Artificial Bee Colony Algorithm for Solving OPF Problem Considering the Valve Point Effect

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ABSTRACT
Artificial Bee Colony Algorithm (ABC) is a viable optimization algorithm, based on simulating of the foraging behavior of honey bee swarm. This paper is examined the ability of Artificial Bee Colony algorithm for solving the Optimal Power Flow (OPF) problem considering the valve point effects in a power systems. The objective functions considered are: fuel cost minimization, the valve point effect and multi-fuel of generation units. The proposed algorithm is applied to determine the optimal settings of OPF problem control variables. The feasibility of the proposed algorithm has been tested on the IEEE 30-bus and IEEE-57 bus test systems, with different objective functions. Several cases were investigated to test and validate the robustness of the proposed algorithm in finding the optimal solution or the near optimal solution for each objective. Moreover, the obtained results are compared with those available recently in the literature. Therefore, the ABC algorithm could be a useful algorithm for implementation in solving the OPF problem.

Keywords
Optimal Power Flow (OPF), Artificial Bee Colony algorithm (ABC), Valve-Point Effect.

1. INTRODUCTION
The optimal power flow is one of important optimization problem in the power system. It was introduced first time in 1968 by Dommel and Tinney [1], and it is currently considered one of the most useful tools for modern power systems operations and planning [2, 3, 4, 5], because it is a backbone of power system. In general, the OPF is a nonlinear programming (NLP) problem that determines the optimal control set points of the system to minimize a given objective function, subject at the same time to equality and inequality constraints imposed by the power system. In other words, is to determine the optimal combination of real power generations, voltage magnitudes, shunt capacitor, and transformer tap settings to minimize a desired objective function. Several conventional optimization methods such as linear programming (LP), interior point method, reduced gradient method and Newton method (Huneault & Galiana, 1991; Momoh, Adapa, & El-Hawary, 1999[6]) have been applied to solve OPF problem assuming convex, differentiable and linear cost function. But unfortunately, these methods face problems in yielding optimal solution in practical systems due to nonlinear and non-convex characteristic [7] like valve point effects loading in fossil fuel burning plants [8-3]. Hence, it becomes essential to develop optimization algorithms that are capable of overcoming these drawbacks and handling such difficulties. Complex constrained optimization problems have been solved by many population-based optimization algorithms in the recent years. These techniques have been successfully applied to non-convex, non-smooth and non-differentiable optimization problems. Some of the population-based optimization methods are genetic algorithm [3], Particle Swarm Optimization [9], Differential Evolution [10] Evolutionary Programming [11].

Recently, a new evolutionary computation algorithm, based on simulating the foraging behavior of honey bee swarm called “Artificial Bee Colony” (ABC), has been developed and introduced by Karaboga in 2005 for real-parameter optimization. Since ABC algorithm is simple in concept, easy to implement, and has fewer control parameters, it has been widely used in many optimization applications and was successfully applied to some practical problems, such as unconstrained numerical optimization [12-15], constrained numerical optimization [16-17], digital filter design [18], aircraft attitude control [19], and made a series of good experimental results. In this paper ABC algorithm has been employed to IEEE 30-bus and IEEE-57 bus test systems having linear/nonlinear operating constraints, smooth / non-smooth cost curves under different objective functions. The objective functions used in this study are minimization of fuel cost, valve point effect and multi-fuel of generation units. The potential and effectiveness of the proposed algorithm are demonstrated and the results are compared with the existing algorithms in the literature survey.

2. PROBLEM FORMULATION
The objective of OPF is to minimize the production cost while satisfying all the equality and inequality constraints, and can be written in the following form

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

$$\text{Subject to:} \quad \begin{cases} g(x,u)=0 \\ h(x,u)\le 0 \end{cases} \tag{2}$$

where

$F(x,u)$: Objective function;

$g(x,u)$: Equality constraints;

$h(x,u)$: Inequality constraints;

x : Vector of dependent variables consisting of slack bus active power, load bus voltages, generators reactive powers and transmission lines.

u : Vector of independent variables consisting of the generators’ active powers except slack bus, generators’ voltages, transformers’ tap settings and shunt VAR compensators.

