International Journal of Control and Automation
Vol. 11, No. 2 (2018), pp.55-74
http//dx.doi.org/10.14257/ijca.2018.11.2.06

An Effective Non-Traditional Algorithm for Solving the Problem of Optimal Power Flow with Minimum Environmental Pollution Using Price Penalty Factors

Mohammed Amine Meziane[1] and Youssef Mouloudi[2]

[1,2]Dept. Science and Technology "Electrical Engineering", Faculty of Technology,
Tahri Mohammed University Bechar, Algeria BP 417, 08000 Bechar, Algeria
[1]Laboratory of Analysis, Control and Optimization of Electro-Energetic Systems (CAOSEE)
[2]Smart Grids the renewable energies (ENERGARID)
[1]aminemohmeziane@gmail.com, [2]mouloudiyoussef@yahoo.fr

Abstract

Combined Economic and Emission Dispatch (CEED) problem is one of the important optimization problems concerning power system issues. The objective is to determine and provide an economic condition for generation units, subject to minimize the total fuel cost and environmental pollution caused by fossil based thermal generating units, founded on the generation and transmission constraints. In this paper, Particle Swarm Optimization (PSO) is proposed for solving the CEED problem under some equality and inequality constraints. The effect of four Price Penalty Factors (PPF)such as Min-Max, Max-Max, Min-Min and Max-Min price penalty factors are included in order to convert the bi-objective problem into a single objective function. The validity of the proposed PSO based algorithm is demonstrated for three power system test cases: the IEEE 30-bus system with 6 generators, the 11 generation units system and the Real West Algeria power network consisting of 22 buses with 7 generators. The results are compared to data from SONELGAZ reported in a recent literature and it proves the feasibility of PSO based algorithm for the CEED problem.

***Keywords**: Combined Economic and Emission Dispatch, environmental pollution, practical swarm optimization, data from SONELGAZ, Real West Algeria electrical Network*

1. Introduction

The Optimal Power Flow (OPF) problem is one of the key tools in operation and planning of modern electric utility grid. Operating at absolute minimum cost can no longer be the only criterion for dispatching electric power due to increasing concern over the environmental considerations. The generation of electricity from fossil fuel releases several contaminants, such as SO_x, NO_x and CO_2 into the atmosphere [1].

The global energy infra-structure depends heavily on burning fossil fuels which increases the emissions of several toxic gases like carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxide (NO), therefore, the environmental issue is, recently, taken into account as a part of the OPF problem and the goal, nowadays, is to minimize the cost and mitigate the emissions from the thermal power plants considering the equality and inequality constraints. The aforementioned approach is referred as the Combined Economic and Emission Dispatch problem.

Received (August 9, 2017), Review Result (December 14, 2017), Accepted (December 26, 2017)

ISSN: 2005-4297 IJCA

Modern Power systems consist of a large interconnected generation, transmission and distribution utilities, systems of such size leads to inevitable losses and the mitigation of these losses are targeted by lowering the production cost, maximizing reliability and by ensuring continuity of service.

The OPF problem summarize the different methods used to achieve the aforementioned goal and it was first discussed by Carpentier in 1962 [2], the main purpose of OPF is to find the optimal output power of generators to minimize the total generation cost and satisfy the equality and inequality constraints.

The traditional methods used to solve this economic load dispatch problem are the Lambda iteration method, Gradient, Newton, linear programming and interior point method. Recently, meta-heuristic techniques such as Simulated Annealing, Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Tabu search algorithm are used to solve this problem [3].

In this paper, Particle Swarm Optimization has been proposed to solve the CEED problem, using a price penalty factors based technique to convert the bi-objective CEED problem into a single objective function. The proposed algorithm has been implemented on three different test systems, the standard IEEE 30-bus, the Real west Algeria 22-bus system and eleven generators system. Satisfactory simulation results show the effectiveness of the proposed algorithm.

2. Mathematical Formulation of CEED Problem

2.1. Economic Dispatch

Generally, the OPF problem can be formulated as a constrained optimization, and the fuel cost function F_i (P_i) of generating unit “i” usually can be expressed as a quadratic polynomial:

$$F_c = \sum_{i=1}^{ng} F_i(P_{Gi}) = \sum_{i=1}^{ng}(a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \tag{1}$$

Where, F_c is total Fuel Cost; $F_i(P_{Gi})$ Fuel cost of the i_{th} generator; P_{Gi} is real power generation of a generator unit *i;* $a_i b_i c_i$ is cost coefficients of generating for the unit *i in* [\$/MW^{2}h], [\$/MWh] and [\$/h] respectively; ng is number of generating units.

2.2. Emission Dispatch

The problem for minimization of the quantity of the emissions is formulated by the following equation if the valve point effect is not taken into account.

$$E_T = \sum_{i=1}^{ng}(d_i P_{Gi}^2 + e_i P_{Gi} + f_i) \tag{2}$$

Where, E_T is total emission; d_i, e_i, f_i is emission coefficients of generating unit *iin* [kg/MW^{2}h], [kg/MWh] and [kg/h] respectively.

2.3. Constraints

2.3.1. Equality Constraint

$$\sum_{i=1}^{n} P_i = P_G = P_D + P_L \tag{3}$$

Where, P_G is total power generation of the system; $P_D$is total demand of the system; P_L is total transmission loss of the system

The transmission loss can be expressed as **[4]**:

$$\mathrm{P_L} = \sum_{i=1}^{n}\sum_{i=j}^{n} \mathrm{P_i B_{ij} P_j} + \sum_{i=1}^{n} \mathrm{B_{0i} P_i} + \mathrm{B_{00}} \tag{4}$$

Where, $\mathrm{P_i}$is active power generation of unit *I*; $\mathrm{P_j}$ is active power generation of unit *j*; $\mathrm{B_{ij}}$, $\mathrm{B_{0i}}$, $\mathrm{B_{00}}$is transmission loss coefficients

2.3.2. Inequality Constraints

$$P_{i,min} \leq P_i \leq P_{i,max} \tag{5}$$

Where, $P_{i,min}$ is minimum value of real power allowed at a generator *I*; $P_{i,max}$ is maximum value of real power allowed at a generator *i*

2.4. Combined Economic and Emission Dispatch CEED

Mathematic equation for CEED problem **[5-7]** is given by the objective functions (1) and (2).

The price penalty technique is used to convert the bi-objective optimization problem into a single objective optimization.

