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Multi-variable single-objective optimal power flow of IEEE-14 bus system using artificial bee colony algorithms

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Abstract

Artificial bee colony (ABC) algorithm is one of the most nature-inspired algorithms used to solve optimization problems in different engineering fields, such as optimal power flow (OPF) used in power distribution systems. In this paper, ABC algorithms along with MATLAB software are used to optimize IEEE-14 bus distribution systems. Three main objectives are considered including reduction of fuel cost, reduction of power losses and reduction of voltage deviations in IEEE-14 bus system that are merged into one objective function and optimized for the whole system. The ABC algorithm objective function of 8271.59457, results in fuel cost of 8104.84 ($/h), power losses of 7.90741 (MW) and voltage deviation of 0.06278 (p. u.). These results help decision makers and operators of this kind of power distribution systems to operate in the best possible way with improved efficiency.

Keywords: IEEE-14 Bus System; Optimal Power Flow; Artificial Bee Colony; Fuel Cost; Power Losses; Voltage Deviations.

1. Introduction

Power losses, fuel cost and voltage deviations are the most important and critical variables or factors in operating any power distribution system. In 1962, the optimal power flow (OPF) method was validated [1] in order to optimize such kind of systems.

In any power distribution system, power losses due to long distance between the generators and the final loads, environmental issues, and human errors are the most parameters that need to be controlled by the operators. Voltage deviations among the loads are important to maintain the stability of the system. Furthermore, the fuel cost is a fluctuating variable that changes based on the daily/weekly/monthly oil market prices, and becomes a very important issue in power distribution systems.

Initially, optimization techniques commonly used to solve OPF problems includes linear programming [2], nonlinear programming [3], interior point methods [4], and quadratic programming methods [5]. These classical approaches can solve a single objective function including one variable, due to point-to-point approaches used in OPF problems. Initial conditions are needed which introduce a complex function which in turn makes these algorithms inadequate to solve OPF problem, and the insecure convergence properties of these classical approaches make it not as good in optimizing power distribution systems.

Recently, genetic algorithms (GA) open the door wide in front of solving complex optimization problems with random variable and multi-objective function. Many researchers use OPF in optimizing the fuel cost, power losses using different search algorithms. Particle swarm optimization (PSO) algorithm is

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used to optimize the cost of IEEE- 30 bus system [6, 7]. It is also used to optimize multi-objective function including the fuel cost and power losses [8], a multi-objective harmony search (MOHS) [9].

This paper focuses on optimizing fuel cost, power losses and voltage deviations in one objective function for IEEE- 14 bus system using artificial bee colony (ABC) algorithm.

1.1. OPF mathematical formulation

In this work, the objective of an optimal power flow (OPF) algorithm is to perform IEEE- 14 bus system with normal performance, low operational cost, lower power losses, and low voltage deviations in one objective function.

The standard OPF is formulated mathematically as a general constrained optimization problem

$$Minimize\ f(x_1, x_2, x_3) \tag{1}$$

$$Subject\ to\ h(x_1, x_2, x_3) \tag{2}$$

$$and\ g(x_1, x_2, x_3) \geq 0 \tag{3}$$

where f (x_1, x_2, x_3) is the objective function, h (x_1, x_2, x_3) is the equality constraints, g (x_1, x_2, x_3) is the inequality constraints, and (x_1, x_2, x_3) are the objectives to be minimized.

There are mainly three objectives which are considered in this paper as one objective function: minimizing the fuel cost of the generated power, minimizing the active power loss, and minimizing the deviations in voltage magnitudes at the loads. The objective function will be minimized as the power system is running under normal operating conditions while the system parameters are operating within their limits.

