IAES International Journal of Artificial Intelligence (IJ-AI)
Vol. 4, No. 3, September 2015, pp. 89~96
ISSN: 2252-8938

A New DG Allocation Approach Based on Biogeography-Based Optimization with Considering Fuzzy Load Uncertainty

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Article Info

Article history:

Received May 23, 2015
Revised July 13, 2015
Accepted August 2, 2015

Keyword:

Biogeography-based optimization (BBO)
Distributed generation
Fuzzy load uncertainty
Power loss reduction
Voltage profile

ABSTRACT

A new distributed generation placement method based on biogeography-based optimization (BBO) is investigated in this paper. A significant novelty of this study lies in considering fuzzy load uncertainty. For this purpose a fuzzy backward- forward sweep load flow is proposed. The main objectives of this study is minimizing power losses and improving voltage profile. A comparative study between optimal location and sizing under typical load condition and fuzzy load uncertainty is presented. To verify the efficiency of proposed BBO method, it is conducted on IEEE 33 bus distribution system, also a comparative study between proposed BBO approach and particle swarm optimization (PSO), Technical-learning based optimization (TLBO), Artificial bee colony (ABC), Imperialist competitive algorithm (ICA) is investigated. The simulation results show the excellent and superior performance of proposed BBO approach in comparison with the other intelligent methods.

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1. INTRODUCTION

Nowadays the nature of distribution networks is changing from passive to active by installation of small power sources called distributed generations (DGs). The penetration level of these non-conventional units is increasing and it is expected that this growth will continue along with customer's demand. Therefore it is obvious that their integration creates remarkable technical and economical challenges for the Distribution Network Operators (DNOs) or developers and industries [1]. A properly planned DG, can be beneficial to the distribution system and will have positive economical and technical impacts. The economical advantages are deferral of network replacement [2], reduction the cost of both network and DG [3] and energy price [4]. Technical advantages include various indices such as active and reactive power loss reduction [5], reliability improvement [6,7], improvement in the network voltage stability [8] and security [9]. From grid planning perspective, several researchers have developed interesting approaches for optimal DG planning due for a defined objective function. In [10], a fast analytical method for DG sizing and allocation for loss reduction in primary distribution systems is presented. The authors in [11] studied a fuzzy logic-based method to determine the optimum DG units locations by considering technical parameters such as power losses, voltage level and cable loading. Ref [12] presented a combined GA and PSO method to solve optimal DG location and sizing in distribution networks. Although most of the above mentioned approaches are generally able to also result in minimum overall energy and power losses, the problem of minimizing losses has been investigated using a single demand level.

In [13], the practice of minimizing power losses by examining only a single load demand condition is unlikely to lead to an overall optimal energy loss especially when a renewable generation could be connected to distribution networks. Therefore, a multi-period AC power flow technique is used to cater for variability of demand and generation in DG planning and optimization [14]. Also in recent years, applying probabilistic (or stochastic) power flow analysis is widely used to consider the uncertainties associated to the distribution network loads [15,16]. A methodology to evaluate dispersed photovoltaic (PV) impact on loss reduction using probabilistic power flow in a distribution line is studied in [17], also it has shown that by considering both stochastic generation and loading conditions, uniform DG sitting would have the highest impact on power loss reduction in a distribution line.

Authors in [18–21] have shown that from the concept of multiple objective approaches, load models can significantly affect the optimal location and sizing of DGs in distribution systems. In one of the new researches, El-Zonkoly proposed a multi-objective index-based DG size-location optimization problem including different load models using particle swarm optimization (PSO) technique. Also it has shown that by placement of a DG at most of the system buses the value of the short circuit level increased and in the case of the industrial load model, the maximum increase is experienced [22].

In [23], a methodology is proposed to study the effect of load models on the evaluation of energy losses based on time series simulations to take into account both the variations of renewable generation and load demand. However the authors considered the detailed load model such as demand profile and demand type, by considering a single wind power as a renewable DG, only the impact of load models on energy losses is investigated. In these studies, however loads have been modeled as voltage dependent for residential, industrial and commercial load types, the demand has been considered as a single load level, without differences in the pattern of each type.