Hence x & u can be expressed as:

$$x^T = [P_{G1}, V_L ... V_{LNB}, Q_{G1} ... Q_{GNG}, S_{L1} ... S_{LNL}] \tag{3}$$

$$u^T = \left[P_{G2}....P_{GNG}, V_{G1}....V_{GNG}, Q_{Sh1}......,Q_{ShNC}, T_1....T_{NT} \right] \quad (4)$$

where

NB	:	Number of load buses;
NG	:	Number of generators;
NTL	:	Number of Transmission Lines;
NT	:	Number of regulating transformers;
NC	:	Number of shunt Volt Amperes Reactive (VAR) compensators.

2.1. Equality Constraints

The equality constraint set typically consists of the load flow equations, which are given below:

$$\begin{cases} P_{Gi} - P_{Li} = \sum_{j=1}^{N} |V_i||V_j| \left(G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij} \right) \\ Q_{Gi} - Q_{Li} = \sum_{j=1}^{N} |V_i||V_j| \left(G_{ij}\sin\delta_{ij} - B_{ij}\cos\delta_{ij} \right) \end{cases} \quad (5)$$

where

V_i, V_j	Voltage of i^{th} and j^{th} bus respectively;
P_{Gi}, Q_{Gi}	Active and Reactive power of i^{th} generator;
P_{Li} Q_{Li}	Active and Reactive power of i^{th} load bus;
G_{ij}, B_{ij}, δ_{ij}	Conductance, Admittance and Phase difference of voltages between i^{th} and j^{th} bus.
N	Number of buses.

2.2. Inequality Constraints

- *Generator constraints:*

Generator voltage magnitudes, active and reactive power of i^{th} bus lies between their upper and lower limits as given below:

$$\begin{cases} V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max} \\ P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \\ Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \end{cases} \quad (6)$$

$V_{Gi}^{\min}$, $V_{Gi}^{\max}$:	Minimum and maximum generator voltage of i^{th} generating unit;
$Q_{Gi}^{\min}$, $Q_{Gi}^{\max}$:	Minimum and maximum reactive power of i^{th} generating unit.
$P_{Gi}^{\min}$, $P_{Gi}^{\max}$:	Minimum and maximum active power of i^{th} generating unit.

- Voltage magnitudes at each bus in the network

$$V_N^{\min} \le V_N \le V_N^{\max}$$

- The transmission Lines

$$|S_{NTL}| \le S_{NTL}^{\max}$$

- The discrete transformer tap settings

$$T_{NT}^{\min} \le T_{NT} \le T_{NT}^{\max}$$

2.3. Objective Function

In order to demonstrate the effectiveness and robustness of the proposed algorithm, several cases with different objectives are indicated below.

- Minimization of fuel cost: The aim of this type of problem is to minimize the total fuel cost of all generating unit which is represented as a quadratic function of its power output and it is formulated as follows:

$$\text{Min} \quad f(x,u) = \sum_{i=1}^{NG} \left(a_i P_{Gi}^2 + b_i P_{Gi} + c_i \right) \quad (7)$$

Where f : is the total fuel cost (\$/hr); a_i, b_i, c_i : fuel cost coefficients of generator i ; P_{Gi} : power generated in (p.u).

In the most of the nonlinear optimization problems, the constraints are considered by generalizing the objective function using penalty terms [19]. In OPF problem the hard inequalities of P, V, Q , and, S are added to the objective function and any unfeasible solution obtained is rejected. The above penalty function is expressed mathematically as follows: [20].

$$F = f(x,u) + k_P \left(P_{G1} - P_{G1}^{\lim} \right)^2 + k_V \sum_{i=1}^{NB} \left(V_{NLB} - V_{NLB}^{\lim} \right)^2 + k_Q \sum_{i=1}^{NG} \left(Q_{Gi} - Q_{Gi}^{\lim} \right)^2 + k_S \sum_{i=1}^{NL} \left(S_{NTL} - S_{NTL}^{\lim} \right)^2 \quad (8)$$

- *Non-smooth cost function with Valve-point effects:*

The valve-point boiler of generating units taken in consideration by adding a sine component to the quadratic cost function. Typically, the fuel cost function of the generating units with valve-point is represented as follows [8]:

$$F = a_i P_{Gi}^2 + b_i P_{Gi} + c_i + \left| d_i \sin\left(e_i \left(P_{Gi}^{\min} - P_{Gi} \right) \right) \right| \quad (9)$$

d_i and e_i are the cost coefficients of the unit with valve-point effects.

