Biogeography Based Novel AI Optimization with SSSC for Optimal Power Flow

Sandeep Gupta[1*], Navdeep Singh[2], Kirti Joshi[3]
1- Department of Electrical Engineering, JECRC University, Jaipur, Rajasthan-303905, India.
Email: jecsandeep@gmail.com (Corresponding author)
2- Department of Electrical Engineering, MMMUT Gorakhpur UP- 273010, India.
Email: navdeepsingh26nov@gmail.com
3- Department of Electrical Engineering, JECRC University, Jaipur, Rajasthan-303905, India.
Email: kirtijosi@gmail.com

Received: November 2017 Revised: January 2018 Accepted: February 2018

ABSTRACT:
This paper objective presents static synchronous series compensation FACTS device with biogeography based optimization (BBO) to deal for obtaining worthwhile power flow control. The biogeography based optimization method is utilized to find the optimal fitted child sets by surviving parents with the help of migration and mutation Jaipur process. The present BBO technique from the evolutionary strategy with static synchronous series compensator provides improved outcomes in comparison to other optimization methods. The simulation outcomes illustrate that the proposed BBO algorithm is efficacious, secure and correct to search the optimized values with SSSC based FACTS devices. The proposed method is considering the solution quality an optimistic substitute method for extricating the OPF problems. The simplification and effectiveness of this method are validated on the IEEE 57 bus and 75 bus Systems. In this paper, from the outcome results, it is clearly shown that the proposed technique execution can be properly and effectively applied to the optimal position of multiple OPF problems. i.e. BBO based algorithm with SSSC FACTS device is found better results when compared to without SSSC device in all aspects.

KEYWORDS: BBO, Optimal Power Flow (OPF), SSSC Device, FACTS Device, Optimization Technique.

1. INTRODUCTION

The power system optimal power flow (OPF) is a consequential contraption for both in operating and designing stages. The objective of an optimal power flow is to realize the position of control elements for cost-effective and protected operation of a power system. One of the various objectives is to obtain generating units schedule to assemble the mandatory demand at lowest production cost and working constraints, by amending the control factors of the power system. Since years ago the optimal power flow problem has been carefully investigated due to the financial implication. For solving this problem, several optimization techniques have been appeared in the power system industry so far [1], [2].

Evolutionary algorithms solve the complex problem of the OPF like implicit and explicit function. Because of the exceptional enhancement in the potential of computers in current years, evolutionary methods are being used to find a solution to reduce the drawback of the classical techniques. In these methods, genetic algorithm (GA) [3-9], particle swarm optimization (PSO) [5], [9], evolutionary programming (EP) [4], [5], and differential evolution (DE) are mostly used.

Optimization technique has been processed by the theory of bio-geography [10]. Mainly, the migration and mutation based concepts are used in the BBO based optimization technique. In the GA & PSO, information between solutions is shared with the help of BBO technique only. A poor solution of the system is taken the new characteristics from best solutions by the BBO algorithm. Due to the addition of new characteristics, low quality solutions are improved with up gradation. In previous year, non-convex, bulky and difficult economic load dispatch problems are solved with BBO technique [2], [11].

The stability of the power system can be improved and heavy loading of transmission line is reduced by the FACTS devices [12]. For this, FACTS equipment should control their various factors such as current, voltage, impedances, & phase angle of system. Among FACTS devices, Static synchronous series compensator (SSSC) is the important device for the system stability. At the base frequency a voltage source converter (VSC) is used for SSSC device which produces a disciplinable alternating current voltage. It can be acclimated by modifying the series reactance of line by infusing a voltage into the line. In SSSC device, DC energy storage can be used at DC end. SSSC device injects a voltage with 90° lagging the line current, thus the valuable line inductance is reduced to damp the power swings; but the constitutional function of the SSSC device is to maintain stability of the system under steady state and unwonted circumstances by monitoring the power flow [13].

