Hybrid Optimization of Emission and Economic Dispatch by the Sigmoid Decreasing Inertia Weight Particle Swarm Optimization

Joko Pitono, Adi Soeprijanto, and Takashi Hiyama

***Abstract*—**This paper present an efficient and reliable technique of optimization which combined fuel cost economic optimization and emission dispatch using the Sigmoid Decreasing Inertia Weight Particle Swarm Optimization algorithm (PSO) to reduce the cost of fuel and pollutants resulting from fuel combustion by keeping the output of generators, bus voltages, shunt capacitors and transformer tap settings within the security boundary. The performance of the proposed algorithm has been demonstrated on IEEE 30-bus system with six generating units. The results clearly show that the proposed algorithm gives better and faster speed convergence then linearly decreasing inertia weight.

***Keywords*—**Optimal Power Flow, Combined Economic Emission Dispatch, Sigmoid decreasing Inertia Weight, Particle Swarm Optimization.

I. Introduction

THE electrical energy supply system faces its main problem with efficiency on the generator, transmission, and distribution system or combination of these three matters. Problem solving efforts are concentrated on minimizing operational cost of fuel consumption which has become the objective function and other requirements as the constraints. There are various OPF formulation depends on its objective functions and certain constraints being developed. The researchers have developed and concentrate on OPF problems solving by considering the system security [1], [2].

The last optimization techniques have been developed in a different area of electrical energy system are single objective function PSO, multiple objective functions PSO, and hybrid PSO. Singh and Erlich have tried to estimate of optimal block incremental cost from the instantaneous incremental heat rate curve of generating unit using PSO approach [3]. K. Thanushkodi has achieved a very appropriate results in applying PSO technique to solve Economic Dispatch using a smooth and non-smooth cost function by considering the effects of valve-point loading [4],[5].

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Z.Al-Hamouz has successfully demonstrated PSO algorithm application for the problem of Optimal Reactive Power Planning with the minimization of short-term operating costs and investment costs [6]. These researchers used PSO based on linearly decreasing inertia weight algorithm, so to get the convergence results requires relatively more time. This research use sigmoid decreasing inertia weight PSO optimization algorithm because of its superiority of avoiding minimum local and efficiency in computing so that it can fix the previous research's weaknesses.

Another problem faced by electricity nowadays is the pollutant comes from fuel consumption needs as its primary energy source. Diversification of various energy sources have been done , one of these diversifications which are used by power plants as its fuel is coal. It's able to produce electrical energy with relatively low cost , but the impact of pollution caused by burning coal to get attention. The use of coal as a fuel can cause pollutants to pollute the air with carbon dioxide (CO_2), sulfur dioxide (SO_2) and oxides of nitrogen (NO_X). These pollutants are able to cause acid rain that responsible to damage forests and plantation. It also brings a greenhouse effect which caused global temperature raise on the surface of the earth and carries along other side effects.

To anticipate the pollutant problem, the PSO proposed algorithm contains two objective functions, i.e. economic objective function (fuel cost and transmission losses) and emission objective function.

II. Methodology

A. Problem Formulation

OPF problem is non-linear optimization problem with objective function and constraints are not linear. This used to calculate the generation system and distribution of electric power in order to obtain the best results and most profitable. Methods of problem solving in the conventional OPF, namely the Newton method, Gradient and Interior Point, has been used extensively. OPF problem solving required non-linear equations, the description of optimization, security and operation of power systems which in general can be written in Equation (1) to Equation (3).

$$\text{minimize} \quad F(x,u) \tag{1}$$

$$\text{subject to} \quad g(x,u) = 0 \tag{2}$$

$$h(x,u) \leq 0 \tag{3}$$

where,

$$x^T = \left[\delta \;\; V_L^T \right]$$

$$u^T = \left[P_G^T \;\; V_G^T \;\; t^T \;\; Q_{SH}^T \right]$$

Equation (1) defines the general objective function, whereas equality constraints represented in Equation (2), Equation (3) is the inequality constraints from the vector argument x and u.