- *Piecewise quadratic fuel cost functions*

In power system operation conditions, many thermal generating units may be supplied with multiple fuel sources like coal, natural gas and oil. The fuel cost functions of these units may be dissevered as piecewise quadratic fuel cost functions for different fuel types [20]. Thus, the fuel cost function should be practically expressed as:

$$F_i(P_{Gi}) = \begin{cases} a_{i1}P_{Gi}^2 + b_{i1}P_{Gi} + C_{i1} & fuel\ 1, & P_{Gi}^{\min} \le P_{Gi} \le P_{Gi1} \\ a_{i2}P_{Gi}^2 + b_{i2}P_{Gi} + C_{i2} & fuel\ 2, & P_{Gi1} < P_{Gi} \le P_{Gi2} \\ \vdots \\ a_{ik}P_{Gi}^2 + b_{ik}P_{Gi} + C_{ik} & fuel\ k, & P_{Gik-1} < P_{Gi} \le P_{Gi}^{\max} \end{cases} \quad (10)$$

where a_{ik}, b_{ik} , and c_{ik} are cost coefficients of the i^{th} generator using the fuel type.[21-22].

3. ARTIFICIAL COLONY BEE ALGORITHM (ABC)

Artificial bee colony (ABC) algorithm is among of newest simulated evolutionary algorithms. The algorithm was firstly proposed by Turkish scholar KARABOGA [23]. Three types of bees are considered in the ABC: employed, onlooker and scout bees. The number of employed bees is equal to the number of food sources and an employed bee is assigned to one of the sources (SN).[24] The position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution [24][35].

In the ABC algorithm, each cycle of the search consists of three steps: sending the employed bees onto the food sources and then measuring their nectar amounts; selecting of the food sources by the onlookers after sharing the information of employed bees and determining the nectar amount of the foods; determining the scout bees and then sending them onto possible food sources.[34] At the initialization stage, a set of food source positions are randomly selected by the bees using this equation

$$U_i^j = U_{\min}^j + rand\ (0,1)\,.\left(U_{\max}^j - U_{\min}^j\right) \tag{11}$$

where $j \in \{1,2........,D\}$ (D is the number of parameters to be optimized). The bees in second step search for a new location in the current position vector neighborhood; search formula is

$$V_i^j = U_i^j + \varphi_i^j \left(U_i^j - U_k^j\right) \tag{12}$$

Where $k \in \{1,........,N\}$ and $j \in \{1,2........,D\}$ are randomly chosen indexes, and k is determined randomly, it has to be different from i, φ_i^j is a random number between [-1, 1]. From (13), we can see that as the difference between the parameters of U_i^j and U_k^j decreases, the perturbation on the position U_i^j decreases, too. Thus, as the search approaches to the optimum solution in the search space, the step length is adaptively reduced. An onlooker bee chooses a food source depending on the probability value associated with that food source, pi calculated by the following expression (13):

$$P_i = \frac{Fitn_i}{\sum_{k=1}^{SN} Fitn_k} \tag{13}$$

where $Fitn_i$ is the fitness value of the solution i which is proportional to the nectar amount of the ith food source. For minimization problem, $Fitn_i$ can be calculated using the following expression:

$$Fitn_i = \begin{cases} \dfrac{1}{1+F_i} & \text{if } F_i \geq 0 \\ 1+|F_i| & \text{if } F_i < 0 \end{cases} \tag{14}$$

where F_i is the value of the objective function.

In a cycle, after all employed bees and onlooker bees complete their searches, the algorithm checks to see if there is any exhausted source to be abandoned. Providing that a position cannot be improved further through limit, then that food source is assumed to be abandoned. The food source abandoned by its bee is replaced with a new food source U_i^j randomly discovered by the scout using the equation (11). Finally memorize the best food source position (solution) achieved, else modify parameters variables by changing the position of individuals and evaluate fitness (equation (12)) till maximum Cycle Number (MCN). The flowchart of ABC algorithm is drawn in figure 1.

