Load Flow Computation via Artificial Bee Colony Algorithm

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ABSTRACT
This paper proposes the application of artificial bee colony ABC algorithm to the load flow computation in power systems. The proposed algorithm is based on a metaheuristic searching technique and it's used to avoid the ill-conditioning problem of Jacobain matrix. The load flow problem is addressed as an optimization problem. ABC algorithm is considered as a new computational model for the system power flow obtainment, where this model provides a strong convergence. The results obtained reveal the importance of the proposed algorithm in finding a load flow solution of a highly stressed power system and ill- conditioned system as compared with traditional methods such as the Newton-Raphson method, where the Newton-Raphson method diverges due to problems of the Jacobian matrix in these situations. The proposed algorithm is applied for 6-bus and 14-bus systems.

Keywords
Load Flow Studies, Newton-Raphson Method, Artificial Bee Colony Algorithm, highly loaded system, Ill-conditioned system.

1. INTRODUCTION
Load flow calculations are very important in power system analysis. It can be considered as a basic in power system planning and operation. Given a particular loading status of the system, the load flow study aims to find the bus voltages (magnitudes and angles) and the power flow in transmission lines. So far, several numerical techniques have been used efficiently to solve load flow problem [1-2]. Unfortunately, these techniques suffer from slow convergence and sometimes divergence when the power system operates in ill-conditioned situations such as the prescribed range of (R/X) ratio for a transmission line in power system is high or when the system is heavily loaded. Theoretically, for n bus system, there are (2^{n-1}) solutions for load flow problem. Some of these solutions are stable and the remaining unstable [3-4]. Dynamically, when the system is heavily loaded, the stable and unstable solutions will be close to each other and eventually they become one solution at particular loading condition, which is referred to as the maximum loadability point. In dynamic literature, this point also called saddle-node bifurcation point [5]. The conventional load flow techniques fail to converge near this point due to small eigenvalues of Jacobain matrix; where the jacobaib matrix tends to be singular (i.e. ($\det(J) \cong 0$) [6]. Several methods have been developed to avoid singularity of the traditional load flow jacobian by adopting continuation power flow [7-8]. Recently, the fields of swarm intelligence have attracted many researches as a branch of artificial intelligence that deals with the collective behaviour of swarms such as flocks of bird, colonies of aunts, schools of fish, swarm of bees [9-10]. The important features of swarm intelligence are self-organization, scalability, adaptation, speed. The swarm intelligence techniques have been applied in many power system studies [11-14] .In this paper, the load flow problem is approached as an optimization problem by using swarm intelligence. The objective function is to minimize the power mismatch. This paper is organized as follows: section 2 reviews the Newton-Raphson (NR) technique in solving load flow problem. The basics model of ABC is presented in section 3. Section 4 discusses the results obtained by applying the proposed algorithms on a typical system. Finally, section 5 presents the conclusion.

2. FORMALTION OF LOAD FLOW EQUATIONS
The electrical power system consists of various buses; these buses are interconnected through transmission lines. Each line has series impedance (Z) in addition to the total line charging admittance (y). The unknown variables in load flow study are the voltage magnitude and phase angle of the bus voltage in power system.

The net current injected at bus i into N bus system is given by the following Equation:

$$I_i = Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{iN}V_N = \sum_{n=1}^{N} Y_{in}V_n \tag{1}$$

Where:
$Y_{in} = Y_{in}\angle\theta_{in} =$ The element of admittance matrix (Y_{bus}).
$V_n = V_n\angle\delta_n =$ The voltage magnitude $|V_n|$of bus n and δ_n is the voltage angle of n.

The apparent power entering into the system at bus i is:

$$S_i^* = V_i^* I_i = V_i^* \sum_{in}^{N} Y_{in}V_n \tag{2}$$

The net active and reactive power injected into the system at bus i is:

$$P_i - jQ_i = V_i^* \sum_{in}^{N} Y_{in}V_n \tag{3}$$

By substituting Equation (1) into (3), we obtain:

$$P_i - jQ_i = \sum_{n=1}^{N} |Y_{in} V_i V_n| \angle(\theta_{in} + \delta_n - \delta_i) \tag{4}$$

Resolving the equation above into the real and imaginary parts

$$P_i = \sum_{n=1}^{N} |Y_{in} V_i V_n| \cos(\theta_{in} + \delta_n - \delta_i) \tag{5}$$

$$Q_i = -\sum_{n=1}^{N} |Y_{in} V_i V_n| \sin(\theta_{in} + \delta_n - \delta_i) \tag{6}$$

Where:

P_i and Q_i represent the net active and reactive power respectively.