Objectives:

$$\boldsymbol{Minimize}\ (x_1, x_2, x_3) = W_1\, f(x_1) + W_2 f(x_2) + W_3 f(x_3) \tag{4}$$

$$f(x_1) = \sum_{i=1}^{N} \left(\alpha_i + \beta_i P_{gi} + \gamma_i P_{gi}^2\right) \tag{5}$$

where:

x_1: the value of total generation fuel cost,

x_2: the value of total power loss,

x_3: the value of voltage deviation,

P_{gi}: the amount of generations in MW at unit *i*,

α_i, β_i, γ_i: fuel cost coefficients for i^{th} unit,

N: number of busses including the slack bus,

W_1, W_2, W_3: weighting factors for fuel cost, power losses and voltage deviation, respectively.

$$\sum_{i=1}^{N} P_{Gi} - \sum_{j=1}^{M} P_{Dj} - P_L = 0 \tag{6}$$

$$\sum_{i=1}^{N} Q_{Gi} - \sum_{j=1}^{M} Q_{Dj} - Q_L = 0 \tag{7}$$

$$P_{Gi}^{Min} \leq P_{Gi} \leq P_{Gi}^{Max} \tag{8}$$

$$Q_{Gi}^{Min} \leq Q_{Gi} \leq Q_{Gi}^{Max} \tag{9}$$

$$P_i = V_i \sum_{j=1}^{N} V_j \{G_{ij} COS(\delta_i - \delta_j) + B_{ij} SIN(\delta_i - \delta_j)\} \tag{10}$$

$$Q_i = Vi \sum_{j=1}^{N} V_j \{G_{ij} SIN(\delta_i - \delta_j) - B_{ij} COS(\delta_i - \delta_j)\} \tag{11}$$

$$P_L = \sum_{i=1}^{N} \{g_{ij}(V_i{}^2 + V_j{}^2) - 2 V_i V_j g_{ij} COS(\delta_i - \delta_j)\} \tag{12}$$

where:

P_{Gi}, Q_{Gi}: the generator real power and reactive power at bus *i* respectively,

P_{Di}, Q_{Di}: the real power demand and reactive power demand at bus *i* respectively,

P_L, Q_L: the real and reactive power losses respectively,

P_{Gi}^{Min}, P_{Gi}^{Max}: minimum and maximum values of real power generation at bus *i* respectively,

Q_{Gi}^{Min}, Q_{Gi}^{Max}: minimum and maximum values of reactive power generation at bus *i* respectively,

P_i, Q_i: the active and reactive power flowing at bus *i* respectively,
V_i, V_j: the voltage magnitude at bus *i* and bus *j* respectively,
G_{ij}, g_{ij}: the conductance between bus *i* and bus *j*,
B_{ij}: the susceptance between bus *i* and bus *j*.

1.2. Artificial Bee Colony Algorithm (ABC)

ABC algorithm is an artificially-intelligent algorithm inspired by the bee's behavior in finding the food sources. The bee colony comprises three different groups of bees which are: employed bees, onlookers and scouts. Based on the assumption that only one employed bee is selected for one food source or the number of employed bees in the colony is equal to the number of food sources around the hive. The employed bees in one colony find their special food source and bring it back to special location in the colony and send a special signal as a dance for others in its area. The employed bee that completes its mission in finding the food source becomes a scout and starts to search for finding a new food source. Onlooker bees receive the signal dance of the employed bees and choose food sources amount based on special dance type. The process is repeated based on bee's memory: the employed bees find a food source in neighbor source, while the onlookers watch and register the food source and its amount based on the employed bees dance, finally the best food source found so far is registered [10, 11]. Fig. 1 below illustrates the flow chart of ABC algorithm in optimizing power flow problems.

2. Methodology

MATLAB software is used to simulate IEEE-14 bus systems shown in Fig. 2 below. A MATLAB code is written in order to optimize three parameters including the fuel cost, power losses and voltage deviations as separated three objective functions. On the other hand, another MATLAB code is generated in order to optimize these three parameters (fuel cost, power losses and voltage deviation) in one objective function. Normally, optimizing one parameter on power distribution system (for example fuel cost) provides the best results for the intended parameter (fuel cost), while the other ignored parameters (power losses and voltage deviations) resulted in unsatisfactory results. On the other hand, merging the three parameters in one objective function results in the best compromise for the whole IEEE-14 bus power distribution system. IEEE-14 bus system consists of three generators; each one has a minimum and a maximum power limit standard, and fuel cost coefficients standard as shown in Table 1. The weighting factors for IEEE-30 bus systems are as follow: fuel cost (W1) is equal to 1.001; power loss (W2) is equal to 17.487; and voltage deviation (W3) is equal to 324.511.