B. Objective Function

1) Economic objective function

Most commonly used objective in the OPF problem formulation is the minimization of the total operation cost of fuel needs to producing electrical energy per hour. The economic objective function for the entire power system can than be expressed as the sum of the quadratic cost model at each generating unit as in Equation (4).

$$F_{ec}(x,u) = \sum_{i=1}^{NG} \left(a_i + b_i P_{Gi} + c_i P_{Gi}^2 \right) \tag{4}$$

where, P_{Gi} is the real power output of an ith generator; NG is the number of generating units; a_i, b_i and c_i, fuel cost curve coefficients an ith generator, respectively. The total power generation must over the total demand (P_D) and the real power loss in the transmission lines (P_L). Hence,

$$\sum_{i=1}^{NG} P_{Gi} = P_D + P_L$$

2) Emission objective function

The emission objective function can be represented as the sum of all types of emission considered, such as oxides of nitrogen (NO_X), oxides of sulphur (SO_X) and carbon dioxide (CO_2). In the present study, only one type of emission NOx is taken as index from the viewpoint of environment conservation. The amount of NOx emission is given as a function of generator output, that is, the sum of quadratic and exponential function as Equation (5).

$$F_E = \sum_{i=1}^{NG} \left(A_i + B_i P_{Gi} + C_i P_{Gi}^2 + D_i \exp(E_i P_{Gi}) \right) \tag{5}$$

where, A_i, B_i, C_i, D_i and E_i are the coefficients of ith generator's NO_X emission characteristic. The pollution control cost can be obtained by assigning a cost factor to the pollution level expressed as Equation (6).

$$F_{pc} = w\, F_E \tag{6}$$

where w is the emission control cost factor

3) Total objective function

The total objective function is obtained by considering the generation cost and the cost of pollution level control in the same time, so that will occur the minimisation of the generation cost but maximise the emission cost and vice versa. This problem is very complex in its achievement, so the solutions may be obtained in which fuel cost and emission cost are combined in a single function with difference weighting factor [9]. This objective function as Equation (7).

$$F = \alpha\, F_{ec} + (1-\alpha) F_{pc} \tag{7}$$

where F is the total objective function, α is a weighting satisfies $0 \leq \alpha \leq 1$. The boundary values $\alpha = 1$ and $\alpha = 0$ give the condition for the pure minimisation of fuel cost function and the pure of the pollution control level.

C. Types of Equality Constraints

During the minimization objective function, it is necessary to make sure that the system still generates and supplies the load demands plus losses in transmission lines. The equality constraints are the power flow equations that describe the bus injected active power and reactive power of the ith bus. Injection of active power and reactive power at bus i is defined in equation (8) and Equation (9).

$$P_i = P_{Gi} - P_{Di} = \sum_{j=1}^{NB} V_i V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) \tag{8}$$

$$Q_i = Q_{Gi} - Q_{Di} = \sum_{j=1}^{NB} V_i V_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right) \tag{9}$$

Where P_{Gi} and Q_{Gi} are actve and reactive power generation at bus i; P_{Di}, Q_{Di} are the real and reactive power demands at bus i; V_i, V_j, the voltage magnitude at bus i, j; θ_{ij} is the admittance angle; B_{ij} and G_{ij} are the real and imaginary part of the admittance and N_B is the total number of buses.

D. Types of Inequality Constraints

Vector x consists of dependent variables and vector u of control variables. The variables $h(x,u)$ constitute a set of system operating constraints that include :

The variable vector x consists of the following :

a. Branch flow limits

$\left| S_{Li} \right| \leq S_{Li}^{max}$ $\qquad$ i = 1.......NL

b. Voltage at load buses

$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{min}$ $\qquad$ i = 1.......NL

c. Reactive power at generator

$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}$ $\qquad$ i = 1.......NG

d. Active power at *slack bus*

$P_{G}^{min} \leq P_{G} \leq P_{G}^{max}$

The control variable u consists of the following :

