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Economic-Emission Load Dispatch Using Particle Swarm Optimization

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Abstract-The economic-emission load dispatch (EELD) of thermal units by means of particle swarm optimization (PSO) algorithm is proposed. The EELD is formulated as a bi-objective problem including the fuel cost and polluting emission of generating units. The bi- objective problem is converted into a single objective function by combining the cost equation and the emissions equation using weight factor. A simultaneous research of minimum total generation fuel cost and the toxic gases emission when satisfying the load demand and some constraints is carried out. The proposed PSO algorithm has been implemented on Algerian network. Two cas studies are evaluated. The first one consists of 59 bus and 10 generators. The seconde one consists of 114 bus and 15 generators. A comparison with other algorithms reported in the literature shows the effectiveness of the proposed EELD to evaluate polluting effects and to motivate promoting clean energy as wel.

Keywords: Economic-emission load dispatch, economic dispatch, pollution emission, fuel cost, particle Swarm optimization.

1. INRODUCTION

The major challenge of the power system is to generate the adequate quantity of electricity to meet the demand for electricity of the consumers at the lowest possible cost. The cost of operating of the generators is not proportional with their outputs therefore the challenge for electrical power utilities is to try to balance the total load among generators. For that, the sizes of electric power system are increasing rapidly to meet the total demand of load but the rate of increase of electrical power demand is superior than the rate of increase of generation. For that, it is important to operate electrical power system in economic manner.

In recent years, many countries have concentrated on the reduction of the quantity of different polluting gases produced from fossil fuel to the production of electrical energy. The gaseous pollutants emitted by the production units cause dangerous effects with the human beings and the environment like the Sulfur Oxides (SO_2), Nitrogen Oxides (NO_x) and Carbon Dioxide (CO_2), etc. Thus, the optimization of production cost should not be the only objective but the reduction of emission must also be taken into account [1].

The condition corresponds to minimum cost with minimum emission combining both the objective functions into economic-emission load dispatch (EELD). The aim of EELD is to operate the production units that produce electrical energy with minimized the fuel cost and emissions of production units, while satisfying the total load demand and operational constraints. Fuel cost and emission functions, are independent of each other, which make the EELD problem bi-objective. The bi-objective problem is converted into a single objective function by combining the cost equation and the emissions equation using weight factor.

Different techniques have been reported in the literature concerning to the economic emission load dispatch problem based on evolutionary algorithms such as genetic algorithm [2], particle swarm optimization [3], simulated annealing [4], artificial bee colony optimization [5,6], …etc.

In this paper, PSO algorithm is proposed to solve EELD problem. The program of this method has been developed on the MATLAB environment. The proposed algorithm has been implemented on Algerian network for two case studies: network consists of 59 bus with 10 generators and network consists of 114 bus with 15 generators. In order to see the effectiveness of the proposed algorithm, the results obtained of 59 bus system have been compared with other algorithms reported in the literature. The one of 114 bus system has been simulated with chosen parameters values of the emission function. The obtained results for this network could also be compared with other similar available works.

2. PROBLEM FORMULATION

2.1 Objective functions

Mathematically, the EELD problem can be written in the following form:

$$\text{Minimise}\left[\sum_{i=1}^{N_g}\left\{F\left(P_{gi}\right), E\left(P_{gi}\right)\right\}\right] \tag{1}$$

Where :

P_{gi} : Active power generation of i^{th} unit (MW).

F : Total fuel cost of generation ($/h) .

E : Total emission in the system (Ton/h)

N_g : Number of thermal units.

A. Cost function

The total fuel cost of thermal plant is expressed as a sum of multiple quadratic cost function in terms of real power generation and is mathematically defined as follows:

$$F\left(P_{gi}\right)=\sum_{i=1}^{N_g}\left(c_i+b_iP_{gi}+a_iP_{gi}^2\right) \tag{2}$$

Where, a_i b_i and c_i are the fuel cost coefficients of the i^{th} generating units.