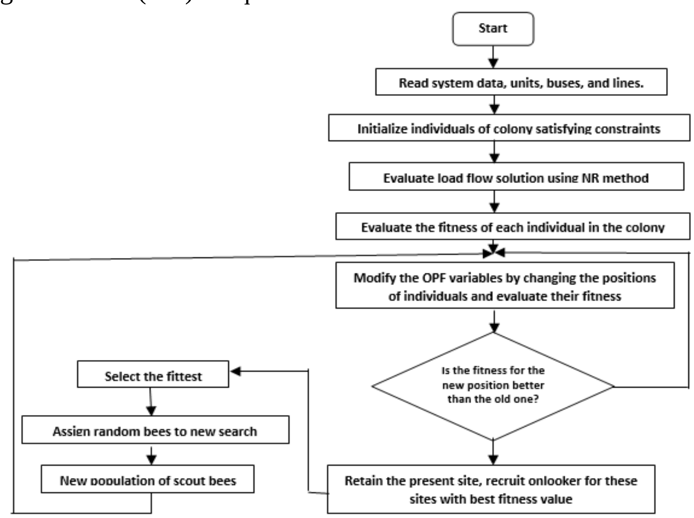

Fig. 1. OPF flow chart based on ABC algorithm.

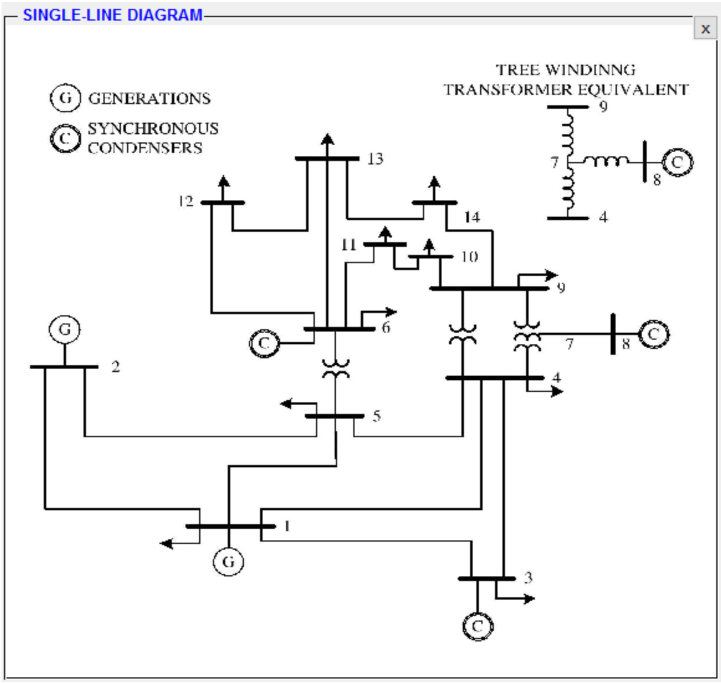

Fig. 2. Single-line diagram of IEEE -14 bus system

Table 1. The values of generator fuel cost coefficients

Generators	Generation Limits (MW)		Fuel Cost Coefficients		
	P_{min}	P_{max}	α_i (\$/(MWhr)^2)	β_i (\$/MWhr)	γ_i (\$/hr)
G1	10	160	0.005	2.450	105.000
G2	20	80	0.005	3.510	44.100
G3	20	50	0.005	3.890	40.600

The MATLAB software is used to run the ABC algorithms for 100 iterations, and five runs per algorithm. Intel ®core™i7-490s CPU @ 3.2GHz processor, 12.0 GB internal memory, and 64-bit operating system is used in the simulation process.

MATLAB simulation is carried out using ABC algorithm to optimize single parameters (fuel cost, power loss, or voltage deviations) in different three-objective function, where the number of food source (SN) is chosen to be 25 which is equal to the number of employed or onlooker bees [12]. The maximum number of iterations for each run is 100, and the simulation is performed for 5 runs. The aforementioned procedure is repeated for three parameters in single-objective function to determine the best operating parameters for IEEE 14 bus system at all .A comparison between the three mentioned algorithms is carried out.

