIPSO)

PSO, as an optimization tool, provides a population-based search procedure in which individuals called *particles* change their position (states) with time [10]. In a PSO system, particles fly around in a multi-dimensional search space. Let *p* and *v* denote a particle co-ordinate (position) and its corresponding flight speed (velocity) in a search space respectively. Therefore, each i_{th} particle is treated as a volume less particle, represented as $p_i = (p_{i1}, p_{i2}, \ldots, p_{id})$ in the d-dimensional space. The best previous position of the i_{th} particle is recorded and represented as $p_{besti} = (p_{besti1}, p_{besti2}, \ldots\ldots\ldots p_{bestid})$. The index of the best particle among all the particles is treated as global best particle, is represented as g_{bestd}. The velocity for the i_{th} particle is represented as $v_i = (v_{i1}, v_{i2}, \ldots\ldots\ldots, v_{id})$. Further information regarding PSO can be obtained from [1] and [11].
The modified velocity and position of each particle can be calculated using the current velocity and the distance from p_{besti} to g_{bestd} as shown in the following formulas [1],

$$v_{id}^{(t+1)} = v_{id}^{t} * w + c_1 * rand(\,) * (p_{bestid}^{t} - p_{id}^{t}) + c_2 * Rand(\,) * (g_{bestd}^{t} - p_{id}^{t}) \tag{10}$$

$$p_{id}^{(t+1)} = p_{id}^{t} + v_{id}^{(t+1)} \tag{11}$$

w, known as inertia weight factor, often decreases linearly from about 0.9 to 0.4 during a run. In general, *w* is set according to the following equation,

$$w = w_{max} - [(w_{max} - w_{min})*It]/(It_{max}) \tag{12}$$

Here, w_{max} is the maximum inertia weight, w_{min} is the minimum inertia weight, It is current no. of iterations, It_{max} is maximum no. of iterations.

In WIPSO, in order to improve the global search capability of standard PSO, inertia weight factor, cognitive and social components have been adjusted.

The velocity-update equation (10) using the modified inertia weight factor i.e. using the WIPSO method can be rewritten as [9]:

$$v_{id}^{(t+1)} = v_{id}^{t} * w_{new} + c_1 * rand( ) * (p_{bestid}^{t} - p_{id}^{t}) + c_2 * Rand( ) * (g_{bestd}^{t} - p_{id}^{t}) \tag{13}$$

Where,

$$w_{new} = w_{min} + w * rand1( ) \tag{14}$$

w is calculated using equation (12).

$$c_1 = c_{1max} - (c_{1max} - c_{1min}) * (It/It_{max}) \tag{15}$$

$$c_2 = c_{2max} - (c_{2max} - c_{2min}) * (It/It_{max}) \tag{16}$$

c_{1min}, c_{1max} – initial and final values of the cognitive component

c_{2min}, c_{2max} – initial and final values of the social component

rand1( ) – randomly generated number between (0,1)

Figure 1 below shows the comparison in variation of inertia weight factor *w*, as obtained from equations (12) and (14) for 60 iterations.

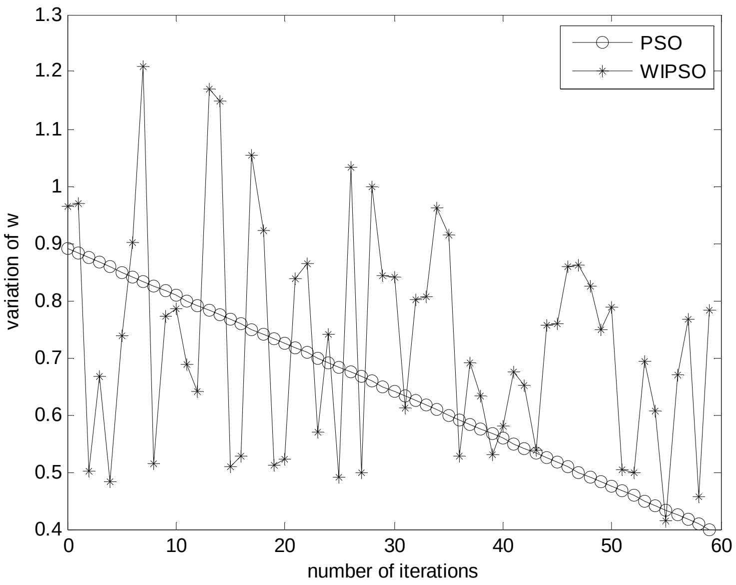

Fig. 1: Comparison of weights by the two methods

4. WIPSO algorithm applied to the CEED problem

The sequential steps of the proposed WIPSO strategy are given below.

Step1: Choose the population size, maximum number of iterations, w_{min}, w_{max}, c_{1min}, c_{1max}, c_{2min}, and c_{2max}.
Step2: The particles of the swarm are initialized randomly according to the limit of each generating unit. These initial particles must be feasible candidate solutions that must satisfy the operating constraints.
Step3: Set generation counter t = 1.
Step4: Evaluate the fitness of each particle according to the objective function.
Step5: Particles are accelerated to new positions by adding new velocities to their current positions. The new velocity is calculated using the equation (13)
The positions of the particles are updated using (11).
Step6: If the evaluation value of each particle is better than previous p_{bestid}, the current value is set to p_{bestid}. If the best p_{bestid} is better than g_{bestd}, this new value is set as g_{bestd}. An objective function value at g_{bestd} is set as F_{best}.
Step7: If the number of iterations reaches the maximum than the process is stopped and F_{best} is the minimum operation cost of the economic/emission dispatch problem. Otherwise, the above process is repeated from step2.