4. NUMERICAL RESULTS AND ANALYSIS

IEEE 30- bus test System

The standard IEEE 30-bus test system was used to test effectiveness of ABC algorithm. The test system consists of six generating units interconnected with 41 branches of a transmission network to serve a total load of 283.4 MW and 126.2 Mvar. The bus data and the branch data are presented in the reference [25]. Three different types of generator cost curves which are: a quadratic model, a piecewise quadratic model and a quadratic model with sine component have been considered as follows:

```
Data : Read system data, unit data, bus-data , line-data
       and set the control Parameters of the ABC algorithm
NP    :The number of colony size (Number of Foods)
MCN   :Maximum Cycle  Number
Limit:  Maximum number of trial for abandoning a source
begin
    Initializations
for  k =1  to NP do
    u(k) <---- random solution by  equation 11
    fk <---- f(u(k)); trial <---- 0;
end
Cycle =1;
While Cycle < MCN do
  // Employed Bees phase:
  for  k =1  to NP do
     u' <---- a new solution produced by Eq  12
     f(u') <---- evaluate new solution using
                 Newton-Raphson method;
     if f(u')<fk then (Calculate the fitness
                      function using 14)
       u(k) <---- u'; fk <---- f(u'); trial(k) <---- 0;
     else
       trial(k) <---- trial(k)+1;
     end

  end
   //Calculate probabilities for onlooker bees
       by  equation (13)
   // Onlooker bees phase
     K <---- 0 ;  t <---- 0 ;
   While t < NP do
      r <---- rand(0,1)
     // probabilistic selection  P(k)
```

```
        if r < P(k) then
           t ← t+1;
         u' ← a new solution produced by 13
         f(u') ← evaluate new solution;
          if f(u') < f_k then
             u(k) ← u';  f_k ← f(u'); trial(k) ← 0;
          else
          trial(k) ← trial(k)+1;
          end
        end
        end
      k ← k+1;
       if k ← NP+1; k ← 1;
       end
   // Scout bees phase
     ind={ k : trial(k)=max (trial)
    if trial(ind )>Limit then
    u(ind) ← random solution by Eq 12
     f_ind = f(u(ind))
     trial(ind ) ← 0;
    end
    MCN = MCN+1;
end
```

Fig. 1. Flowchart for the ABC-Algorithm

1. Case.1: Quadratic cost curve model

To demonstrate the consistency and robustness of the proposed algorithm, 30 independent runs for each case were conducted performed for reaching the optimal. In this case the unit cost curves are represented by quadratic functions (1). The voltage magnitude of generator (PV) is set between 0.95-1.1. The maximum and minimum voltages of all load buses (PQ) are considered to be 1.05 - 0.95 in pu. The operating range of all transformers is set between 0.90 -1.1 with an adjustable step size of 0.01p.u.

The solution details for the minimum cost are provided in Table I, the average cost of solution obtained was 799.766$/hr with the minimum being 799.66 $/hr 8.8097 MW losses and maximum of 800.063$/hr. Fig 2 shows the convergence curve of ABC–OPF for the trial run that produced the minimum cost solution. It is important to note that all control and state variables remained within their permissible limits.

Table 1. Best control variables settings for different test case

Variable	Case 1	Case 2	Case 3	Case 4
P_{G1} (MW)	177.3762	175.6484	199.5897	139.9926
P_{G2} (MW)	48.5834	48.8422	50.9467	54.9704
P_{G5} (MW)	21.3299	21.6699	15	23.9236
P_{G8} (MW)	20.958	22.4669	10	33.2779
P_{G11} (MW)	11.9622	12.6419	10.	18.4633
P_{G13} (MW)	12	12.00	12	19.4613
V_{G1} (pu)	1.1	1.0421	1.0134	1.1
V_{G2} (pu)	1.0839	1.0276	0.9849	1.0802
V_{G5} (pu)	1.0548	1.0169	0.9865	1.0531
V_{G8} (pu)	1.0573	1.0020	0.97	1.0615
V_{G11} (pu)	1.1	1.0630	1.0254	1.1
V_{G13} (pu)	1.1	1.0451	1.1	1.1
T_{6-9}	1.04	0.97	1.01	1.02
T_{6-10}	0.90	0.93	1.1	0.90
T_{4-12}	1.04	0.99	0.90	1.03
T_{27-28}	0.97	0.94	0.90	0.97
Fuel Cost ($/h)	799.669	803.9613	930.1114	646.566
Loss (MW)	8.8097	9.8693	14.1364	6.6891
$\Sigma\|V_i\text{-}V_{ref}\|$	1.271	0.0193	0.5815	1.1172