Then the CEED problem can be expressed as:

$$F_T = \sum_{i=1}^{ng} \left[\left((\mathrm{a_i P_{Gi}^2} + \mathrm{b_i P_{Gi}} + \mathrm{c_i}) \right) + h_i \left((\mathrm{d_i P_{Gi}^2} + \mathrm{e_i P_{Gi}} + \mathrm{f_i}) \right) \right] \tag{6}$$

Where, F_T is total CEED‘s fuel cost; h_i is price penalty factor (PPF)

The CEED problem is formulated by the criterion (6) and under the constraints (3) to (5).

2.5. Price Penalty Factors PPF

The PPF **[8-12]** for CEED problem is formulated taking the ratio fuel cost and emission value of the corresponding generators as follows:

1) Min-Max price penalty factor is described as :

$$h_i = \frac{\mathrm{a_i P_{Gi,min}^2} + \mathrm{b_i P_{Gi,min}} + \mathrm{c_i}}{\mathrm{d_i P_{Gi,max}^2} + \mathrm{e_i P_{Gi,max}} + \mathrm{f_i}} \tag{7}$$

2) Max-Max price penalty factor is described as :

$$h_i = \frac{\mathrm{a_i P_{Gi,max}^2} + \mathrm{b_i P_{Gi,max}} + \mathrm{c_i}}{\mathrm{d_i P_{Gi,max}^2} + \mathrm{e_i P_{Gi,max}} + \mathrm{f_i}} \tag{8}$$

3) Min-Min price penalty factor is described as :

$$h_i = \frac{\mathrm{a_i P_{Gi,min}^2} + \mathrm{b_i P_{Gi,min}} + \mathrm{c_i}}{\mathrm{d_i P_{Gi,min}^2} + \mathrm{e_i P_{Gi,min}} + \mathrm{f_i}} \tag{9}$$

4) Max-Min price penalty factor is described as :

$$h_i = \frac{\mathrm{a_i P_{Gi,max}^2} + \mathrm{b_i P_{Gi,max}} + \mathrm{c_i}}{\mathrm{d_i P_{Gi,min}^2} + \mathrm{e_i P_{Gi,min}} + \mathrm{f_i}} \tag{10}$$

3. Overview of Basic PSO Algorithm

The PSO is a population based stochastic optimization technique, was first introduced by James Kennedy and Russell Eberhart in the USA, and is one of modern heuristic algorithms **[13]**.

Inspired from two concepts **[14]**:

✓ The observation of swarming habits of animals such as birds or fish.

- ✓ The field of evolutionary computation (such as genetic algorithms).

3.1. PSO Concepts

- ✓ The PSO algorithm maintains multiple potential solutions at one time.
- ✓ During each iteration of the algorithm, each solution is evaluated by an objective function to determine its fitness.
- ✓ Each solution is represented by a particle in the fitness landscape (search space).
- ✓ The particles "fly" or "swarm" through the search space to find the maximum value returned by the objective function.

3.2. Maintained Information

Each particle maintains:

- ✓ Position in the search space (solution and fitness).
- ✓ Velocity.
- ✓ Individual best position.

In addition, the swarm maintains its global best position.

3.3. Canonical PSO Algorithm

The PSO algorithm consists of just three steps:

- ✓ Evaluate fitness of each particle.
- ✓ Update individual and global bests.
- ✓ Update velocity and position of each particle.

These steps are repeated until some stopping condition is met.

3.4. Velocity Update

Each particle's velocity is updated using this equation:

$$V_i(t+1) = \omega V_i(t) + c_1 r_1[Pbest_i(t) - X_i(t)] + c_2 r_2[Gbest_i(t) - X_i(t)] \tag{11}$$

Where, i is the particle index; ω is the inertia coefficient; c_1, c_2 are acceleration coefficients $0 \leq c_1, c_2 \leq 2$; r_1, r_2 are random values, $0 \leq r_1, r_2 \leq$ regenerated every velocity update; V_i is the particle's velocity at time t ; X_i is the particle's position at time t; P_{best} is the particle's individual best solution as of time t; G_{best} is the swarm's best solution as of time t.

3.5. Velocity Update – Inertial Component

- ✓ Keeps the particle moving in the same direction it was originally heading
- ✓ Inertia coefficient ω usually between 0.8 and 1.2
- ✓ Lower values speed up convergence, higher values encourage exploring the search space

3.6. Velocity Update – Cognitive Component

- ✓ Acts as the particle's memory, causing it to return to its individual best regions of the search space
- ✓ Cognitive coefficient c1 usually close to 2

- ✓ Coefficient limits the size of the step the particle takes toward its individual best P_{best}

3.7. Velocity Update – Social Component

- ✓ Causes the particle to move to the best regions the swarm has found so far
- ✓ Social coefficient c2 usually close to 2
- ✓ Coefficient limits the size of the step the particle takes toward the global best G_{best}

3.8. Position Update

Each particle's position is updated using this equation:

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{12}$$

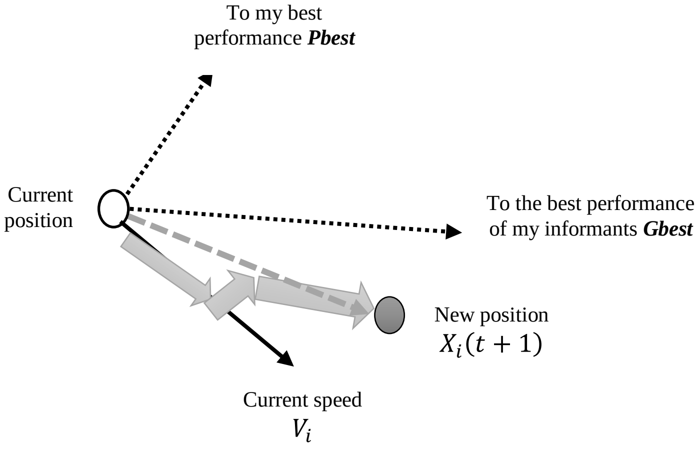

Figure 1. Simple Schematic Diagram of the Displacement of a Simple Particle

To achieve its next move, each particle combines three trends:

Follow its own speed, Return to its best performance, Go to the best performance of its informants (Figure 1).

4. PSO Algorithm for Solution of the CEED Problem

The fuel cost equation is given in (1) and is solved subject to the constraints (3), (4), and (5). The emission function is given in (2) and the price penalty factors (7) to (10) are used to formulate the single objective function (6) of the CEED problem.