The net scheduled power at bus i is:

$$P_{i.sch} = P_{gi} - P_{di} \tag{7}$$

Where:

P_{gi} = The scheduled power that generated at bus (i).

P_{di} = The scheduled power demand of load at bus (i).

So, the mismatch of active power (ΔP_i) at bus i is:

$$\Delta P_i = P_{i.sch} - P_{i.cal} = (P_{gi} - P_{di}) - P_{i.cal} \tag{8}$$

Similarly, the mismatch of reactive power (ΔQ_i) at bus i is:

$$\Delta Q_i = Q_{i.sch} - Q_{i.cal} = (Q_{gi} - P_{di}) - P_{i.cal} \tag{9}$$

where $P_{i.cal}$ and $Q_{i.cal}$ are calculated from equations (5) & (6) at guess values.

Equations (5) & (6) represent a non-linear power flow equations; these equations can be solved numerically by NR method [15]. By applying Taylor series expansion to equations (5) & (6), the linearized form of these equations can be expressed as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \tag{10}$$

Where J_1, J_2, J_3 and J_4 are the elements of jacobian matrix, which represented the partial derivatives of P_i and Q_i with respect to corresponding δ and $|V|$, $\Delta\delta$ and ΔV are the correction values.

The correction values in the kth iteration as follows:

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{11}$$

$$V_i^{(k+1)} = V_i^{(k)} + \Delta V_i^{(k)} \tag{12}$$

The main steps of NR method implementation [15]:

1. Assume the initial guess values for state variables $\boldsymbol{\delta_i^{(0)}}$ and $|\boldsymbol{V_i}|^{(\boldsymbol{0})}$.
2. Use the initial values to compute $P_{i.cal}^{(0)}$ and $Q_{i.cal}^{(0)}$ from Eqs. (5) and (6), in addition to the partial derivative elements of Jacobian matrix.
3. Now, solve the equation (10) by using the initial corrections values ($\Delta\delta_i^{(0)}$ and $|V_i|^{(0)}/|V_i|^{(0)}$).
4. Add the corrections that obtained previously to the initial values of state variables $\delta_i^{(0)}$ and $|V_i|^{(0)}$ to obtain:

$$\delta_i^{(1)} = \delta_i^{(0)} + \Delta\delta_i^{(0)}$$

$$V_i^{(1)} = V_i^{(0)} + \Delta V_i^{(0)}$$

5. Use the new values of state variables $\delta_i^{(1)}$ and $|V_i|^{(1)}$ as initial value to the second iteration and continues. This process continues until the power mismatches ΔP_i and ΔQ_i satisfy convergence conditions and the convergence conditions is

$$\left\| \Delta P^k, \Delta Q^k \right\| < \varepsilon \tag{13}$$

Where $\varepsilon =$ the tolerance which usually set between (10^{-4}-10^{-6}); and $\left\| \Delta P^k, \Delta Q^k \right\|$ is a norm, which represented the maximum element in power mismatches vector (ΔP and ΔQ).