5. Test Systems and Results

In order to show the effectiveness of the WIPSO strategy over the PSO strategy, two test systems have been taken into consideration. The first system consists of three generating units [12] with a load demand of 850 MW. The second system is the IEEE 30-bus, six generator system with a load demand of 2.834 pu on a 100 MVA base.

Case1: Three Generator System
For this system,
PSO parameters are:
Maximum iterations = 200, population size = 10, w_{max} = 0.9, w_{min} = 0.4, acceleration constants c_1 = 2, c_2 = 2
WIPSO parameters are [9]:
Maximum iterations = 200, population size = 10, w_{max} = 1.2, w_{min} = 0.3, c_{1min} = 1.5, c_{1max} = 2.2, c_{2min} = 1.5, c_{2max} = 2.2
The results for best fuel cost are shown in table 1 and the results for best NO_x emission are shown in table 2 (δ_i, ϵ_i are taken zero for this case). Table 3 shows the best compromise solution between the fuel cost and the NO_x emission.

Table 1 - Best fuel cost (P_D = 850 MW)

Power Output (MW)	PSO	WIPSO
P1	435.7096	435.9519
P2	299.3724	299.3284
P3	130.7301	130.5296
Best Fuel Cost ($/hr)	8344.592738	**8344.592723**
NOx Emission (Kg/hr)	0.098663	0.098637
Losses (MW)	15.8122	15.8099

Table 2 - Best NO_x emission (P_D = 850 MW)

Power Output (MW)	PSO	WIPSO
P1	509.4062	511.4865
P2	249.4290	246.6277
P3	105.8945	106.5713
Fuel Cost ($/hr)	8365.5721	8366.7676
Best NOx Emission (Kg/hr)	0.09592393825	**0.09592393197**
Losses (MW)	14.7298	14.6857

Table 3 - Best compromise solution (P_D = 850 MW)

Power Output (MW)	**PSO**	**WIPSO**
P1	472.6821	472.3685
P2	277.8983	279.8732
P3	114.6501	113.0350
Best Fuel Cost ($/hr)	8350.0804	**8350.1282**
Best NOx Emission (Kg/hr)	0.0965020	**0.0964890**
Losses (MW)	15.2306	15.2768
Price Penalty Factor for NOx	147582.788	147582.788
Total Cost ($/hr)	22592.1221	**22590.2476**

Case2: Six Generator System
For this system,
PSO parameters are:
Maximum iterations = 200, population size = 25, w_{max} = 0.9, w_{min} = 0.4, acceleration constants c_1 = 2, c_2 = 2
WIPSO parameters are [9]:
Maximum iterations = 200, population size = 25, w_{max} = 1.2, w_{min} = 0.3, c_{1min} = 1.5, c_{1max} = 2.2, c_{2min} = 1.5, c_{2max} = 2.2
The results for best fuel cost are shown in table 4 and the results for best NO_x emission are shown in table 5. Table 6 shows the best compromise solution between the fuel cost and the NO_x emission.

Table 4 - Best fuel cost (P_D = 2.834 pu)

Power Output (pu)	**PSO**	**WIPSO**
P1	0.1175	0.1164
P2	0.3159	0.3180
P3	0.6253	0.6262
P4	0.9559	0.9633
P5	0.4976	0.4763
P6	0.3582	0.3704
Best Cost (pu)	608.9691	**608.9513**
NOx Emission (pu)	0.2028	0.2029
Losses (pu)	0.0367	0.0369

Table 5 - Best NO_x emission (P_D = 2.834 pu)

Power Output (pu)	**PSO**	**WIPSO**
P1	0.1453	0.4051
P2	0.5924	0.4586
P3	0.8283	0.5081
P4	0.3098	0.5196
P5	0.5713	0.4672
P6	0.4119	0.5097
Best NOx Emission (pu)	0.1868	**0.1862**
Fuel Cost (pu)	650.1467	636.7158
Losses (pu)	0.0254	0.0345

Table 6 - Best compromise solution (P_D = 2.834 pu)

Power Output (pu)	**PSO**	**WIPSO**
P1	0.0814	0.0168
P2	0.3284	0.4049
P3	0.4864	0.6105
P4	0.9767	0.8449
P5	0.4678	0.5652
P6	0.5390	0.4271
Best NOx Emission (pu)	0.2032	**0.2017**
Best Fuel Cost (pu)	613.9789	**612.8263**
Losses (pu)	0.0459	0.0357
Price Penalty Factor for NOx	63.9491	63.9491
Total Cost (pu)	626.9755	**625.7250**

6. Conclusion

The presented weight improved PSO algorithm has been applied to the CEED problem in this paper. The performance of the WIPSO strategy has been compared to the standard PSO strategy using two different generating systems, one consisting of a three generator system and the other comprising a six generator system. The results obtained show that the proposed WIPSO strategy outperforms the standard PSO strategy in terms of solution quality and avoids premature convergence thereby enhancing the global search capability.

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