The above problem is solved by the application of PSO algorithm, which is adopted to incorporate the specifics of the CEED problem. This is done by the following way shown in the Flowchart of the PSO algorithm (Figure 2):

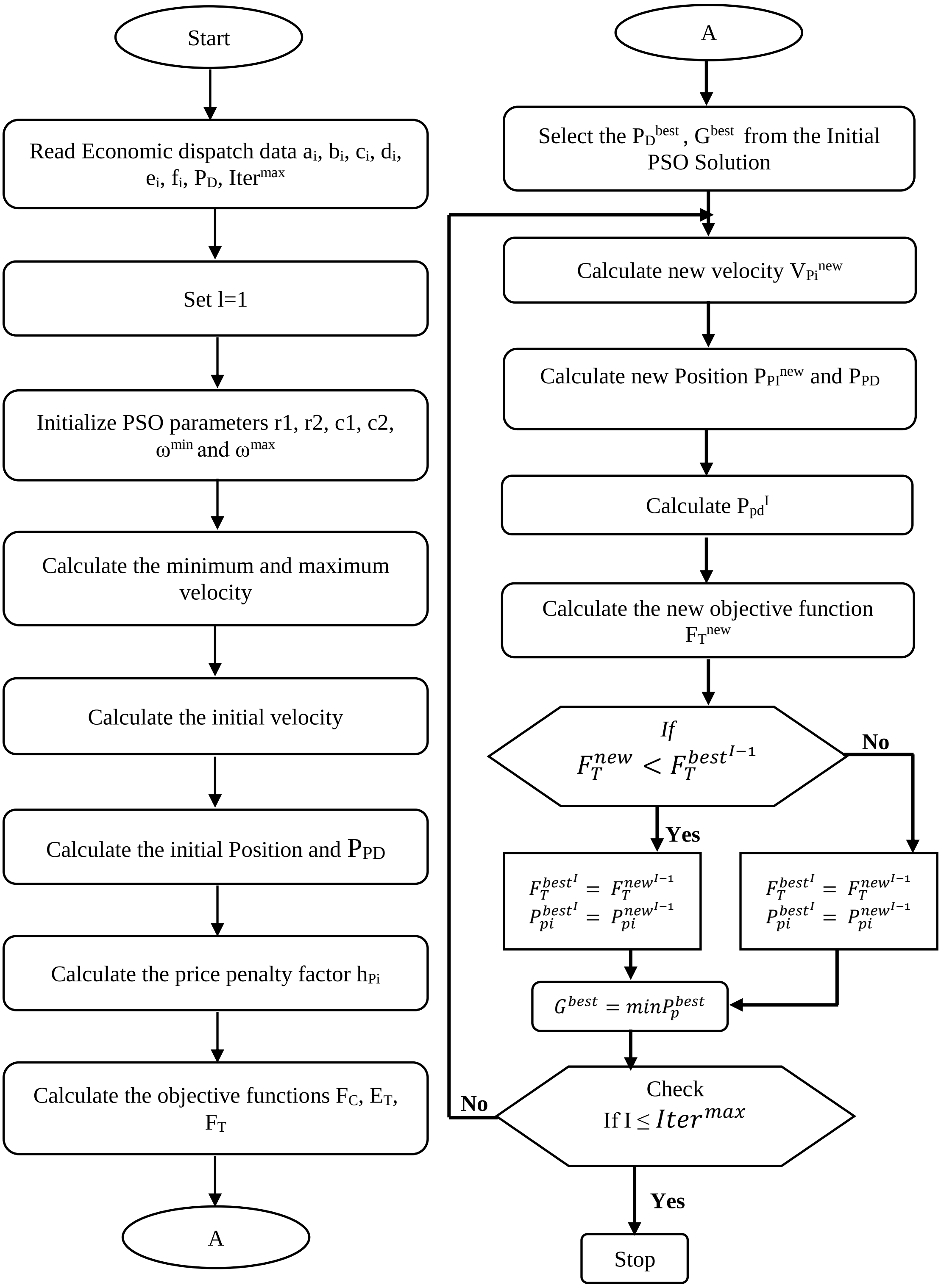

Figure 2. Flowchart for the Proposed Application of PSO Algorithm for CEED Problem Solution

The optimal setting of the PSO control parameters are given in the Table 1 below:

Table 1. The Initial Setting of the PSO Control Parameters

Minimum weight ω_{min}	0.4
Maximum weight ω_{max}	0.9
Weight ω	0.65
Acceleration factors $c_1,\ c_2$	0.7, 0.6
Total number of iterations m	25
Total number of particles in the swarm N_P	10

5. Simulation, Numerical Result and Discussion

Here, the results of two different case studies have been brought to verify and show the feasibility of the proposed PSO algorithm to solve the CEED problem.

The programming of the CEED using the PSO method has been applied by the use of the MATLAB software environment, tested on a CORE i5, personal computer with 2.20 GHz and 4 GO RAM.

5.1. Application Study

The PSO algorithm shown in the previous flowchart is applied to solve the CEED problem for IEEE 30-bus system (Figure 3) and real oust Algeria 22-bus system (Figure 12).

5.1.1. Case study 1: IEEE 30-Bus System with 6 Generators

The system has the total load demand of 250 [MW]. Table2 present data of fuel cost and generator limits. The emission coefficients of generatorsare given in Table 3. While Table 4show the transmission loss coefficient for the considered system.

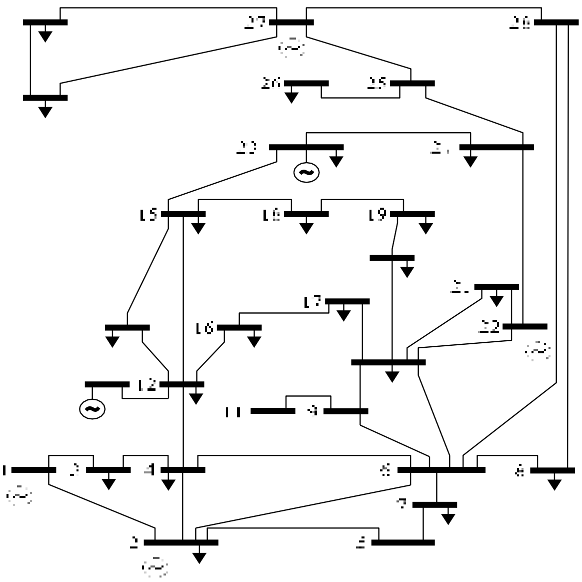

Figure 3. Single Line Diagram of the IEEE 30-Bus Test System

Table 2. Power Generation Limits and Cost Coefficients for IEEE 30-Bus System

Bus	$P_{G,max}$[MW]	$P_{G,min}$[MW]	$a_i[\$/MW^2h]$	$b_i[\$/MWh]$	$c_i[\$/h]$
1	200	50	0.00375	2.00	0
2	80	20	0.01750	1.70	0
5	50	15	0.06250	1.00	0
8	35	10	0.00824	3.25	0
11	30	10	0.02500	3.00	0
13	40	12	0.02500	3.00	0