This paper presents a novel DG planning approach based on biogeography-based optimization (BBO) algorithm in order to loss reduction and voltage profile improvement in the distribution network. For considering uncertainty and stochastic nature of loads, a fuzzy representation of loads is presented in this study. The proposed method is applied to IEEE-33 test system and the obtained simulation results verified the proper performance of presented approach. All the simulations are carried out on Matlab environment.

2. PROBLEM FORMULATION

2.1. Objective Function

In this paper, the objective functions are minimizing power losses and improving voltage profile by means of optimizing the following equation:

$$Objective\ Function = Min[(W_1 * P_{Loss}) + (W_2 * VI)] \tag{1}$$

Where, P_{Loss} is power losses which is evaluated as below:

$$P_{Loss} = \sum_{1}^{N_b}\sum_{1}^{N_b}[a_{ij}(P_i P_j + Q_i Q_j) + b_{ij}(Q_i P_j - Q_j P_i)] \tag{2}$$

Where

$$a_{ij} = \frac{R_{ij}}{V_i V_j}\cos(\delta_i - \delta_j)\ ,\ b_{ij} = \frac{X_{ij}}{V_i V_j}\sin(\delta_i - \delta_j)$$

$Z_{ij} = R_{ij} + jX_{ij}$ are the network impedance matrix components and N_b is the number of distribution network buses [24].

Also the in equation (1), improving voltage profile is obtained by minimizing the index (VI) which defines as follows [25]:

$$VI = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{|V_i - V_{tg}|}{V_{tg}}\right) \tag{3}$$

In equation (3), V_{tg} is V_{target} which defines as 1pu. N is total the number of buses and V_i is the voltage at bus i. Improving voltage profile could be provided by closing the index (VI) to zero, so it should be minimized.

W_1 and W_2 are the weights of objectives and given the same values as 0.5.

2.2. Constrains

The optimization process of DG allocation includes some technical constrains as follows:

1. The Limitation of Voltage:

$$V_{\min} \le V_i \le V_{\max} \tag{4}$$

Where $V_{\min}$ and $V_{\max}$ indicate the minimum and maximum permissible voltage (±5%) and V_i is the voltage at bus i.

2. The power balance constraint:

$$\sum_{g=1}^{N_g} Pg_{gw/DG} + \sum_{d=1}^{N_{DG}} Pg_d = P_d + P_L \tag{5}$$

Where N_g and N_{DG} are the whole number of traditional generation unit and whole number of DGs, $Pg_{gw/DG}$ is the value of active power of traditional power generation unit g with introducing of DG, P_{gd} is the amount of active power of DG unit d, P_d is the whole load demand and P_L is the whole loss of active power.

3. Active and reactive power constraint:

$$P_{gi}^2 + Q_{gi}^2 \le S_{gi,max}^2 \tag{6}$$

Where Q_{gi} and $S_{gi,max}$ depicts the amounts of reactive and apparent power of the ith DG [26].

2.3. Fuzzy Load Flow

At any time, load can be shown as a fuzzy number. For example, load at time ti can be represented as a triangular fuzzy number (TFN) as depicted in Figure 1a. in this fuzzy load representation, Lhp is the load with highest membership values or load with highest possibility of occurrence and Lmin, Lmax are the lower and upper limits of load, respectively.

Other shapes for fuzzy numbers based on operator insight or gathered information can also be utilized. For consideration of uncertainty in load, a backward–forward sweep load flow method with fuzzy load is used [27].

Due to fuzzy modelling of loads, variables are treated as TFNs with real and/or imaginary parameters; mathematical operators applied in the fuzzy domain and load flow results are obtained in the fuzzy domain. In Figure 1b, voltage at node k is presented as TFN in which Vhp is the voltage with highest membership value and Vmin, Vmax are the lower and upper limits of voltage, respectively.

For a given condition in the distribution network, by running the fuzzy load flow, the result of power flow through the line segments and substations give also fuzzy numbers. Therefore active and reactive power losses obtain fuzzy numbers. as shown in Figure. 1c, where P_{Lhp} is the active power loss with highest membership value and P_{Lmin} , P_{Lmax} are the lower and upper limits of power losses, respectively. Same concept is used for the expression of reactive power losses and voltages at different nodes.