Table 2. Comparison of the simulation results for CASE-1

Methods	Best	Average	Worst
ABC	799. 669	799.766	800.063
EADDE [27]	800.2041	800.2412	800.2748
MDE[28]	802,376	802,382	802,404
BBO[29]	799,1116	799,1985	799,2042
LDI-PSO[20]	800.7398	801.5576	803.8698
GSA[20]	798.675143[a]	798.913128	799.028419

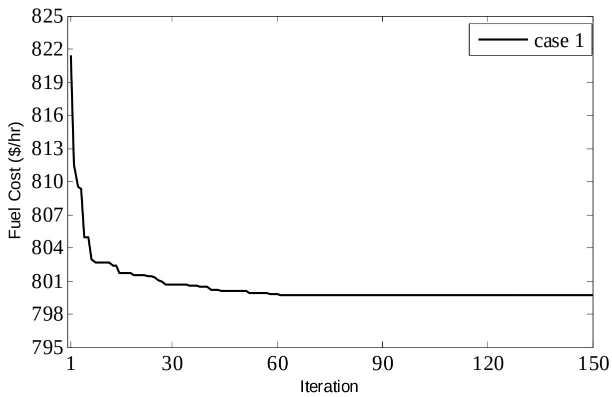

Fig. 2. Convergence curve of the OPF-ABC to Case 1

2. Case.2: voltage profile improvement

Bus voltage is one of the most important security and service quality indices. Considering only cost-based objectives in OPF problem may result in a feasible solution that has unattractive voltage profile. So, in this case a two-fold objective function will be considered in order to minimize the fuel cost and improve voltage profile by minimizing the load bus voltage deviations from 1.0 per unit. The objective function can be expressed [19]:

$$f\left(x,u\right)=\sum_{i=1}^{NG}\left(a_i P_{Gi}^2+b_i P_{Gi}+c_i\right)+\eta\sum_{i=1}^{NPQ}\left|V_i-1.0\right| \qquad (18)$$

where η is a suitable weighting factor, to be selected by the user. Value of η in two test systems is chosen as 100. The optimal setting of the control variables are given in Table I. Voltage profile in this case is compared to that of case (1) as shown in Fig 3; It is quite evident that the voltage profile is improved compared to that of Case (1), and if somebody throw a glance at Fig 3 remark clearly that the voltage magnitudes in load buses: 3,4,6,7,12,14, 28 and 29 related at case (1), overtaken the upper limit fixed at 1.05 in pu, with 2.29%, 1.67%, 0.81%, 0.65%, 1.33%, 0.25%, and 0.33%, respectively, this is justified by the strategy of penalty function which presents no problems when enforcing soft limits. However in case (2), all overtaking signaled previously in case (1) are closer at 1 pu. (See Fig 3).

It is decreased from 1.271 pu in Case (1) to 0.0193 pu in case (2). The result obtained from the proposed algorithm reduces 98.4815% in this case. Table III summarizes the comparison results of the voltage profile improvement. Table IV list lists the statistical results in terms of the best, mean, and worst voltage deviation. From these results, it is clear that ABC obtained a lower value and has a better than those reported in the literature.