Table 3. Pollution Coefficients for the IEEE 30-Bus System

Bus	d_i[kg/MW^{2}h]	e_i [kg/MWh]	f_i[kg/h]
1	0.0126	-0.90	22.983
2	0.0200	-0.10	25.313
5	0.0270	-0.01	25.505
8	0.0291	-0.005	24.900
11	0.0290	-0.004	24.700
13	0.0271	-0.0055	25.300

Table 4. Transmission Loss Coefficients

<table>
<tr><th colspan="6">B</th></tr>
<tr><td>0.000218</td><td>0.000103</td><td>0.000009</td><td>-0.000010</td><td>0.000002</td><td>0.000027</td></tr>
<tr><td>0.000103</td><td>0.000181</td><td>0.000004</td><td>-0.000015</td><td>0.000002</td><td>0.000030</td></tr>
<tr><td>0.000009</td><td>0.000004</td><td>0.000417</td><td>-0.000131</td><td>-0.000153</td><td>-0.000107</td></tr>
<tr><td>0.000010</td><td>-0.000015</td><td>-0.000131</td><td>0.000221</td><td>0.000094</td><td>0.000050</td></tr>
<tr><td>0.000002</td><td>0.000002</td><td>-0.000153</td><td>0.000094</td><td>0.000243</td><td>-0.000001</td></tr>
<tr><td>0.000027</td><td>0.000030</td><td>-0.000107</td><td>0.000050</td><td>-0.000001</td><td>0.0003458</td></tr>
<tr><th colspan="3">B_0</th><td colspan="2">B_{00}= 0.000014</td><td></td></tr>
<tr><td>0.000003</td><td>0.000021</td><td>-0.00056</td><td></td><td></td><td></td></tr>
<tr><td>0.000034</td><td>0.000015</td><td>0.000078</td><td></td><td></td><td></td></tr>
</table>

The results, including the optimal values of the generated power, generation cost, the emission level and power losses are reported in Table5 for all the price penalty factor. Figure 4-11 illustrates the convergence property of the proposed algorithm for case study 1.

Table 5. The Best Obtained Results of IEEE 30-Bus System

criterion	Min-Max	Max-Max	Min-Min	Max-Min
P_1 [*MW*]	107.8	80.906	58.702	54.674
P_2 [*MW*]	43.792	52.296	63.827	59.209
P_3 [*MW*]	35.277	51.385	51.416	42.094
P_4 [*MW*]	21.718	34.126	25.048	36.58
P_5 [*MW*]	23.374	14.878	21.466	30.063
P_6 [*MW*]	22.606	20.213	32.953	30.378
Transmission Loss	4.5703	**3.8033**	**3.4223**	**2.9989**
Total output	256.18	255.53	256.19	254.65
Load demand	250	250	250	250
Fuel Cost [$/h]	**721.33**	783.79	818.56	795.4
Emission [kg/h]	**279.85**	305.3	325.79	319.65
Total Cost [$/h]	**844.21**	1429.6	834.93	2266.1
Temps [S]	**0.261669**	0.243196	0.303118	0.272172

Table 6. Graphical Representation of the Best-Obtained Simulink Results for IEEE 30-Bus System

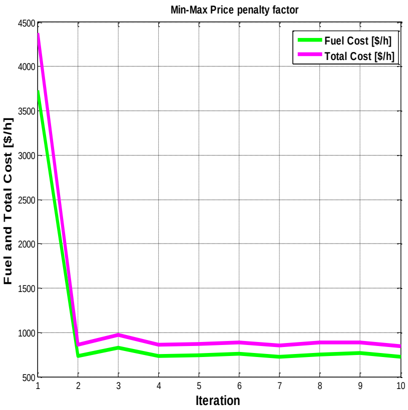	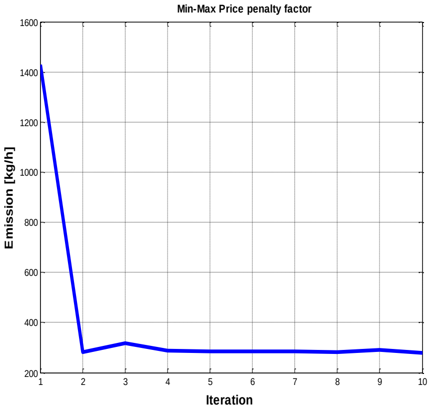
Figure 4. Convergence Profile of Fuel Cost and Total Cost (CEED) OBTAIned by PSO Algorithm	**Figure 5. Convergence Property of Emission Values Obtained by PSO Algorithm**

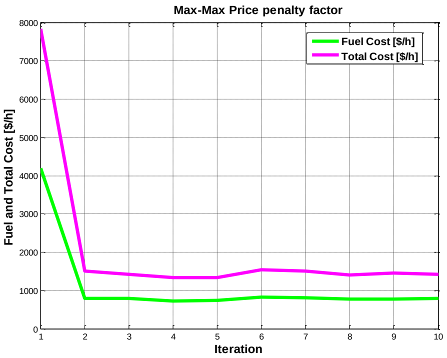

Figure 6. Convergence Profile of Fuel Cost and Total Cost (CEED) Obtained by PSO Algorithm

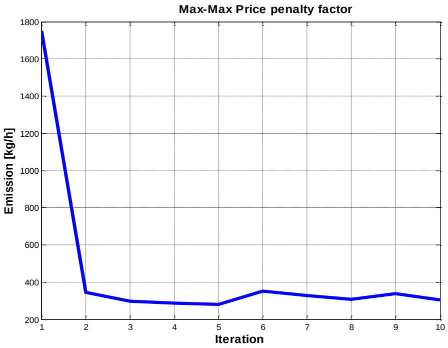

Figure 7. Convergence Property of Emission Values Obtained by PSO Algorithm

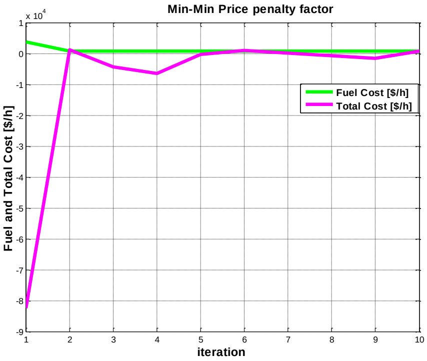

Figure 8. Convergence Profile of Fuel Cost and Total Cost (CEED) Obtained by PSO Algorithm

