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Solving Bi-Objective Optimal Power Flow using Hybrid method of Biogeography-Based Optimization and Differential Evolution Algorithm: A case study of the Algerian Electrical Network

This paper proposes a new hybrid metaheuristique algorithm based on the hybridization of Biogeography-based optimization with the Differential Evolution for solving the optimal power flow problem with emission control. The biogeography-based optimization (BBO) algorithm is strongly influenced by equilibrium theory of island biogeography, mainly through two steps: Migration and Mutation. Differential Evolution (DE) is one of the best Evolutionary Algorithms for global optimization. The hybridization of these two methods is used to overcome traps of local optimal solutions and problems of time consumption. The objective of this paper is to minimize the total fuel cost of generation, total emission, total real power loss and also maintain an acceptable system performance in terms of limits on generator real power, bus voltages and power flow of transmission lines. In the present work, BBO/DE has been applied to solve the optimal power flow problems on IEEE 30-bus test system and the Algerian electrical network 114 bus. The results obtained from this method show better performances compared with DE, BBO and other well known metaheuristique and evolutionary optimization methods.

Keyword: Optimal power flow, Hybrid BBO/DE algorithm, Biogeography-based optimization (BBO), Differential evolution (DE), Pollution Control, Algerian electrical network.

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1. Introduction

The optimal power flow (OPF) problem is important tools in operation and control of large modern power systems based FACTS technology and Renewable energy, it was first discussed by Carpentier in 1962[1], the main purpose of OPF is to find the optimal solution to an objective function subject to the power flow constraints and other operational constraints, such as generator minimum output constraints, transmission stability and voltage constraints, and limits on switching mechanical equipment.

The environment (gaz emissions) can be considered as part of electric system planning [2]. That is, minimization of pollution emission. Oxides of nitrogen NOX emissions will be considered in the OPF problem for environmental protection. Power production from fossil burning and energy use may bring about significant adverse environmental effects through NOX emissions. So the total emission in the objective function will be considered in the OPF problem [3].

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Biogeography-based optimization (BBO) is new stochastic evolutionary algorithm developed by Dan Simon in 2008 [4]. It based on the theory of island biogeography, which is the study of the geographical distribution of biological organisms. It's similar to genetic algorithms (GA). BBO searches for the global optimum mainly through two mechanisms: Migration and Mutation.

Differential evolution (DE) is one of the best and very fast evolutionary algorithms for global optimization, invented by Price and Storn in 1995 [5]. DE technique is a technically simple, population based evolutionary algorithm for minimizing non-linear and multi-modal objective functions. It using three basic operations, namely: mutation, crossover, and selection operators.

This paper presents a hybridization of a biogeography-based optimization algorithm with another stochastic optimization algorithm named differential evolution for solving the optimal power flow problem with pollution control. The proposed method is tested on IEEE 30-bus system [6] and the Algerian electrical network 114-bus [7].The simulation results of BBO/DE algorithm are compared to the results of biogeography-based optimization algorithm BBO [8] and the differential evolution DE [7].

This paper is organized as follows; Section 2 present the problem formulation. Section 3 gives a brief description of BBO and DE algorithm, the application of BBO/DE into optimal power flow is also described in this section. In section 4, the simulation results and discussions are presented. Finally, conclusion is stated in Section5.

2. Problem Formulation

A. Formulation of OPF

The standard OPF problem can be written in the following from:

$Minimize\ (F(x))$ (the objective function) (1)

Subject to: $g(x) = 0$ (the equality constraints) (2)

$h(x) \leq 0$ (the inequality constraints) (3)

Where x is the vector of control variables, It can be generated active power P_g, generation bus magnitudesV_g, and transformers tap setting T… etc.

$$x = [P_g, V_g, T \ldots] \tag{4}$$

B. Objectives functions

In this paper, OPF is formulated with two objective functions as follows:

- **Minimization of cost of generation**

The OPF problem can be expressed as minimizing the cost of production of the real power which is given by a quadratic function of generator power output P_{g_i}as [9,10].

$$F(x) = \sum_{i=1}^{ng} (A_i + B_i P_{Gi} + C_i P_{Gi}^2) \tag{5}$$

Where: $\boldsymbol{F}$ is The fuel cost function, $\boldsymbol{A_i}, \boldsymbol{B_i}, \boldsymbol{C_i}$ are the fuel cost coefficients, $\boldsymbol{i}$ represent the corresponding generator (1,2,.....ng), $\boldsymbol{P_{G_i}}$ is the generated active power at bus I and $\boldsymbol{ng}$ is number of generators including the slack bus.

- **Minimization of polluted gas emission**

The objective function that minimizes the total emissions (NOx emission) can be expressed as [11,12]:

$Minimize\ (F_E)$

$$F_E(x) = \sum_{i=1}^{ng}(a_i + b_i P_{Gi} + c_i P_{Gi}^2 + d_i \exp(e_i P_{Gi})) \tag{6}$$

Where a_i, b_i, c_i, d_i and e_i are the parameters estimated on the basis of unit emissions test results.

The total objective function is described by [13]:

$$F_{tot}(x) = \alpha\, F + \mathrm{w}(1-\alpha)F_E \quad [\$/h \tag{7}$$

Where α is a weighting satisfies (0 ≤α ≤ 1) and w is the emission control cost factor [10].

C. OPF constraints

The constraints of the OPF problem can be split into two parts: The equality and inequality constraint:

The equality constraints reflect the physics of the power system, equality constraints *g(x)* are the real and reactive power balance equations.

$$P_{g_i} - P_{d_i} = V_i \sum_{j=1}^{N} V_j\ (g_{ij}\cos\delta_{ij} + z_{ij}\sin\delta_{ij}) \tag{8}$$

$$Q_{g_i} - Q_{d_i} = V_i \sum_{j=1}^{N} V_j\ (g_{ij}\sin\delta_{ij} + z_{ij}\cos\delta_{ij}) \tag{9}$$

Where P_{g_i}, Q_{g_i} are the active and the reactive power generation at bus i;P_{d_i}, Q_{d_i} are the real and the reactive power demand at bus i, V_i, V_j the voltage magnitude at bus i, j , respectively; g_{ij}, z_{ij} are the real and imaginary part of the admittance (*Yij*); *δij* is the phase angle difference between buses *i* and *j* respectively and *N* is the total number of buses.