B. Emission function

The total amount of released emission is given by:

$$E(P_{gi})=\sum_{i=1}^{N_g}10^{-2}\left(\gamma_i+\beta_iP_i+\alpha_iP_i^2+\eta_i\exp(\delta_iP_{gi}^2)\right) \tag{3}$$

Where α_i , β_i, γ_i , δ_i and η_i are the emission coefficients of the i^{th} unit.

C. Handing bi-objective

The EELD problem can be formulated by combining two independent objectives, which are emission and fuel cost. In this way, the bi-objective EELD problem is expressed in a single-objective form. To solve the EELD problem, this form is intended to minimize while satisfying the constraints expressed above. The single-objective EELD problem is formulated as follows:

$$F_T = \sum_{i=1}^{N_g} \left[wF(P_{gi}) + (1-w)h.E(P_{gi}) \right] \quad (4)$$

Where w is weight factor $(0 \le w \le 1)$ and h is the price penalty factor in \$/h. It is the ratio between maximum fuel cost and maximum emission, and is described as follows:

$$h = \frac{F(P_{gi}^{\max})}{E(P_{gi}^{\max})} \quad (5)$$

2.2. Contraints

In this process, some equality and inequality constraints must be satisfied. The equality constraint is called a power balance. The inequality constraint is called a generation capacity constraint.

A. Equality constraint

The total power generation must supply the total power demand by the load and the total acive power losses (P_L). Thus the equality constraint is expressed as:

$$\sum_{i=1}^{Ng} P_{gi} = P_D + P_L \quad (6)$$

Where :

P_D: Load of the system (MW).

P_L: active power losses of the system (MW).

where P_L is called network losses, which can formulated as follows:

$$P_L = B_{00} + \sum_{i=1}^{N} B_{0i} P_{gi} + \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \left(P_{gi} B_{ij} P_{gj} \right) \quad (7)$$

Where B_{oo},B_{0i} and B_{ij} are the loss coefficients.

B. Inequality constraint

The power output of each unit must be less than or equal to maximum power generation and also be greater than or equal to the minimum power generation. Thus the inequality constraint is expressed as:

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max}, i = 1 \ldots . N_g \quad (8)$$

Where, $P_{gi}^{\min}$, $P_{gi}^{\max}$ are the minimum and maximum power generation limit of the the i^{th} unit.

3. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Kennedy and Eberhart , inspired by social behavior of bird flocking or fish schooling [7]. PSO provides a population based search procedure in which individuals called particles change their positions with time. All of particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles.

In PSO process, each particle is updated by following two best values. The first one is the best solution of the particules. This value is called P_{best}. The seconde value is the best solution of the particle swarm optimizer, obtained by any particle in the population. This best value is called G_{best}. After finding the best values, the particle updates its velocity and positions.

The velocity and position vectors of particle i are respectively are given by:

$$X_i = (x_{i1}, x_{i2} .... x_{in}) \quad (9)$$

$$V_i = (v_{i1}, v_{i2} .... v_{in}) \quad (10)$$

The best previous position of the particle i is recorded and represented by:

$$P_{besti} = (x_{i1}^{best}, x_{i2}^{best} .... x_{in}^{best}) \quad (11)$$

The updated velocity and position of the particle i at (k+1) iteration is found by the following equations:

$$X_i^{(k+1)} = X_i^{(k)} + V_i^{(k+1)} \quad (12)$$

$$V_i^{(k+1)} = wV_i^{(k)} + c_1\, rand_1 (Pbest_i^{(k)} - X_i^{(k)}) + c_2\, rand_2\, (Gbest_i^{(k)} - X_i^{(k)}), \quad i = 1....n \quad (13)$$

Where:

n : Number of particles.

k : Number of iterations.

w : Inertia weight factor.

$V_i^{(k)}$: The velocity of the particle i at iteration k.

$X_i^{(k)}$: The current position of particle i at iteration k.

c_1 and c_2 : Acceleration constants.

$rand_1$ and $rand_2$ are two uniform random values in the range [0,1].