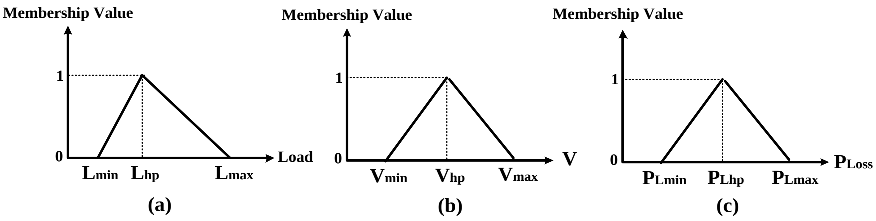

Figure 1. Fuzzy Load Modelling – Triangular Membership for Power Load (a) – Voltage Constraint in Fuzzy Domain (b) – Active Power Loss Constraint in Fuzzy Domain (c)

3. BIOGEOGRAPHY THEORY

Biogeography Based Optimization (BBO) approach which is based on biogeography theory, has been proposed in 2008 by Dan Simon [28]. The procedure of BBO is an example of natural process that can be utilized to solve general problems of optimization. In BBO, each individual is assumed as an island (or a habitat), and the features subscription thorough individuals are depicted as emigration and immigration (figure 2). Each solution property is named a suitability index variable (SIV). Geographical regions that are appropriated as residences for biological types are said to have a high habitat suitability index (HSI). The meaning of a high HSI of a habitats is proper performance on the optimization problem whereas a low HSI shows improper performance on the optimization problem. Intelligent algorithms solve the optimization problem using Intensification the population. In BBO generating next generation performed by immigrating solution properties to the other islands, and giving solution properties by emigration from the other islands. Then mutation is done for all the population. This mutation procedure is similar to GA algorithm's mutation.

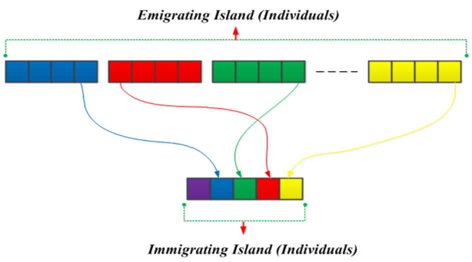

Figure 2. Emmigration and Immigration of Species and New Island

In BBO, each individual has its own immigration rate, depicted by λ, and emigration rate, depicted by μ. A proper solution has higher μ; Therefor, it has a very high probability of borrowing properties from other solutions, helping it to improve for the next generation illustrated in Figure 3.

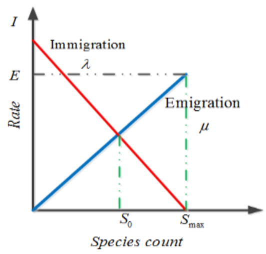

Figure 3. Species Model of a Single Habitat

3.1. Proposed method steps

This study proposed a new approach based on BBO algorithm which is investigated to determine the optimal location and capacity of Distributed generation units which is applied to improve voltage profile as the main factor for power quality improvement and reduce power losses of the distribution network. Also in this investigation, the fuzzy load uncertainty is considered to make the investigation more practical. Due to triangular membership function selection for loads, all the output details from power flow and optimization process including voltage at different nodes and power losses have three values as lower and upper limits and highest membership value of apparent variables. The proposed algorithm steps are performed as follow:

1. Step 1: Enter the network's load data and run fuzzy power flow to evaluate voltage ate different nodes and power losses.
2. Step 2: Define penalty functions in order to prevent violating constrains.
3. Step 3: Initialize the BBO parameters including maximum species count, maximum migration rates, and maximum mutation rate and an elitism parameter.
4. Step 4: Initialize habitats depending upon habitat size within feasible region. Set the iteration counter m= 0.
5. Step 5: DG installation and calculate power flow.

6. Step 6: Checking network constrains. If the solutions violate the constrains, then apply the penalty, otherwise go to next step.
7. Step 7: Add the counter by 1. Check whether it is less than the maximum iteration limit. If no, print the output results.
8. Step 8: If yes, calculate the HSI value for the given μ & λ and Select the optimum HSI value based on elitism parameters.
9. Step 9: Modify each non-elite habitat using immigration & emigration rate.
10. Step 10: Check for conceivability. If yes, HSI is computed.
11. Step 11: Species count probability is updated and recalculated the HSI.
12. Step 12: Go to step 7 for the next iteration. This procedure can be finished after a conceivable problem solution has been found.