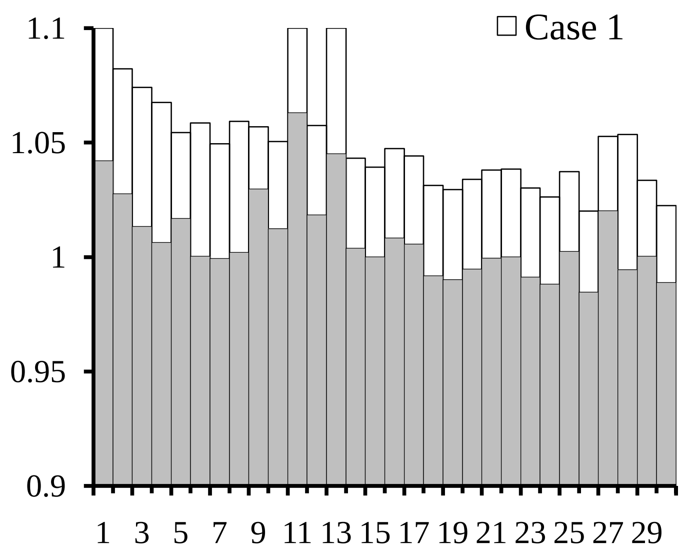

Fig. 3. System Voltage Profile

Table 3. Comparison of the simulation results for CASE-2

Variable	PSO [27]	GSA[20]	ABC
P_{G1} (MW)	173.68	173.32094	175.6484
P_{G2} (MW)	49.10	49.2639	48.8422
P_{G5} (MW)	21.81	21.56779	21.6699
P_{G8} (MW)	23.30	23.2745	22.4669
P_{G11} (MW)	13.88	13.7745	12.6419
P_{G13} (MW)	12.00	11.9643	12.00
VG1 (pu)	1.0142	1.0269	1.0421
V_{G2} (pu)	1.0022	1.00998	1.0276
V_{G5} (pu)	1.0170	1.0142	1.0169
V_{G8} (pu)	1.0100	1.00868	1.0020
V_{G11} (pu)	1.0506	1.05028	1.0630
V_{G13} (pu)	1.0175	1.01634	1.0451
Q_{G1} (MVA)	-	-	-9.4195
Q_{G2} (MVA)	-	-	20.0582
Q_{G5} (MVA)	-	-	48.8269
Q_{G8} (MVA)	-	-	36.9327
Q_{G11}(MVA)	-	-	17.1459
Q_{G13}(MVA)	-	-	20.0499
T_{6-9}	1.0702	1.07133	0.97
T_{6-10}	0.9000	0.9000	0.93
T_{4-12}	0.9954	0.9965	0.99
T_{27-28}	0.9703	0.9732	0.94
Total Fuel Cost ($/h)	806.38	804.31484	803.9613
Losses (MW)	10.37	9.76593	9.8693
VD	0.0891	0.093269	0.0193

Table 4. Comparison of the simulation results for CASE-2

Methods	Voltage profile improvement		
	Best	*Average*	*Worst*
ABC	0.0193	0.02777	0.0497
GSA [20]	0.093269	0.093952	0.094171
BBO [29]	0.1020	0.1105	0.1207
PSO [26]	0.0891	NA	NA
DE [30]	0.1357	NA	NA

3. Case 3: Quadratic cost curve model with sine Component

In this case, the generating units of buses 1 and 2 are considered to have the valve-point effects on their characteristics. The cost coefficients for these units are given in Reference [27]. The fuel cost coefficients of the rest generators have the same values as a case (1). The voltage magnitude of generator is set to $0.95 \le V_i \le 1.1$.The maximum and minimum voltages of all load buses are considered to be 1.05 - 0.95 in pu. Limits of transformer tap settings are taken as $0.90 \le V_i \le 1.1$ p.u with an adjustable step size of 0.01p.u. The set of optimal solutions of control variables are presented in Table I. The comparison results are presented in Table V. From simulation results it is very obvious that ABC algorithm has better quality of solutions than EP, IEP, MDE and BBO. It is clear that the minimum fuel cost obtained from the proposed algorithm is 929.902 $/h with an average cost of 930.971 \$/h and a maximum cost of 932.428 \$/h, which is less than MDE algorithm and is more than BBO algorithm. But the sum of real power of generating units was given as 294.464MW in BBO approach and real power loss was 12.18MW whereas load was 283.4 MW. So power generation is not matching load plus losses. This approach did not meet the load demand for this case [20]. The convergence curve of ABC algorithm for the OPF problem with minimum fuel cost is shown Fig 4.The results obtained confirm the ability of the proposed ABC algorithm to find accurate OPF solutions in this case study.