An adaptable property of the new BBO based evolutionary algorithm stimulated the authors to apply this theorem with SSSC device in the power system engineering. Therefore, the authors are proposed a BBO based algorithm incorporating with SSSC FACTS device to control the optimal power flow in the system. After that the proposed method is successfully applied to IEEE 57-bus and 75-bus systems to confirm the efficiency and correctness of this topology.

The remaining paper is prepared as follows. Section 2 explains the mathematics with equivalent circuit of SSSC device. Biogeography based optimization technique (BBO) minimization cost factor is proposed with their constraints in Section 3. This section also presents the proposed algorithm steps in sequential. Case studies (IEEE 57 & 75 bus systems) with outcome results are expounded in Section 4. Finally, Section 5 presents the paper conclusion.

2. PROBLEM FORMULATION WITH SSSC DEVICE

BBO based AI method with SSSC appliance is used to reduce the generation fuel cost and to get the better system outcomes by keeping the voltage & thermal constraints.

2.1. Quadratic Function

The quadratic function based equation for generator power is found from the generator cost features. This quadratic function with SSSC device can be illustrated as follows [4], [9]:

Fuel Cost;

$$S = \sum_{i=1}^{NG} F_I\,(P_I) = \left(\sum_{i=1}^{NG}(A_i\, P_{Gi}^2 + B_i\, P_{Gi} + C_i\right) \qquad (1)$$

Where, the quadratic polynomial for the cost factors of the i-th generator are represented by A_i , B_i and C_i respectively; Objective function is represented by symbol 'S', lowest output of i-th generating division is represented by P_I and the number of committed generators is represented by symbol 'NG'.

2.2. Equivalent Circuit of the SSSC Device

The optimum location of FACTS devices in the test-system is the important factor before modeling for reducing the generation cost function and the investment cost of device. For this, real power flow performance index can be used and objective function will be optimized by controlling the power system. While, large power system has many non-linear equality and inequality constraints. Therefore, these constraints are kept in mind; a typical steady state injection model structure of the SSSC is taken as shown in Fig. 1. This modeling is done with the help of continuation power flow and OPF techniques [14, 15].

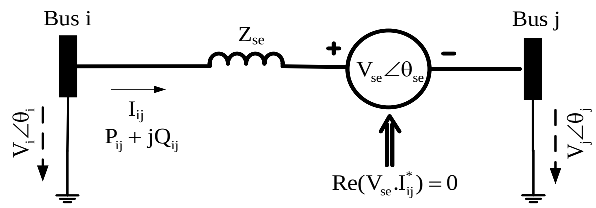

Fig. 1. A typical diagram of SSSC device.

From the circuit diagram of SSSC, the power flow constraints can be taken such as:

$$P_{ij} = V_i^2 g_{ii} - V_iV_j(g_{ij}\cos\cos\theta_{ij} + b_{ij}\sin\sin\theta_{ij}) \\ -V_iV_{se}\left(g_{ij}\cos\cos(\theta_i-\theta_{se}\right) + b_{ij}\sin\sin(\theta_i-\theta_{se})) \qquad (2)$$

$$Q_{ij} = -V_i^2 b_{ii} - V_iV_j(g_{ij}\sin\sin\theta_{ij} + b_{ij}\cos\cos\theta_{ij}) - \\ V_iV_{se}\left(g_{ij}\sin\sin(\theta_i-\theta_{se}\right) + b_{ij}\cos\cos(\theta_i-\theta_{se})) \qquad (3)$$

$$P_{ji} = V_j^2 g_{ji} - V_iV_j(g_{ij}\cos\cos\theta_{ji} + b_{ij}\sin\sin\theta_{ji}) + \\ V_jV_{se}\left(g_{ij}\cos\cos(\theta_j-\theta_{se}\right) + b_{ij}\sin\sin(\theta_j-\theta_{se})) \qquad (4)$$

$$Q_{ji} = -V_i^2 b_{jj} - V_iV_j(g_{ij}\sin\sin\theta_{ji} + b_{ij}\cos\cos\theta_{ji}) + \\ V_jV_{se}\left(g_{ij}\sin\sin(\theta_j-\theta_{se}\right) + b_{ij}\cos\cos(\theta_j-\theta_{se})) \qquad (5)$$