3. ARTIFICIAL BEE COLONY ALGORITHM APPLIED TO THE LOAD FLOW COMPUTATION

3.1 Artificial bee colony algorithm

ABC algorithm is one of the newest optimization algorithms that mainly based on the collective behaviour of insects colonies and other animal societies. The ABC algorithm is inspired by the nature behavior of honey bee swarm in search of food sources. This algorithm uses a certain communication way to find the best food sources. The purpose of use ABC algorithm is to solve multidimensional and multimodal optimization problems. Karaboga proposed the ABC algorithm in 2005[9]; he applied this behavior of honey bee swarm in his work to solve numerical problems. In this algorithm, the bee colony consists of three groups: employed bees, onlookers and scouts. The bee colony is divided into two halves, the first half of colony includes employed bees; and the second half includes the onlookers. These bees will search the food sources by using certain behaviors among them. The scouts bees begin to search for food sources randomly, when the scouts find the food sources, they convert to employed bees, then return to the hive and execute the waggle dance to exchange the information about the quality and position of the food sources with onlooker bees. Then, the onlooker bees will select the best food source position based on the waggle dance information. After finding the food source, the abandoned food sources are determined and replaced with new randomly generated ones by the scout bees. Each time the employed and onlooker bees finish their job, the optimal food source are registered. To utilize the ABC algorithm, there is some control parameters that should be set [16]; They are number of variables (Nvar), lower bound of variables (Lb), upper bound of variables (Ub), population size (colony size) (nPop), number of onlooker bees (nOnlooker), maximum number of iterations (MaxIt)(the stopping criteria), abandonment limit parameter (Limit) and acceleration coefficient upper bound (A).

3.2 Steps of ABC implementation [17]

1. Initialize the solutions (food sources).
2. Evaluate the population (the nectar quantity).
3. Generate new solutions (food sources) by using neighborhood search.
4. Apply the roulette wheel selection (choose the best fit individuals).
5. Calculate the probability rate (Pi) related with solutions;

$$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i} \quad (14)$$

The fitness values (fit) computed which expressed as:

$$fit_i = \begin{cases} \frac{1}{1+f_i} & if \quad f_i \geq 0 \\ 1 + abs(f_i) & if \quad f_i < 0 \end{cases} \quad (15)$$

Usually, the value of Pi is between {0, 1}.

6. Find the new solutions for the onlookers depending on the probability Pi related with the solutions.
7. Re-apply roulette wheel selection.
8. Find the abandoned solution if exists, change it with new randomly generated solution.
9. Register the best solution achieved so far.
10. Cycle=cycle +1 (until maximum cycle number is reached).

3.3 ABC application for load flow computation

ABC optimization is applied to obtain the bus voltage magnitude ($|V_i|$) and voltage phase angle (δ_i) by minimize the value of objective function [18], which gives as:

$$min\, f(x), x = (x_1, x_2, \dots, x_i, \dots, x_{n-1}, x_n) \quad (16)$$

This objective function constrained by the inequalities lower bound (Lb) and upper bound (Ub).

$$Lb \leq x_i \leq Ub$$

The optimization process starts with setting the number of solutions (food sources) in (ABC) algorithm, which represent the number of flowers, the bees will reach to food sources, and then compute the nectar's quantity, the food sources are initialized by using a random number generator.

The voltage magnitude and voltage phase angle are limited in range $0.5 \leq V_i \leq 1.05$ and $-5 \leq \delta_i \leq 5$.

The objective function (F) that designed to determine the load flow problem by using ABC algorithm is:

$$F = \sqrt{\sum \Delta Pi^2 + \sum \Delta Qi^2} \quad (17)$$

where i =1, 2, 3… number of bus bars

In ABC algorithm, the objective function (fitness value) describes the quality of food source (solution). The food source that has the best quality will be registered in a memory as a best food source (solution) ever found. The neighborhood search process that uses to obtain the best fitness value will continue by employed bees and onlookers. The fitness value will be computed for each new solution (food source), the new solution (food source) that having the best fitness value will be the new reference in memory. The optimization process will continue to looking for the food source near to hive, which depending on the probability that computed previously from fitness value. The new solution (food source) after neighborhood search will be registered if its fitness value is better. The optimization process will continue until reach to the best fitness value or reach to the maximum cycle number afterwards the solution converges and the mismatch power is close to zero the whole application of ABC algorthim approach in load flow computation is as shown in Fig(1).