The inequality constraints reflect the limits on physical devices in the power system as well as the limits created to ensure system security that they are presented in the following inequalities:

- Limits on active power at generator buses: $\mathrm{P_{g_i}}^{\min} \le \mathrm{P_{g_i}} \le \mathrm{P_{g_i}}^{\max}$ (10)
- Limits on reactive power at generator buses: $\mathrm{Q_{g_i}}^{\min} \le \mathrm{Q_{g_i}} \le \mathrm{Q_{g_i}}^{\max}$ (11)
- Limits on voltage magnitude of at the all buses: $\mathrm{V_i}^{\min} \le \mathrm{V_i} \le \mathrm{V_i}^{\max}$ (12)
- Limits on tap positions of a transformer : $\mathrm{T}^{\min} \le \mathrm{T} \le \mathrm{T}^{\max}$ (13)
- Limits on the bus voltage phase angles: $\theta_i^{\min} \le \theta_i \le \theta_i^{\max}$ (14)
- Limits on transmission lines loading : $\mathrm{S_{li}}^{\min} \le \mathrm{S_{li}} \le \mathrm{S_{li}^{max}}$ (15)

3. BBO/DE for optimal power flow

1. Biogeography based optimization (BBO)

The biogeography-based optimization algorithm a new bio-inspired optimization technique developed by Dan Simon in 2008[4], is strongly influence by the equilibrium theory of island biogeography [14]. The basic premise of this theory is that the rate of change in the number of species on an island depends critically on the balance between the immigration of new species onto the island and the emigration of species from the island. Island in BBO is defined as any habitat that is isolated geographically from other habitats. Well suited habitats for species are said to have high habitat suitability index (HSI) while habitats that are not well suited said to have low HSI. Each habitat consists of features that decide the HSI for the habitat. These features are considered as independent variable and called suitability index variables (SIV) which map the value of the HSI of the habitat. High HSI habitats have large number of species while low HSI habitats have small number of species [15].

The immigration rate λ and the emigration μ rate are functions of the number of species in the habitat and a good solution has higher μ and lower λ (Figure.1)

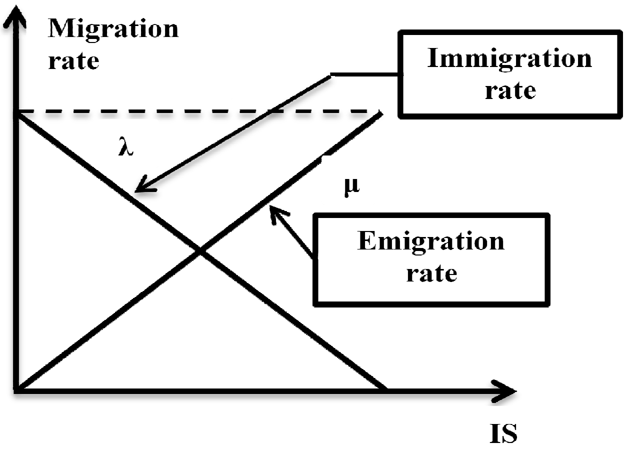

Figure.1 Species model of a single habitat

The immigration and emigration rate when there are S species in the habitat is given by:

$$\lambda_k = I\left(1 - \frac{k}{n}\right) \tag{16}$$

$$\mu_k = E\left(\frac{k}{n}\right) \tag{17}$$

Where I: is the maximum possible immigration rate. E is the maximum possible emigration rate. k is the number of species of the kth individual in the ordered population according to the fitness.

There are two main operators, the migration and the mutation. One option for implementing the migration operator can be described as follow

Habitat migration

```
for i=1 to NP do
    Select $X_i$ with probability $\lambda_i$
    if rndreal (0,1) < $\lambda_i$ then
      for $j$=1 to NP do
        Select $X_j$ with probability $\mu_j$
        if rndreal (0,1) < $\mu_j$ then
            Randomly select a variable σ from $X_j$
            Replace the corresponding variable in $X_i$ with σ
        end if
      end for
    end if
end for
```

where; the population consists of *NP =n* parameter vectors. rndreal (0,1) is a uniformly distributed random real number in (0,1) and *Xi(j)* is the *jth* SIV of the solution *Xi*

In BBO the mutation is modeled as SIV mutation using species count probabilities to determine mutation rate. Very high HSI and very low HSI solutions are likely to be mutated to a different solution using the mutation rate m that is calculated using

$$m(s) = m_{max}\left(1 - \frac{P_S}{P_{max}}\right)$$
(18)

Where m(s) is the mutation rate, m_{max} is the maximum mutation rate, Ps is the probability that S species in a habitat, and P_{max} is the maximum probability that S species in a habitat. When a solution is selected for mutation then we replace a randomly chosen SIV in the habitat with a new randomly generated SIV [16].

- **Algorithm of BBO applied to OPF**

In the optimal power flow problem each habitat represent a candidate solution consist of SIVs. Each SIV represents the output power generated by a generation unit.
1. Initialize BBO parameters.
2. Generate a random set of habitats that consists of SIVs representing possible solutions.
3. Calculate HIS and their rates μ and λ for all habitats.
4. Identify and save the best solutions based on the HSI value.
5. Modify the non elite habitat using the migration process.
6. Modify the non-elite habitat by probabilistic mutation operation based on mutation rate then go to step (3).
7. After specified number of generation this loop is finished.

2. DE algorithm

Differential Evolution (DE) is a stochastic algorithm, which has been used in many optimization problems due to its simplicity and efficiency. DE is , invented to solve the global optimization by Storn and Price in 1995 [5] .

DE technique is a technically simple, population based evolutionary algorithm for minimizing non-linear and multi-modal objective functions. It using three basic operations, namely: mutation, crossover, and selection operators (figure 2).

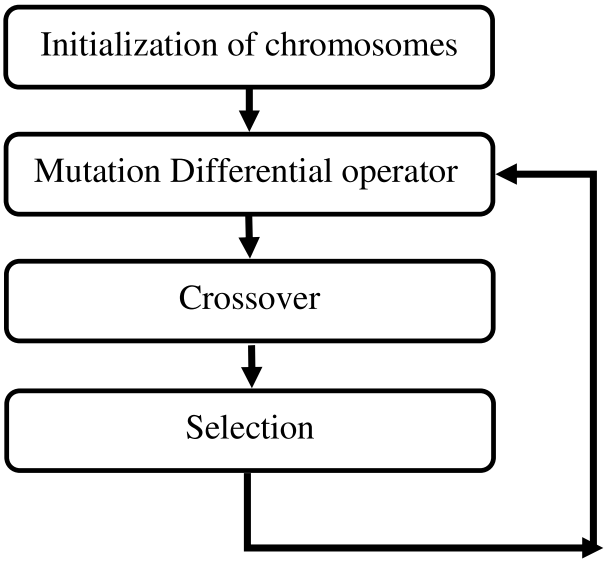

Figure. 2 DE cycle of stage

- **Initialization**

The population is initialized by randomly generating individuals (equation (19))[17].

$$X_{ij}^{0} = X_j^{min} + rand * \left(X_j^{max} - X_j^{min}\right) \qquad i = 1,2, \dots Np \qquad \& \qquad j = 1,2, \dots D \quad (19)$$

Where ; the jth variable of the given problem has its lower $X_j^{min}$and upper X_j^{max} bound. Np is the size of the population and D is the number of decision variables.