Where

$g_{ii} = g_{ij}$; $b_{jj} = b_{ij}$; $b_{ii} = b_{ij}$; and $g_{ii} + jb_{ij} = 1/Z_{se}$ in this paper, active power in and out via the DC link is used as an operating constraint of the SSSC device which is found such as:

$$PE = \mathrm{Re}\left(V_{se}I^*_{ji}\right) = 0$$

or

$$(-V_iV_{se}\left(g_{ij}\cos\cos(\theta_i-\theta_{se}\right) + b_{ij}\sin\sin(\theta_i-\theta_{se})) \\ +(V_jV_{se}\left(g_{ij}\cos\cos(\theta_j-\theta_{se}\right) + b_{ij}\sin\sin(\theta_j-\theta_{se})) = 0 \qquad (6)$$

$$P_{Ji} - P_{ji}^{\,specifed} = 0 \qquad (7)$$

$$Q_{Ji} - Q_{ji}^{\,specifed} = 0 \qquad (8)$$

Where, Eq. (7) represents the active power flow constraint and Eq. (8) represents the reactive power flow constraint. $P_{ji}^{specifed}$ is the specified real power flow and $Q_{ji}^{specifed}$ represents the specified reactive power flow.

If $V_{se}\angle\theta_{se}$ is used as an equivalent voltage injection from SSSC device, Then the boundaries of this factor are taken as follows:

$$V_{se}^{\min} \le V_{se} \le V_{se}^{\max} \quad (9)$$

$$\theta_{se}^{\min} \le \theta_{se} \le \theta_{se}^{\max} \quad (10)$$

Where,

$$V_{se} = 0.04\,p.u,\ V_{se}^{\min} = 0.001,\ V_{se}^{\max} = 0.2,$$

$$\theta_{se} = 87.13°,\ \theta_{se}^{\min} = 90°,\ \theta_{se}^{\max} = 180°.$$

3. BBO TECHNIQUE

Biogeography is natural way of circulating population on the habit which characterizes the species with movement from one habitat to another. Due to this movement, we have got best species with better characteristics in comparison to old and poor characteristics, based species are destructed from total population. A habitat is represented by any isle (area). Boundary of this area is confined by the other habitats. The factors that delineate the habitability are evoked habitat suitability index (HSIs). It is the unconstrained factors of the habitat. In geographical areas, biological species have a high HSI.

The migration and immigration process are the two most important term in this field. The relocation of some species from a habitat to an outside habitat is known as emigration process and ingress of some species into one area from an outside area is known as immigration process. To understand, the immigration and emigration terms probabilistic mathematically based model is taken. Let $P_s(t)$notifies the possibility that s number of species with time t exists in a fix habitat. Then at time $(t + \Delta t)$ the possibility is:

$$P_s(t+\Delta t) = P_s(t)(1-\lambda_s\Delta t-\lambda_s\Delta t) + P_{s-1}\lambda_{s-1}\Delta t + P_{s+1}\lambda_{s+1}\Delta t \quad (11)$$

Where, the term λ_s symbolizes the immigration rates, the symbol μ_s represents the emigration rates. The symbol's' shows the sorts in the habitat. Eq. (11) must hold s species at time $(t + \Delta t)$ with one of the under mentioned conditions:

1. If s species are lying in the habitat with time t, then emigration or immigration factors will be take place between time t and $(t + \Delta t)$.
2. If (s+1) species are occurred in the habitat with time t, then one species immigrated between time t and $(t + \Delta t)$.
3. If (s-1) species are occurred in the habitat with time t, then one species emigrated between time t and $(t + \Delta t)$.