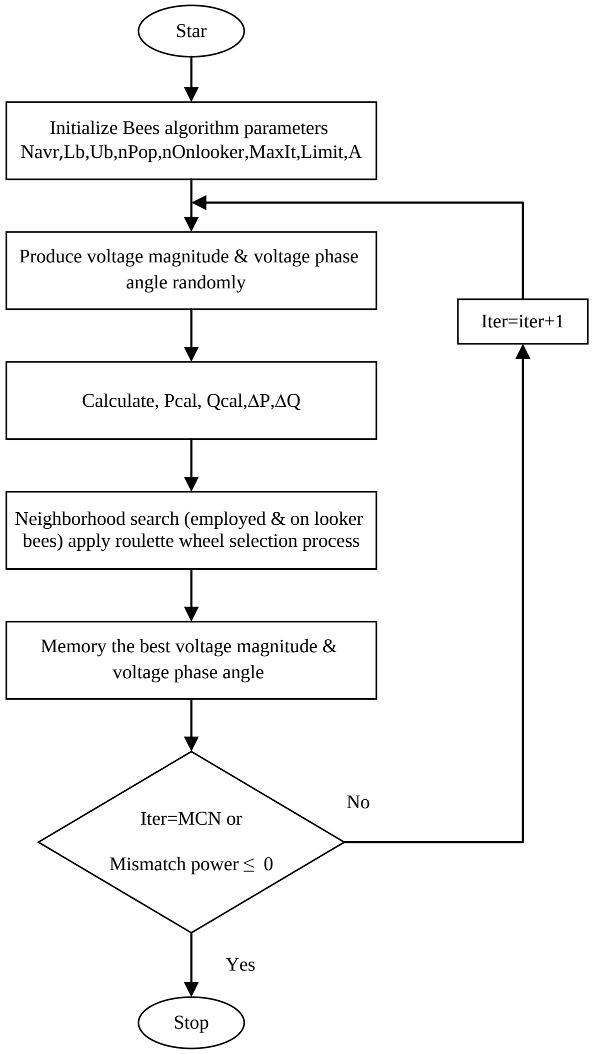


Figure 1: Application ABC algorithm in load flow solution

4. RESULTS AND DISCUSSION

The ABC algorithm is being applied to the 6 and 14 IEEE bus system as follows:

4.1 Test case 6 - bus system

The ABC method is applied to the 6-bus system with a particular loading condition [19] shown in Figure (2). After initialize the control parameters of ABC algorithm, each variable was initialized with random number using random number generator. The elements of power mismatches vector (ΔP and ΔQ) are computed using Esq. (8) & (9). The best food source (load flow solution) will be selected by applying roulette wheel selection.

A comparison between the results that obtained from conventional NR methd with that found from ABC algorithm are given in table (1), (2) and (3). As shown from these tables, the results obtained are roughly identical. The final objective function value in ABC optimization process after 15000 iteration is 1.5902×10^{-11}. The performance of ABC algorthim to obtain the best solution is clarified by graph that shown in Figure (3).

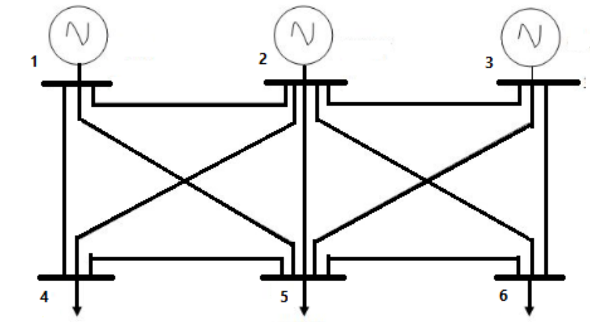


Figure 2: Test case 6-bus system

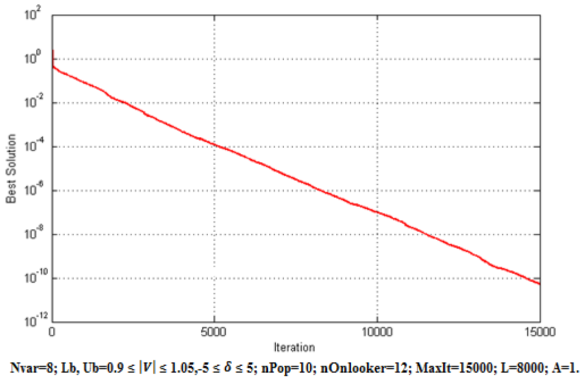


Figure 3: The performance of ABC algorithm, best solution versus iteration

Table 1: Results of system (bus voltages)

