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Efficiency of Bat Optimization Algorithm in Optimal Reactive Power Dispatch Problems

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ABSTRACT: In this paper, the recent metaheuristic algorithm of bat optimization algorithm(BOA), is implemented for solving optimal reactive power dispatch (ORPD) problems. BOA can outperform several robust and efficient metaheuristic algorithms in solving engineering problems. ORPD problem is taken as a multi-modal and constrained optimisation problem with large number of control variables. Real power loss minimization and sum of voltage deviation minimization are the objectives of ORPD problem. The proposed algorithm was tested on the standard IEEE 30 and 57 bus power systems. The simulation results prove the outperformance of BOA over other algorithms compared from the literatures.

KEYWORDS: Optimal reactive power dispatch, Bat optimization algorithm loss minimization, voltage deviation minimization.

I. Introduction

Solution of optimal power flow (OPF) problem is very important in operation and planning of power systems that was introduced in 1960s [1-6]. ORPD problem is a sub set of optimal power flow problems [7, 8]. This problem is taken by large number of researcher across the world [9-12]. Because of the economic importuned of the ORPD problem only this of must important [9]. The aim of ORPD is to find the optimal values for generator bus voltages, transformers tap positions and VAR outputs from compensating devices for achieving low loss levels [9-11, 13-16].The problem is highly nonlinear and equality and inequality constraints are handled. These constraintsare represented as the power flow equations[17]. The problem has discontinued variables of transformer tap position and VAR compensator and continues variables of generator bus voltages [17, 18].

During the past three decades, numerous metaheuristics optimization technics are developed by mimicking intelligent behavior existing in nature.Thosealgorithms have been widely implemented for solving ORPD problem due to their excellent exploration and exploitation characteristics. Bat optimization algorithm (BOA) is an efficient optimizer that can outperform several well-established metaheuristics on ORPD task. The main contribution of this work is to utilize the BOA for solving the ORPD problem. For this purpose, twocommonly used IEEE 30-bus and 57-bus test systems are utilized. The results obtained are compared with those of other state of the art optimisation algorithms in the literatures. Experimental results of the ORPD problem verify that the BOA can demonstrate a better performance.

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The rest of the paper is organized as follows: Section 2 describes the ORPD mathematical problem; Section 3 explains the proposed BOA for solving ORPD problem; Section 4 is devoted to the numerical results and discussions, finally, conclusions are drawn in the last section.

II. ORPD MATHEMATICAL PROBLEM

The objective of this work is to improve the stability of the system by minimizing the active power loss and the sum of load bus voltage deviation. The two objectives are considered separately.

2.1 Objective function

The objective function of this work is to find the optimal control variables values that minimizes the active power loss and voltage deviation at load buses.

2.1.1Active power loss minimization (PL)

The total active power of the system can be calculated as follows [19].

$$P_L = \sum_{k=1}^{N_L} G_k [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_j)] \qquad (1)$$

Where, $N_L$is the total number of lines in the system; G_k is the conductance of the line 'k'; $V_i$and V_j are the magnitudes of the sending end and receiving end voltages of the line; $\delta_i$and δ_j are angles of the end voltages.

2.1.2 Load bus voltage deviation minimization (VD)

Load bus voltage magnitude should be maintained within the allowable range to ensure quality of service [20]. Voltage profile can be improved by minimizing the deviation from the reference value (it is taken as 1.0 p.u. in this work).

$$VD = \sum_{K=1}^{N_{PQ}} |(V_i - V_{ref})| \qquad (2)$$

2.2 Constraints

This ORPD optimization problem is subjected to the following equality and inequality constraints.

2.2.1. Equality constraints:

Power Flow Constraints:

$$P_{Gi} - P_{Di} = \sum_{j=1}^{N_B} V_i V_{ij} Y_{ij} \cos(\delta_{ij} + \gamma_j - \gamma_i) \qquad (3)$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{N_B} V_i V_{ij} Y_{ij} \sin(\delta_{ij} + \gamma_j - \gamma_i) \qquad (4)$$

2.2.2 Inequality constraints:

Voltage Constraint:

$$V_i^{\min} \le V_i \le V_i^{\max}; i \in N_B \qquad (5)$$

Transformer tap constraint:

$$T_i^{\min} \le T_i \le T_i^{\max}; i \in N_T \qquad (6)$$

Shunt VAR constraint:

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$$Q_{C_i}^{\min} \le Q_{C_i} \le Q_{C_i}^{\max}; i \in N_C \quad (7)$$

Transmission line flow limit:

$$S_i \le S_i^{\max}; i \in N_1 \quad (8)$$

In this research, power loss and total voltage deviation indexes have been used as objective function for ORDP problem. Control variables of the ORPD problem include VG, voltage at PV buses; T, transformer tap settings; QC, vector of shunt capacitor/inductor.