The acceleration constants c_1 and c_2 were often set to be 2 according to past experiences [8]. The inertia weight is employed to control the velocity. In general, the inertia weight w is set according to the following equation:

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter.\max}\, x\ iter \quad (14)$$

Where :

w_{max} : Initial weight.

w_{min} : Final weight.

iter : Current iteration number.

iter.max : Maximum iteration number.

4. PSO APPLIED TO EELD

Our objective is to minimize the objective function of the EELD defined by (15), taking into account the equality and inequality constraints.

The cost function implemented in PSO is defined as:

$$F_T = \sum_{i=1}^{N_g} \left[wF(P_{gi}) + (1-w)h.E(P_{gi}) \right] \quad (15)$$

Our objective is to search active power generation P_{gi} set in their admissible limits to achieve the optimization problem. At initialization, the active power generation is selected randomly between maximum and minimum power generation. The PSO algorithm applied to EELD can be presented in the following steps.

Step 1: Input parameters of system, specify the parameters for PSO, and specify the maximum and minimum power generation.

Step 2: The particles are randomly generated between the maximum power generation and minimum power generation.

Step 3: Calculate the evaluation value of each particle.

Step 4: Calculate the fitness value of objective function of each particle. The current evolution is $m = 1$.

Step 5: Initialize the inertia weight, the initial velocity and the factors c_1, c_2,.

Step 6: Modify the velocity and position of each particle.

Step 7: If a particle violates its position limits in any dimension, set its position at the proper limits. Calculate each particle's new fitness.

Step 8: calculate the transmission losses for each particles of the population.

Step 9: Update : $m = m + 1$.

Step 10 : If the stopping criteria is satisfied then go to step 11. Otherwise go to step 6.

Step 11: The particle generates is the global optimum.

5. SIMULATION RESULTS

In order to illustrate the efficiency and robustness of the proposed algorithms, two case studies are tested on Algerian network : network consists of 59 bus with 10 generators and network consists of 114 bus with 15 generators. The results obtained from the PSO are compared with other optimization techniques, which have been reported in the literature.

The PSO parameters used for the simulation are:

- Number of Particles : 50
- Number of iterations : 100
- w_{min} : 0.4
- w_{max} : 0.9
- c_1 : 2
- c_2 : 2

5.1. Case 1 (10 generators)

In this case, the PSO algorithm is used to solve the EELD of a network which consists of 59 bus, 10 generators and 83 branches. It supplies a total load of 684.1 MW. The generator of the bus N° 13 is out of service [9].

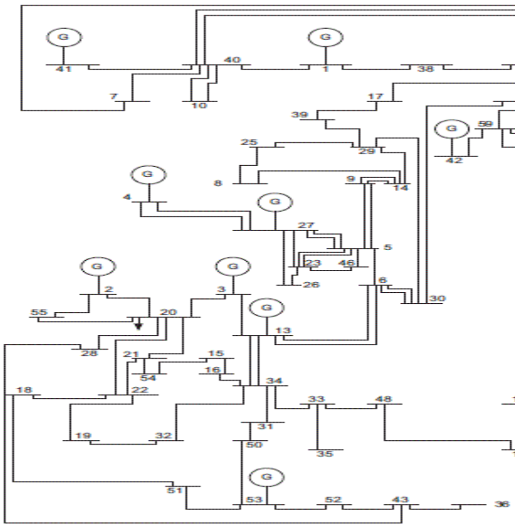

Figure 1 Single line diagram of the Algerian production and transmission network (59-bus) before 1977

The parameters of the cost function and generators limits are listed in TABLE I. Those of the emission function are listed in TABLE II.