Bus No. (i)	NR-method		ABC-algorithm	
	V_i	δ_i	V_i	δ_i
1	1.05	0.0	1.05	0.0
2	1.05	-3.63504	1.05	-3.635016
3	1.07	-4.11771	1.07	-4.117675
4	0.98901	-4.18073	0.989013	-4.180701
5	0.98316	-5.30650	0.981364	-5.306448
6	1.00408	-5.85697	1.004079	-5.856946

Table 2: Results of system by using NR method (power flow in lines)

The lines		P_{ij}	Q_{ij}	P_{ji}	Q_{ji}
i	j	(MW)	(MVAR)	(MW)	(MVAR)
1	2	28.4034	-13.0927	-27.5162	14.8671
1	4	43.4856	22.5284	-42.3978	-18.1773
1	5	35.9025	15.2932	-34.7974	-11.1493
2	3	2.0279	-8.7896	-1.9910	8.9741
2	4	33.5456	47.3105	-32.0202	-44.2596
2	5	16.0950	18.1738	-15.5604	-16.5702
2	6	25.8477	15.4578	-25.2718	-13.8123
3	5	16.9774	24.2558	-16.0586	-21.9589
3	6	45.0136	62.0269	-43.9875	-56.8967
4	5	4.4180	-0.7160	-4.3770	0.7979

Table 3: Results of system by using (ABC) algorithm (power flow in lines)

The lines		P_{ij}	Q_{ij}	P_{ji}	Q_{ji}
i	j	(MW)	(MVAR)	(MW)	(MVAR)
1	2	28.4032	-13.0926	-27.5160	14.8670
1	4	43.4853	22.5285	-42.3975	-18.1775
1	5	35.9022	15.2934	-34.7972	-11.1496
2	3	2.0278	-8.7896	-1.9909	8.9741
2	4	33.5455	47.3107	-32.0201	-44.2598
2	5	16.0949	18.1740	-15.5603	-16.5704
2	6	25.8480	15.4581	-25.2720	-13.8126
3	5	16.9774	24.2560	-16.0586	-21.9591
3	6	45.0143	62.0276	-43.9883	-56.8973
4	5	4.4180	-0.7159	-4.3770	0.7978

4.2 Test case 6-bus system with a heavy load condition

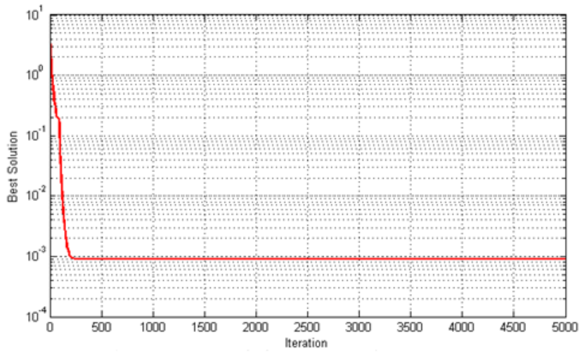
To simulate the heavy load condition the load at bus 4, 5 and 6 are increased as shown in appendix A. It is found that the conventional NR method is failed to converge. However, when the ABC algorithm is applied, the solution converges as shown in tables (4) & (5). The final objective function value in ABC optimization process after 5000 iteration is 8.99×10^{-4}. The performance of ABC method to obtain the best solution is clarified by graph that shown in Figure (4).

Table 4: Results of system by using ABC algorithm (buses voltages)

Bus No. (i)	V_i	δ_i
1	1.0500	0
2	1.0500	-52.3630
3	1.0700	-63.0819
4	0.7575	-46.0854
5	0.6721	-58.3285
6	0.8341	-68.0498

Table 5: Results of system by using ABC algorithm (power flow in lines)

The lines		P_{ij}	Q_{ij}	P_{ji}	Q_{ji}
i	j	(MW)	(MVAR)	(MW)	(MVAR)
1	2	435.0761	-2.9125	-263.375	346.3134
1	4	334.4332	191.8157	-267.023	77.8239
1	5	247.6581	177.9457	-180.175	75.1133
2	3	80.2621	-16.611	-77.2154	31.8444
2	4	55.1868	284.3133	-17.1462	-208.232
2	5	62.0638	112.8464	-47.0196	-67.7138
2	6	145.9062	78.5922	-128.467	-28.7684
3	5	43.7692	144.496	-19.8774	-92.7303
3	6	123.5007	231.0694	-111.509	-171.111
4	5	29.2177	4.4536	-26.1730	1.6358



Nvar=8; Lb, Ub=0.5 ≤ $|V|$ ≤ 1.05,-5 ≤ δ ≤ 5; nPop=6; nOnlooker=8; MaxIt=500; L=300; A=1.

