A New Enhancement on PSO Algorithm for Combined Economic-Emission Load Dispatch Issues

Rashid H. Al-Rubayi[1]   Mohammed Kdair Abd[1]*   Firas M. F. Flaih[2]

[1]Department of Electrical Engineering, University of Technology, Iraq
[2]State Company of North Distribution Electricity, Ministry of Electricity, Iraq
* Corresponding author's Email: 30098@uotechnology.edu.iq

Abstract: Economic dispatch issues in power system aim to try getting an optimal plan for the power generators to minimize the fuel cost (*FC*) in parallel with satisfying system constraints. This paper proposes a new enhancement based on particle swarm optimization (PSO) algorithm called multiple inertia weight PSO (MIW-PSO) to solve the combined economic and emission load dispatch (CEELD) issues in the modern electrical power systems. Two electrical test systems are investigated in this study to validate the competence of the proposed algorithm. The obtained results for CEELD case using MIW-PSO compared with MOCPSO indicate a promising performance in terms of minimizing *FC* and pollutant emission (*PE*) are reduced 84.96 *$/h* and 12.01 *kg/h* for the first test system. As well as, for the second test system, compared with NSGA-RL are reduced 0.241 *$/h* and 3.15 *kg*/h. Moreover, the proposed algorithm has more accuracy, better convergence time, and higher quality solutions for the minimum CEELD compared with other methods.

Keywords: PSO, Economic dispatch, Emission, Load dispatch.

1. Introduction

Electrical energy management and emission reduction are important issues in power transmission and distribution systems; economic dispatch (ED) is using to solve such problems. In classical ED, the *FC* function is presented as a primary target function with the use of constraints, and in most cases, these restrictions are neglected. Given the limitations of the ED problem, most traditional methods have unsuccessful in addressing complex problems since of its unreliability and several requisite tests such as direct Newton–Raphson method, analytical solution technique, lambda-iteration method [1-3], linear programming techniques, non-linear dynamic and mixed-integer quadratic programming [4-6].

Numerous studies with respect to ED with *FC* and *PE* have been improved using enhanced intelligent algorithms. These improved methods such as Pareto genetic algorithm (NPGA) [7, 8], modified group search optimization (MGSO) algorithm [9], differential harmony search (DHS) [10], parallel

hurricane optimization algorithm (PHOA) [11], real coded chemical reaction optimization (RCCRO) [12], biogeography/based optimization (BBO) [13] and seeker optimisation algorithm (SOA) [14] have been published. However, these methods are affected by performance in large-scale systems.

Furthermore, concerning hybrid forms solving complex ED problems, it was suggested to use differential evolution (DE) with BBO algorithm (DE/BBO) [15] in thermal generators of power systems under demand equality constraint and operating constraint. DE/BBO worked on accelerating the convergence quickness of both the algorithm and get better solution quality.

Intelligent optimization is widespread in recent years because it has information-exchange and handover mechanisms. Intelligent optimizations such as, bacterial foraging (BF) with modified PSO, which includes benefits of BF effect in PSO to solve the complex dynamic ED [16], also in [17] proposed a fuzzified multi-objective PSO algorithm to investigate the environmental ED, which is to

decrease the *FC* and *PE* at same time. References [18] and [19] applied chaotic sequences and crossover operation with PSO (CCPSO), also combined DE with PSO algorithms (DEPSO). The authors have proven an ability to create a good quality of solution it is motivated to enhance the above-stated control variables, but these learning parameters might melody the exploration ability of the intelligent algorithm that has enhanced convergence ratio only. The authors in [20], proposed a learner non-dominated sorting genetic algorithm (NSGA-RL) to reduce the operation cost and emission as two objectives to be optimized at the same time. The advantage of this approach is non-time spending coefficients tuning, gives convenient and consistent solutions.

Moreover, The authors in [21] proposed a modify and mix of parameters BF and PSO, this method called MBF-PSO where particles change locality to get close to the best location and find the optimum minimum global. Also, considers DE is a powerful statistical method and quick convergence to solving non-linear and non-convex problems, which reduces search ability that leads to an upper probability of obtaining an optimum solution. In order to overcome this disadvantage, the proposed [22] variable DE with fuzzy adaptive PSO (FAPSO-VDE) is used to solve the non-convex ED problem. Where DE is the major optimizer and PSO is used to maintain the population variety and prevent causing leading to deceitful the location optimal for every improvement in the solution and applied of the DE. The Multi-objective chaotic PSO (MOCPSO) method has been introduced to solve ED, in which the Pareto-dominance method is used to various-objective problems; it gave results, and higher quality solutions for the reduce *FC* and *PE* [23].