TABLE I.
Parameters of the cost function and generators limits
(Algerian network - 59 bus)

Unit	a ($/MW^2.h)	b ($/MW.h)	c ($/h)	Pmin (MW)	Pmax (MW)
1	0.0085	1.5	0	8	72
2	0.0170	2.5	0	10	70
3	0.0085	1.5	0	30	510
4	0.0085	1.5	0	20	400
13	0.0170	2.5	0	15	150
27	0.0170	2.5	0	10	100
37	0.0030	2.0	0	10	100
41	0.0030	2.0	0	15	140
42	0.0030	2.0	0	18	175
53	0.0085	1.5	0	30	450

TABLE II.
Parameters of the emission function of Algerian network (59 bus)

Unit	α_i	β_i	γ_i	η_i	δ_i
1	4.091	–5.554	6.490	2.10^{-4}	2.857
2	2.543	–6.047	5.638	5.10^{-4}	3.333
3	4.258	–5.094	4.586	1.10^{-6}	8.000
4	5.326	–3.550	3.380	2.10^{-3}	2.000
13	4.258	–5.094	4.586	1.10^{-6}	8.000
27	6.131	–5.555	5.151	1.10^{-5}	6.667
37	4.091	–5.554	6.490	2.10^{-4}	2.857

41	2.543	–6.047	5.638	5.10^{-4}	3.333
42	4.258	–5.094	4.586	1.10^{-6}	8.000
53	5.326	–3.550	3.380	2.10^{-3}	2.000

The simulation results for three chosen inertia weight (*w*=1, *w*=0, *w*=0.5) are given in TABLE III.

TABLE III.
Simulation results

Parameters	*w*=1	*w*=0	*w*=0.5
P_1 (MW)	33.1469	30.6466	67.4358
P_2 (MW)	43.0305	46.5243	33.4488
P_3 (MW)	148.8998	141.688	132.3610
P_4 (MW)	102.2890	90.0476	86.9834
P_{13} (MW)	0.00	0.00	0.00
P_{27} MW)	44.4552	54.0854	23.0543
P_{37} (MW)	43.2258	32.7717	36.3986
P_{41} (MW)	64.8964	75.2798	61.7151
P_{42} (MW)	79.4826	85.3585	98.9332
P_{53} (MW)	143.4049	147.440	162.4777
P_L (MW)	18.7311	19.7424	18.7079
Cost ($/h)	1799.5	1814.1	1758.4
E (Ton/h)	0.5148	0.4210	0.4453

For comparison purposes, the results reported in [10] are shown in TABLE IV.

TABLE IV.
Comparison of the results

P	*w*=1 PSO	*w*=0 PSO	*w*=0.5 PSO	*w*=1 [10]	*w*=0 [10]	*w*=0.5 [10]
P_1	33.14	30.64	67.43	41.27	30.599	36.831
P_2	43.03	46.52	33.44	37.31	70.00	53.17
P_3	148.8	141.6	132.3	133.8	109.40	119.0
P_4	102.2	90.04	86.98	142.3	79.80	138.3
P_{13}	0.00	0.00	0.00	0.00	0.00	0.00
P_{27}	44.45	54.08	23.05	24.80	80.58	22.860
P_{37}	43.22	32.77	36.39	39.70	34.86	39.80
P_{41}	64.89	75.27	61.71	39.54	70.04	59.90
P_{42}	79.48	85.35	98.93	119.7	100.6	109.5
P_{53}	143.4	147.4	162.4	123.4	128.0	122.9
P_L	18.73	19.74	18.70	17.92	19.819	18.281
Cost	1799.5	1814.1	1758.4	1769.7	1854.8	1765.7
E	0.514	0.421	0.445	0.530	0.4213	0.4723

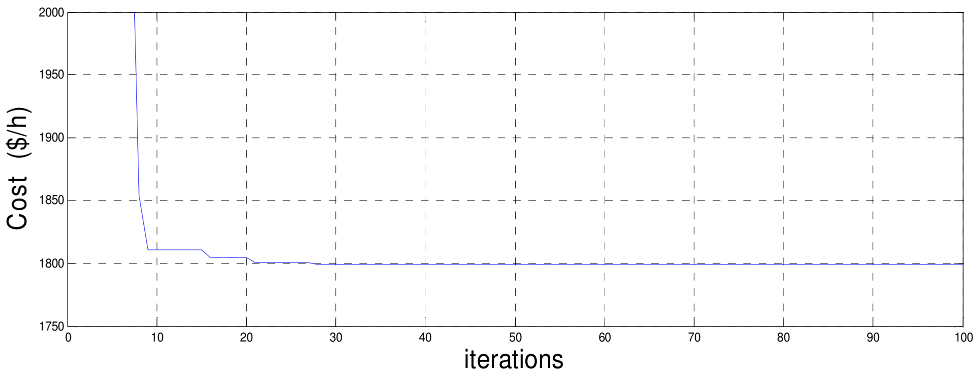

Figure 2 Convergence characteristic of 59 bus system : Cost minimization (case : *w* = 1)