The following BBO parameters have been used, population size=50, Habitat Modification Probability=1, Immigration Probability bounds per gene= [0, 1], elitism parameter = 4, step size for numerical integration of probabilities=1, maximum λ and μ rates for each island=1 and Mutation Probability=0.05

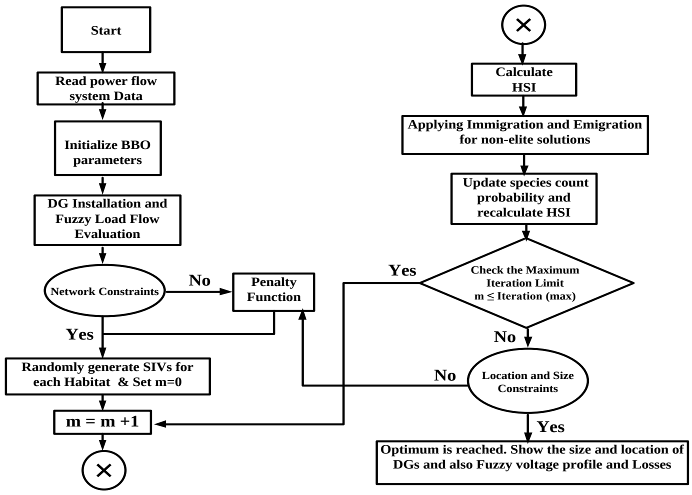

Figure 4. Flowchart of Proposed BBO Approch

4. SIMULATION RESULTS

In order to investigate the performance of the proposed approach, the IEEE 33-bus radial distribution test system is utilized in this section**.** Figure 5 shows the single line diagram of the test system. The total amounts of the active and reactive loads of the system are 3.715 MW and 2.3 MVAr, respectively. In addition, as mentioned in [29], the initial amount of the active and reactive power losses before DG allocation are 210.84 kW and 143.114 kVAr, respectively. Load is assumed as a triangular fuzzy number as shown in Figure 1(a) in section 2.3. Minimum load and maximum load on buses are 90 and 110%, respectively, of load with highest membership value. Loads with highest membership values on various buses are shown in appendix (table 4).

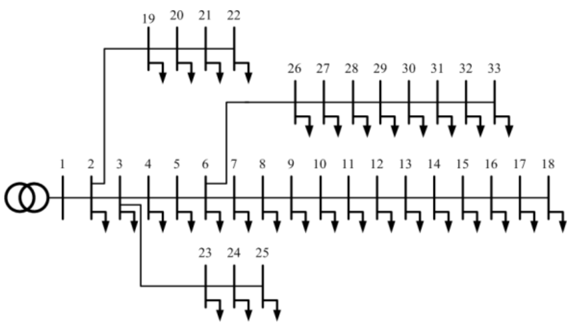

Figure 5. Single Line Diagram of 33-Bus Distribution Test System

Optimal DG placement and sizing with considering load uncertainty is investigated. fuzzy load flow is applied in order to load uncertainty consideration. Table 1 hows the node voltages results of initial fuzzy load flow and DG placement under fuzzy uncertainty. It should be noted that because of fuzzy load flow consideration, all the voltages at different nodes and power losses take three values and that is due to the triangular fuzzy membership function as mentioned in section 2.3. These three values include lower and upper limits depicted by min and max indices respectively and also highest membership (hp) value.

Table 1. Results of Bus Voltages in Fuzzy Load Flow, before and after DG Placement using BBO Method