- **Mutation**

The mutation operator of DE occupies quite an important function in the reproduction cycle. This operation creates mutant vectors $X_i^{'k}$ by perturbing a randomly selected vector X_a^k with the difference of two other randomly selected vectors $X_b^k$and X_c^kat the th iteration equation (20) [18]

$$X_i^{'k} = X_a^k + Fx * \left(X_b^k - X_c^k\right) \qquad i = 1,2, \dots Np \qquad (20)$$

Where ; F is the scaling factor, it used to control the amount of perturbation in the process (F∊ [0 2]) ,

- **Crossover**

Based on the mutant vector, the parent vector is mixed with the mutated vector to create a trial vector, which is used in the selection process according to the following equation:

$$X_{ij}^{''k} = \begin{cases} X_{ij}^{'k} & if\ rand\ j < Cr\ or\ j = randn \\ X_{ij}^{k} & otherwise, \end{cases} \tag{21}$$

Where, i = 1, 2, 3 , . . ., Np; j = 1, . . ., ,D. $X_{ij}^{k}, X_{ij}^{'k}$ *and* $X_{ij}^{''k}$ are jth individual of ith target vector, mutant vector, and trial vector at k*th* iteration respectively. Cr e [0, 1] is the Crossover constant [19].

- **Selection**

Selection process is used among the set of trial vector and the updated target vector to choose the best. At last the fitness of the vector X_i^k and X_i^{k+1} is compared, and the best is chosen to generate offspring through greedy selection, that is:

$$X_i^{k+1} = \begin{cases} X_i^{''k} & iff(X_i^{''k}) \le f(X_i^{''k}) \\ X_i^{k} & otherwise, \end{cases} \quad \text{i=1,2,... Np} \tag{22}$$

The selection operator is repeated for both pair of target/trial vector until the new population is completed. The pseudo-code of the DE algorithm is shown as [18] :

The Pseudo-code of the DE algorithm

```
Generate the initial population P
Evaluate the fitness for each individual in P
while The termination criterion is not satisfied
    for $i = 1$ to NP
        Select uniform randomly $r_1 \neq r_2 \neq r_3 \neq i$
        $j_{rand} = randint(1, D)$
        for $j = 1$ to $D$ do
            if randj (0, 1) > CR or j ==$j_{rand}$
                $U_i(j) = X_{r_1}(j) + F\,(X_{r_2}(j) - X_{r_3}(j))$
            else
                $U_i(j) = X_i(j)$
            end
        end
    end
for $i = 1$ to $NP$
    Evaluate the offspring $U_i$
    if $U_i$ is better than $P_i$
        $P_i = U_i$
    end
    end
end
```

Algorithm of DE applied to OPF

- Representation of the problem variables: In the economic dispatch problem each vector in the DE population represent a candidate solution. The vector of that solution consist of all the optimization variables of the problem. For the case of minimization of cost the output power generated by a generation unit are the optimization variables.

- Formation of the evaluation function : Differential evolution searches for the optimal solution by maximize the fitness function, and for that reason an evaluation function which provides a determine of the quality of the problem solution must be provided.,The objective is to minimize the total cost while satisfying all equality constraints by running the Newton Raphson power flow algorithm and inequality constraints by adding a quadratic penalty function to the objective function.

3. Hybrid BBO-DE

The BBO algorithm, without hybridization, does not have much diversity in local or sub optimal solutions. In BBO-DE, a hybrid migration operator of BBO is applied along with operators of DE which combines the searching of DE with the operation of BBO effectively to speed up the convergence property and to find better quality results. The structure of the BBO-DE algorithm is very simple and almost same to original BBO algorithm with small changes due to mutation operator of DE. Complete BBO-DE process is shown as :

Algorithm : The main procedure of BBO/DE

```
Generate the initial population P
Evaluate the fitness for each individual in P
While the halting criterion is not satisfied do
    for each individual, map the fitness to the number of species
    calculate the immigration rate $\lambda_i$ and the emigration rate $\mu_i$ for each individual $X_i$
    Modify the population with the hybrid migration operator shown in offspring $U_i$
  for $i = 1$ to NP
        Select uniform randomly $r_1 \neq r_2 \neq r_3 \neq i$
        $j_{rand} = randint(1, D)$
        for $j = 1$ to $D$ do
          if randj (0, 1) < CR or j ==$j_{rand}$
                $U_i(j) = X_{r_1}(j) + F(X_{r_2}(j) - X_{r_3}(j))$
          else
                $U_i(j) = X_i(j)$
          end
        end
Evaluate the offspring
        if $U_i$ is better than $P_i$ then
            $P_i = U_i$
        endif
    end for
end while
```

4. Application Study

The OPF with emission control using Hybrid BBO-DE has been developed and implemented by the use of Matlab 9. The applicability and validity of this method have been tested on IEEE 30-bus system and Algerian network (114-bus).

A. Application on the IEEE 30-bus system

The IEEE 30-bus system consists of 6 generators at n°:1, 2, 5, 8, 11 and 13, 41 transmission lines and 4 transformers between buses (6-9), (6-10), (4-12) and (28-27) (Figure 3).

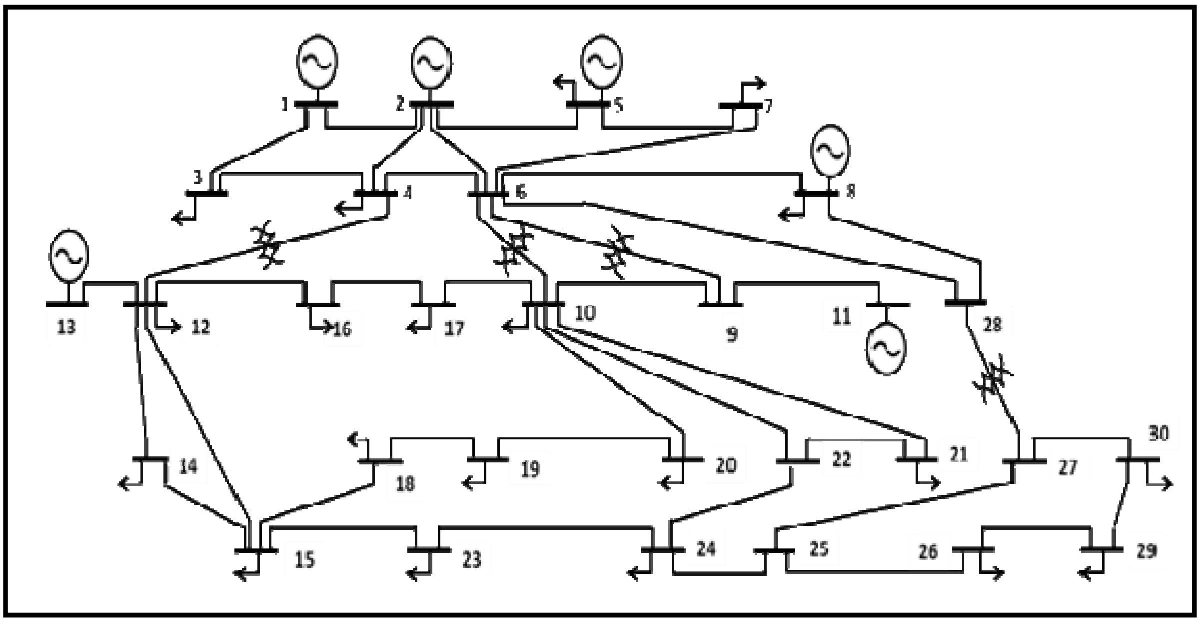

Figure. 3 Topology of the IEEE 30-Bus electrical network

The active power generating limits and the unit costs of all generators of the IEEE 30-bus test system are presented in Table 1 [13], and the pollution coefficients of generators are presented in Table 2 [20]. The emission control cost factor for this system was taken as 550.66 $/Ton [21] and the total active load in the system was 283.4 MW.