Figure 2 shows the convergence characteristic of the fuel cost of the case corresponding to w=1 .

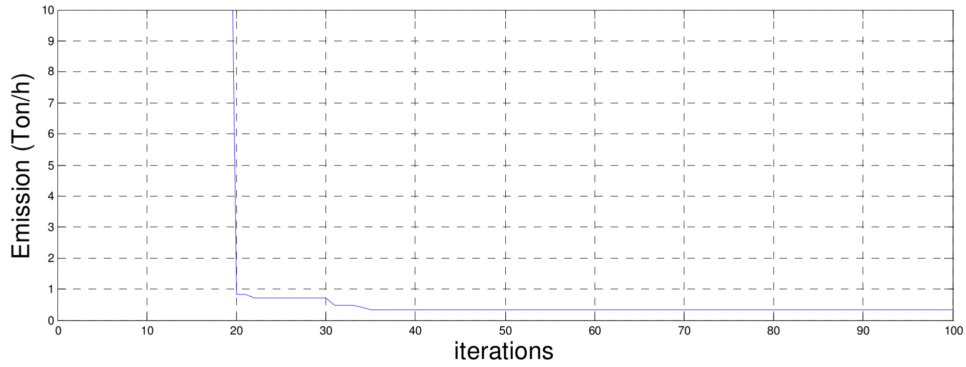

Figure 3 Convergence characteristic of 59 bus system : Emission minimization (case : w = 0)

Figure 3 shows the convergence characteristic of the emission of the case corresponding to w=0 .

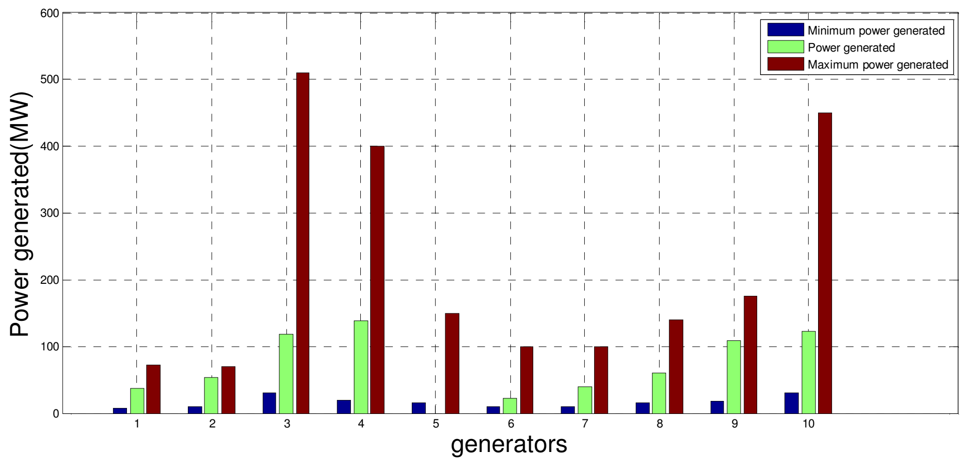

Figure 4 Power generated of 59 bus system (case : w = 0.5)

Figure 4 shows the power generated of 59 bus system corresponding to w=0.5 .

5.2. Case 2 (15 generators)

In this case, we will use PSO algorithm to solve the problem of EELD of the Algerian network. This network consists of 114 bus 15 generators, 159 lines and 16 transformers [11]. This network supplies a total load of 3727 MW.