In this paper, we proposed a new MIW to developed PSO technique; the classical PSO algorithm improved its convergence characteristics for reducing *FC* and *PE* in the uncertain energy production expense and random load. The MIW-PSO method has a better balance between local and global search abilities, and it can reach the minimum location quickly.

Further efforts have been made to improve convergence and global research optimization capabilities to improve the applicability of PSO as a successful method in solving various energy system problems.

In this paper, the features are listed as follows:

- New enhancement on PSO algorithm is introduced to get the best optimum solution for CEELD problems in power systems and provide more realistic analyses.

- Study the optimization results obtained from the proposed algorithm including a formulation of CEELD problem with losses;
- Results comparison of the CEELD solutions obtained from MIW-PSO with other optimization algorithms.

This paper is organization as follows:

In section 2, presented the formulation of CEELD problem. Section 3 introduced classical PSO and proposed multiple inertia weight PSO (MIW-PSO), respectively. Section 4 presents the implemented of the proposed approach and its flowchart.

In section 5, we presented the optimization results with the proposed algorithm, including a study of two cases and compared the results with previously published researches and plot the results. Eventually, conclusions and future research are presented in section 6.

2. Formulation of CEELD problem

The CEELD problem is a double mathematical programming problem that is concerned with attempting to get the optimum solution that concurrently improves two different goals for minimizing FC and PE. The model can be described of the CEELD mathematical as follows: [9, 20, 24]:

1) Objective Function

There are two objective functions for CEELD. The first one is to reduce *FC* value of generation (*$/h*), which can be simulated as follows:

$$\min FC = \sum_{k=1}^{M} FC_k \qquad (1)$$

where,

$$FC_k = \sum_{k=1}^{M} \left(A_k P_k^2 + B_k P_k + C_k \right) \qquad (2)$$

where, FC_k is the cost function of kth generator; A_k, B_k and C_k cost coefficients of kth generator; P_k is the output power of kth generator; k is a number of generators to the operating system and k equal 1 to M.

The second objective is to the minimum value of total *PE* (*kg/h*) is expressed as follows:

$$\min PE = \sum_{k=1}^{M} PE_k \qquad (3)$$

where,

$$PE_k = \sum_{k=1}^{M} \left(\alpha_k P_k^2 + \beta_k P_k + \gamma_k \right) \qquad (4)$$

where, PE_k is the pollutant emission of kth generator; α_k, β_k and γ_k are coefficients of kth generator emission.

The main objective function (MOF) of CEELD problem is presented as follows:

$$\min MOF = [FC, PE] \tag{5}$$

The MOF is the sum of the fuel and emission costs. The emission costs are obtained by multiplying the value of emission by the price of penalty factor (d). The MOF in Eq. (5) can be reformulated as:

$$MOF = FC + d\ PE \tag{6}$$

2) Constraints

The constraints are included:

i) Power balance constraint: the total output power generation should be equal to total load demand (P_d) and total real losses (P_{Loss}). Eq. (7) is described as a power balance constraint (MW).

$$\sum_{k=1}^{M} P_k - P_d - P_{Loss} = 0 \tag{7}$$

Where the P_{Loss} by transmission network is giving as follows:

$$P_{Loss} = \int_{k=1}^{M}\int_{z=1}^{M} P_k B_{kz} P_z + \int_{k=1}^{M} P_k B_{ok} + B_{oo} \tag{8}$$

where, P_k and P_Z are active power injection at k^{th} and z^{th} buses; (B_{kz}, B_{ok}, B_{oo}) are the transmission and matrix of loss coefficients;

ii) Unit power capacity constraint: for stable operation, the real output power by each generator is constrained between lower and upper limits. Eq. (9) clarifies the real output power generation constraint, as follow:

$$P_k^{\min} \le P_k \le P_k^{\max} \tag{9}$$

iii) Safety constraints: for safe operation, the transmission line loading (S_L) is constrained by the upper limit. Eq. (10) clarifies the safety constraint, as given below [7, 24]:

$$|S_{Lk}| \le S_{Lk}^{\max}, \quad k = 1,...,ML \tag{10}$$

where ML is a number of transmission lines.