If time Δt is a very short time $(\Delta t \to 0)$ then the possibility of more than one immigration or emigration can be negligence and Eq. (11) may be representing such as:

$$P_s = \begin{cases} -(\lambda_s+\mu_s)P_s + \mu_{s+1}\,\&\,P_{s+1} & S=0 \\ -(\lambda_s+\mu_s)P_s + \lambda_{s-1}P_{s-1} + \mu_{s+1}\,\&\,P_{s+1} & 1\le S\le S_{\max-1} \\ -(\lambda_s+\mu_s)P_s + \lambda_{s-1}\,\&\,P_{s-1} & S=S_{\max} \end{cases}$$

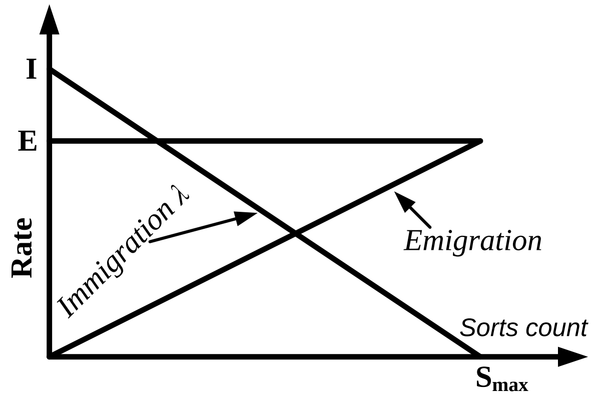

Fig. 2. Habitat model of sorted natives by fitness.

Fig. 2 represents the straight-line graph for habitat model by fitness function. From this Fig. if number of species is k then the value of emigration rate (μ_k) and immigration rate (λ_k) are find out from the following equations:

$$\mu_k = \frac{E_k}{n} \quad (12)$$

$$\lambda_k = I\left(1-\frac{k}{n}\right) \quad (13)$$

When,

$$E = I, \lambda_k + \mu_k = E \quad (14)$$

Where, the highest emigration rate is represented by symbol 'E', the most immigration rate is denoted by the term 'I' and the counting of overall species in the habitat is 'n' numbers.

Thus, BBO has two mechanisms, migration and mutation and HSI represents the eminence of every applicant solution which is represented by HSI value. By this value, every outcome can be improved based on other outcomes. This happens by habitat modification probability (P_{mod}) factor. The main object of BBO is to make use of sort count contingency to move toward the solution. The mutation rates can be resolved by P_s [7]. The mutation rate of every set of solution can be evaluated in respect of species countstendency using Eq. (15) [10]:

$$M_r = m_{\max}\left(\frac{1-P_{N_s}}{P_{\max}}\right) \quad (15)$$

Where, Mr is the habitat mutation rate and Ns contains species; the maximum mutation rate is represented by m_{max} and the maximum tendency is represented by P_{max}. This complete proposed biogeography based optimization method is enlightened as a flow chart in Fig.3 and the requirement of parameters in the topology are considered in Appendix A. Applications of this proposed topology with different case studies are explained in the next section.

4. NUMERICAL EXAMPLE AND CASE STUDY

The presented BBO scheme to solve OPF based Reactive power problem integrated with SSSC FACTS device is examined on the IEEE 57-bus and IEEE 75-bus systems [16]. The presented method is executed with the help of MATLAB software; to demonstrate the outcomes of power flow management ability of the SSSC device with suggested OPF based BBO technique.

4.1. IEEE-57 Bus System

This bus system is taken as shown in Fig. 4 [18]. The generator's cost curve coefficients are shown in Table 1. The objective function S is considered as the total fuel cost from Eq. (1). The effectiveness of the BBO technique has been demonstrated by considering the following two cases with two different objective functions.