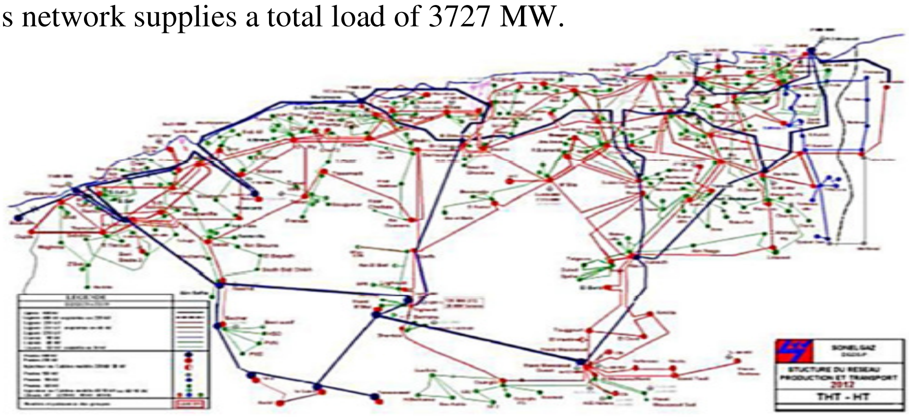

Figure 5 Topologies of the Algerian network

The parameters of the cost function and generators limits are in TABLE V. The parameters of the emission function are proposed in TABLE VI.

TABLE V
Parameters of the cost function and generators limits
(Algerian network - 114 bus)

Unit	a ($\$/MW^2.h$)	b ($/MW.h)	c ($/h)	Pmin (MW)	Pmax (MW)
4	0.0085	1.5	0	135	1350
5	0.0085	1.5	0	135	1350
11	0.0170	2.5	0	10.0	100
15	0.0170	2.5	0	30.0	300
17	0.0085	1.5	0	135	1350
19	0.0170	2.5	0	34.5	345
22	0.0170	2.5	0	34.5	345
52	0.0170	2.5	0	34.5	345
80	0.0170	2.5	0	34.5	345
83	0.0170	2.5	0	30.0	300
98	0.0030	2	0	30.0	300
100	0.0030	2	0	60.0	600
101	0.0030	2	0	20.0	200
109	0.0170	2.5	0	10.0	100
111	0.0170	2.5	0	10.0	100

TABLE VI.
Proposed parameters of the emission function
(Algerian Network -114 bus)

Unit	α_i	β_i	γ_i	η_i	δ_i
4	4.091	–5.554	6.490	2.10^{-4}	2.857
5	4.091	–5.554	6.490	2.10^{-4}	2.857
11	4.258	–5.094	4.586	1.10^{-6}	8.000
15	5.326	–3.550	3.380	2.10^{-3}	2.000
17	4.258	–5.094	4.586	1.10^{-6}	8.000
19	4.258	–5.094	4.586	1.10^{-6}	8.000
22	4.258	–5.094	4.586	1.10^{-6}	8.000
52	4.258	–5.094	4.586	1.10^{-6}	8.000
80	4.258	–5.094	4.586	1.10^{-6}	8.000
83	4.258	–5.094	4.586	1.10^{-6}	8.000
98	4.258	–5.094	4.586	1.10^{-6}	8.000
100	4.091	–5.554	6.490	2.10^{-4}	2.857
101	4.091	–5.554	6.490	2.10^{-4}	2.857
109	4.258	–5.094	4.586	1.10^{-6}	8.000
111	4.258	–5.094	4.586	1.10^{-6}	8.000

The simulation results for three chosen inertia weight (w=1, w=0, w=0.5) are given in TABLE VII. For comparison purposes, the results reported using BAT algorithm (BA) in [11] are shown in TABLE IX.