3. Proposed algorithm

3.1 Classical PSO

The classical PSO algorithm proposed in 1995 and sophisticated on by Kennedy and Eberhart is a stochastic optimization method that depends on the movement intelligence of particle [21-23, 25]. It applies to the thought of the social conducts of swarms. Each particle has position and velocity; it can be renewed given by the following equations:

$$V_k^{m+1} = wV_k^m + c_1 r_1 (P_{best\ k}^m - X_k^m)$$
$$+ c_2 r_2 (G_{best\ k}^m - X_k^m) \tag{11}$$

$$X_k^{m+1} = X_k^m + V_k^m \tag{12}$$

Where $V_k = [v_k^1, v_k^2,...,v_k^m]$ is velocity of particle k at iteration m; $X_k = [x_k^1, x_k^2,...,x_k^m]$ is position of particle k at iteration m; P_{best} is best position achieved of a specific particle k; G_{best} is best particle achieved of the group; (c_1, c_2) is acceleration factors which control the maximum extent step size; w is constant inertia weight that controls the influence of preceding velocity of partial on its current one; (r_1, r_2) are two random numbers that are statically distributed between [0, 1]. In general, the value of each component in V_k should be fastened to the between [v_{min}, v_{max}] to monitoring the excessive wandering of particles external the search space.

3.2 Multiple inertia weight PSO (MIW-PSO)

In this sub-section, to achieve a higher quality fineness of the algorithm to find out the optimum global solution for the CEELD problem in energy system operation. The classical PSO is enhanced by linear decreasing of the multiple inertia weights (MIW). This linear decreasing of the MIW is used to get the preferable solution. Where here for the MIW-PSO, $w = [w_{G.Starting}, w_{S.Ending}]$ is inertia weight and updated by two different weight factors at various stages of the calculations.

Here, the proposed new $w_{G.Starting}$ and $w_{G.Ending}$ of the MIW-PSO loop program in each iteration are calculated as in Eq. (13) and Eq. (14) respectively, as shown below:

$$w_{G.Starting} = w_{\max} - (w_{\max} - w_{\min})(\frac{m}{iter_{\max}}) \tag{13}$$

$$w_{G.Ending} = \frac{2}{\left|2 - Q - \sqrt{\left|Q^2 - 4Q\right|}\right|}\left(\frac{m}{iter_{max}}\right) \quad (14)$$

Where $w_{G.Starting}$ in Eq. (13) is used at the starting of MIW-PSO loop program and $w_{G.Ending}$ in Eq. (14) is used at the ending of MIW-PSO loop in each iteration. w_{max}, w_{min} are maximum and minimum of inertia weight values $\in$ [0.9,0.4]; Q equals to $w_{max} + w_{min} \gg 1.8$; m is current iteration, and $iter_{max}$ is maximum iteration numbers.

4. Implementation of MIW-PSO for the optimal solution of CEELD problem

In this section, the implementation of the proposed MIW-PSO for solution CEELD problem is written as below.

Step1: Start the program.

Step2: Initializing (generation of the swarm, position, velocity, w_{max}, w_{min}, r_1, r_2, c_1, c_2).

Step3: Read system (bus, generation, and lines data).

Step4: Set maximum iteration number equal $iter_{max}$ =G.

Step5: Evaluate the fitness of all particles based on:

Case Study (1):

    a) For PED using Eq. (2) as an objective function (P_{best} and G_{best}).

    b) For PPE using Eq. (4) as an objective function (P_{best} and G_{best}).

Case Study (2): for CEELD using Eq. (5), and Eq. (6) as an objective function (P_{best} and G_{best}).

Step6: Set $G = (G - 1)$.

Step7: Estimate $w_{GStarting}$ value from Eq. (13) and updating the velocity of particles from Eq. (11).

Step8: Use Eq. (12) to modify the position of particles with constraints for obtained the new position.

Step9: Computing the new fitness and updated the P_{best} and G_{best}.

Step10: Calculate $w_{GEnding}$ value from Eq. (14).

Step11: If a stopping condition is satisfied, print the G_{best} (Optimum output power of the generation production units). Otherwise, return to **Step6**.

Step12: Calculate:

    a) *PE* and *MOF* values using Eq. (3) and Eq. (6) for PED.

    b) *FC* and *MOF* values using Eq. (1) and Eq. (6) for PPE.

Step13: Print the results

Step14: End the program.