Figure 4: the performance of ABC algorithm, best solution versus iteration

4.3 Test case 14-bus system

The ABC method is applied to the 14-bus system with a particular loading condition (bus data given in appendix B.) Shown in Fig (8) [20]. After initialize the control parameters of ABC, the ABC algorithm give similar results in comparison with the conventional NR method as shown in table (6), (7) and (8). The final objective function value in ABC optimization process after 200000 iteration is 1.9147×10^{-8}. The performance of ABC method to obtain the best solution is clarified by graph that shown in Figure (6).

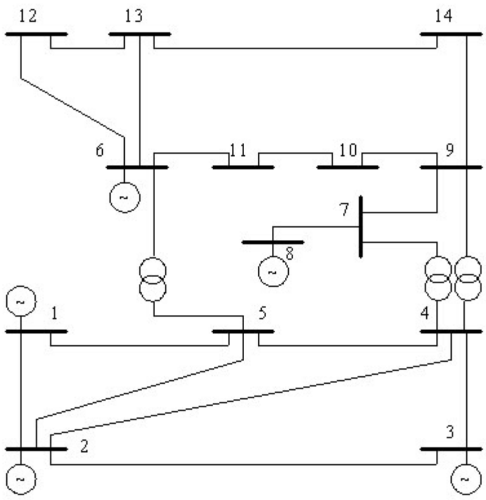
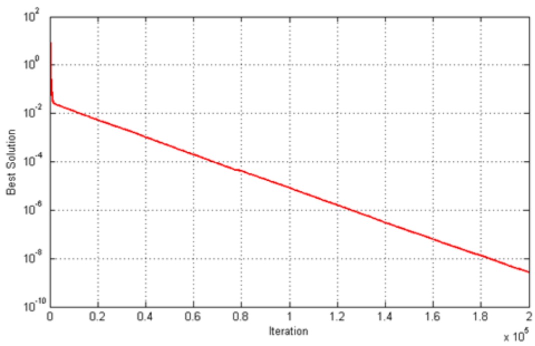


Figure 5: Test case 14-bus system



Nvar=22; Lb, Ub=0.5 ≤ $|V|$≤ 1.05,-5 ≤δ≤ 5; nPop=7; nOnlooker=28; MaxIt=2× 10^5; L=13000; A=1.

Figure 6: The performance of ABC algorithm, best solution value versus iteration

Table 6: Results of system (bus voltages)

Bus No. (i)	NR-method		ABC-algorithm	
	V_i	δ_i	V_i	δ_i
1	1.0500	0	1.0500	0
2	1.0400	-6.1641	1.0400	-6.1641
4	1.0350	-13.2308	1.0350	-13.2308
5	0.9956	-12.1726	0.9956	-12.1726
5	0.9973	-10.6553	0.9973	-10.6553
6	1.0400	-19.6049	1.0400	-19.6049
7	1.0148	-17.6030	1.0148	-17.6030
8	1.0400	-19.3628	1.0400	-19.3628
9	1.0006	-19.3632	1.0006	-19.3632
10	0.9973	-19.9492	0.9973	-19.9492
11	1.0097	-20.2317	1.0097	-20.2317
12	0.9961	-20.5128	0.9961	-20.5128
13	1.0097	-20.5537	1.0097	-20.5537
14	0.9901	-20.8042	0.9901	-20.8042

Table 7: Results of system by using NR method (power flow in lines)

