Multi Objective Based BBO for Optimal Placement of TCSC in Transmission Lines

Asha Deepthi Vijay
Department of Electrical and Electronics Engineering
Federal Institute of Science And Technology , Angamaly, Kerala, India

Rinku Scaria
Department of Electrical and Electronics Engineering
Federal Institute of Science And Technology , Angamaly, Kerala, India

Abstract- Flexible Alternating Current Transmission Systems devices can be used to effectively control the power distribution and the power transfer capability, to reduce active power losses, to improve stabilities of the power network, to decrease the cost of power production and to fulfill the other control requirements by controlling the power flow in the network. However to what extend the performance of FACTS devices can be brought out highly depends upon its location and settings of FACTS devices. This dissert presents the application of Biogeography based algorithm in deciding the optimal location and size of thyristor controlled series capacitor(TCSC).The proposed approach has been evaluated with three different objectives namely device cost minimization, voltage profile improvement and elimination of line overloads. In this work, BBO has been applied on standard IEEE 14 Bus ,IEEE 30 Bus power systems.

Keywords – Biogeography based algorithm, Thyristor controlled series capacitor(TCSC).

I. INTRODUCTION

The electrical energy demand increases continuously leading to an augmented stress of the transmission lines and higher risks for faulted lines. Power flow over the transmission lines is mainly limited by some network characteristics such as thermal limits, stability limits, and voltage limits. Such limitations can be removed by adding new transmission and/or generation capacity. However, such solution is difficult for environmental, economical and political reasons. Flexible Alternating Current Transmission Systems (FACTS), which is a concept proposed by N.G. Hingorani , are designed to remove such limitations and meet operator’s goals without having to undertake major system additions.[4]

Among the FACTS devices, TCSC is one of the most effective measures for enhancing the stability, ameliorating the dynamic characteristics of power system, and increasing the transfer capability of the transmission system by reducing the transfer reactance between the buses at which the line is connected. However, to achieve the above mentioned benefits, the TCSC should be properly installed in the network with appropriate parameters. TCSC can be installed in different locations and therefore the effective will be different, then we will face the problem of where should we put the TCSC. Following factors can be considered in the optimal installation of TCSC, the topology of the system, the stability margin improvement, the power transmission capacity increasing, and the power blackout prevention.

The voltage instability has been found to be responsible for several major network collapses in many countries. This situation is normally due to the stressed condition as a result of the increase in reactive power load. It was recognized that Ac power transmission over long lines was limited by series reactive impedance of the line, series capacitive compensation introduced to cancel a portion of the reactive line impedance and thereby increase the transmittable power. Series compensation is highly effective in both controlling power flow in the line and in improving stability.

The rest of the paper is organized as follows., Biogeography based optimization is explained in section II, problem formulation in section III, flowchart for the proposed method and in section VI, simulation results in section V and concluding remarks are given in section VI.

II. PROPOSED OPTIMIZATION TECHNIQUE

A. Biogeography Based Optimization

BBO is a population based, stochastic optimization technique developed by Dan Simon in 2008, which is based on the concept of biogeography that deals with nature's way of distribution of species.[2]

In context of biogeography, a habitat is defined as an Island (area) that is geographically isolated from other Islands. Geographical areas that are well suited as residences for biological species are said to have a high habitat suitability index (*HSI*). The variables that characterize habitability are called suitability index variables (*SIVs*).

The rate of immigration and the emigration are functions of the number of species in the habitat. Habitats with a high *HSI* have a low species immigration rate as they are already saturated with species. As a result, these high *HSI* habitats are more static in their species distribution than low *HSI* habitats. On the contrary emigration rate of high *HSI* habitats are high. The large numbers of species on high *HSI* islands have many opportunities to emigrate into neighboring habitats having less number of species and share their characteristics with those habitats. For this reason habitats with a low *HSI* have a high species immigration rate.[1]

Figure 2 illustrates a model of species movement process in a single habitat with straight line immigration and emigration curves. This concept of biogeography has evolved a new optimization process, known as biogeography-based optimization (BBO) [3]. In biogeography-based optimization process,, a good solution is similar to an island with a high Habitat Suitability Index (*HSI*), and a poor solution is equivalent to an island with a low *HSI*. High *HSI* solutions resist change more than low *HSI* solutions and tend to share their features with low *HSI* solutions. (This does not mean that the superior features disappear from the high *HSI* solution; the shared features still remain in the high *HSI* solutions, while at the same time appearing as new features in the low *HSI* solutions.). In this way poor solutions accept a lot of new features from good solutions. This addition of good features to low *HSI* solutions may raise the quality of those solutions. Mathematically the concept of emigration and immigration is represented by a probabilistic model. If $Ps(t)$denotes the probability that a habitat contains exactly S species at time t, at time $t+\Delta t$ the probability is

$$Ps(t+\Delta t) = Ps(t)(1 - \lambda s\Delta t - \mu s\Delta t) + Ps{-}1\lambda s{-}1\Delta t + Ps{+}1\mu s{+}1\Delta t \ldots\ldots\ldots(1)$$