The flowchart of the proposed approach based on the MIW-PSO is shown in Fig. 1.
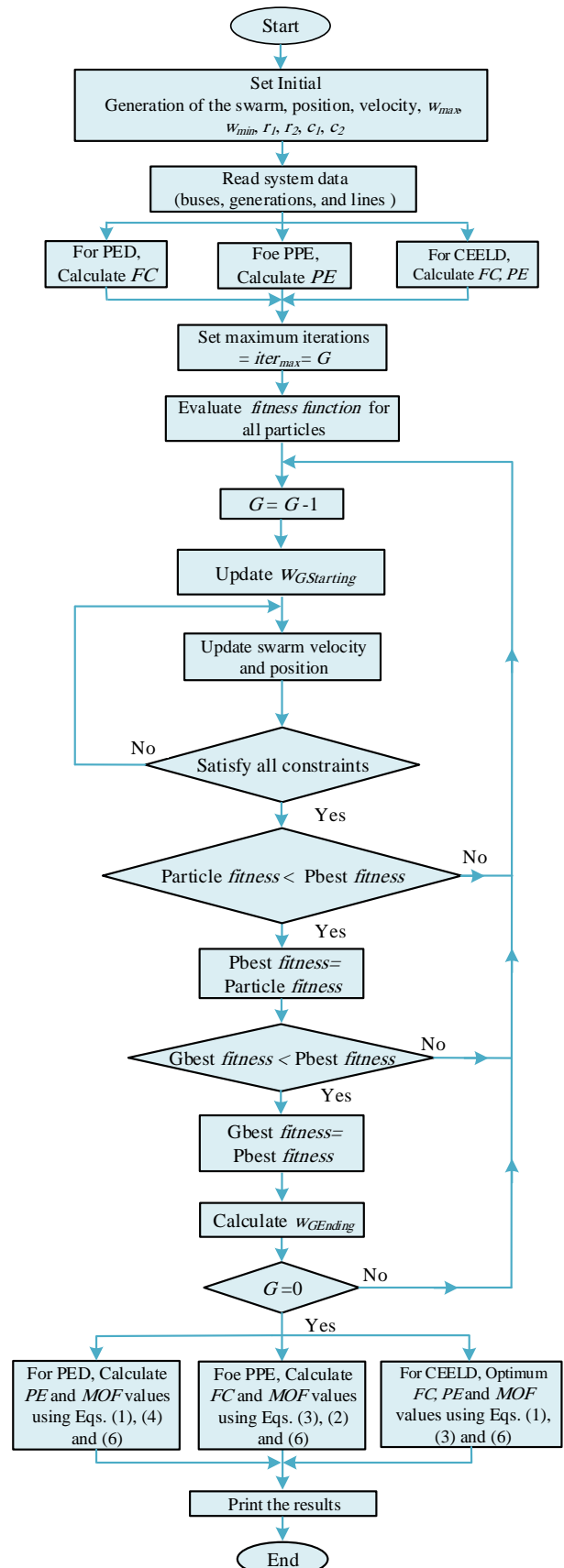

Figure.1 Flowchart for MIW-PSO

5. Simulation results

For investigating the viability and impact of the proposed MIW-PSO for solving CEELD issues, a comprehensive simulation of the study of the test systems is performed. The proposed method is tested on two systems.

The first test system is 4-bus with six-generating units, as shown in Fig. 2. Secondly, test system is the IEEE standard 30-bus with six generator; the single line diagram shown in Fig. 3.

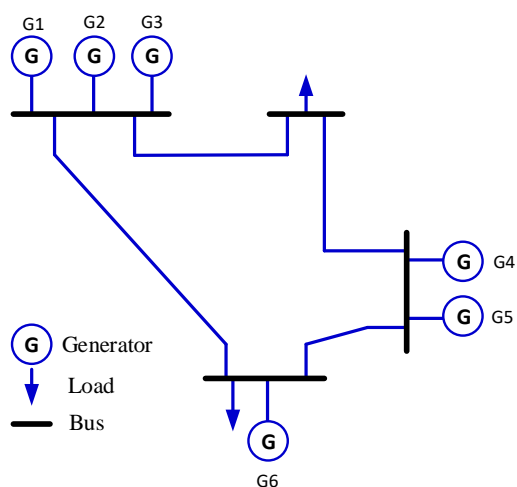The proposed MIW-PSO method is employed to simulate the case studies on an Intel® Core™ i5-