In this problem, equality constraints are active power balance equation and reactive power balance equation that are considered during power flow calculations. The inequality constraints considered in this problem are as follows.

III. BAT OPTIMIZATION ALGORITHM

3.1 Bat Algorithm

The bat algorithm is a swarm intelligence based method introduced in ref.[21]. This optimization algorithm is developed by theecholocation behavior of bats in searchingtheir prey. Bats emit a very loud sound pulse and listen to the echo returning from the prey/object. Bats fly randomly using frequency, velocity and position to search for prey. Pulse rate and loudness differ depending on the type of the bat. The bat algorithm is formulated imitating the ability of bats to find their prey.Each bat in bat algorithm represents a potential solution in the population of solutions.

Frequency, velocity and position ofeach bat in the population are updated for the next generation. It means that the bat algorithm uses a frequency tuningtechnique to provide the diversity of the solutions in the population. The bat algorithm has the advantage of combining apopulation-based algorithm with local search.

The role of pulse rate and loudness in this algorithm is to control the equalcombination of population-based and local search processes. This algorithm employs the variations of pulse rates and loudness of bats to try to balance the exploration and exploitation during the search process. The simplifications and idealization rules of bat behavior that are considered and proposed are taken from [22].

The algorithm involvesa progression of generations, where a set of solutions undergo modifications through random change of the signal bandwidth which is increasedusing harmonics. The loudness and pulse rate are updated when the new solution is accepted. The frequency, velocity andposition of the solutions are computed based on following formulas:

$$f_i = f_{\min} + (f_{\max} - f_{\min})\beta, \quad (9)$$

$$V_i^t = V_i^{t-1} + (X_i^t - X_*) f_i, \quad (10)$$

$$X_i^t = X_i^{t-1} + V_i^t \quad (11)$$

The value of β is a randomly chosen between [0, 1],$f_i$represents the frequency of thei^{th} bat that controls the speed and rangeof movement of the bats,$V_i$and$X_i$are the velocity and position ofi^{th} bat, respectively, andX_*corresponds to the globalbest at time stept.

Local search is used in order to maintain the diversity of the solutions in the population.

The local search is applied to the solutions under consideration of a certain condition in the bat algorithm. This local searchfollows the random walk as given in Eq. (4).

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$$X_{new} = X_{old} + \in A^t \qquad (12)$$

Where $\in$ is a random number lies between [-1,1] that controls the direction and power of the random walk and A^t denotes the average loudness till now.

The pulse rate r_i and the loudness A_i are updated in each iteration. The loudness decreases when a bat finds its prey while the pulse rate increases at the same time. The loudness A_i and pulse rate r_i are updated according to the following equations. Here, 'a' and 'c' are constant values and are taken from a range of α [0,1] and γ>0. In our work, both values of 'a' and 'c' are set to 0.9 as in[43].

$$A_i^{t+1} = \alpha A_i^t, \qquad r_i^{t+1} = r_i^0[1-\exp(-\gamma t)], \qquad (13)$$

3.2 BOA algorithm implementation for ORPD problem

Bat algorithm is proposed to find minimum loss and voltage deviation by adjusting the decision variables:

Step 1: Initialize the number of population including bat position X_i and velocity V_i. Here, X_i is defined as the set of V_i, T_i and Q_{ci}. set the initial value of velocity v_i= (0).

Step 2: Set the initial frequencies fi, pulse rates ri and the loudness Ai for each bats.
Frequency should respect its lower and upper bounds condition $f_{min} \leq f_i \leq f_{max}$. In this problem f_{min} and f_{max} defined as 2 and 10 respectively.
Pulse r_i is taken in range [0,1], while loudness varies in range [A_{min}, A_0]. A_{min} is minimum value and A_0 large positive; in this case [A_{min}, A_0] = [0, 20].

Step 3: Compute fitness value for each bat population which is the total power loss or total voltage deviation using Eqns. 1 and 2.