Upper and lower magnitude voltage limits are set as: $0.95 \leq V \leq 1.1$ pu.

Upper and lower bounds on the bus voltage phase angles $-14 \leq \theta_i \leq 0$ °

Upper and lower transformer tap setting T limits are set as: $0.9 \leq T \leq 1.1$ pu.

The BBO-DE parameters are set as:

- Population size NP : 100.
- Maximum number of generations Gmax : 200.
- Mutation probability: 0.01.
- Maximum immigration rate: I = 1.
- Maximum emigration rate: E = 1.
- Crossover constant CR : 0.9.
- Weighting factor F: 0.5.

Table 1. Power generation limits and cost coefficients for IEEE 30-bus system

bus	**$Pg_{i(min)}$ (MW)**	**$Pg_{i(max)}$ (MW)**	A_i **($/h)**	$B_i.10^{-2}$ **($/MWh)**	$C_i.10^{-4}$ **($/MW^{2}h)**
1	50	200	0.00	200	37.5
2	20	80	0.00	175	175.0
5	15	50	0.00	100	625.0
8	10	35	0.00	325	83.0
11	10	30	0.00	300	250.0
13	12	40	0.00	300	250.0

Table 2. Emission coefficients for IEEE 30-bus system

bus	$a.10^{-2}$ (Ton/h)	$b.10^{-4}$ (Ton/ MWh)	$c.10^{-6}$ (Ton/ MW²h)	$d.10^{-4}$ (Ton/ MWh)	$e.10^{-2}$ (Ton/MWh)
1	4.091	-5.554	6.490	2.00	2.857
2	2.543	-6.047	5.638	5.00	3.333
5	4.258	-5.094	4.586	0.01	8.000
8	5.326	-3.550	3.380	20.00	2.000
11	4.258	-5.094	4.586	0.01	8.000
13	6.131	-5.555	5.151	10.00	6.667

To demonstrate the effectiveness of the proposed approach (BBO/DE-OPF) two cases to be discussed:

Case A: the vector of control variables include only the generated active powers;

$$x = [P_{g_i}] \tag{23}$$

Case B: the vector of control variables include the generated active powers, magnitude voltages of generators and transformer tap settings.

$$x = [P_{g_2}, P_{g_5}, P_{g_8}, P_{g_{11}}, P_{g_{13}}, V_1, V_2, V_5, V_8, V_{11}, V_{13}, T_{6-9}, T_{6-10}, T_{4-12}, T_{28-27}] \tag{24}$$

Case A: The results of the case 1 including the generation cost, generated active power and the power losses are shown in Table 3.

Table 3. Results of minimum fuel cost for IEEE 30-bus system

	Min	BBO-OPF	DE-OPF	BBO/DE-OPF	Max
Pg1 [MW]	**50**	176.611	176.786	176.7467	**200**
Pg2 [MW]	**20**	48.624	48.841	48.8509	**80**
Pg5 [MW]	**15**	21.523	21.527	21.5256	**50**
Pg8 [MW]	**10**	21.825	21.749	21.7620	**35**
Pg11 [MW]	**10**	12.170	12.140	12.1552	**30**
Pg13 [MW]	**12**	12.271	12.000	12.0000	**40**
Ploss [MW]	**-**	**9.624**	**9.643**	**9.6405**	**-**
Cost [$/hr]	**-**	**802.721**	**802.704**	**802.6765**	**-**
Time [s]	**-**				**-**

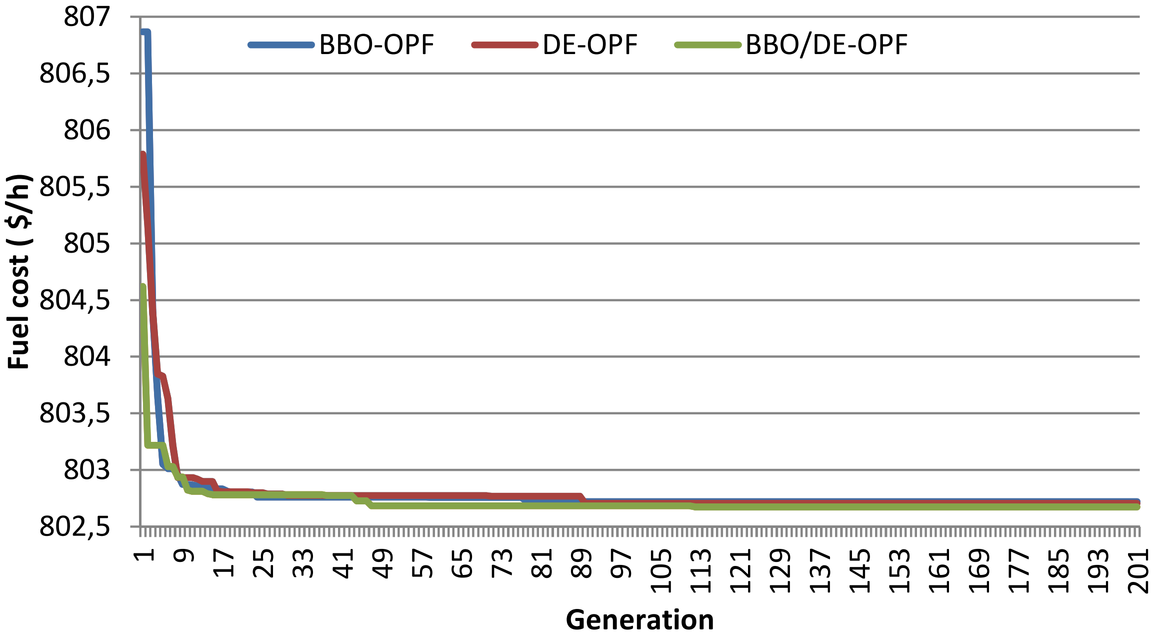

Figure 4 . The convergence of fuel cost for IEEE 30-bus system

From Table 3, We can observe that the hybrid BBO/DE give an acceptable solution (802.6765 compared with 802.721 and 802.704) ($/h) and it is best than BBO and DE in solving the optimal power flow. The active powers of the 6 generators as shown in this table are in their limits.