3. Numerical Results and Discussions

Table 2 provides the MATLAB statistical results for optimizing the IEEE-14 bus system based on ABC search algorithms. For the first experiment, the fuel cost is optimized regardless of the other parameters for IEEE-14 bus power distribution function. This procedure is repeated for the second and third simulation experiments with different optimized parameters, the last experiment showed the results for optimizing the IEEE-14 bus power distribution system as a whole system parameter in one objective function. It is noticed that the lower and best fuel cost is obtained in the first simulation which is about 8084.04$/hr. The problem occurs for the other parameter where the power loss is 9.4153 MW and the voltage deviation between loads is considered high (about 0.08605 p. u.). In the second experiment, the power loss is optimized but the fuel cost and voltage deviation are not. For the third experiment, the same thing happens to the non-optimized parameters. In the last simulation, the fuel cost, power losses and voltage deviation are compromised and the IEEE-14 bus whole system is optimized with one objective function. After five runs for each algorithm with 100 iterations each run, the ABC algorithm shows the best fuel cost of 8104.84($/h), best power losses of 7.90741 (MW) and best voltage deviation of 0.06278 (p. u.) and, hence, the objective function of 8271.59457.

Figs. 3, 4 and 5 below show the convergence profile for ABC algorithms to optimize fuel cost, power losses and voltage deviation as three different objectives respectively. The objective function using ABC algorithm shown in Fig. 3 follows an exponential function where the particles need much time to be directed to the new corrected position. On the other hand, once the particles find new corrected position the accuracy or the error will be eliminated in less time. After 33 iterations, the objective function including the fuel cost only reaches approximately the minimum value.

Table 2. Fuel Cost, Power Loss and Voltage Deviation as one objective function with ABC algorithms for the IEEE-14-bus system statistical results

Optimized function	Objective Function	Fuel Cost ($/h)	Power Loss (MW)	Voltage Deviation (p.u.)	Minimum objective function	Maximum objective function	Mean objective function	Standard deviation objective function	Mean TOC(s) it's the time to run OPF
Fcost	8084.039	8084.04	9.41535	0.08605	8084	8105.6	8093.8	8.0592	72.9098
Ploss	0.00623	10142.95	0.62316	0.24951	0.0062	0.0117	0.0089	0.0024	75.7501
VD	0.03303	8276.85	6.39017	0.03303	0.033	0.0515	0.0406	0.008	73.7597
Fcost_Ploss_VD	8271.594	8104.84	7.90741	0.06278	8271.6	8300.3	8284	10.9374	80.1387

Figs. 4 and 5 show the convergence profile for ABC algorithm when optimizing power losses and voltage deviation respectively. It is clear that this algorithm does not need as many iterations to minimize these two variables.