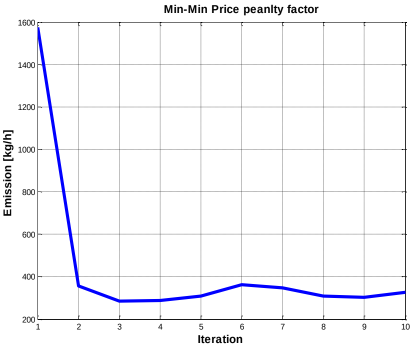

Figure 9. Convergence Property of Emission Values Obtained by PSO Algorithm

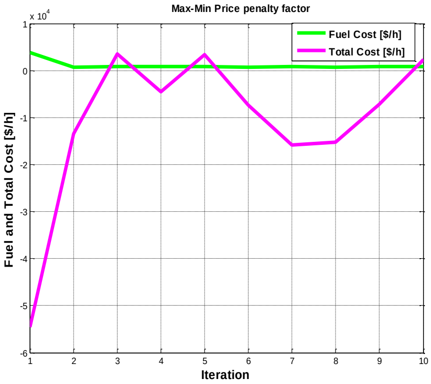

Figure 10. Convergence Profile of Fuel Cost and Total Cost (CEED) Obtained by PSO Algorithm

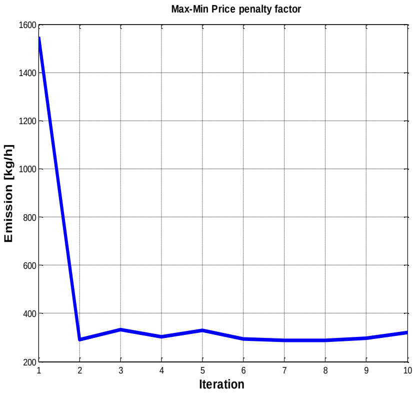

Figure 11. Convergence Property of Emission Values Obtained by PSO Algorithm

As illustrated in Table 5 the active powers of the 6 generators are all within their allowable limits.

PSO algorithm using Min-Max Price penalty factor gives minimum fuel cost, pollution control and total fuel cost CEED, with acceptable computation time. When using the Max-Max, Min-Min, Max-Min penalty factor the transmission power loss value is less in comparison with the Min-Max penalty factor, which demonstrates the ability of the PSO algorithm to find the optimal points in a search space, since meta-heuristic PSO generate random solution for each execution.

Figure 4 and 5 shows the convergence for the best solutions of the minimum fuel and total cost. It can be seen that the convergence of PSO when using Min-Max price penalty factor is faster and more effective than the other price penalty factor, for example at the iteration 2 the fuel and total cost by Min-Max price penalty factor is lower than those obtained by other Price penalty factor. And this applies to emission values.

5.1.2. Case study 2: Real West Algeria 22-Bus System with 7 Generators

The proposed PSO algorithm is tested for solving the CEED problem in power network real, West Algeria (Figure 12).

The test system consists of 7 thermal units, 15 load buses and 31 transmission lines, 03compensator var static SVC [3* (+40Mvar et)10Mvar)]. The total system demand is 856 MW.

Table 7. Power Generation Limits and Cost Coefficients for the 22-Bus Power Network Real, West Algeria 220 kv

Bus	$P_{G,max}$[MW]	$P_{G,min}$[MW]	a_i[\$/MW^{2}h]	b_i[\$/MWh]	c_i[\$/h]
1	500	100	0.007	7.5	240
2	200	50	0.008	7	200
3	300	80	0.0085	7.5	220
4	150	50	0.009	7	200
5	200	50	0.009	9	220
6	120	50	0.0075	10	190
7	80	10	0.009	6.3	180

The best solutions of solving this problem by the proposed algorithm are shown in Table 8. The obtained results satisfy the desired generating unit’s constraints. The convergence property of the algorithm for all the price penalty factor is illustrated in figure (13-20).