Figure 4 shows the convergence for the best solutions of the minimum fuel cost. It can be seen that the convergence of BBO/DE is fast than BBO and DE, for example at the iteration 47 the fuel cost by BBO/DE-OPF (802,684 $/h) is lower than those obtained by BBO (802,764 $/h) and DE methods (802,776 $/h).

Case B :The results including the generation cost, the emission level, total cost, generated active power, magnitude voltage, power losses and transformer tap settings are shown in Table 4.

The table 4 gives the optimum generations for minimum total cost in three cases:

- Alpha = 1: Minimum generation cost
- Alpha = 0.5: Equal influence of generation cost and the emission level in the objective function.
- Alpha = 0: Minimum emission is taken as the objective function.

From the results seen in Tables 4, it’s clear that the BBO-DE/OPF method can obtain more important results of fuel cost and lower emission level than the other methods for example in case :1 the generation cost of BBO/DE-OPF is (799.741 $/hr) with real power loss (8.813 MW and emission level (0.368 Ton/hr) compared with the results obtained with BBO/OPF method (800.045 $/hr, 8.901 MW and 0.368 Ton/hr) and with DE-OPF (799.744 $/hr, 8.914 MW and 0.368 Ton/hr).

Table 4 . Optimum generations for minimum total cost in three cases

	Alpha=1			**Alpha=0 ,5**		
	BBO-OPF	**DE-OPF**	**BBO/DE-OPF**	**BBO-OPF**	**DE-OPF**	**BBO/DE-OPF**
Pg1 (MW)	177.075	176.908	177.016	129.670	130.100	130.269
Pg2 (MW)	48.641	48.762	48.714	56.954	57.076	56.820
Pg5 (MW)	21.427	21.301	21.325	25.424	25.540	25.588
Pg8 (MW)	21.026	21.306	21.250	35.000	35.000	34.997
Pg11(MW)	11.837	12.027	11.908	23.147	22.377	22.294
Pg13(MW)	12.294	12.010	12.001	19.237	19.349	19.478
Vg1 (pu)	1.096	1.100	1.100	1.090	1.100	1.100
Vg2 (pu)	1.087	1.098	1.088	1.082	1.091	1.091
Vg5 (pu)	1.065	1.061	1.062	1.059	1.069	1.070
Vg8 (pu)	1.070	1.071	1.070	1.071	1.078	1.078
Vg11 (pu)	1.099	1.100	1.100	1.090	1.100	1.100
Vg13 (pu)	1.092	1.100	1.100	1.090	1.100	1.100
T6-9 (p.u)	0.975	0.983	0.982	1.100	0.988	0.979
T6-10 (p.u)	0.961	0.950	0.950	1.098	0.950	0.951
T4-12 (p.u)	1.018	1.010	1.011	1.005	1.010	1.018
T2827(p.u)	0.974	0.967	0.968	1.100	0.973	0.972
Ploss(MW)	**8.901**	**8.914**	**8.813**	**6.031**	**6.046**	**6.045**
Cost[$/hr]	**800.045**	**799.744**	**799.741**	**818.412**	**817.777**	**817.748**
Emission Cost[$/hr]	**0.368**	**0.368**	**0.368**	**0.270**	**0.271**	**0.271**
Total Cost[$/hr]	**1002.900**	**1002.700**	**1002.500**	**966.980**	**966.816**	**966.812**

	Alpha=0		
	BBO-OPF	**DE-OPF**	**BBO/DE-OPF**
Pg1 (MW)	68.056	68.076	68.095
Pg2 (MW)	70.901	70.867	70.883
Pg5 (MW)	50.000	50.000	49.999
Pg8 (MW)	35.000	34.100	35.000
Pg11(MW)	30.000	30.000	30.000
Pg13(MW)	32.817	32.761	32.725
Vg1 (pu)	1.090	1.100	1.100
Vg2 (pu)	1.084	1.096	1.096
Vg5 (pu)	1.063	1.076	1.078
Vg8 (pu)	1.070	1.085	1.085
Vg11 (pu)	1.062	1.100	1.100
Vg13 (pu)	1.090	1.098	1.100
T6-9 (p.u)	1.086	0.985	0.985
T6-10 (p.u)	1.100	0.950	0.951
T4-12 (p.u)	1.100	1.010	1.012
T28-27(p.u)	1.100	0.977	0.976
Ploss(MW)	**3.373**	**3.305**	**3.303**
Emission Cost[$/hr]	**933.616**	**933.219**	**933.166**
Cost[$/hr]	**0.217**	**0.217**	**0.217**
Total Cost[$/hr]	**1053.330**	**1052.90**	**1052 .9**

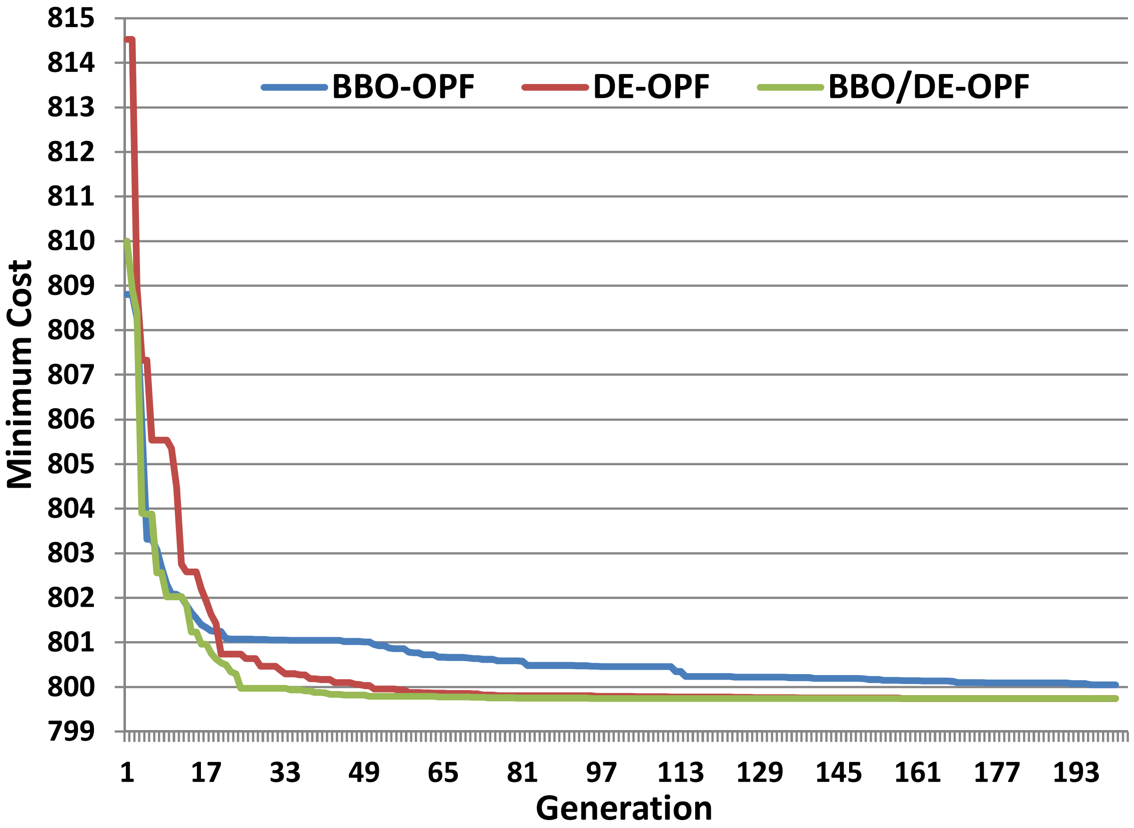

Figure. 5 The convergence of fuel cost for alpha=1.