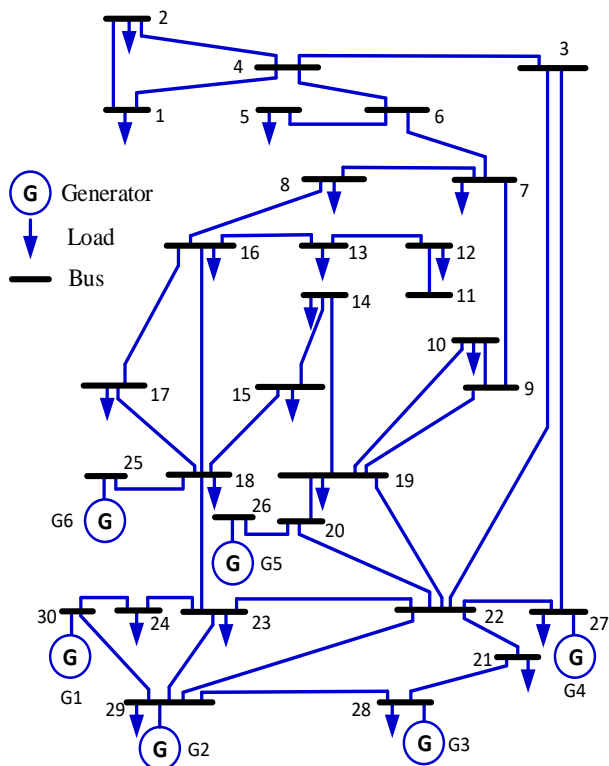Figure.2 Single line diagram of a 4-bus system

Figure.3 Single line diagram of a 30-bus system

2450 CPU@2.5GHz personal computer with 4 GB RAM. The values of *FC*, emission coefficients, transmission loss coefficients, generation limits of unites and price of penalty factor ($d = 3$ ($/kg$)) are given in [2, 9, 11, 20, 23, 24].

5.1 Case study 1: Pure economic dispatch (PED) and pure pollutant emission (PPE)

The proposed method is applied to the mentioned two test systems, including the power losses system. In this case study, PED and PPE issues are solved separately using the proposed MIW-PSO. Table 1 to Table 4 illustrate the numerical results and comparative for the problem. From Table 1 to Table 4, we can see in the second to eighth columns contain the generated power (per/unit), and the cost of each unit is listed for two test systems. The ninth and ten columns show the content per-unit emission and run time for each method.

The obtained results in Tables 1 and 2 for PED case using MIW-PSO algorithm compared with MOCPSO method [23] indicate a promising performance in terms of minimizing *FC* and *PE* are reduced about 0.08 *$/h* and 0.09 *kg/h* for test 4-bus system. Also, for test 30-bus system is compared with MGSO [9] are reduced 0.7723 *$/h* and 2.6 *kg/h*.

For PPE case, obtained results in Tables 3 and 4 by using MIW-PSO algorithm compared with MOCPSO method [23] indicate a promising performance in terms of minimizing *FC* and *PE* are reduced about 309.94 *$/h* and 2.05 *kg/h* for test 4-bus system. Also, for test 30-bus system is compared with MGSO method [9] are reduced 2.025 *$/h* and 0.4 *kg/h*, respectively.

Nevertheless, by economic dispatch, the *FC* is lesser compared to *PE*, but the emission is higher. Also, at emission dispatch, *PE* is lesser compared to economic dispatch, but *FC* is higher. Figs. 4 and 5 provide the *MOF* results which represent the summation of fuel and emissions costs for proposed. The numerical results for PED and PPE cases using MIW-PSO algorithm compared with MOCPSO method [23], where *MOF* reduced about 0.35 ($/h$) and 316.09 ($/h$) for test 4-bus system, respectively.

As well, Figs. 6 and 7 provide the numerical results of *MOF* for PED and PPE cases using MIW-PSO algorithm compared with MGSO method [9], where *MOF* is reduced about 8.5723 ($/h$) and 3.225 ($/h$) for test 30-bus system, respectively.

Moreover, we noticed that the *MOF* reduction rate is large compared with the methods mentioned above, which prove the success of the proposed method in finding the best and fastest solutions.