Step 4: Sort the population according to the ascending order of the total loss or voltage deviation and find the global best X_*.

Step 5: Modify frequency of bat population using Eqn. (9).Update Velocity using (10) and location using (11).

Step 6: if($rand > r_i$)

Step 7: Generate local solution around the global best solution using Eqn. (12)

Step 8: End if

Step 9:Calculate fitness value from new solution using Eqns. (1) and (2).

Step 10:if ($rand < A_i$ & $f(X_i) < f(\boldsymbol{X}_*)$)

Step 11:Accept the new solution

Step 12:Increase r_i and Ai by using (13)

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Step 13: End if

Step 14:Print the results.

IV. NUMERICAL RESULTS AND DISCUSSIONS

To demonstrate the performance and effectiveness of the proposed BOA based approach, it has been applied for ORPD problems in IEEE 30 and 57 bus power systems. The parameters of these case studies are taken from [23]. The BOA algorithm has been implemented in MATLAB R2009b computing environment and the simulations are run using a core i5 based 4GB RAM computer. The population size is set to 50 and the maximum number of iterations taken as 300.

4.1. IEEE 30 bus power system

The single line diagram of the system is given in Fig. 1. In this section, the results obtained from IEEE 30 bus power system are presented. Generator data, line data, load data, reactive power sources, voltage magnitudes of buses and transformer tap settings can be found in ref. [23]. IEEE 30-bus power system has 19 control variables. There are 6 generator bus voltages, 4 transformer tap settings and 9 SVC devices in the test system. The total real power demand of the system in base load condition is 2.834 p.u.

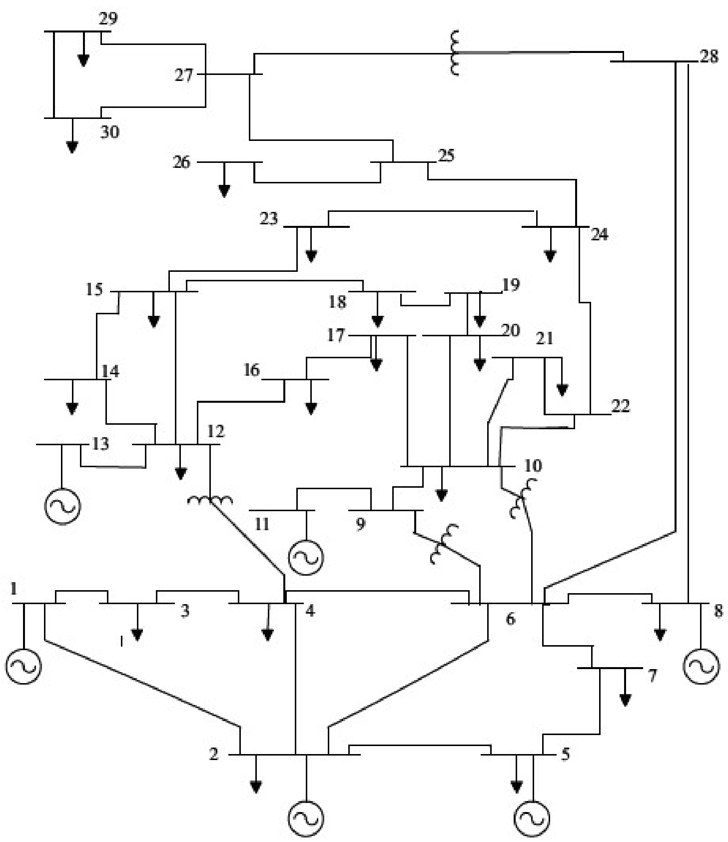

Fig. 1 –*One-line diagramof IEEE 30 bus system*

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4.1.1.Active power loss minimization

This section discusses the performance of BOA algorithm in active power loss minimization as the objective function. The results reported by the algorithm are given in Table 1. The best results achieved by BOA method has been compared with that of other algorithms in Table 1. The bestactive power loss achieved by the BOA is 4.5321 MW which is less than that what is produced by other algorithms mentioned in the Table 1.