a. Active power at generator

$P_{Gi}^{min} \leq P_{Gi} \leq P_{Gi}^{max}$ $\qquad$ i = 1.......NG

b. Generator bus voltage

$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}$ $\qquad$ i = 1.......NG

c. Transformer tap setting

$t_{i}^{min} \leq t_{i} \leq t_{i}^{max}$ $\qquad$ i = 1.......ntran

d. Bus shunt capacitor

$b_{SCi}^{min} \leq b_{SCi} \leq b_{SCi}^{max}$ $\qquad$ i = 1.......NC

E. Particle Swarm Optimization

PSO algorithm is based on particles inside a population that work together to solve the existing problems regardless of its physical positions. PSO algorithm combines the local search method and global search method to balance between exploration and exploitation. PSO has several similarities with GA. A system is started from a population formed by random solutions, and system will seek for optimization through random generation changes. Each particle stores the position traces in the search space is defined as the best solution has been achieved. Personal best (pbest) is the best the value of the particle, while the global best (gbest) is the best value which takes into account all the particles in the population. In every iteration, each particle is given information about the latest gbest value that occurs the mechanism to share information in one direction to make the process of finding the best solution with rapid convergence movement. PSO algorithm consists of three steps, namely determining the particle's position and velocity, velocity update, and position update. The position x_k^i and velocity v_k^i of particles randomly initialized using the value of the highest and lowest variable according to the design, while the rand (r) is a random value between 0 and 1. Each particle tries to update its position using such information, current position, current velocity, distance between the current position of the pbest and the current position of gbest. Mathematically particle velocity update (v_{k+1}^i) shown in Equation (10).

$$v_{k+1}^i = v_k^i + c_1 r_1 (p_k^i - x_k^i) + c_2 r_2 (p_k^g - x_k^i) \qquad (10)$$

Achieving the results obtained from the new velocity calculation for each particle based on the distance from pbest owned and distance from the gbest position. Particle position update (x_{k+1}^i) shown in Equation (11).

$$x_{k+1}^i = x_k^i + v_{k+1}^i \qquad (11)$$

1) PSO with Lineare Decreasing Inertia Weight.

In 1998 Shi and Eberhart came up with what they called PSO with inertia. The inertia weight ω_k is multiplied by the previous velocity in the standard velocity equation and is linearally decreased from $\omega_{start} = 0.9$ to $\omega_{end} = 0.4$ during the iterations to obtain the best performance compared PSO with inertia weight value is fixed . A nonzero inertia weight introduces a preference for the particle to continue moving in the same direction it was going on the previous iteration. Decreasing the inertia over time introduces a shift from the exploratory (global search) to the exploitative (local search) mode. Hence,

$$v_{k+1}^i = \omega_k v_k^i \, c_1 r_1 (p_k^i - x_k^i) + c_2 r_2 (p_k^g - x_k^i) \qquad (12)$$

where,

$$\omega_k = \omega_{start} - \frac{\left(\omega_{start} - \omega_{end}\right)}{k_{maks}} k$$

2) PSO with Sigmoid Decreasing Inertia Weight.

Instead of linearly decreasing of inertia weight, sigmoid decreasing inertia weight was used to reduce convergence time. Figure 2.1. show decreasing mechanism comparison of both method.

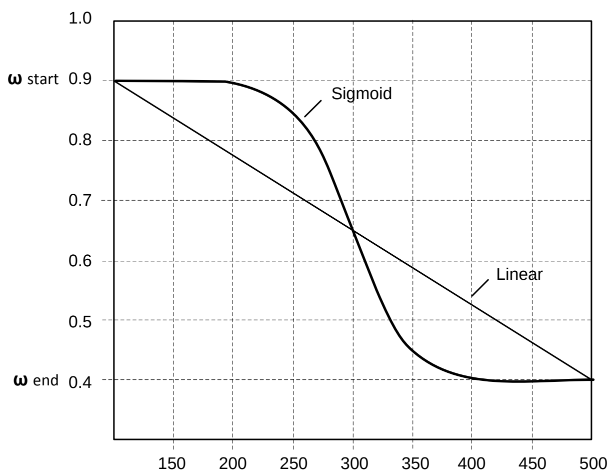

Fig. 1. Linear and Sigmoid Decreasing Inertia Weight

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In sigmoid decreasing enertia weight value at each iteration does not always change. At the beginning of the process of PSO, the value of the sigmoid decreasing enertia weight has a value ω_{start} (large) for a few moments to do a global search. Toward the end of the process of PSO for some time has a value ω_{end} (small). There is very short inertia weight graduation between large and small one. Hence, this method will provide a balance between global and local searching to give the PSO faster iteration in gaining the same results. The proposed function of sigmoid is given as Equation (13).

$$\omega_k = \frac{\omega_{start} - \left(\omega_{start} - \omega_{end}\right)}{\left(1 + \exp^{(-(k - 0.25*500)}\right)} \qquad (13)$$

where,

k is number of iterations.