Table 1. Numerical and comparative results for PED (4-bus system)

Method	Power of generation						FC ($/h)	PE (kg/h)	Run time (s)
	P_1 (pu)	P_2 (pu)	P_3 (pu)	P_4 (pu)	P_5 (pu)	P_6 (pu)			
MIW-PSO	0.3371	0.1265	1.5052	1.4850	2.9519	2.9357	47187.33	857.72	0.158
MM [2]	0.3377	0.1265	1.5056	1.4850	2.9629	2.9363	47188.29	857.74	0.189
MOCPSO [23]	0.3371	0.1265	1.5056	1.4850	2.9630	2.9372	47187.41	857.81	9.82
MOPSO [23]	0.3167	0.1476	1.4958	1.4890	2.9344	2.9710	47189.45	857.80	8.56

Table 2. Numerical and comparative results for PED (30-bus system)

Method	Power of generation						FC ($/h)	PE (kg/h)	Run time (s)
	P_1 (pu)	P_2 (pu)	P_3 (pu)	P_4 (pu)	P_5 (pu)	P_6 (pu)			
MIW-PSO	0.1097	0.3023	0.5211	1.020	0.5042	0.3351	603.6501	219.4	2.064
MGSO [9]	0.1182	0.3017	0.5302	1.017	0.5263	0.3628	604.4224	222	2.38
MBFA [27]	0.1141	0.3108	0.5994	0.9816	0.5048	0.3559	607.6700	219.8	NA
FSBF [26]	0.1173	0.3049	0.5983	0.9780	0.5129	0.3545	606.5080	219.6	3.5099
NSBF [26]	0.1209	0.2863	0.5835	0.9928	0.5239	0.3518	605.9900	222	3.89

Table 3. Numerical and comparative results for PPE (4-bus system)

Method	Power of generation						FC ($/h)	PE (kg/h)	Run time (s)
	P_1 (pu)	P_2 (pu)	P_3 (pu)	P_4 (pu)	P_5 (pu)	P_6 (pu)			
MIW-PSO	1.1491	1.1491	1.4233	1.4233	2.0410	2.0409	49907.62	694.87	0.127
MM [2]	1.2451	1.2451	1.4031	1.4031	2.0415	2.0415	50217.62	696.99	0.189
MOCPSO [23]	1.2451	1.2451	1.4031	1.4031	2.0414	2.0414	50217.56	696.92	9.84
MOPSO [23]	1.1802	1.1802	1.4389	1.4389	2.0706	2.0706	49872.35	697.56	8.60

Table 4. Numerical and comparative results for PPE (30-bus system)

| Method	Power of generation						FC ($/h)	PE (kg/h)	Run time (s)
	P_1 (pu)	P_2 (pu)	P_3 (pu)	P_4 (pu)	P_5 (pu)	P_6 (pu)			
MIW-PSO	0.4034	0.4489	0.5418	0.3547	0.5410	0.5122	642.6450	193.8	2.162
MGSO [9]	0.4105	0.4620	0.5424	0.3880	0.5403	0.5102	644.6700	194.2	NA
MBFA [27]	0.4055	0.4609	0.5444	0.3986	0.5440	0.5134	644.4300	194.2	NA
FSBF [26]	0.4135	0.4652	0.5390	0.3894	0.5398	0.5174	645.3981	194.2	NA
NSBF [26]	0.4253	0.4776	0.5820	0.3652	0.5183	0.4948	647.7413	194.4	NA
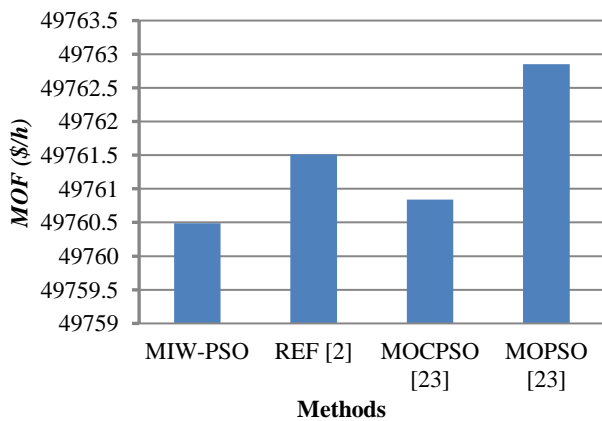
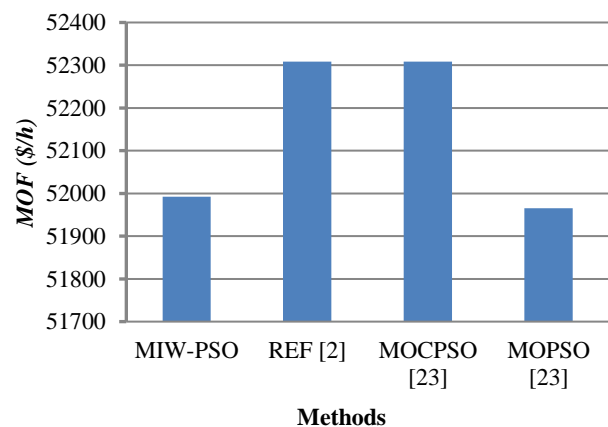