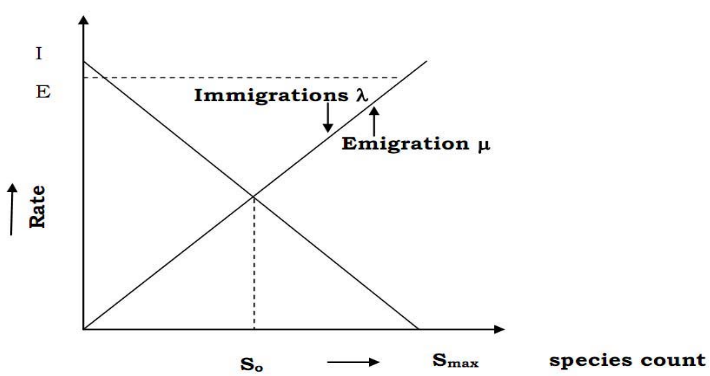


Figure 2. Species model of single habitat

where λs and μs are the immigration and emigration rates. when there are S species in the habitat. If time Δt is small enough so that the probability of more than one immigration or emigration can be ignored then taking the limit of equation (2) as $\Delta t \rightarrow 0$ gives the following equation

$$Ps = \begin{cases} -(\lambda s + \mu s)Ps + Ps{+}1\mu s{+}1; & S = 0, \\ -(\lambda s + \mu s)Ps + Ps{+}1\mu s{+}1 + Ps{-}1\lambda s{-}1; & 1 \le S \le Smax - 1 \\ -(\lambda s + \mu s)Ps + Ps{-}1\lambda s{-}1; & S = Smax \end{cases} \qquad (2)$$

From the straight-line graph of figure 2, the equation for emigration rate mu_k and immigration rate $lambda_k$ for k number of species is derived as per following way

$$\mu_k = E^* k \;/\; n \qquad (3)$$

$$\lambda_k = I * (1 - k/n) \qquad (4)$$

where, E and I are the maximum emigration rate and maximum immigration rate respectively. n is the total number of species in the habitat. When

$$E = I$$

$$\lambda k + \mu k = E \quad (5)$$

B. Migration

With probability *Pmod*, known as Habitat Modification Probability each solution can be modified based on other solutions. If a given solution *Si* is selected to be modified, then its immigration rate λi is used to probabilistically decide whether or not to modify any suitability index variable *(SIV)* in that solution. After selecting any *SIV* of that solution for modification, emigration rates μj of other solutions *Sj* (*Sj* is $j - th$ solution set other than *Si*, i.e. *j* _= *i*) are used to select which solutions among the population set will migrate randomly to chosen *SIVs* to the selected solution *Si*

C. Mutation

In BBO species count probabilities *Ps* are used to determine mutation rates. The probabilities of each species count can be calculated using the differential equation (2). Each habitat member has an associated probability, which indicates the likelihood that it exists as a solution for a given problem. If this probability is very low then that solution is likely to mutate to some other solution. Similarly if the probability of some solution is higher then that solution has very little chance to mutate. Mutation rate of each set solution can be calculated in terms of species count probability using the following equation:

$$m(s) = m_{\max}\left[\frac{1 - P_S}{P_{\max}}\right] \quad (6)$$

where, *mmax* is a user-defined parameter [2]

III. PROBLEM FORMULATION

The main objective of this thesis work is to determine the optimal location and settings of the TCSC for best utilization of existing transmission systems. This can be achieved through eliminating or minimizing overloaded lines, improving the voltage profile and minimizing the cost of installation of device. But since the cost of installing FACTs in general and TCSC in particular is too high ,therefore the objective function in this thesis is developed in such a way to find a compromise solution to this problem .The objective function is defined as a summation of three terms as shown below:

$$\text{Min } F = w_1 C_{TCSC} * s + w_2 (LVD) + W_3 (LL) \quad (7)$$

$w_1 = 0.5$, $w_2 = 0.25$, $W_3 = 0.25$

(i) C = COST

$$C_{TCSC} = 0.0015s^2 - 0.7130s + 153.75 \quad \text{Rs/Kvar} \quad (8)$$

Where S= operating range of TCSC ,

$$S = I\, Q_2 I - I Q_1 I \quad (9)$$

Q_2 = reactive power flow in the line after installing TCSC device in MVAR

Q_1 = reactive power flow in the line before installing TCSC device in MVAR

TCSC device constraint:

$$-0.8X_L \leq X_{tcsc} \leq O.2X_L \text{ p.u}$$

Where

X_{tcsc} = Reactance added to the line by placing TCSC.

X_L = Reactance of the line where TCSC is located.

(ii) LVD = load bus voltage violation

$$LVD = \sum_{i=1}^{nb}\left|\frac{V_i - V_i^{ref}}{V_i^{ref}}\right|^n \quad (10)$$

n_b= number of load buses.

i = Load buses ,where Vis less than Vref .Generator and Slack buses are not considered.