Test Case (1): Standard operation (not including FACTS device),

Test Case (2): IEEE-57 test system with SSSC device. This device is attached between bus number 12 & 25. Here, $P_{minimum}$ value is 0.025125 & $P_{maximum}$ value is 0.40775.

The effect of SSSC FACTS devices on system (IEEE-57 bus system) load ability is shown in Fig. 5. Due to the SSSC device, this system installation cost is shown in Fig. 6. The optimization of the recommended convergence characteristic is shown in Fig. 7 under the preferred SSSC device at the evolution of the objective function. Here, Table 2 represents the objective function based minimization factor, when SSSC FACTS device is chosen. It is clear from the outcome that the entire fuel cost of test system is reduced to 481.9814 $/hr.

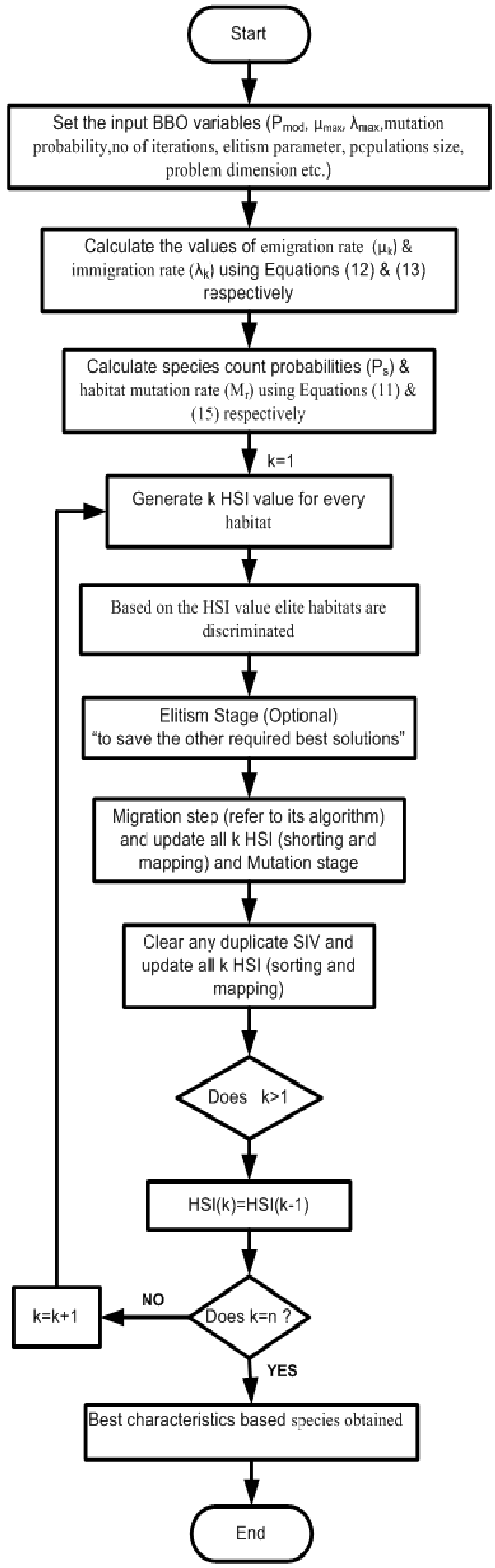

Fig. 3. Flowchart of the proposed BBO topology.