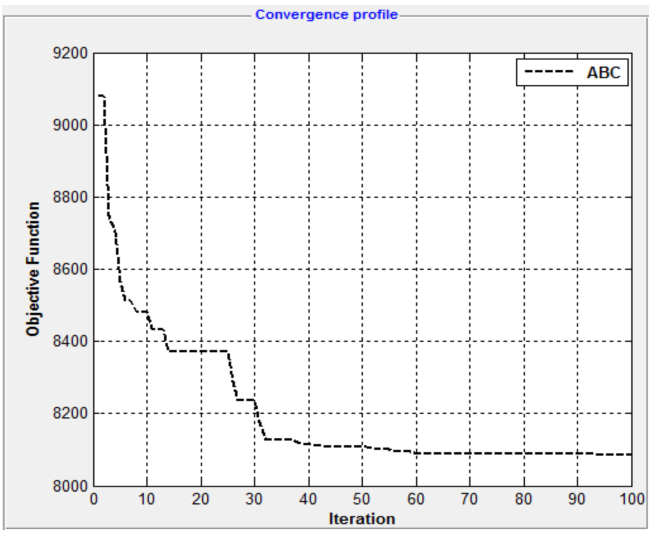

Fig. 3. ABC algorithm convergence profile for fuel cost in IEEE-14 bus system

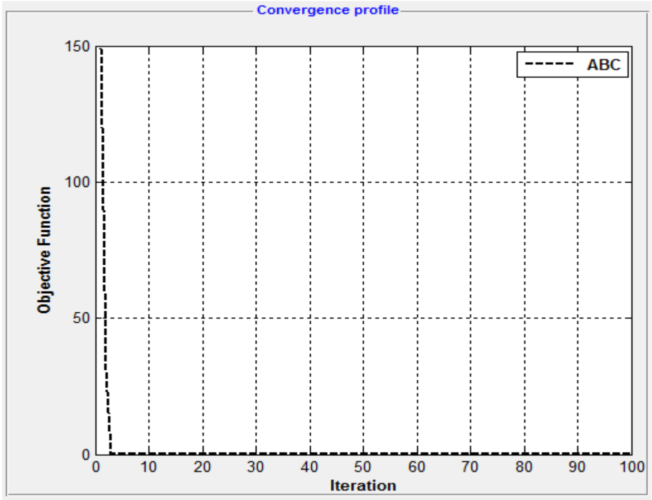

Fig .4 . ABC algorithm convergence profile for power losses in IEEE-14 bus

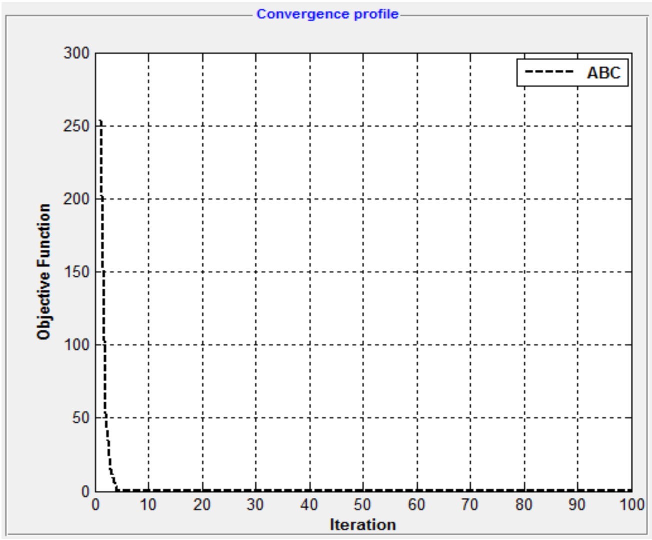

Fig. 5. ABC algorithm convergence profile for voltage deviation in IEEE-14 bus

Fig. 6 shows the convergence profile of ABC algorithm, where it follows a compromise pattern between step and exponential function. The objective function reaches a value of 8271 after 100 iterations. There is a reduction of approximately 18.1% of the initial value of the total objective function. The objective function follows nearly an exponential function. It means that the employed bees keep finding new food source or the ABC algorithm continues minimizing the objective function with fine updates for each iteration. After 100 iterations the objective function reaches the best value of 8271 for IEEE-14 bus system including the three parameters together.

Table 3 below lists the IEEE-14 bus system power under optimum control variable for ABC algorithm, including generator active power Pg (MW), generator reactive power Qg (MVAr), shunt VAR compensations Qc (MVAr), load active power Pload (MW), and load reactive power Qload (MVAr). It is evident that all bus powers are still in the appropriate limit for IEEE-14 bus power distribution system. These results improve the optimizing power flow for IEEE-14 bus system including fuel cost, power losses and voltage deviation as a one combined objective function.

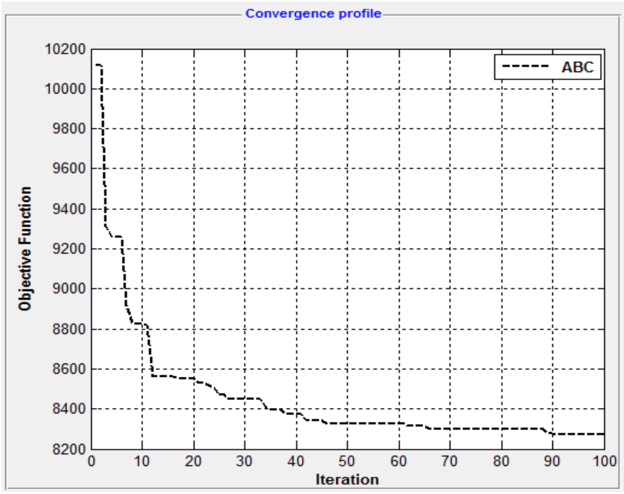

Fig. 6. ABC algorithm convergence profile for fuel cost, power losses, and voltage deviation in IEEE-14 bus.