Table 5. Comparison of the simulation results for CASE-3

Methods	Voltage profile improvement		
	Best	**Average**	**Worst**
ABC	929.9021	930.971	932.428
BBO[30]	919.7647	919.8389	919.8876
MDE[32]	930.793	942.501	954.073
EP [31]	955.508	957.709	959.379
IEP [31]	953.573	956.460	958.263

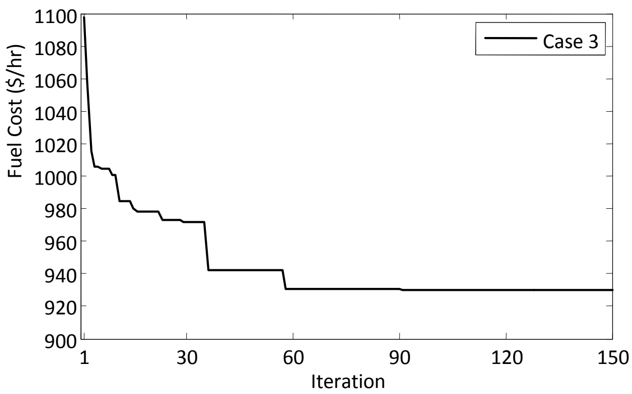

Fig. 4. Convergence curve of the OPF-ABC to Case 3

The cost coefficients for these units are given in *Ref* [9]. The cost characteristics of the first and second generators are defined in equation (10). The proposed algorithm is applied to this case considering the limit of controls variables has the same limits as a third Case. The results obtained optimal settings of control variables for this case study are listed in Table I, which shows that the ABC has best solution for minimizing of fuel cost in the OPF problem. The best fuel cost result obtained from the ABC approach is compared with other algorithms in Table VI. The average cost of solution obtained was 648.6970\$/hr with the minimum being 646.891\$/hr and maximum of 650.9820\$/hr. According to results of the third and fourth cases, it appear that ABC algorithm has better results compared to other algorithms previously reported in the literature.

Table 6. Comparison of the simulation results for CASE-4

Outputs	CASE-4 Piecewise				
	DGA[8]	**DE[28]**	**IEP [30]**	**MDE [28]**	**ABC**
P_{G1}	139.95	139.96	139,996	140.00	140.00
P_{G2}	55.00	54.984	54.9849	55.00	55.00
P_{G5}	23.28	23.910	23.2558	24.000	25.9317
P_{G8}	34.36	34.291	34.2794	34.989	34.3422
P_{G11}	19.16	21.161	17.5906	18.044	16.6520
P_{G13}	18.85	16.202	20.7012	18.462	18.1906
Total (MW)	290.60	290.509	290.808	290,495	290.116
Fuel Cost	648.40	648.38	649.312	647.846	646.890
Losses (MW)	7.204	7.109	7.4081	7.095	7.0527

IEEE 57- bus test System

In order to verify the robustness and efficiency of the proposed algorithm to the larger power system, the algorithm was tested and examined to standard IEEE 57-bus test system.

The system has totally 27 variables to be optimized, including 7 generators, 17 transformers (treated as tap changer), and 3 capacitor banks installed at buses 18, 25 and 53 respectively. The total load demand of system is 1250.8 MW and 336.4 Mvar under the base of 100 MVA. The bus 1 is selected as slack bus. The single line diagram of this system and the bus data and line data can be retrieved at MATPOWER [33]. The maximum and minimum voltages of all buses are considered to be 0.95 – 1.1 in p.u. The operating range of all transformers is set between 0.90 -1.1. The minimum and the maximum of shunt capacitor banks are 0.0 and 0.3 in p.u. The control parameter settings of the ABC algorithm related to this case study are provided in Table VII below:

Table 7. Control parameter settings

Parameter	IEEE 57-Bus
Population size (NP)	40
Max. Cycle number (MCN)	200
Penalty factor of slack bus real power (K_P)	1000
Penalty factor of reactive power (K_Q)	100
Penalty factor of voltage magnitudes (K_V)	100.000
Penalty factor of transmission line loadings (K_S)	50

The set of optimal solutions of control variables from the proposed algorithm are presented in Table VIII. From this Table, it is clear that the best solution of presented result is that of the GSA marked "a", and he is much less than solution obtained by ABC algorithm but is indeed an infeasible solution, since there exist bus voltage magnitude violations at buses 18,19, 20, 26, 27, 28, 29, 30, 31, 32, 33,42,51,56 and 57 and the true value for the total fuel cost corresponding to the set of optimal solutions of control variables reported by GSA is 45621.4035 $/hr.

The obtained results are compared with that of the particle swarm optimization (PSO), Cuckoo Optimization Algorithm (COA), LDI-PSO, EADDE, GSA and MATPOWER. This comparison confirms the aptitude of the artificial bee colony algorithm to locate de global solution. Fig 5 shows the convergence curve related to improvement of voltage profile (case 2). Also, it is important to note that all optimization variables remained within their permissible limits without any violations.