Table 1

Optimal parameter settings for loss minimization in IEEE 30 bus system

Variable	BOA	FA [55]	BFOA [55]	TLBO [9]	QOTLBO [9]	BBO [46]
Generator voltage						
V_1	1.1000	1.10000	1.1000	1.1000	1.1000	1.1000
V_2	1.0984	1.06440	1.0261	1.0936	1.0942	1.0944
V_5	1.0811	1.07455	1.0696	1.0738	1.0745	1.0749
V_8	1.0839	1.08690	1.1000	1.0753	1.0765	1.0768
V_{11}	1.1000	1.09164	1.1000	1.0999	1.1000	1.0999
V_{13}	1.1000	1.09900	1.1000	1.1000	1.0999	1.0999
Transformer tap ratio						
T_{11}	1.0416	1.00000	0.9800	1.0251	1.0664	1.0435
T_{12}	0.9012	0.94000	0.9400	0.9439	0.9000	0.90117
T_{15}	0.9625	1.00000	1.0500	0.9992	0.9949	0.98244
T_{36}	0.9663	0.97000	0.9800	0.9732	0.9714	0.96918
Capacitor banks						
$QC-10$	5.0000	3.00000	3.1000	0.0500	0.0500	4.9998
$QC-12$	5.0000	4.00000	4.6000	0.0500	0.0500	4.987
$QC-15$	5.0000	3.30000	5.0000	0.0500	0.0500	4.9906
$QC-17$	5.0000	3.50000	2.1000	0.0500	0.0500	4.997
$QC-20$	4.7095	3.90000	3.7000	0.0457	0.0445	4.9901
$QC-21$	5.0000	3.20000	2.3000	0.0500	0.0500	4.9946
$QC-23$	5.0000	1.30000	1.9000	0.0286	0.0283	3.8753
$QC-24$	5.0000	3.50000	2.3000	0.0500	0.0500	4.9867
$QC-29$	1.2307	1.42000	0.1000	0.0258	0.0256	2.9098
P_{Loss}, MW	4.5321	4.56910	4.6230	4.5629	4.5594	4.5511
TVD, p.u.	2.1522	1.77520	1.5300	1.8760	1.9057	NA

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The algorithm takes about 150 iterations to get converged to the global best results indicating the reliable convergence quality.This characteristic is depicted in Fig. 2.

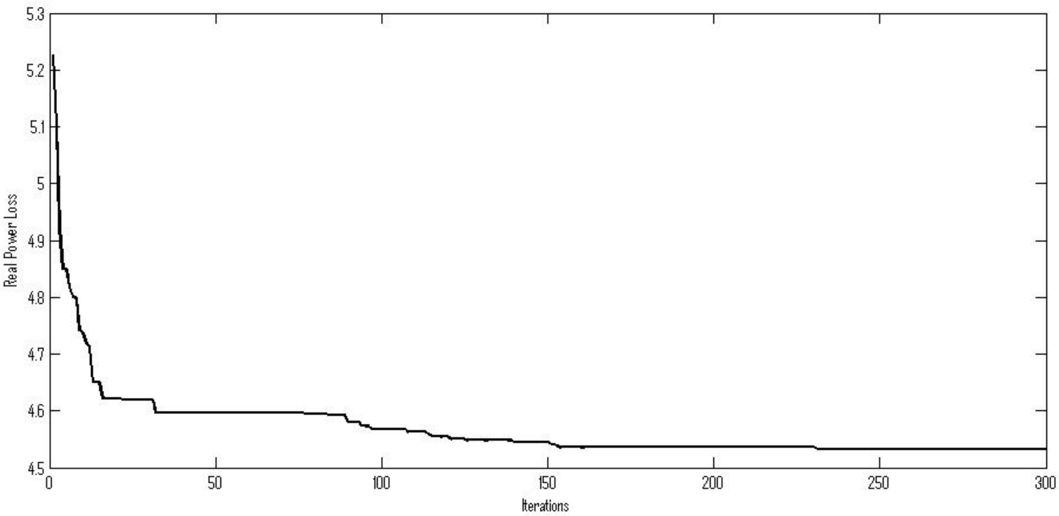

Fig. 2 –*Convergence quality of BOA in loss minimization in IEEE 30 bus system*

4.1.2.VD Minimization

Sum of voltage deviation at all the load buses of the system is the objective taken in this case. The strength of the proposed algorithm is proved by comparing its results with other algorithms like HFA, FA, BFOA.Performance of the BOA algorithm is better than FA and BFOA algorithms. However, voltage deviation minimization by the proposed method is not better than the HFA algorithm.