III. Simulation and Analysis

A. Plant Data

IEEE 30-bus systems is used in this work to test the performance of the proposed algorithm. In this adaptation, buses 1, 2, 3, 5, 11, and 13 are generator buses and others are load buses as shown in Figure 3.1.

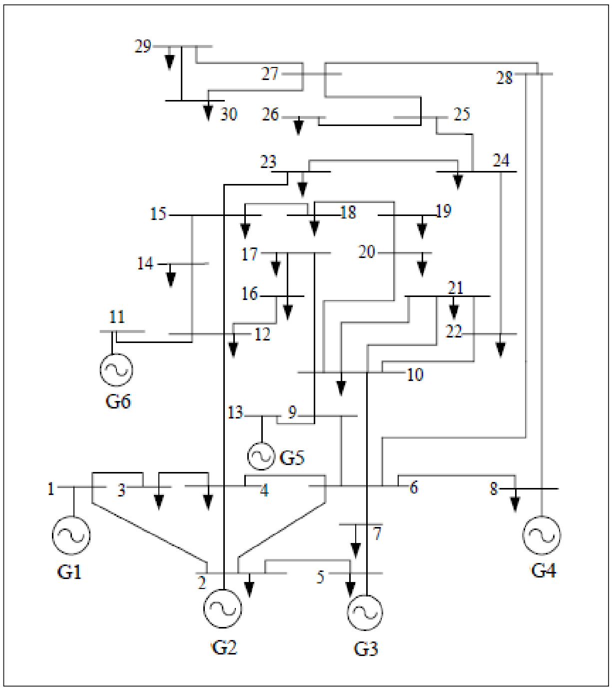

Fig. 2 Single Line Diagram of IEEE 30-Bus System

The NO_X emission characteristics of generators are grouped in Table 3.1. Uper and lower active and reactive power generating limits and the unit cost of all generators of IEEE 30 bus system are presented in Table 3.2.

TABLE I POLLUTION COEFFICIENTS

Bus	A 10^{-2}	B 10^{-4}	C 10^{-6}	D 10^{-4}	E 10^{-2}
1	4.091	-5.554	6.490	2.000	2.857
2	2.543	-6.047	5.638	5.000	3.333
5	4.258	-5.094	4.586	0.010	8.000
8	5.326	-3.550	3.380	20.000	2.000
11	4.258	-5.094	4.586	0.010	8.000
13	6.131	-5.555	5.151	10.000	6.667

TABLE II POWER GENERATION LIMITS AND COST COEFFICIENTS

Bus	Pmin	Pmax	Qmin	Qmax	a	b	c
1	50.00	200.0	-	-	0	2.00	37.5 10^{-4}
Bus	**Pmin**	**Pmax**	**Qmin**	**Qmax**	**a**	**b**	**c**
2	20.00	80.00	-40.00	50.00	0	1.75	175.0 10^{-4}
5	15.00	50.00	-40.00	40.00	0	1.00	625.0 10^{-4}
8	10.00	35.00	-10.00	60.00	0	3.25	83.0 10^{-4}
11	10.00	30.00	-6.00	24.00	0	3.00	250.0 10^{-4}
13	12.00	40.00	-6.00	24.00	0	3.00	250.0 10^{-4}

B. Result and Analysis

The Proposed algorithm was implemented in MATLAB. The performance of the proposed algorithm was tested with 6 generating units. Three experimental load 150.5 MW, 383.4 MW and 400 MW were performed using both the linear decreasing of enertia weight used as a comparison with and the proposed algorithm. The results comparison was then tabulated. The PSO method seems to be sensitive to the tuning of some weights or parameter. According to the experiences of many experiments, the following PSO parameter is be used as shown in Table 3.3.

TABLE III PSO PARAMETERS

PSO Parameters	Value
Maximum number of iterations	500
Population	20
Learning factor C_1 and C_2	2 and 2
Start of inertia weight	0.9
End of inertia weight	0.4
Global error minimum	1 10^{-6}

Power losses in transmission lines and the total cost of fuel and emissions for each experiment in both algorithms have no significant difference, but there is a very significant difference in the achievement of convergence (see table 3.4). At 150.5 MW loading experiments, there is a very striking difference in the achievement of convergence, which the linearly decreasing inertia weight need 420 iterations, while sigmoid decreasing inertia weight need only 120 iterations. In the second experiment with a load of 283.4 MW, there are significant difference in the achievement of convergence that is 220 iterations. In the last experiment with a load of 400 MW, the speed of convergence difference achieved 300 iterations. From the results, with fast convergence, there is a possibility to implement the sigmoid decreasing inertia weight PSO in the on-line operation mode.