Figure.4 *MOF* of PED for 4-bus system
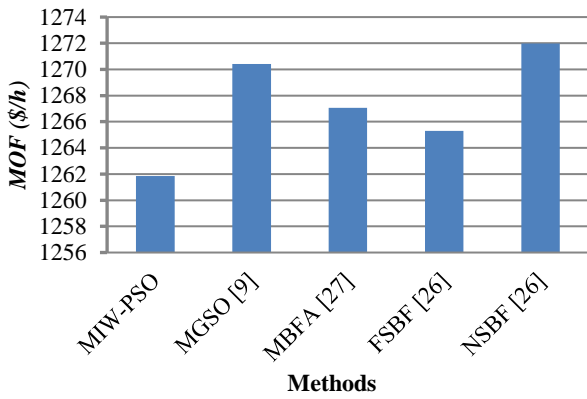

Figure.5 *MOF* of PPE for 4-bus system

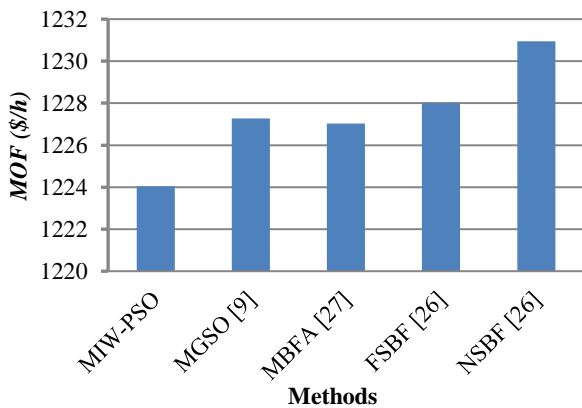Figure.6 *MOF* of PED for 30-bus system

Figure.7 *MOF* of PPE for 30-bus system

5.1 Case study 2: CEELD

This case shows the performance of MIW-PSO approach to solve CEELD problem, including system losses. Table 5 and Table 6 display numerical and comparison results for two systems. Table 5 presents

comparative results for a 4-bus system with MM [2], MOCPSO and MOPSO [23] are found the *FC* value around 47549.87 and 47804.55 (*$/h*) and *PE* between 823.36 and 843.42 (*kg/h*). Furthermore, the *FC* value and *PE* are 47464.91(*$/h*) and 811.35 (*kg/h*), respectively, by using the proposed method.

On the other hand, for the 30-bus system in Table 6 are found the *FC* value around 615.7285 and 617.9531 (*$/h*) and *PE* between 199.8 and 200.5 (*kg/h*). Furthermore, the *FC* value and *PE* are 615.5490 (*$/h*) and 197.9 (*kg/h*), respectively, using the proposed method.

Fig. 8 provides the *MOF* results for CEELD case using MIW-PSO algorithm compared with MOCPSO method [23], where *MOF* is reduced about 120.99 (*$/h*) for test 4-bus system, respectively. As well, Fig. 9 provides the numerical results of *MOF* for CEELD case using MIW-PSO algorithm compared with NSGA-RL method [20], where *MOF* is reduced about 5.8795 (*$/h*) for test 30-bus system, respectively.

In the electricity markets, the dispatcher must be able to deal with electricity power generating units to encounter loads requests in as little time as possible. The dispatcher must be ready for any change in supplies due to a change in loads demand or there may be bottlenecks in the transmission line or a change in system constraints. It all depends on the time, which is the basis of profit and changing prices offers of generating. Results proved, the proposed MIW-PSO is much faster and more efficient than the other methods in treating multiobjective optimization issues.