Table 8. The simulation results for CASE 1&2 - IEEE 57

Control variables			Control variables		
	Case1	**Case2**		**Case1**	**Case2**
P_{G1}	141.3644	144.8137	$T_{24\text{-}25}$	1.000	1.0000
P_{G2}	95.1022	86.6591	$T_{24\text{-}25}$	1.000	1.0000
P_{G3}	44.3351	44.7754	$T_{24\text{-}26}$	1.0373	1.0259
P_{G6}	76.3557	68.3138	$T_{7\text{-}29}$	0.9827	0.9823
P_{G8}	448.2553	469.4979	$T_{34\text{-}32}$	0.9292	0.9419
P_{G9}	99.3042	94.7599	$T_{11\text{-}41}$	0.9446	0.9000
P_{G12}	361.4046	358.8618	$T_{15\text{-}45}$	0.9569	0.9534
V_{G1}	1.0409	1.0402	$T_{14\text{-}46}$	0.9499	0.9537
V_{G2}	1.0383	1.0332	$T_{10\text{-}51}$	0.9782	0.9541
V_{G3}	1.0391	1.0139	$T_{13\text{-}49}$	0.9339	0.9234
V_{G6}	1.0485	1.0161	$T_{11\text{-}43}$	0.9274	0.9296
V_{G8}	1.0610	1.0227	$T_{40\text{-}56}$	0.9829	1.0007
V_{G9}	1.0390	0.9974	$T_{39\text{-}57}$	0.9664	0.9356
V_{G12}	1.0395	1.0001	$T_{9\text{-}55}$	1.0749	0.9744
$T_{4\text{-}18}$	0.9659	0.9818	Q_{C18}	10.1242	13.0556
$T_{4\text{-}18}$	1.0063	0.9818	Q_{C25}	20.3159	16.9229
$T_{21\text{-}20}$	1.0381	0.9970	Q_{C53}	16.7376	14.2064
Total Fuel Cost ($/hr				41705.3	41827.4
P loss (MW)				15.3215	16.8817
Voltage Deviation (VD)				1.9220	0.3013

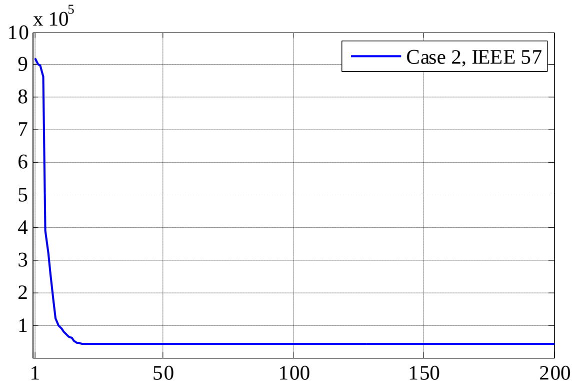

Fig. 1. Convergence curve of the OPF-ABC to IEEE 57 bus

Table 9. Comparison of the simulation results

Approaches	**Fuel cost ($/hr)**	
	Case 1	**Case 2**
BASE-CASE [32]	51347.86	NA
PSO [31]	42109.7231	NA
COA[32]	41901.9977	NA
LDI-PSO [31]	41815.5035	NA
EADDE [30]	41713.62	42051.44
GSA [20]	41695.8717[a]	NA
ABC	41705.3	41827.4

[a] infeasible solution

Table 10. Maximum power flow limit of transmission line of the IEEE 57 bus

Line	**S^{max}**	**Line**	**S^{max}**
1	150	7	100
2	85	8	200
3-4	100	9-13	50
5	50	14	100
6	40	15	200
16-80		100	

5. CONCLUSION

A simple Artificial Bee Colony algorithm is proposed to solve the OPF problem under different formulations and considering different objectives function. The performance of the proposed ABC was tested on the IEEE 30-bus test and IEEE 57 test systems. The results obtained using the ABC algorithm were compared to other methods previously reported in the literature.

The comparison verifies the influentially of the proposed ABC approach over stochastic techniques in terms of solution quality for the OPF problem and confirmed its potential for solving a most nonlinear problems.

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