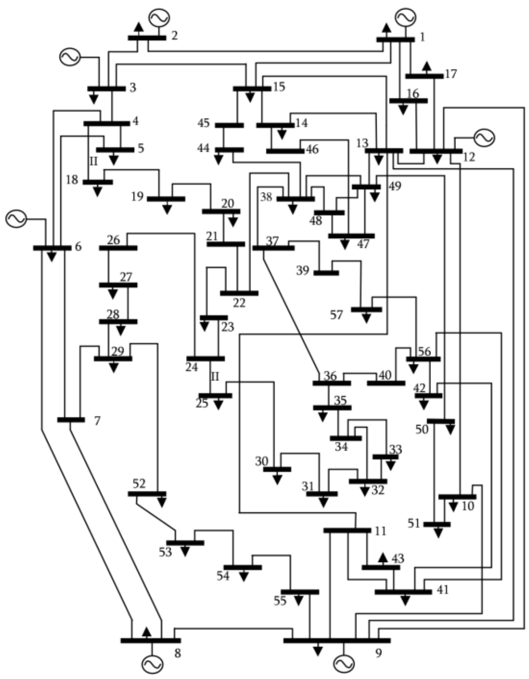

Fig. 4. IEEE-57 Bus System.

Table 1. The cost-curve parameters for IEEE 57-bus system.

BUS No.	Cost Coefficients (p.u.)		
	A (Rs/**MW**^{2}hr)	B (Rs/MWhr)	C (Rs/hr)
1	0.0	18.19	1000
3	0.0	19.8	600
8	0.0	18.92	660
12	0.0	16.69	800
14	0.0	16.79	970
18	0.0	18.7	450
20	0.0	19.14	480
26	0.0	19.79	850

Table 2. Simulation results with & without SSSC device of IEEE 57-bus system and generation limits.

Control Variables	Limits (p.u)		Without SSSC (Rs/hr)	With SSSC (Rs/hr)
	Max	Min		
$\mathbf{P_{G1}}$	0.0	5.765	1. 9898	1.4992
$\mathbf{P_{G3}}$	0.0	1.000	1.6801	0.35432
$\mathbf{P_{G8}}$	0.0	1.400	1.2414	0.0466
$\mathbf{P_{G12}}$	0.0	1.000	0.12061	1.5811
$\mathbf{P_{G14}}$	0.0	5.543	1.0684	0.028267
$\mathbf{P_{G18}}$	0.0	1.000	3.4192	2.2919
$\mathbf{P_{G20}}$	0.0	4.100	0.64098	0.29222
$\mathbf{P_{G26}}$	0.0	1.200	0.88864	4.9273
Total			9.05933	11.020907
Generation1 mincost (Rs/hr)			488.6756	481.9814

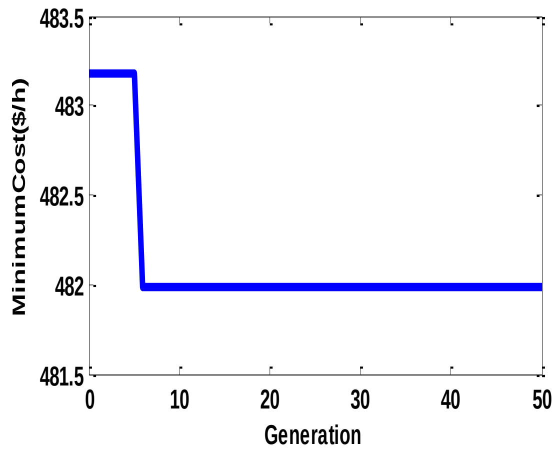

Fig. 5. Convergence of generation cost for IEEE 57-bus system with SSSC device.

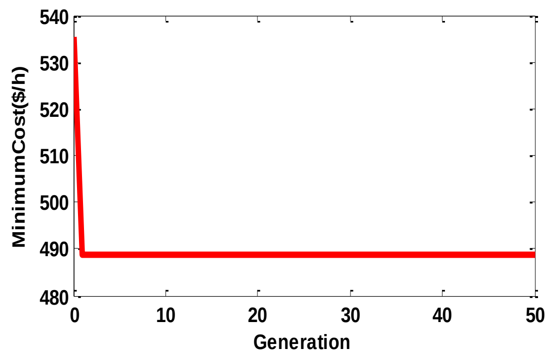

Fig. 6. Generation cost convergence for IEEE 57-bus system without SSSC FACTS device.