Table 5. Numerical and comparative results for CEELD (4-bus system)

Method	Power of generation						FC (*$/h*)	PE (*kg/h*)	Run time (s)
	P_1 (pu)	P_2 (pu)	P_3 (pu)	P_4 (pu)	P_5 (pu)	P_6 (pu)			
MIW-PSO	0.5208	0.3425	2.1102	1.2531	2.9012	2.2306	47464.91	811.35	0.159
MM [2]	0.5182	0.3864	2.4873	1.2214	2.5201	2.2357	47804.55	843.42	0.195
MOCPSO [23]	0.5182	0.3266	2.0879	1.2812	2.9195	2.2357	47549.87	823.36	12.03
MOPSO [23]	0.5231	0.3566	2.1525	1.2051	2.8862	2.2456	47599.95	826.31	10.62

Table 6. Numerical and comparative results for CEELD (30-bus system)

| Method	Power of generation						FC (*$/h*)	PE (*kg/h*)	Run time (s)
	P_1 (pu)	P_2 (pu)	P_3 (pu)	P_4 (pu)	P_5 (pu)	P_6 (pu)			
MIW-PSO	0.2676	0.3681	0.6043	0.6168	0.5302	0.4642	615.5490	197.9	2.086
MGSO [9]	0.2757	0.4200	0.5302	0.6859	0.5287	0.4159	615.7835	200.3	NA
MBFA [27]	0.2595	0.3769	0.5636	0.6759	0.5499	0.4344	616.4960	200.2	NA
FSBF [26]	0.2616	0.3789	0.5733	0.6870	0.5308	0.4307	616.1627	200.5	NA
NSBF [26]	0.2790	0.4063	0.5674	0.6839	0.4953	0.4306	617.9531	200	NA
NSGA-RL [20]	0.2672	0.3606	0.6026	0.6155	0.5324	0.4635	615.7285	0.1998	NA
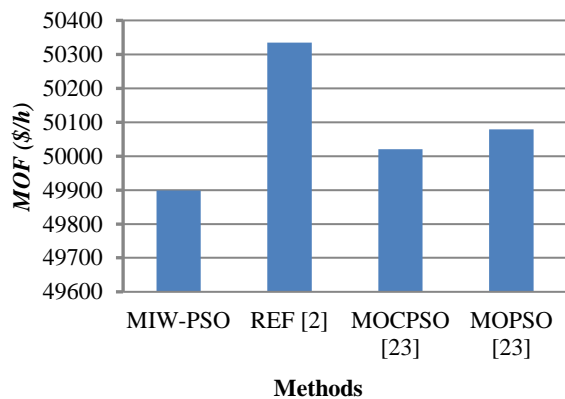
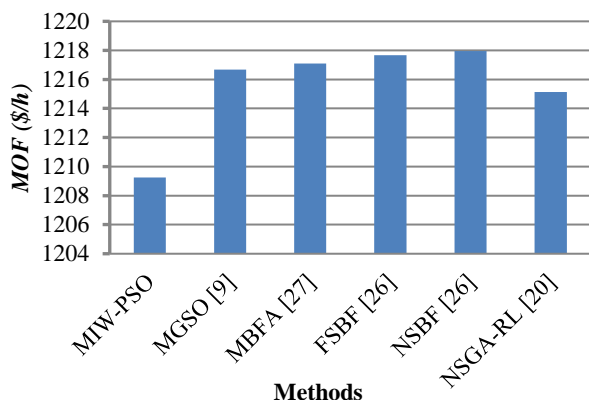**Figure.8** *MOF* of CEELD for 4-bus system

Figure.9 *MOF* of CEELD for 30-bus system

6. Conclusion

In this paper, the main feature is the appropriate introduces of multiple inertia weight effects in PSO (MIW-PSO) to get a better balance between local and global search abilities which can reach a minimum local quickly. The proposed is successfully implemented to solve CEELD issues. The issues mentioned above are solved with two cases are (PED and PPE) and CEELD also, the simulation includes system power losses.

The proposed method has been applied to 4-bus and 30-bus test systems using two cases to prove the success of the improved method. The obtained results for CEELD case using MIW-PSO algorithm compared with MOCPSO, indicate a promising performance in terms of minimizing *FC* and *PE* and reduced about 84.96 (*$/h*), 12.01 (*kg/h*) respectively in the first test system also about 0.241 (*$/h*) and 3.15 (*kg/h*) in the second test system.

From the outcome of our investigation, we conclude that the MIW-PSO gives the optimal performance to solve CEELD problem. Besides, this study has shown that MIW-PSO is more reliable and has a lower run-time for all different simulation objectives with a comparison of other algorithms.

In the future, we planned to incorporate another approach for the technique used in this work or employ an alternative technique to improve the run time, minimizing the *FC* and *PE*, in addition to studying the parameters of each technique which to aid in improving applications of algorithm.

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