Table 3. IEEE-14 bus system power under optimum control variable for ABC algorithms. (all optimized)

Bus Nu	Pg (MW)	Qg (MVAr)	Qc (MVAr)	Pload (MW)	Qload (MVAr)
1	177.2593	1.8215	0	0	0
2	36.261	17.8035	0	21.7	12.7
3	40.7836	18.2033	0	94.2	19
4	0	0	0	47.8	-3.9
5	0	0	0	7.6	1.6
6	0	17.1394	0	11.2	7.5
7	0	0	0	0	0
8	12.6035	10.0103	0	0	0
9	0	0	0	29.5	16.6
10	0	0	0	9	5.8
11	0	0	0	3.5	1.8
12	0	0	0	6.1	1.6
13	0	0	0	13.5	5.8
14	0	0	6.61E-15	14.9	5

Fig. 7 represents a compression of voltage deviation at each bus for IEEE-14 bus system using the four optimization experiments. The convergence for all optimization experiments used at each bus in the system gives a clear insight about the results obtained for combining the fuel cost, power losses and voltage deviation as one objective function. Most of the 14 buses in IEEE-14 bus system have small variations using any of the four optimization experiments; the maximum variation of the bus voltage using these difference variables does exceed the 5% at bus number 14. These results prove the ability of ABC algorithms of optimizing the fuel cost, power losses, and bus voltage variations as a one set or one objective function.

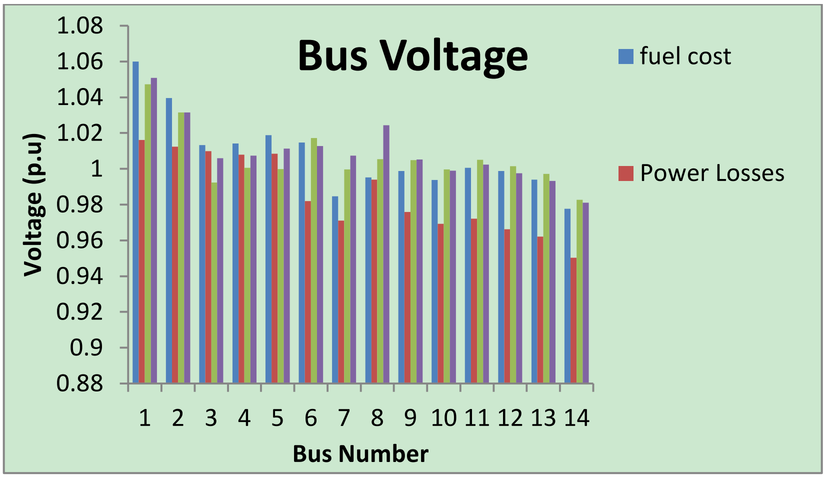

Fig. 7. Voltage variation at each bus for IEEE-14 bus system

4. Conclusion

This paper highlighted a nature-inspired artificial bee colony (ABC) optimization algorithm. Furthermore, this algorithm is used to solve optimal power flow (OPF) including optimizing fuel cost, power losses and voltage deviation in one objective function instead of multi-objective function for IEEE-14 bus system. MATLAB software is used in the optimizing process and it is found that the ABC algorithm is efficient in optimizing such multivariable problems with one objective function. The ABC algorithm shows fuel cost of 8104.84 ($/h), power losses of 7.90741(MW), voltage deviation of 0.06278 (p. u.), and total objective function of 8271.59457. The generators, loads and shunt capacitance power for all busses under optimum control variable matches each other with slight variations using ABC algorithm when one variable or more are optimized, which improves the results of using one objective function to optimize the different variables under discussion (fuel cost, power losses and voltage deviations) in IEEE-14 bus system.

Conflict of Interest

The authors declare no conflict of interest. The authors whose names are listed in this work certify that they have NO affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

Author Contributions

All authors have participated in (a) conception and design, or analysis and interpretation of the data; (b) drafting the article or revising it critically for important intellectual content; and (c) approval of the final version.

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