TABLE IV FASTER CONVERGENCE OF THE PROPOSED ALGORITHM

Gen	Linearly Decreasing Inertia Weight PSO			Sigmoid Decreasing Inertia Weight PSO		
P_{G1}	80.252	176.709	199.999	80.258	176.71	200.00
Gen	Linearly Decreasing Inertia Weight PSO			Sigmoid Decreasing Inertia Weight PSO		
P_{G2}	25.522	48.825	68.329	25.517	48.824	68.417
P_{G3}	15.00	21.496	42.713	15.00	21.496	42.622
P_{G4}	10.00	21.742	35.00	10.00	21.742	35.00
P_{G5}	10.00	12.134	30.00	10.00	12.134	30.00
P_{G6}	12,00	12.00	40.00	12.00	12.00	39.999
Total P_G	152.775	292.906	416.037	152.775	292.906	416.037
Total Demand	150.5	283.4	400.0	150.5	283.4	400.0
Power Loss	2.2746	9.506	16.037	2.2747	9.506	16.037
Total Cost	375.212	802.302	1404.4	375.212	802.302	1404.2
Emission	0.2390	0.3671	0.4367	0.2390	0.3671	0.4367
Iterations	440	340	480	120	160	180

IV. CONCLUSION

The sigmoid decreasing inertia weight for economic and emission dispatch was proposed to achieve faster convergence time. The proposed algorithm has been tested at IEEE 30 bus system with 6-generating units and show that although the proposed algorithm provides more and less same operation cost but the proposed algorithm give more quickly convergence compared with linearly decreasing inertia weight. The speed of convergence of the proposed algorithm can achieve 2 times faster. With this performance, there is a possibility to implement the proposed algorithm in on-line mode operation.

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REFERENCES

[1] Yong-Hua Song, *Modern Optimisation Techniques in Power System*. Kluwer Academic Publisher, Netherlands, 1999, ch. 1.
[2] E. Pablo, M.R. Juan, “Optimal Power Flow Subject to Security Constraints Solved With a Particle Swarm Optimizer,” IEEE Transactions On Power Systems, Vol. 23, No. 1, pp. 33-40, February 2008.
[3] S.N. Singh, I. Erlich, “Particle Swarm Based Optimal estimation of Block Incremental Cost Curve,” The 14th International Conference on Intelligent System Application to Power System, Kaohsiung Taiwan, pp. 257-263, November 2007.
[4] R. Thanushkodi, Vinodh, “An Efficient Particle Swarm Optimization for Economic Dispatch with Valve-Point Effect,” Applied Computing Conference, Istanbul Turkey, pp. 182-187, May 2008.
[5] Jong-Bae Park, Yun-Won Jeong, “An Improved Particle Swarm Optimization for Economic Dispatch with Valve-Point Effect,” International journal of Innovation in Energy Systems and Power, Vol. 1, No. 1, pp. 1-7, November 2006.
[6] Z. Al-Hamouz, S. Al-Sharif, “Application of Particle Swarm Optimization Algorithm for Optimal Reactive Power Planning, Control and Intelligent System, “ Control and Intelligent Systems, Vol. 35, No. 2, pp. 66-72, 2007.
[7] R. Hassan, B. Cohanim, “A Comparison of Particle Swarm Optimization and The Genetic Algorithm,” Massachusetts Institute of Technology Cambridge, pp. 1-13, 2004.
[8] F. Cus, U. Zuperl, “High speed end-milling optimisation using Particle Swarm Intelligence,” Journal of Achievements in Materials and Manufacturing Engineering, Vol. 22, pp. 75-78, June 2007.
[9] Linda Slimani, T. Boukir, “Economic power dispatch of power system with pollution control using multiobjective Ant Colony Optimization,” International Journal of Computation Intelligence Research, Vol.3, No.2, pp. 145-153, 2007.

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