Table 2

Optimal parameter settings for voltage deviation in IEEE 30 bus system

Variable	BOA	HFA [55]	FA [55]	BFOA [55]
Generator voltage				
V_1	1.0031	1.003458	0.99770	0.9500
V_2	0.9500	1.016380	1.02170	1.0702
V_5	1.0139	1.019451	1.01672	0.9645
V_8	1.0195	1.018221	1.00100	1.0258
V_{11}	1.0024	0.982272	1.04810	1.0375
V_{13}	1.0592	1.015460	1.01910	0.9914
Transformer tap ratio				
T_{11}	1.0208	0.990000	1.04000	0.9800
T_{12}	0.9000	0.900000	0.90000	0.9600
T_{15}	1.1000	0.980000	0.98000	1.0200

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T_{36}	0.9580	0.960000	0.96000	0.9900
Capacitor banks				
QC-10	5.0000	3.200000	3.60000	4.8000
QC-12	5.0000	0.500000	1.30000	1.3000
QC-15	5.0000	4.900000	2.70000	4.5000
QC-17	5.0000	0.100000	0.90000	2.0000
QC-20	5.0000	3.800000	4.20000	4.3000
QC-21	5.0000	5.000000	2.70000	3.9000
QC-23	5.0000	5.000000	3.00000	4000
QC-24	4.1482	3.900000	1.70000	4.5000
QC-29	0.7069	1.500000	1.80000	3.4000
P_{Loss}, MW	9.8949	5.750000	6.34000	10.570
TVD, p.u.	0.1016	0.098000	0.11570	0.1490

Minimization of sum of voltage deviation is done by BOA algorithm in an excellent way. Keeping the best results throughout the optimization process is seen from Fig. 3. The number of iterations needed is about 175 for this case.

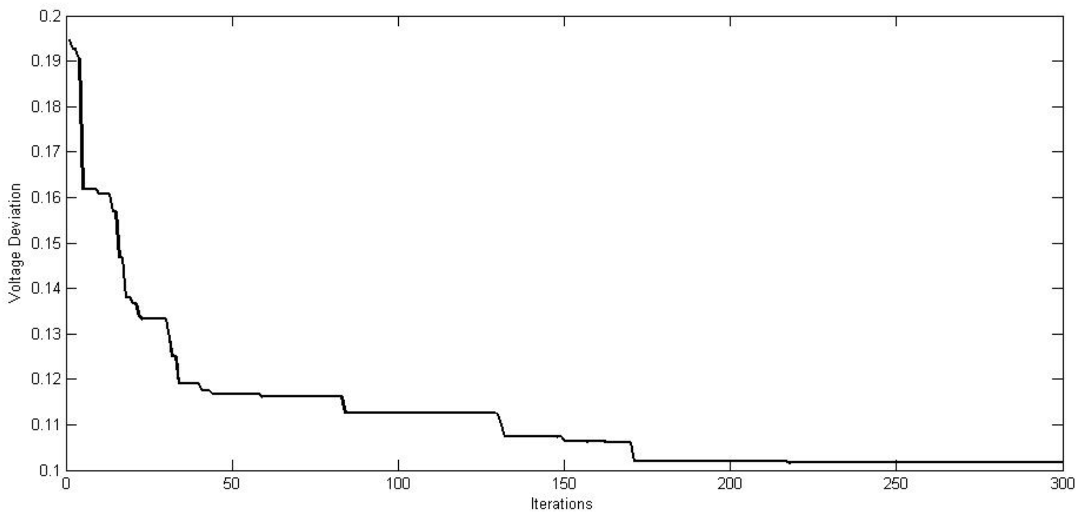

Fig. 3 –*Convergence quality of BOA in voltage deviation in IEEE 30 bus system*

4.2.Results for IEEE 57 bus power system

In the following section, IEEE 57-bus system, whose single line diagram is as Fig. 4, is used in order to evaluate the efficacy of BOA. The data of this power system can be seen in [23]. ORPD problem for this system should be solved as a 25-dementional search space with 7 generator voltages, 15 transformer taps, and 3 reactive power sources.

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4.2.1. Active power loss Minimization

Table 3 shows the obtained results of power loss minimization in IEEE 57 bus power system. To reveal the superiority of the suggested strategy, in Table 3 BOA based results have been presented along with results of other optimizers including NGBWCA, WCA, OGSA and GSA.