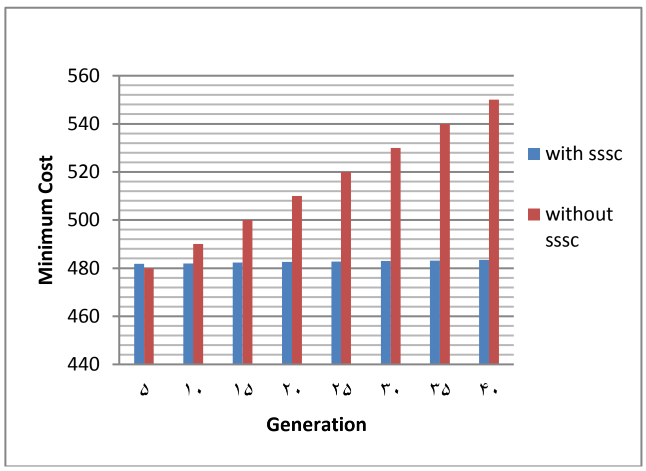

Fig. 7. Minimum cost vs. generation for IEEE 57-bus system with and without SSSC device.

4.2. IEEE-75 Bus System

Indian Utility is used for loading of the 75-bus data system by Uttar Pradesh State Electricity Board (UPSEB) [17, 18]. The value of the cost coefficients are given in Table 3. The proposed BBO technique has been demonstrated by considering the following two conditions such as follows:

Test Case (1): standard operation (without FACTS device installation),

Test Case (2): IEEE-75 test system with SSSC device. This device is attached between bus number 12 & 25. Here, $P_{minimum}$ value is 0.025125 & $P_{maximum}$ value is 0.40775.

Table 3. The cost-curve parameters for IEEE 75-bus system.

BUS No.	Cost Coefficients(p.u.)		
	A (Rs/MW^2hr)	B (Rs/MWhr)	C (Rs/hr)
1	0.0	35	3600
2	0.0	59.356	600
3	0.0	67.348	680
4	0.0	69.096	680
5	0.0	67.348	680
6	0.0	74.916	760
7	0.0	76.348	760
8	0.0	74.916	760
9	0.0	50.704	520
10	0.0	72.872	720
11	0.0	69.696	680
12	0.0	17.592	160
13	0.0	29.112	280
14	0.0	64.112	640
15	0.0	43.108	440

Table 4. Simulation results for IEEE 75-bus system and generation limits.

Control Variables	Limits (p.u)		Without SSSC (Rs/hr)	With SSSC (Rs/hr)
	Max	Min		
P_{G16}	0.0	15.00	1.4073	0.0615275
P_{G20}	0.0	3.00	0.24673	4.57445
P_{G24}	0.0	2.00	0.66642	1.54196
P_{G25}	0.0	1.70	0.083483	1.243
P_{G27}	0.0	2.40	0.62596	0.373026
P_{G28}	0.0	1.20	1.1841	10.9749
P_{G30}	0.0	1.00	2.0502	0.507624
P_{G32}	0.0	1.00	2.1121	0.978059
P_{G34}	0.0	5.70	0.43204	0.27975
P_{G37}	0.0	1.20	1.5808	1
P_{G39}	0.0	2.00	0.58145	6.41388
P_{G42}	0.0	13.00	0.92831	1
P_{G46}	0.0	9.00	0.58009	0.719442
P_{G55}	0.0	1.50	0.59116	1.35318
P_{G64}	0.0	4.54	0.66587	1.86455
Total			13.73601	32.88535
Generation1 mincost (Rs/hr)			653.8406	643.9447

Table 4 shows the outcomes of IEEE 75-bus system and generation limits. From these results we can say that BBO topology with SSSC device is capable to improve the system performance within their outcomes limits. It is clear from the outcomes that the total fuel cost has reduced 643.9447 $/hr in IEEE-75 bus system.