TABLE VII.
Simulation results

Parameters	*w*=1	*w*=0	*w*=0.5
P_4 (MW)	530.9690	381.7860	345.1037
P_5 (MW)	426.0222	283.5047	356.3807
P_{11} (MW)	100.000	100.000	99.2514
P_{15} (MW)	200.000	228.4398	220.0761
P_{17} (MW)	365.3098	345.7010	347.3287
P_{19}(MW)	193.8420	312.3333	308.1247
P_{22} (MW)	235.2274	301.4724	285.1531
P_{52} (MW)	200.1342	273.4913	269.4993
P_{80} (MW)	244.9993	288.1296	274.5388
P_{83} (MW)	160.5824	246.9560	226.1996
P_{98} (MW)	168.5021	238.2144	254.9712
P_{100} (MW)	600.000	498.5712	467.5945
P_{101}(MW)	200.000	183.1530	170.7121
P_{109} (MW)	100.000	54.0787	100.000
P_{111} (MW)	98.2162	91.8138	100.000
P_L (MW)	96.8046	100.6454	97.9338
Cost($/h)	19496.22	21165.02	20914.11
E (Ton/h)	49297.23	11409. 32	12331.02

TABLE IX.
Comparison of the results (case: w = 1)

Parameters	Case : *w*=1	BA [11]
P_4 (MW)	530.9690	519.6647
P_5 (MW)	426.0222	413.9853
P_{11} (MW)	100.0000	100.000
P_{15} (MW)	200.000	188.6200
P_{17} (MW)	365.3098	468.4487
P_{19}(MW)	193.8420	206.2758
P_{22} (MW)	235.2274	203.6417
P_{52} (MW)	200.1342	149.1470
P_{80} (MW)	244.9993	171.2775
P_{83} (MW)	160.5824	204.1964
P_{98} (MW)	168.5021	205.5997
P_{100} (MW)	600.000	600.000
P_{101} (MW)	200.000	200.000
P_{109} (MW)	100.000	100.000
P_{111} (MW)	98.2162	100.0000
P_L (MW)	96.8046	103.9054
Cost($/h)	19496.22	19439.99

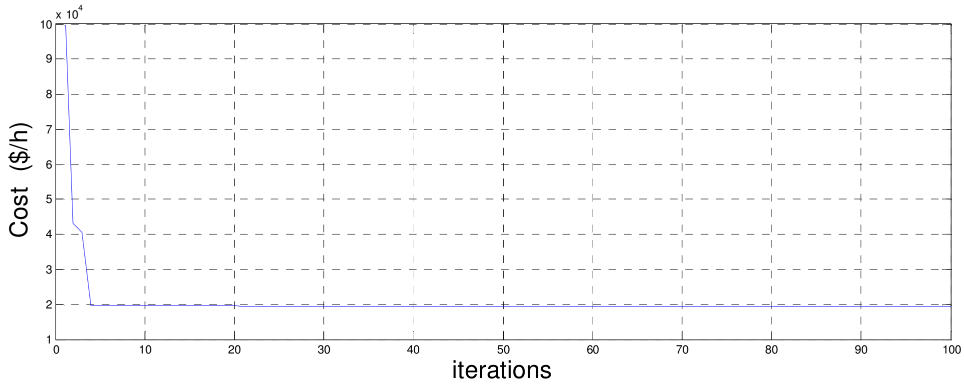

Figure 6 Convergence characteristic of 114 bus system : Cost minimization (case : *w* = 1)

Figure 6 shows the convergence characteristic of the fuel cost of the case corresponding to *w*=1 .

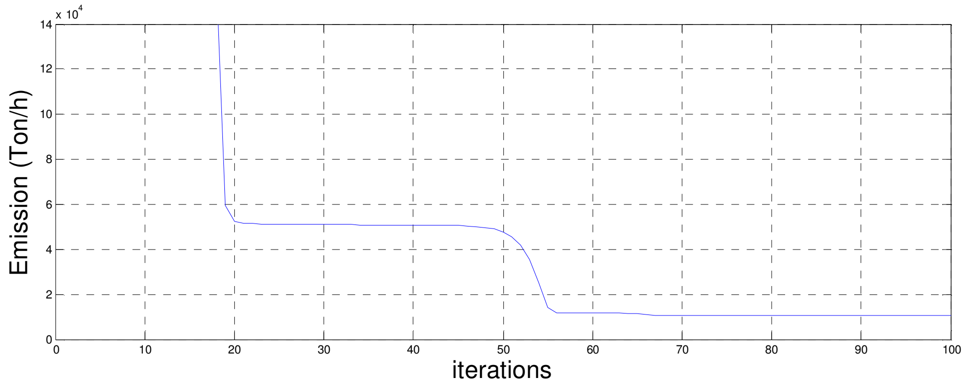

Figure 7 Convergence characteristic of 114 bus system : Emission minimization (case : *w* = 0)