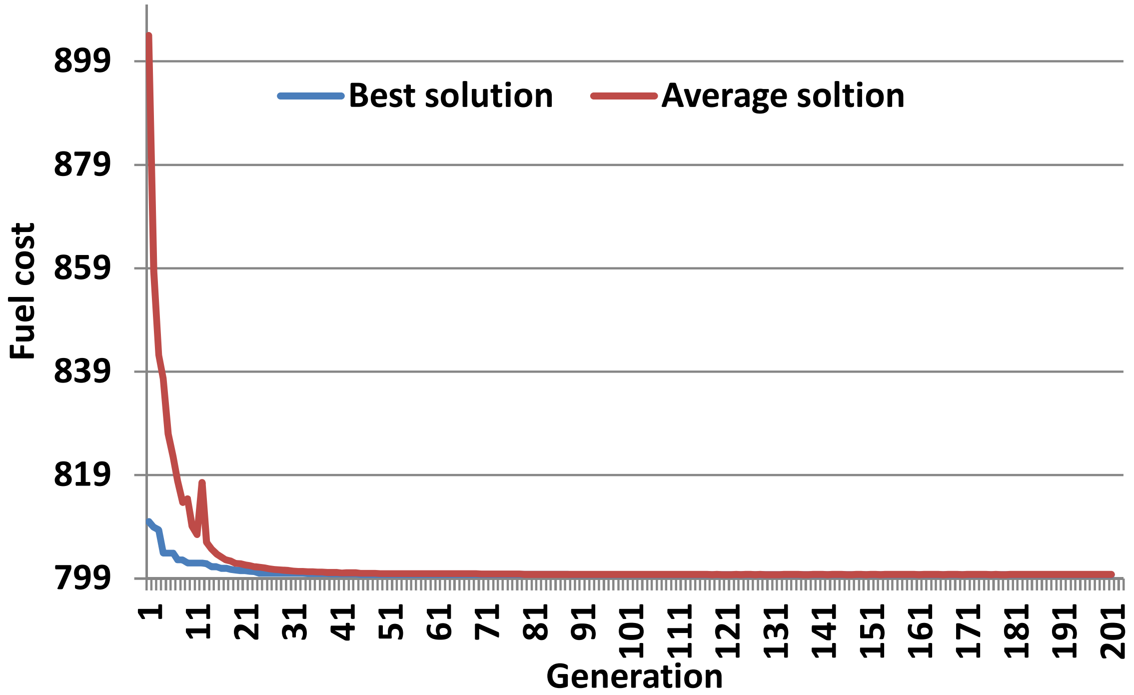

Figure. 6 Average and best solution of fuel cost of BBO/DE-OPF for alpha=1

Figure 5 show clearly that the convergence of fuel cost of BBO-DE/OPF is better than BBO-OPF and DE-OPF methods. For alpha=1: the cost of generation of BBO/DE-OPF at iteration 27 is 799,977 $/hr lower than BBO-OPF and DE-OPF (801,062 and 800,637) $/hr at the same iteration.

Figure 6 shows the typical convergence characteristics for the best solutions and the average solutions obtained for all generation. It can be seen that the convergence is fast for the proposed BBO/DE and the deviation is little between the best (799,741 $/hr) and the average value (799,748 $/hr) of the optimum.

B. Application on the Algerian network 114-bus

The BBO/DE-OPF has been also tested on the Algerian network 114 bus. It consists of 114 buses, 15 generators, 159 lines and 16 transformers. The slack bus is the bus N° 4 (Figure 7).