The lines		P_{ij}	Q_{ij}	P_{ji}	Q_{ji}
i	j	(MW)	(MVAR)	(MW)	(MVAR)
1	2	187.3716	-32.9546	-181.009	52.3796
1	5	89.5267	11.2106	-85.5372	5.2584
2	3	64.8415	-8.6338	-62.9825	16.4657
2	4	64.1892	8.2466	-61.9391	-1.4190
2	5	50.2786	10.8946	-48.8850	-6.6399
3	4	-1.5175	24.5268	1.8952	-23.5627
4	5	-57.6481	15.1013	58.1263	-13.5926
4	7	46.7537	-7.1342	-46.7537	11.7492
4	9	23.1382	0.5306	-23.1382	2.3817
5	6	68.6959	-12.7480	-68.6959	24.2759
6	11	10.8779	10.6856	-10.6737	-10.2580
6	12	12.2063	12.0504	-11.8720	-11.3546
6	13	20.4117	13.9107	-20.0385	-13.1759
7	8	18.4000	-14.2169	-18.4000	15.1417
7	9	28.3537	13.5461	-28.3537	-12.4913
9	10	11.9049	-0.4596	-11.8599	0.5793
9	14	9.0869	-0.2717	-8.9820	0.4949
10	11	-0.1401	-6.3793	0.1737	6.4580
12	13	-3.2280	-3.2454	3.2746	3.2876
13	14	3.2639	4.0883	-3.2180	-3.9949

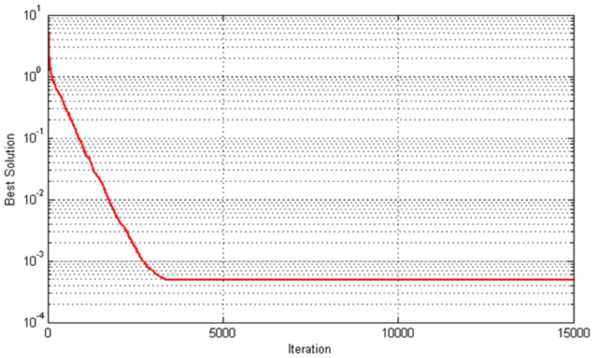
Table 8: Results of system by using ABC algorithm (power flow in lines)

The lines		P_{ij}	Q_{ij}	P_{ji}	Q_{ji}
i	j	(MW)	(MVAR)	(MW)	(MVAR)
1	2	187.3716	-32.9546	-181.009	52.3796
1	5	89.5267	11.2106	-85.5372	5.2584
2	3	64.8415	-8.6338	-62.9825	16.4657
2	4	64.1892	8.2466	-61.9391	-1.4190
2	5	50.2786	10.8946	-48.8850	-6.6399
3	4	-1.5175	24.5268	1.8952	-23.5627
4	5	-57.6481	15.1013	58.1263	-13.5926
4	7	46.7537	-7.1342	-46.7537	11.7492

4	9	23.1382	0.5306	-23.1382	2.3817
5	6	68.6959	-12.7480	-68.6959	24.2759
6	11	10.8779	10.6856	-10.6737	-10.2580
6	12	12.2063	12.0504	-11.8720	-11.3546
6	13	20.4117	13.9107	-20.0385	-13.1759
7	8	18.4000	-14.2169	-18.4000	15.1417
7	9	28.3537	13.5461	-28.3537	-12.4913
9	10	11.9049	-0.4596	-11.8599	0.5793
9	14	9.0869	-0.2717	-8.9820	0.4949
10	11	-0.1401	-6.3793	0.1737	6.4580
12	13	-3.2280	-3.2454	3.2746	3.2876
13	14	3.2639	4.0883	-3.2180	-3.9949

4.4 Test case 14-bus ill conditioned power system

When the prescribed range of (R/X) ratio for a transmission lines in system is increased by 3.14 times, the conventional NR method failed to converge, while the (ABC) algorithm converged to the solutions shown in table (9). After initialize the control parameters of ABC, The final objective function value in ABC optimization process after 15000 iteration is 4.526×10^{-4}. The performance of ABC method to obtain the best solution is clarified by graph that shown in Fig (7).



Nvar=22; Lb, Ub=0.7 ≤ $|V|$ ≤ 1.00; -5 ≤ δ ≤ 5; nPop=5; nOnlooker=28; MaxIt=15000; L=18000; A=1.