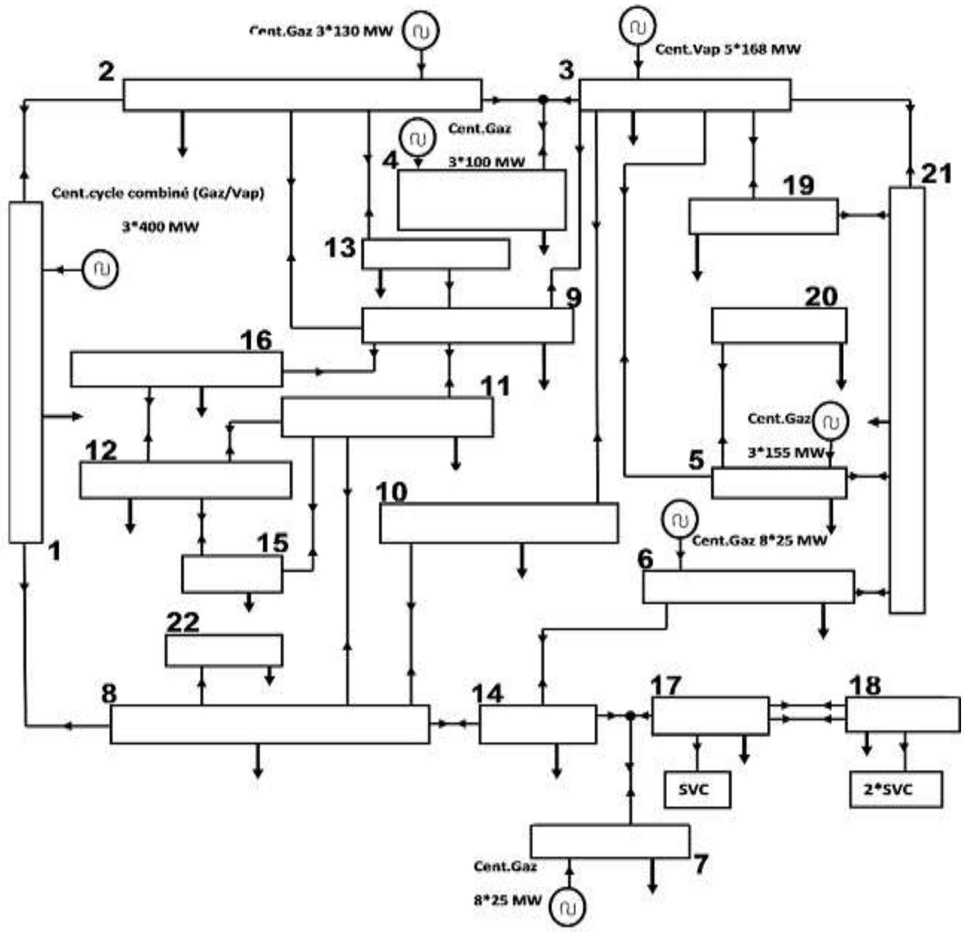

Figure 12. Power Network Real, West Algeria 220kV of the 22-Bus

Table 8. The Best Obtained Results of 22-Bus Power Network Real, West Algeria 220 kv

criterion	**Min-Max**	**Data Frome SONELGAZ [15]**	**Max-Max**	**Min-Min**	**Max-Min**
P_1 [MW]	100	200	100	100	100
P_2 [MW]	185.69	200	123.65	161.14	121.93
P_3 [MW]	191.72	300	277.09	231.07	247.96
P_4 [MW]	132.13	80	107.34	113.5	142.47
P_5 [MW]	96.892	100	89.872	123.92	118.64
P_6 [MW]	111.23	100	103.75	88.754	90.348
P_7 [MW]	46.767	10	62.762	64.689	61.832
Transmission Loss	**18.4**	**21.4**	**21.9**	**21.2**	**22.6**
Total output	864.429	990	864.464	865.073	883.18
Load demand	856	856	856	856	856

Fuel Cost [$/h]	**8915**	**9104.42**	9044.6	9068.4	9131.4
Emission [kg/h]	**2938.2**	/	3385.6	3140.8	3324.3
Total Cost [$/h]	**11104**	/	15465	28595	75071
Temps [S]	0.248867	/	0.241306	0.249231	0.254852

Table 9. Graphical Representation of the Best Obtained Simulink Results for 22-Bus Power Network Real, West Algeria 220 kv

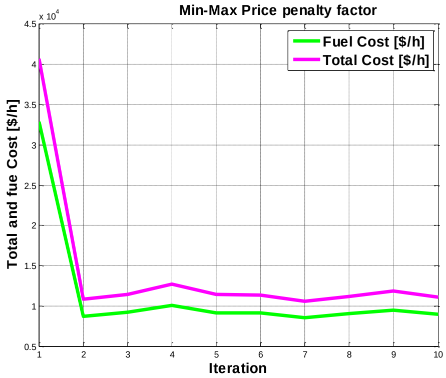	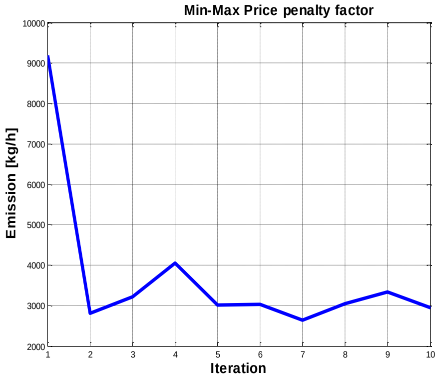
Figure 13. Convergence Profile of Fuel Cost and Total Cost (CEED) Obtained by PSO Algorithm.	**Figure 14. Convergence Property of Emission Values Obtained by PSO Algorithm**
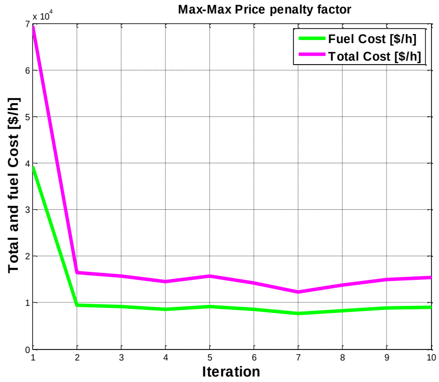	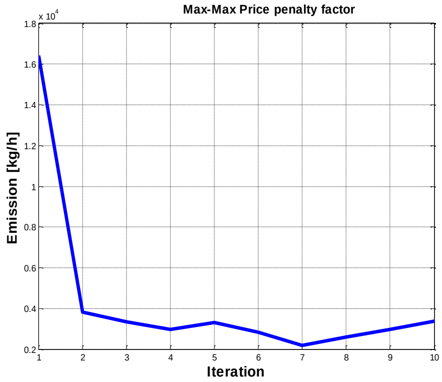
Figure 15. Convergence Profile of Fuel Cost and Total Cost (CEED) obtained by PSO Algorithm	**Figure 16. Convergence Property of Emission Values Obtained by PSO Algorithm**

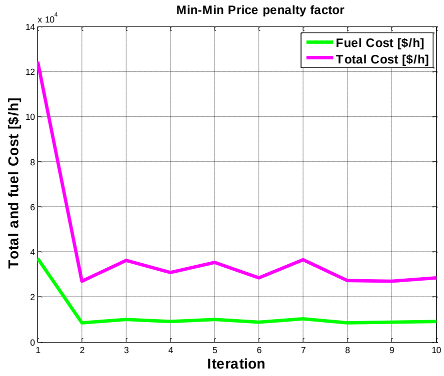

Figure 17. Convergence Profile of Fuel Cost and Total Cost (CEED) obtained by PSO Algorithm

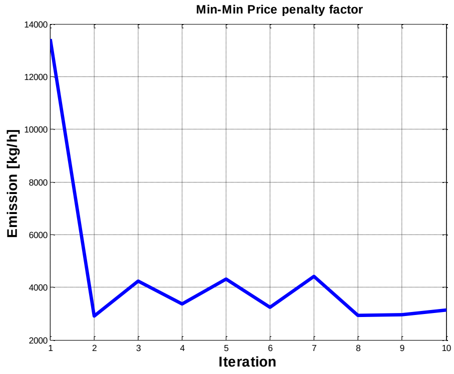

Figure 18. Convergence Property of Emission Values Obtained by PSO Algorithm

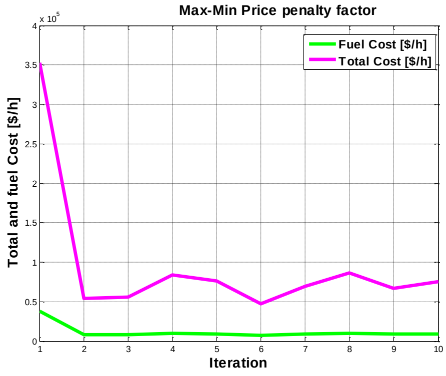

Figure 19. Convergence Profile of Fuel Cost and Total Cost (CEED) Obtained by PSO Algorithm.