Bus number	Vmin (without DG)	Vhp (without DG)	Vmax (without DG)	Vmin (with DG)	Vhp (with DG)	Vmax (with DG)
1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
2	0.9966	0.9970	0.9974	0.9987	0.9991	0.9994
3	0.9803	0.9829	0.9854	0.9942	0.9960	0.9974
4	0.9718	0.9754	0.9790	0.9914	0.9942	0.9965
5	0.9631	0.9679	0.9727	0.9892	0.9927	0.9957
6	0.9427	0.9495	0.9563	0.9836	0.9896	0.9945
7	0.9389	0.9459	0.9530	0.9820	0.9883	0.9935
8	0.9228	0.9323	0.9418	0.9774	0.9855	0.9922
9	0.9156	0.9260	0.9363	0.9767	0.9855	0.9929
10	0.9089	0.9203	0.9316	0.9767	0.9861	0.9939
11	0.9079	0.9194	0.9309	0.9768	0.9863	0.9942
12	0.9061	0.9179	0.9297	0.9771	0.9868	0.9948
13	0.8991	0.9117	0.9244	0.9794	0.9897	0.9983
14	0.8964	0.9094	0.9225	0.9809	0.9913	1.0000
15	0.8947	0.9080	0.9213	0.9794	0.9900	0.9989
16	0.8931	0.9066	0.9202	0.9778	0.9887	0.9978
17	0.8909	0.9046	0.9183	0.9757	0.9869	0.9962
18	0.8901	0.9040	0.9179	0.9750	0.9863	0.9957
19	0.9960	0.9965	0.9970	0.9981	0.9986	0.9989
20	0.9918	0.9929	0.9940	0.9938	0.9950	0.9959
21	0.9910	0.9922	0.9934	0.9930	0.9943	0.9953
22	0.9903	0.9916	0.9929	0.9922	0.9936	0.9948
23	0.9763	0.9793	0.9823	0.9938	0.9956	0.9970
24	0.9689	0.9726	0.9764	0.9932	0.9954	0.9973
25	0.9650	0.9693	0.9736	0.9969	0.9986	1.0000
26	0.9404	0.9475	0.9547	0.9836	0.9896	0.9947
27	0.9376	0.9450	0.9523	0.9834	0.9898	0.9951
28	0.9245	0.9335	0.9426	0.9848	0.9911	0.9964
29	0.9159	0.9253	0.9347	0.9851	0.9925	0.9986
30	0.9117	0.9218	0.9318	0.9864	0.9938	0.9999
31	0.9070	0.9176	0.9282	0.9819	0.9899	0.9966
32	0.9059	0.9167	0.9275	0.9809	0.9891	0.9959
33	0.9056	0.9164	0.9272	0.9805	0.9888	0.9957

By comparing the voltage values in Table 1. Before and after DG placement, a significant improvement in bus voltages is concluded after optimal DG allocation.

The optimization process is performed by using BBO algorithm and obtained simulation results are compared with PSO, ABC, ICA and TLBO algorithms. All the optimization methods are implemented on IEEE-33 bus test system considering fuzzy uncertainty. Table 2 shows the optimal location and sizes of three DGs, minimum voltages and active and reactive power losses before and after optimization process. As mentioned before, voltages and losses are depicted as fuzzy values. It should be noticed that the three allocated DGs have the capability of injecting both active and reactive powers and their maximum capacity is 1.5 MVA.

By looking at Table 2 and comparing the results of optimal DG allocation by different methods, it is clearly concluded that BBO approach resulted more reduction in active and reacative power losses and also the value of minimum voltages in three fuzzy levels of this approach have the best results among the other methods. This proper results is due to selection the optimum location for DGs and the best usage of DGs' capacities that performed by BBO approach. It should be noted that the population size 50 and the maximum number of iteration 120, are considered during the optimization process for all the methods.The details of optimal sizes selection of DGs obtained by BBO method are depicted in Table 3. Loads with highest membership in Table 4.

Table 2. Comparison between Different Algorithms in Optimal DG Allocation with Fuzzy Load Uncertainty