Figure 7: the performance of ABC algorithm, best solution value versus iteration

Table 9: Results of system by using ABC algorithm (buses voltages)

Bus No. (i)	ABC-algorithm	
	V_i	δ_i
1	1.0500	0
2	1.0400	-36.0020
4	1.0350	-55.3166
5	0.8863	-42.2674
5	0.8836	-36.9360
6	1.0400	-49.4221
7	0.9527	-47.8616
8	1.0400	-49.7349
9	0.9255	-49.4257
10	0.9165	-49.5676
11	0.9504	-49.6177
12	0.9351	-47.9158
13	0.9588	-49.3720
14	0.8925	-49.9392

Table 10: Results of system by using ABC algorithm (power flow in lines)

The lines		P_{ij} (MW)	Q_{ij} (MVAR)	P_{ji} (MW)	Q_{ji} (MVAR)
i	j				
1	2	559.0200	-387.770	-222.172	636.1871
1	5	205.5291	-44.3217	-115.839	133.7534
2	3	108.1024	-72.9999	-77.4987	104.1435
2	4	64.6382	5.5576	-55.2763	1.3037
2	5	47.7405	28.8544	-40.9574	-23.8519
3	4	13.0197	82.6894	5.1269	-71.5021
4	5	-56.8516	88.3550	64.6175	-82.4381
4	7	40.2479	-26.7765	-40.2479	32.8601
4	9	18.9670	-5.2517	-18.9670	7.9088
5	6	84.5903	-49.5681	-84.5903	78.4837
6	11	19.2082	8.8579	-17.5816	-8.0352
6	12	15.1571	12.6436	-13.3242	-11.7222
6	13	25.0368	12.2278	-23.0710	-11.2927
7	8	18.3860	-46.9292	-18.3860	51.8598
7	9	21.8758	23.8328	-21.8758	-22.5643
9	10	5.1935	1.7374	-5.1474	-1.7078
9	14	5.1632	1.2461	-4.9899	-1.1571
10	11	-6.8384	-4.0909	7.0951	4.2360
12	13	-1.7619	-2.8761	1.8809	2.9021
13	14	7.7035	2.5915	-7.1950	-2.3414

5. CONCLOUSION

This paper presents an efficient load flow computation by using ABC algorithm that is considered to be one type of swarm intelligence techniques. This algorithm is applied to 6 and 14 bus systems with different conditions, the results obtained have been compared with the results of NR method. The main advantages of ABC algorithm are the flexibility of modeling, accuracy, strong convergence and reliability. In addition, the presented algorithm shows promising results regarding heavily loaded and ill-conditioned systems. For the future work, the control parameters of the ABC algorithm in this field require comprehensive study to choose the best initial setting of the parameters' values to make this algorithm more powerful and able to be applied on large and practical models of power systems. In addition, the proposed algorithm could be used in many studies in power system such as optimal power flow, state estimation and stability studies.

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8. APPENDIX A

Buses Data of 6-bus case with heavily loaded condition

Bus No.	Bus code	V_{mag} Volt	δ Deg	P_{gen} MW	Q_{gen} MVAR	P_{load} MW	Q_{load} MVAR
1	1	1.05	0	0	0	0	0
2	2	1.05	0	80	0	0	0
3	2	1.07	0	90	0	0	0
4	3	1.0	0	0	0	255	130
5	3	1.0	0	0	0	255	130
6	3	1.0	0	0	0	254.13	152

9. APPENDIX B

Buses Data of 14-bus case with and without high R/X ratio

Bus No.	Bus code	V_{mag} volt	δ Deg	P_{gen} MW	Q_{gen} MVAR	P_{load} MW	Q_{load} MVAR
1	1	1.05	0	0	0	0	0
2	2	1.04	0	60	32.4	61.7	42.7
3	2	1.035	0	0	23.4	64.5	29
4	3	1.0	0	0	0	47.8	3.9
5	3	1.0	0	0	0	7.6	1.6
6	2	1.04	0	0	12.2	25.2	18.5
7	3	1.0	0	0	0	0	0
8	2	1.04	0	0	17.4	18.4	12.8
9	3	1.0	0	0	0	30.5	16.6
10	3	1.0	0	0	0	12	5.8
11	3	1.0	0	0	0	10.5	3.8
12	3	1.0	0	0	0	15.1	14.6
13	3	1.0	0	0	0	13.5	5.8
14	3	1.0	0	0	0	12.2	3.5

- Bus code: 1=slack bus , 2=voltage controlled bus(PV bus) & 3=load bus (PQ bus)