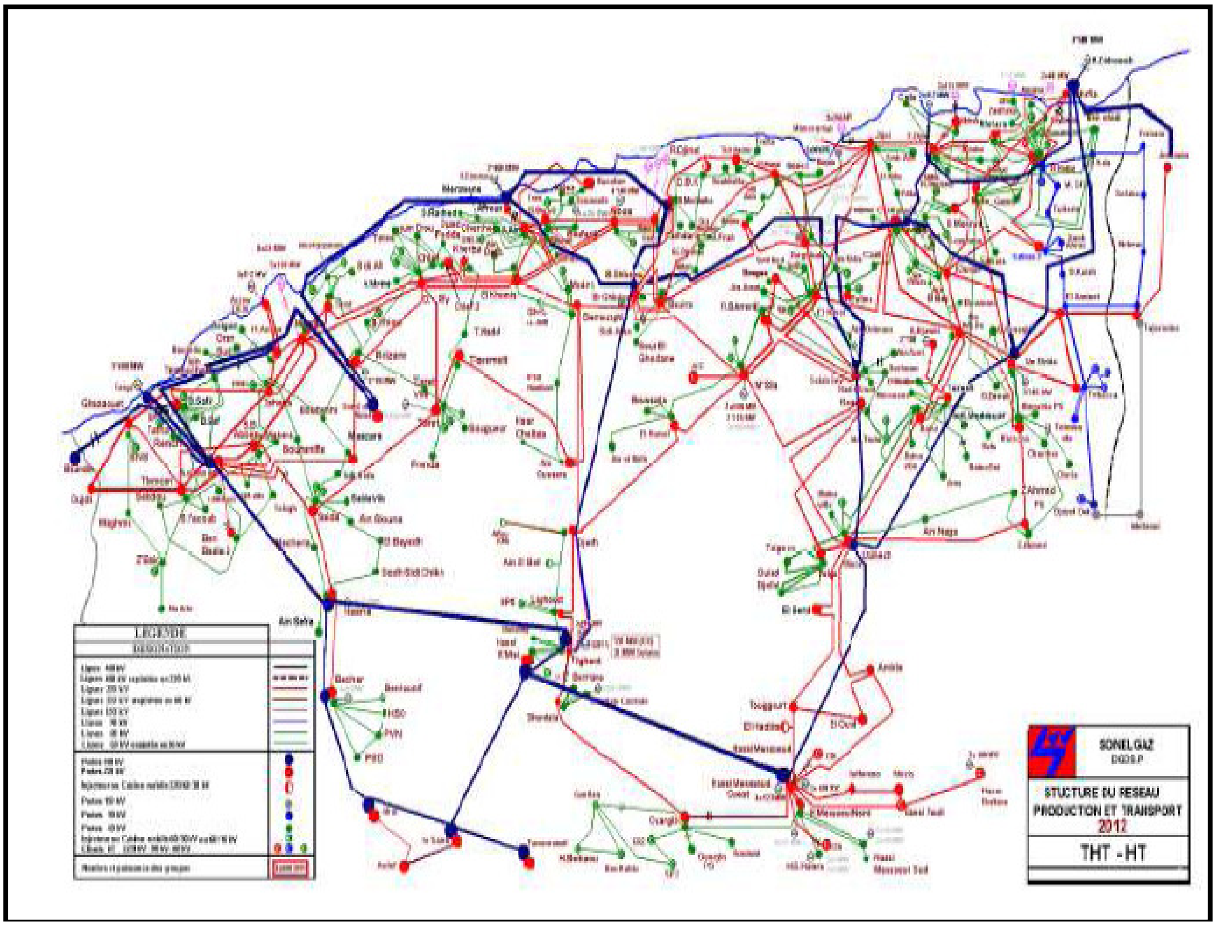

Figure 7. Topology of the Algerian network

The active power generating limits and the unit costs of all generators of the Algerian electrical network 114-bus are presented in Table 5 [7],

Table 5. Power generation limits and cost coefficients for Algerian network (114 bus)

bus	**$Pg_{i(min)}$ (MW)**	**$Pg_{i(max)}$ (MW)**	A_i **(\$/h)**	$B_i.10^{-2}$ **(\$/MWh)**	$C_i.10^{-4}$ **(\$/MW^{2}h)**
4	135,0000	1350,0000	0	1,5000	0,0085
5	135,0000	1350,0000	0	1,5000	0,0085
11	10,0000	100,0000	0	2,5000	0,0170
15	30,0000	300,0000	0	2,5000	0,0170
17	135,0000	1350,0000	0	1,5000	0,0085
19	34,5000	345,0000	0	2,5000	0,0170
22	34,5000	345,0000	0	2,5000	0,0170
52	34,5000	345,0000	0	2,5000	0,0170
80	34,5000	345,0000	0	2,5000	0,0170
83	30,0000	300,0000	0	2,5000	0,0170
98	30,0000	300,0000	0	2,5000	0,0170
100	60,0000	600,0000	0	2,0000	0,0030
101	20,0000	200,0000	0	2,0000	0,0030
109	10,0000	100,0000	0	2,5000	0,0170
111	10,0000	100,0000	0	2,5000	0,0170

The vector of control variables includes the generated active powers and magnitude voltages of generators.

Table 6 present the results of the generation cost, the emission level, total cost, generated active power, generated reactive power, magnitude voltage and power losses.

Table 6 and figure 8 confirm that the better cost value can be found by BBO/ DE method with 200 iterations which is 18673.2391\$/hr when compared with BBO-OPF (18871.2891 \$/hr) and DE-OPF (18739.1254 \$/hr) . We can observe also that the power losses are reduced (83.787 MW) compared with (BBO-OPF : 92.215 MW and DE-OPF : 89.425 MW).

The results of the voltage magnitude and the angles of all buses are shown in figure (9) and figure (10) respectively.

Table 6 Results of minimal cost of 114 Algerian electrical network.

	Min	**BBO-OPF**	**DE-OPF**	**BBO/DE-OPF**	**Max**
Pg4 (MW)	135	430.588	393.488	445.957	135
Pg5 (MW)	135	436.873	403.515	417.612	135
Pg11 (MW)	10	94.861	100.000	99.400	100
Pg15 (MW)	30	204.771	254.403	212.378	300
Pg17 (MW)	135	484.476	438.141	404.010	135
Pg19 (MW)	34.5	209.424	204.731	199.944	345
Pg22 (MW)	34.5	219.587	206.324	215.560	345
Pg52 (MW)	34.5	182.687	238.988	205.595	345
Pg80 (MW)	34.5	220.686	205.222	218.0633	345
Pg83 (MW)	30	179.121	226.727	203.540	300
Pg98 (MW)	30	176.376	152.015	192.639	300
Pg100(MW)	60	598.225	599.281	599.496	600
Pg101(MW)	20	188.578	199.699	199.765	200
Pg109(MW)	10	94.821	93.892	98.513	100
Pg111(MW)	10	98.144	100.000	98.315	100

Vg4 (pu)	0.95	1.054	0.947	1.081	1.1
Vg5 (pu)	0.95	1.084	0.973	1.087	1.1
Vg11 (pu)	0.95	1.082	0.924	1.049	1.1
Vg15 (pu)	0.95	1.046	0.995	0.943	1.1
Vg17 (pu)	0.95	0.921	0.998	1.007	1.1
Vg19 pu)	0.95	1.070	0.941	1.090	1.1
Vg22 (pu)	0.95	0.914	1.050	0.977	1.1
Vg52 (pu)	0.95	1.047	1.046	1.037	1.1
Vg80 (pu)	0.95	1.025	0.964	0.996	1.1
Vg83 (pu)	0.95	1.057	1.062	0.919	1.1
Vg98 (pu)	0.95	1.007	0.981	1.035	1.1
Vg100(pu)	0.95	1.070	0.987	1.065	1.1
Vg101(pu)	0.95	0.968	1.082	0.996	1.1
Vg109(pu)	0.95	1.056	0.948	1.064	1.1
Vg111(pu)	0.95	0.929	0.955	1.075	1.1
Ploss(MW)	-	**92.215**	**89.425**	**83.787**	-
Cost[$/hr]	-	**18871.289**	**18739.125**	**18673.239**	-