Method	Optimal size and location (@bus)	Minimum fuzzy voltages @ bus	Fuzzy active power losses	Fuzzy reactive power losses
Initial		Min(V_{min})=0.8879@18	$P_{L,min}$ (kW)= 130.627	$Q_{L,min}$ (kVAr)= 88.612
	----	Min(V_{hp})=0.9039@18	$P_{L,hp}$ (kW)= 210.843	$Q_{L,hp}$ (kVAr)= 143.114
		Min(V_{max})=0.9246@18	$P_{L,max}$ (kW)= 286.086	$Q_{L,max}$ (kVAr)= 194.280
BBO	1346 MVA @ 20	Min(V_{min})=0.9750@18	$P_{L,min}$ (kW)= 9.507	$Q_{L,min}$ (kVAr)= 7.575
	758 MVA @ 10	Min(V_{hp})=0.9863@18	$P_{L,hp}$ (kW)= 14.089	$Q_{L,hp}$ (kVAr)= 10.932
	915 MVA @ 15	Min(V_{max})=0.9957@18	$P_{L,max}$ (kW)= 23.793	$Q_{L,max}$ (kVAr)= 17.915
PSO	1355 MVA @ 20	Min(V_{min})=0.9729@18	$P_{L,min}$ (kW)= 9.515	$Q_{L,min}$ (kVAr)=7.580
	710 MVA @ 10	Min(V_{hp})=0.9843@18	$P_{L,hp}$ (kW)= 14.693	$Q_{L,hp}$ (kVAr)= 11.408
	912 MVA @ 15	Min(V_{max})=0.9937@18	$P_{L,max}$ (kW)= 25.006	$Q_{L,max}$ (kVAr)=18.871
ABC	1236 MVA @ 20	Min(V_{min})=0.9749@18	$P_{L,min}$ (kW)= 11.129	$Q_{L,min}$ (kVAr)=8.295
	784 MVA @ 10	Min(V_{hp})=0.9863@18	$P_{L,hp}$ (kW)= 18.132	$Q_{L,hp}$ (kVAr)= 13.103
	688 MVA @ 15	Min(V_{min})=0.9957@18	$P_{L,max}$ (kW)= 30.304	$Q_{L,max}$ (kVAr)=21.567
ICA	1205 MVA @ 20	Min(V_{min})=0.9626@18	$P_{L,min}$ (kW)= 13.937	$Q_{L,min}$ (kVAr)=10.171
	884 MVA @ 6	Min(V_{hp})=0.9759@18	$P_{L,hp}$ (kW)= 18.915	$Q_{L,hp}$ (kVAr)= 13.962
	937 MVA @ 15	Min(V_{max})=0.9870@18	$P_{L,max}$ (kW)= 30.041	$Q_{L,max}$ (kVAr)=22.132
TLBO	1350 MVA @ 20	Min(V_{min})=0.9748@18	$P_{L,min}$ (kW)= 9.612	$Q_{L,min}$ (kVAr)=7.628
	755 MVA @ 10	Min(V_{hp})=0.9864@18	$P_{L,hp}$ (kW)= 14.111	$Q_{L,hp}$ (kVAr)= 10.976
	903 MVA @ 15	Min(V_{max})=0.9959@18	$P_{L,max}$ (kW)= 24.035	$Q_{L,max}$ (kVAr)=18.050

Table 3. Optimum Sizes and Locations of Allocated DGs using BBO Approach

DG location	P_{DG} (kW)	Q_{DG} (kVAr)
10	697.6	298.3
15	828.7	391.4
20	953.4	951.7

Table 4. Loads with Highest Membership Values on Buses

Bus number	P (kW)	Q (kVAr)	Bus number	P (kW)	Q (kVAr)
2	100.00	60.00	18	90.00	40.00
3	90.00	40.00	19	90.00	40.00
4	120.00	80.00	20	90.00	40.00
5	60.00	30.00	21	90.00	40.00
6	60.00	20.00	22	90.00	40.00
7	200.00	100.00	23	90.00	50.00
8	200.00	100.00	24	420.00	200.00
9	60.00	20.00	25	420.00	200.00
10	60.00	20.00	26	60.00	25.00
11	45.00	30.00	27	60.00	25.00
12	60.00	35.00	28	60.00	20.00
13	60.00	35.00	29	120.00	70.00
14	120.00	80.00	30	200.00	600.00
15	60.00	10.00	31	150.00	70.00
16	60.00	20.00	32	210.00	100.00
17	60.00	20.00	33	60.00	40.00

5. CONCLUSION

In this study a novel DG allocation approach based on biogeography-based optimization (BBO) algorithm in order to power loss reduction and voltage profile improvement in the distribution network is proposed. Uncertainty and stochastic nature of loads is considered as fuzzy representation of loads in this paper. To show the effectiveness of presented approach, the proposed method is applied to IEEE-33 test system and the obtained simulation results based on DG allocation under fuzzy load uncertainty are compared with some of well known optimization methods including particle swarm optimization (PSO), Technical-learning based optimization (TLBO), Artificial bee colony (ABC), Imperialist competitive algorithm (ICA). The comparison results verified the better performance of presented BBO approach among the introduced optimization methods. All the simulations are implemented on Matlab environment.

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