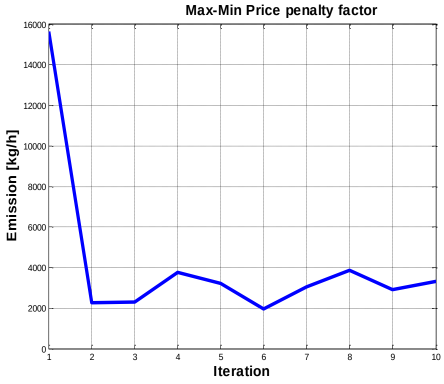

Figure 20. Convergence Property of Emission Values Obtained by PSO Algorithm

Results of Table 8 show an acceptable improvement in the transmission power loss, fuel cost, pollution control and total fuel cost CEED of the system, with acceptable computation time when using the Min-Max price penalty factor in comparison with the Max-Max, Min-Min, and Max-Min penalty factor, which demonstrates that the proposed algorithm has more ability to find the optimal points in a search space compared to data from SONELGAZ in **[15]**.

Figure 13 show clearly that the convergence of fuel and total cost of PSO when using Min-Max price penalty factor is better than other price penalty factor, the cost of generation for Min-Max PPF at iteration 2 is lower than other PPF and emission values at the same iteration.

5.1.3. Case study 3: Eleven Generator Systems

This system contains 11 thermal generating units and the characteristics of the units are given in table 10 and 11 respectively. The considered load demand for the system is 2500 MW. But the *B* loss coefficient matrix is neglected because of limitation in space. This example has quite a large problem search space compared to the previous examples.

After applying and executing the proposed algorithm to the CEED problem, the optimal solution of the eleven generators is given in Table 12. Figures 21-28 shows the convergence of values for the fitness function and emission during iterations.

Table 10. Power Generation and Cost Coefficients of Eleven Generator System

$P_{G,max}$[MW]	$P_{G,min}$[MW]	a_i [\$/MW^{2}h]	b_i [\$/MWh]	c_i[\$/h]
250	20	0.00762	1.92699	387.85
210	20	0.00838	2.11969	441.62
250	20	0.00523	2.19169	422.57
300	60	0.00140	2.01983	552.50
210	20	0.00154	2.22181	557.75
300	60	0.00177	1.91528	562.18
215	20	0.00195	2.10681	568.39
455	100	0.00106	1.99138	682.93
455	100	0.00117	1.99802	741.22
460	110	0.00089	2.12352	617.83
465	110	0.00098	2.10487	674.61

Table 11. Pollution Coefficients of Eleven-Generator System

d_i[kg/MW^{2}h]	e_i[kg/MWh]	f_i[kg/h]
0.00419	-0.67767	33.93
0.00461	-0.69044	24.62
0.00419	-0.67767	33.93
0.00683	-0.54551	27.14
0.00751	-0.40060	24.15
0.00683	-0.54551	27.14
0.00751	-0.40060	24.15
0.00355	-0.51116	30.45
0.00417	-0.56228	25.59
0.00355	-0.41116	30.45
0.00417	-0.56228	25.59

Table 12. The Best Results of Eleven Generators System

criterion	Min-Max	Max-Max	Min-Min	Max-Min
P_1 [MW]	89.425	223.67	220.42	221.14
P_2 [MW]	172.03	210	210	126.71
P_3 [MW]	213.3	104.91	250	235.01
P_4 [MW]	264.93	215.28	104.95	137.2
P_5 [MW]	100.98	204.37	193.71	135.22
P_6 [MW]	183.27	79.55	236.2	170.84

P_7 [MW]	190.38	215	115.24	160.34
P_8 [MW]	359.79	384.03	243.33	416.68
P_9 [MW]	299	279.88	346.96	256.68
P_{10} [MW]	329.33	349.34	250.73	252.92
P_{11} [MW]	298.2	233.97	328.47	387.26
Total output	2500	2500	2500	2500
Load demand	2500	2500	2500	2500
Fuel Cost [$/h]	**12581**	**12817**	**12996**	**12774**
Emission [kg/h]	**1971.4**	**1973.2**	**1818.1**	**1857.3**
Total Cost [$/h]	**16072**	**21070**	**100970**	**201340**
Temps [S]	0.490277	0.362776	0.356488	0.379458

Table 13. Graphical Representation of the Best-Obtained Simulink Results for Eleven-Generator System

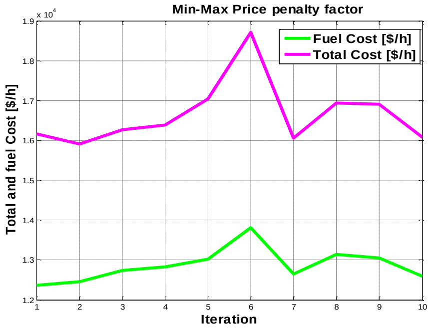

Figure 21. Convergence Profile of Fuel Cost and Total Cost (CEED) obtained by PSO Algorithm

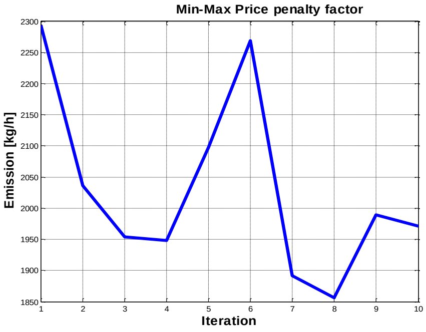

Figure 22. Convergence Property of Emission Values Obtained By PSO Algorithm

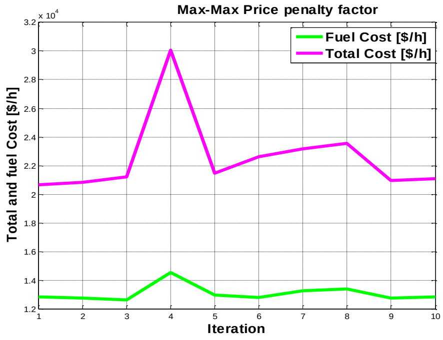

Figure 23. Convergence Profile of Fuel Cost and Total Cost (CEED) obtained by PSO Algorithm.