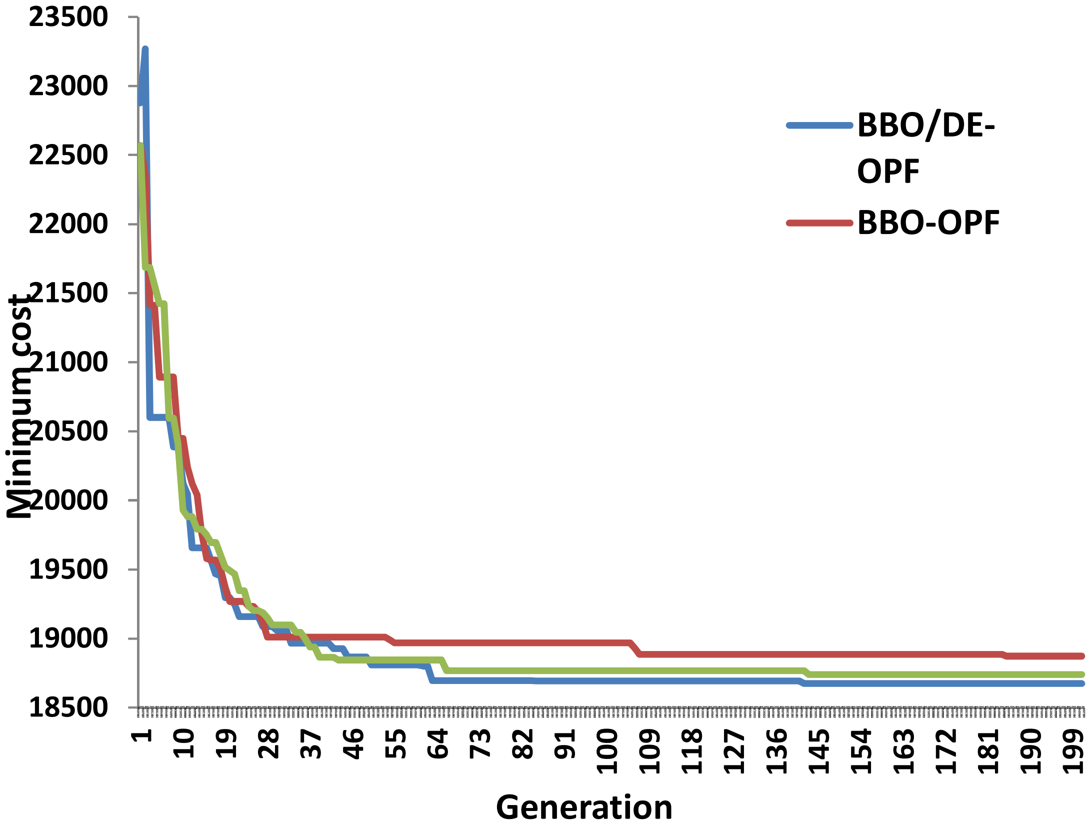

Figure 8. The convergence of fuel cost for the Algerian network

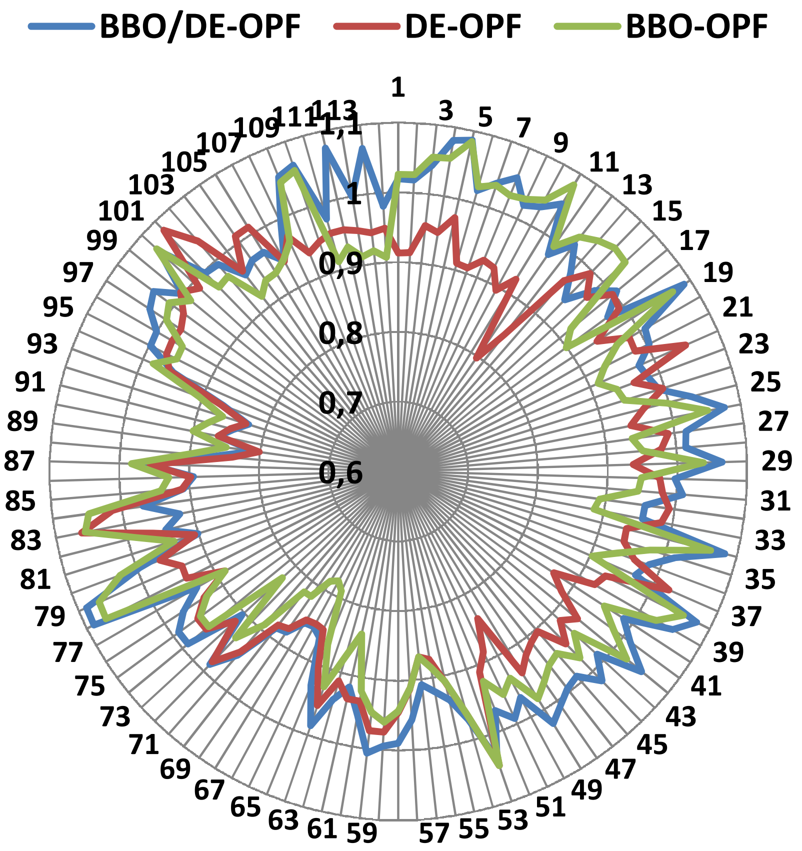

Figure 9. Voltage profile of all buses (pu) of the Algerian electrical network by the BBO/DE-based OPF

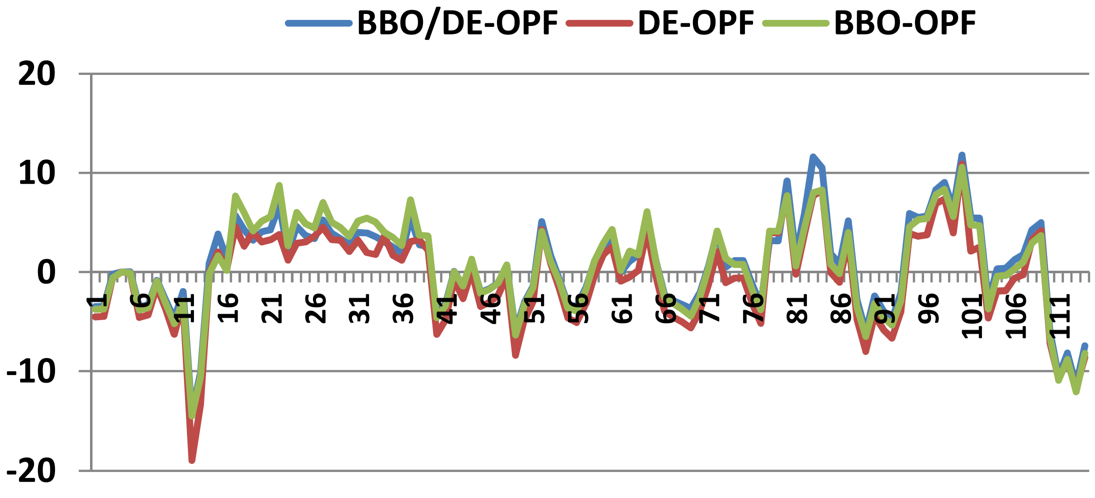

Figure 10. Voltage angles (°) of all buses of the Algerian network

Figure 9 and 10 shows that the results obtained with proposed approach BBO/DE-OPF are better than those obtained by BBO-OPF and DE-OPF for example at the bus 12 the value of the voltage magnitude obtained by DE-OPF is 0,797 pu but with BBO/DE-OPF is with the constraint limit with value 0,992 pu.

5. Conclusion

In this paper, a new stochastic optimization algorithm is a hybridization of biogeography-based optimization with differential evolution has been presented to solve the optimal power flow problem. The BBO/DE-OPF 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. The proposed method is tested on IEEE 30-bus system and the Algerian electrical network. Simulation results show that the solution of optimal power flow problem using a hybridization of biogeography-based optimization with differential evolution is able to minimize the total fuel cost along with minimization of power loss in the system, and it can converge faster than the others recent optimization methods.

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