The comparison shown in Table 2 and 4 provides the statistic outcomes that besmeared the generation cost of each units and total generation cost value. Figs. 7 to 10 represent the convergence characteristic for IEEE 57 & 75 bus system respectively. From these Figures, it can be said that generation cost is minimized with the help of proposed BBO topology with SSSC device and to get better results.

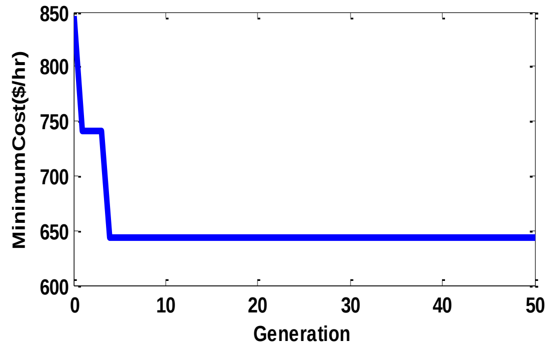

Fig. 8. Convergence of generation cost for IEEE 75-bus system with SSSC FACTS device.

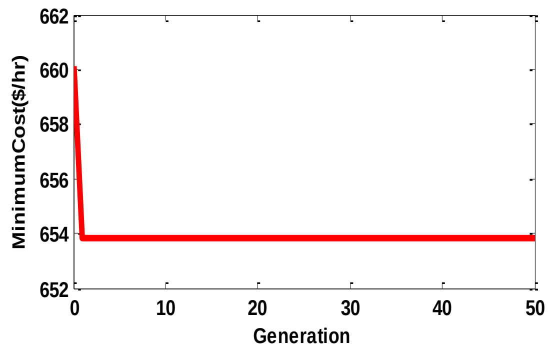

Fig. 9. Convergence of generation cost for IEEE 75-bus system without SSSC FACTS device.

5. CONCLUSIONS

In this paper, a bio-geography based optimization method with the SSSC FACTS device is proposed to resolve the OPF problem. The proposed BBO topology is demonstrated on the IEEE 57-bus and IEEE 75-bus test systems with MATLAB software. In this paper, the best possible position of SSSC FACTS device with minimum generation fuel cost is also found out by the BBO based proposed topology. From the paper simulation results, it is clearly indicated that the proposed technique execution nicely and can effectively be applied to the optimal position of multiple OPF problems. i.e. BBO based algorithm with SSSC FACTS device is found with better results when compared to without SSSC device in all aspects. Finally, it can be said that BBO method has the capacity to get the better quality outcomes and holds better convergence characteristics like as other AI techniques.

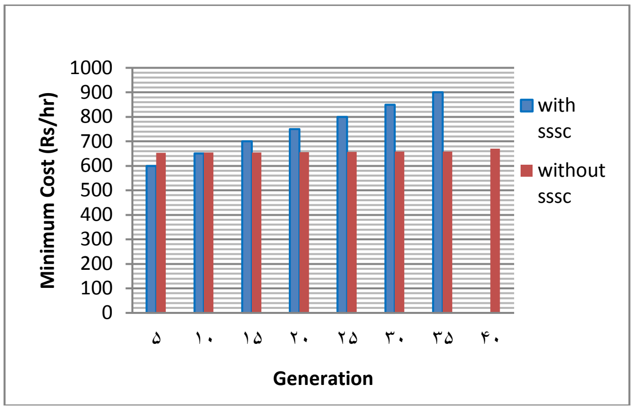

Fig. 10. Generation cost convergence for IEEE 75-bus system with and without SSSC FACTS device.

APPENDIX A

Various parameters for the proposed BBO method are given below:

Habitat mutation probability (P_{mod}) =1;
Mutation probability = 0.006;
Highest rate of immigration, I = 1;
Number of iterations = 50;
Generation units = No. of SIVs of proposed method;
Habitats Reckoning= 50;
Populations size=60;
Problem dimension=25;
Maximum emigration rate E =1;
Elitism parameter=4;

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