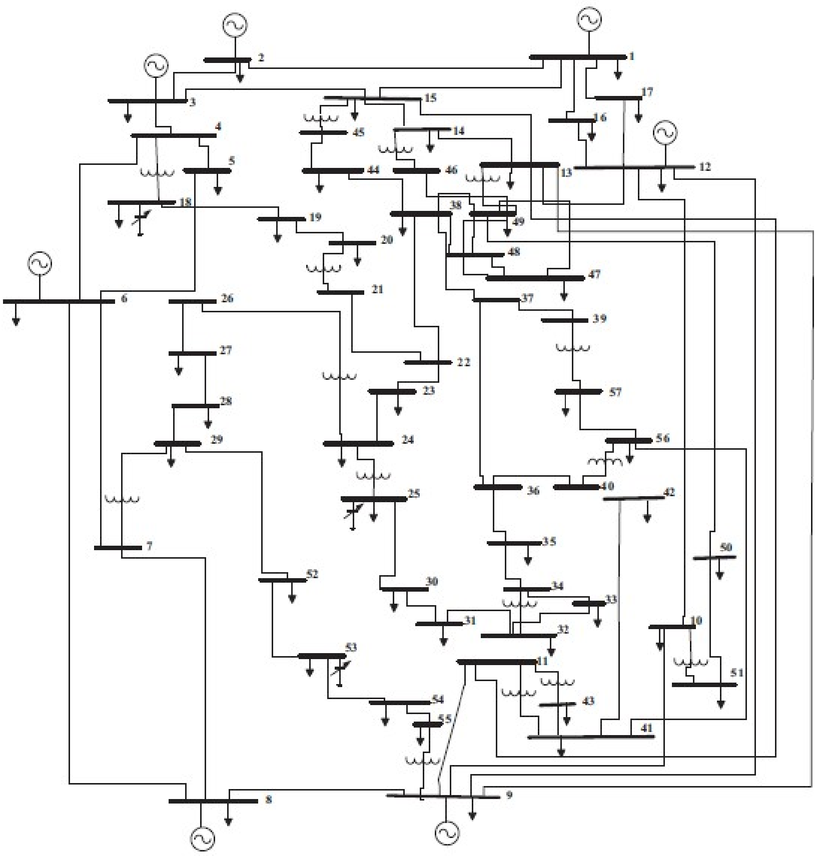

Fig. 4 –*One-line diagram of IEEE 57 bus system*

From Table 3, it can be seen that BOA results realize optimal value of active power loss. Amongst the compared approaches, the best loss value was attained by the proposed strategy. The value of loss returned by BOA is 21.6380 MW. The best solutions obtained by different methods for this objective are presented in Table 3.

Table 3

Optimal parameter settings for loss minimization in IEEE 57 bus system

Variable	BOA	NGBWCA	WCA	OGSA [17]	GSA [47]
Generator voltage					
V_1	1.1000	1.0600	1.0605	1.0600	1.060000
V_2	1.1000	1.0591	1.0602	1.0594	1.060000
V_3	1.0465	1.0492	1.0497	1.0492	1.060000
V_6	1.0882	1.0399	1.0018	1.0433	1.008102

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V_{8}	1.1000	1.0586	1.0600	1.0600	1.054955
V_{9}	1.0912	1.0461	1.0589	1.0450	1.009801
V_{12}	1.0926	1.0413	1.0538	1.0407	1.018591
Transformer tap ratio					
T4_18	0.9125	0.9712	0.9923	0.9000	1.100000
T4_18	0.9012	0.9243	0.9814	0.9947	1.082634
T21_20	0.9535	0.9123	0.9354	0.9000	0.921987
T24_26	1.0023	0.9001	0.9953	0.9001	1.016731
T7_29	1.0056	0.9112	0.9963	0.9111	0.996262
T34_32	1.0150	0.9004	0.9712	0.9000	1.100000
T11_41	1.0266	0.9128	0.9865	0.9000	1.074625
T15_45	0.9817	0.9000	0.9245	0.9000	0.954340
T14_46	0.9838	1.0218	1.0345	1.0464	0.937722
T10_51	0.9803	0.9902	1.0056	0.9875	1.016790
T13_49	0.9620	0.9568	0.9825	0.9638	1.052572
T11_43	1.0218	0.9000	0.9715	0.9000	1.100000
T40_56	1.0150	0.9000	0.9923	0.9000	0.979992
T39_57	1.1000	1.0118	1.0186	1.0148	1.024653
T9_55	1.0238	1.0000	1.0024	0.9830	1.037316
Capacitor banks					
QC-18	0	0.0914	0.0988	0.0682	0.078254
QC-25	10.0000	0.0587	0.0590	0.0590	0.005869
QC-53	6.9956	0.0634	0.0629	0.0630	0.046872
P_{Loss}, p.u.	21.6380	**0.2327**	0.2482	0.2343	0.23461194
TVD, p.u.	2.8802	**1.2710**	1.3852	1.1907	NA