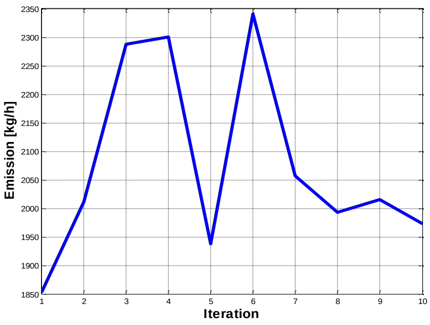

Figure 24. Convergence Property of Emission Values Obtained By PSO Algorithm

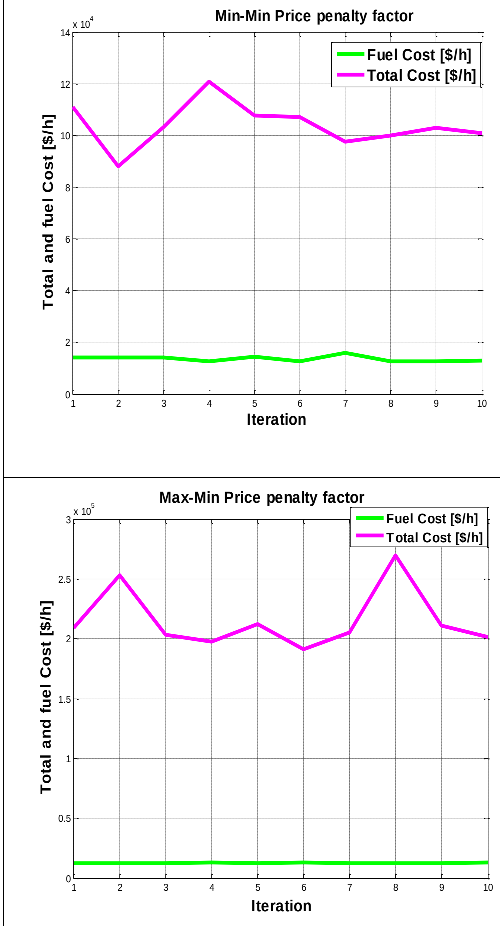

Figure 27. Convergence Profile of Fuel Cost and Total Cost (CEED) Obtained by PSO Algorithm

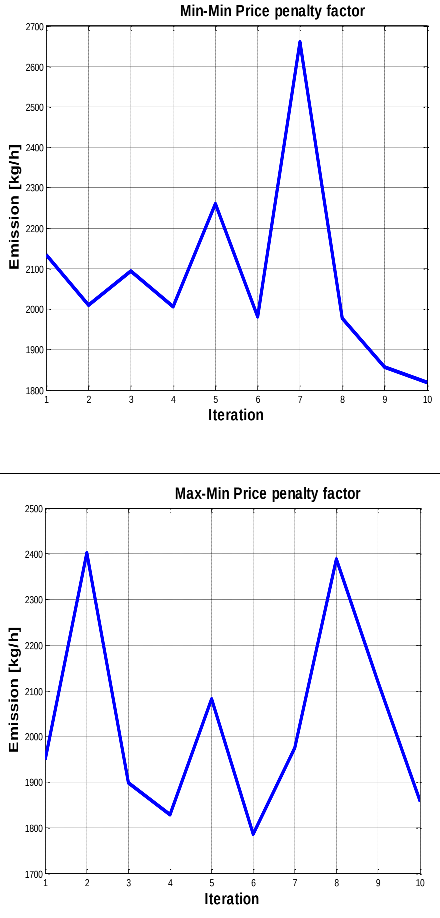

Figure 28. Convergence Property of Emission Values Obtained by PSO Algorithm

The Table 12 shows that the proposed algorithm can find a better results value for the problem when using Min-Max price penalty factor compared to the other price penalty factor such as Max-Max, Min-Min, and Max-Min. The intense of convergence in figures 21-28, also demonstrate that the proposed algorithm is able to find the solution of the problem in large search space more efficiently and faster

Figure 21 and 22 shows that the results obtained with proposed approach PSO when using Min-Max PPF the fuel and total cost are better than those obtained by the other PPF and also for emission values.

6. Conclusions

In this paper, The Algorithm of Particle Swarm Optimization was proposed to solve the CEED problem using four different penalty factors which are Min-Max, Max-Max, Min-Min and Max-Min price penalty factors, and their effectiveness is questioned by testing the Algorithm on IEEE-30 bus system, Real West Algeria 22-bus system with 7 generators and eleven generator systems. On the basis of results obtained, the PSO algorithm has been successfully implemented to solve optimal power flow problem for minimization of the total cost of the generation, the cost of pollution level control and the active power loss. Simulation results, show that the proposed method works, equally well for both small and large case studies and it has been shown that the algorithm can converge faster when using Min-Max price penalty factor than the other price penalty factors.

Acknowledgment

Authors would like to thank the heads of Laboratory of Analysis, Control and Optimization of Electro-Energetic Systems (CAOSEE) and Smart Grids the renewable energies (ENERGARID) at the university TAHRI Mohammed of Béchar (Algeria).

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Authors

Mohammed Amine Meziane, he was born in 1992 at Ain Sefra -Naama-Algeria. In 2015, he received the state master degree in Electrical Engineering from the University of Bechar, Algeria. He is currently a PhD. Student from the University of Bechar, Algeria, Faculty Technology. His areas of interest are stability improvement and optimization in power network, FACTS systems, power filters and applications of power electronics. Correspondence address: Dept. Science and Technology "Electrical Engineering", Faculty of Technology, Bechar University, BP 417, 08000 Bechar, Algeria,

E-mail: aminemohmeziane@gmail.com.

Youssef Mouloudi, he received the state engineer degree in Electrical Engineering in 2006 from the University of Bechar and M.S. and Ph.D. from Bechar University, Algeria. in 2009 and 2013, respectively. He was working at SONELGAZ "Algeria Electrical Society" since 1995. Currently, he is an assistant professor of electrical engineering, Faculty Technology at Bechar University, Algeria. His areas of interest are FACTS systems, power filters, applications of power electronics, and stability improvement. Correspondence address: Dept. Science and Technology "Electrical Engineering", Faculty of Technology, Bechar University, BP 417, 08000 Bechar, Algeria,

E-mail: mouloudiyoussef@yahoo.fr