Figure 7 shows the convergence characteristic of the emission of the case corresponding to *w*=0 .

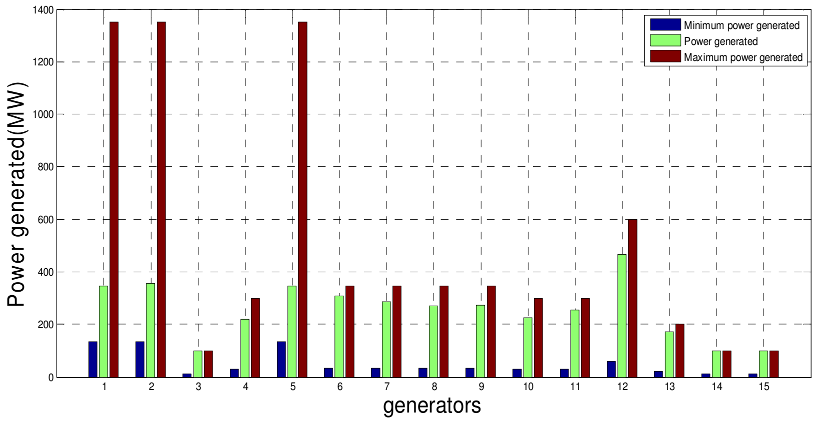

Figure 8 Power generated of 114 bus system (case : *w* = 0.5)

Figure 8 shows the power generated of 114 bus system corresponding to *w*=0.5 .

The simulation results shows that the minimum total emission value is achieved in *w* = 0 and the minimum total fuel cost value is achieved in *w* = 1. It is seen that the EELD provides a compromise between minimum fuel cost and emission.

From simulation results, we notice a great difference among the emission of each test system, this is because of the difference of a power demand of each system.

For example, in the case corresponding to the minimum total operationg cost (case: w=1):

- The fuel cost and the gas emission output of 10 generators system for 684.1 (MW) are 1799.5 ($/h) and 0.5148 (ton/h) respectively. The electrical losses are 18.7311 (MW).
- The fuel cost and the gas emission output of 15 unit system for 3727 (MW) are 19496.22 ($/h) and 49297.23 (Ton/h) respectively. The electrical losses are 96.8046 (MW).

From simulation results, it is clear that the proposed approach gives the best results, regarding both fuel costs and emissions for the EELD problem.

6. CONCLUSION

In this work, the EELD problem has been solved by means of PSO algorithm. It has been formulated as a bi-objective optimization problem. The proposed PSO algorithm has been implemented on Algerian network. Two case studies are evaluated. The first one consists of 59 bus and 10 generators. The second one consists of 114 bus and 15 generators. The simulation results demonstrate the effectiveness and robustness of the proposed PSO algorithm in solving the EELD problem.

In general, the emissions of polluting gases from electricity generation depend on the production technology. The electricity from thermal units is the only one to emit polluting gases in its production process and which causes an increase in emissions of polluting gases especially for high consumption.

In power systems of Algeria, exclusively thermal units are operating to supply electricity to load. In addition, the polluting gases produced at thermal units include NOx, CO_2 and SO_2.

In a dozens years, Algeria has experienced growth in terms of demand for electric energy at the order of 10 % per year. If the average electricity production in Algeria is 15 GW, we must strengthen the Algerian production park by almost 1.5 GW. For that, the renewable energy such as solar and wind energy must be implemented in large scale electrical networks.

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