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Fig. 5 is the plot of better convergence characteristics of BOA algorithm in loss minimization. The performance of BOA based method is proved in the large IEEE 57 bus power system here.

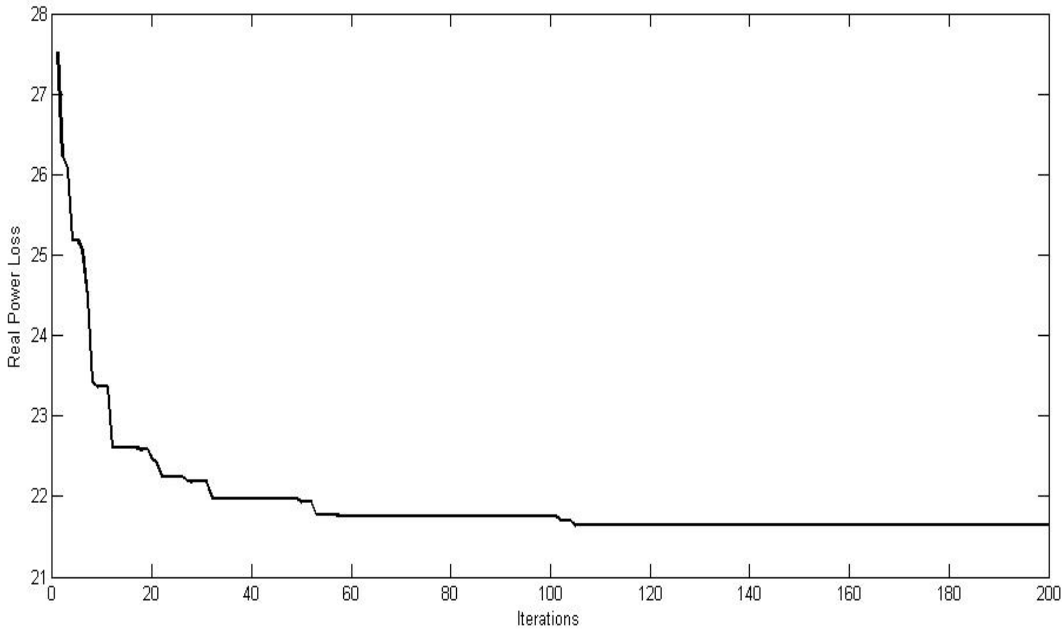

Fig. 5 –*Convergence quality of BOA in loss minimization in IEEE 57 bus system*

4.2.2. VD Minimization

In Table 4, the best solutions obtained by BOA for VD minimization have been tabulated along with the results of NGBWCA, WCA and OGSA algorithms. From this Table, it can be recognized that BOA outperforms other compared methods. The simulation outcomes of VD minimization indicate that the proposed BOA provides better solutions than other algorithms. The proposed method outperforms all the three other algorithms in bringing out best results for VD minimization.

Table 4

Optimal parameter settings for voltage deviation in IEEE 57 bus system

Variable	BOA	NGBWCA	WCA	OGSA[17]
Generator voltage				
V1	0.9770	1.0151	1.0242	1.0138
V2	1.0795	0.9810	0.9953	0.9608
V3	0.9757	1.0002	1.0098	1.0173
V6	0.9879	1.0039	1.0176	0.9898
V8	1.0440	1.0198	1.0268	1.0362
V9	1.0202	1.0254	1.0283	1.0241

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V12	1.0438	1.0081	1.0125	1.0136
Transformer tap ratio				
T4–18	0.9436	1.0185	1.0217	0.9833
T4–18	1.0076	0.9601	0.9614	0.9503
T21–20	0.9647	0.9458	0.9496	0.9523
T24–26	0.9944	0.9919	0.9901	1.0036
T7–29	0.9755	0.9951	0.9986	0.9778
T34–32	0.9224	0.9000	0.9000	0.9146
T11–41	0.9000	0.9622	0.9634	0.9454
T15–45	0.9558	0.9058	0.9063	0.9265
T14–46	0.9822	0.9764	0.9801	0.9960
T10–51	1.0089	1.0600	1.0631	1.0386
T13–49	0.9020	0.9100	0.9131	0.9060
T11–43	0.9845	0.9302	0.9294	0.9234
T40–56	1.0350	0.9770	0.9782	0.9871
T39–57	1.0424	1.0271	1.0286	1.0132
T9–55	0.9974	0.9000	0.9053	0.9372
Capacitor banks				
QC-18	9.9841	0.0550	0.0593	0.0463
QC-25	9.9686	0.0590	0.0591	0.0590
QC-53	9.9773	0.0381	0.0382	0.0628
PLoss, p.u.	42.6229	0.2920	0.3002	0.3234
TVD, p.u.	0.6333	0.6501	0.6631	0.6982

Voltage deviation minimization, a highly non liner optimization problem is handled in a nice manner by the BOA

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algorithm. The algorithm retains the better results and converged to the best results.

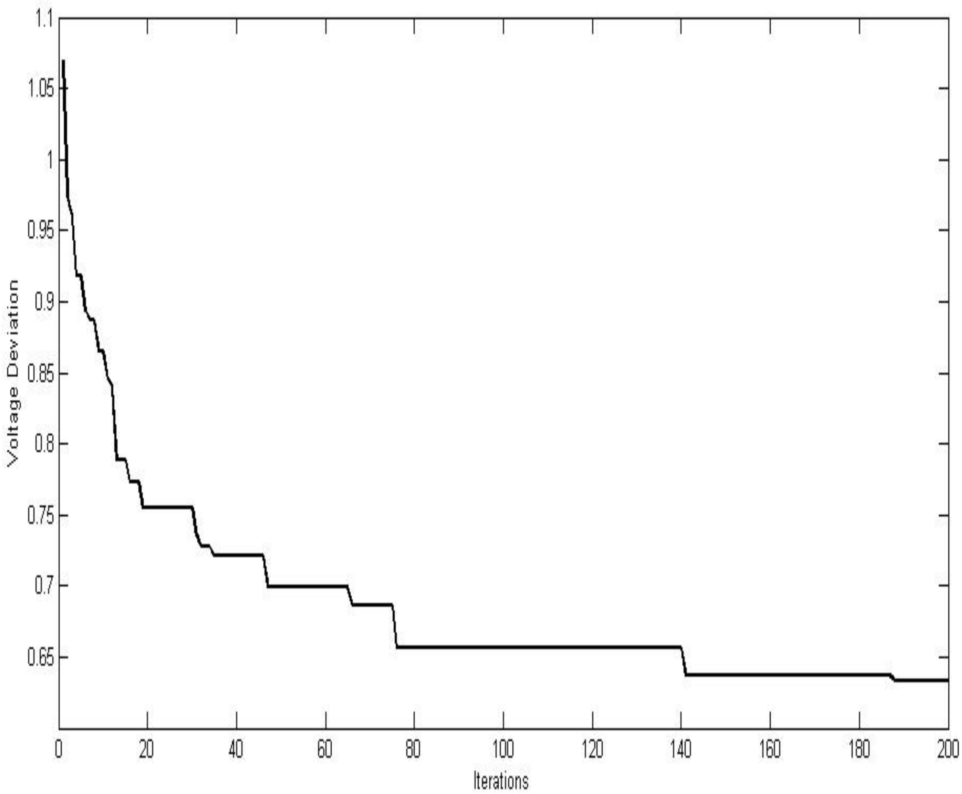

Fig. 6 –*Convergence quality of BOA in voltage deviation in IEEE 57 bus system*

V. CONCLUSIONS

In this work, the BOA algorithm is implemented in ORPD with two objectives. The efficiency of the proposed BOA is tested on IEEE-30 and IEEE-57 bus power systems. The experimental results and statistical data clearly demonstrate the efficiency of the BOA algorithm in solving ORPD problems. The strength of the proposed algorithm is proved in both the challenging tasks in ORPD problem.

The algorithm is efficient and easy to be implemented for engineering optimizations. Hybridization of the proposed BOA with other well-established metaheuristic optimisation algorithms may be tried for improved performance. Use of recently developed metaheuristic algorithms is recommended for ORPD problem.

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