V_i^{ref}= pre specified reference value of the voltage magnitude at the ith load bus.
V_i = voltage magnitude of the ith load bus

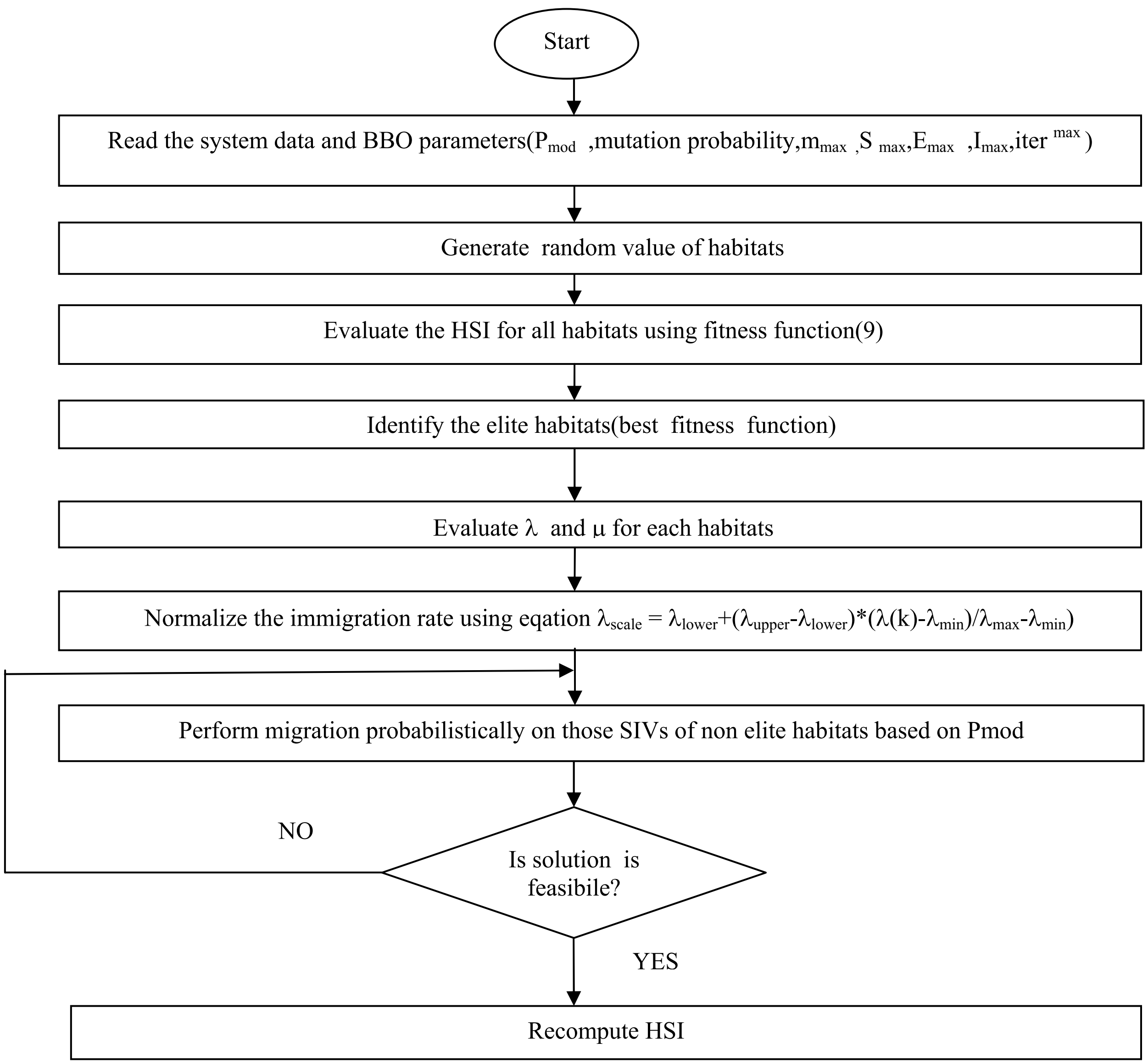
(iii)LL= Line Loading

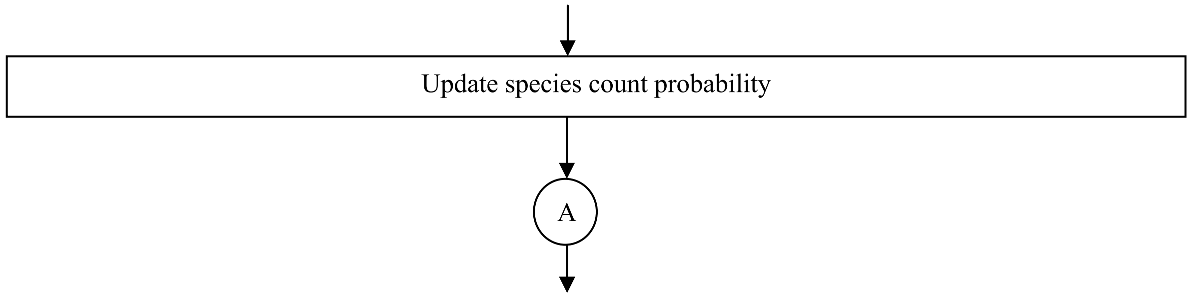
$$LL = \sum_{k=1}^{nl} \left(S_k \Big/ S_k^{\max} \right)^n \qquad (11)$$

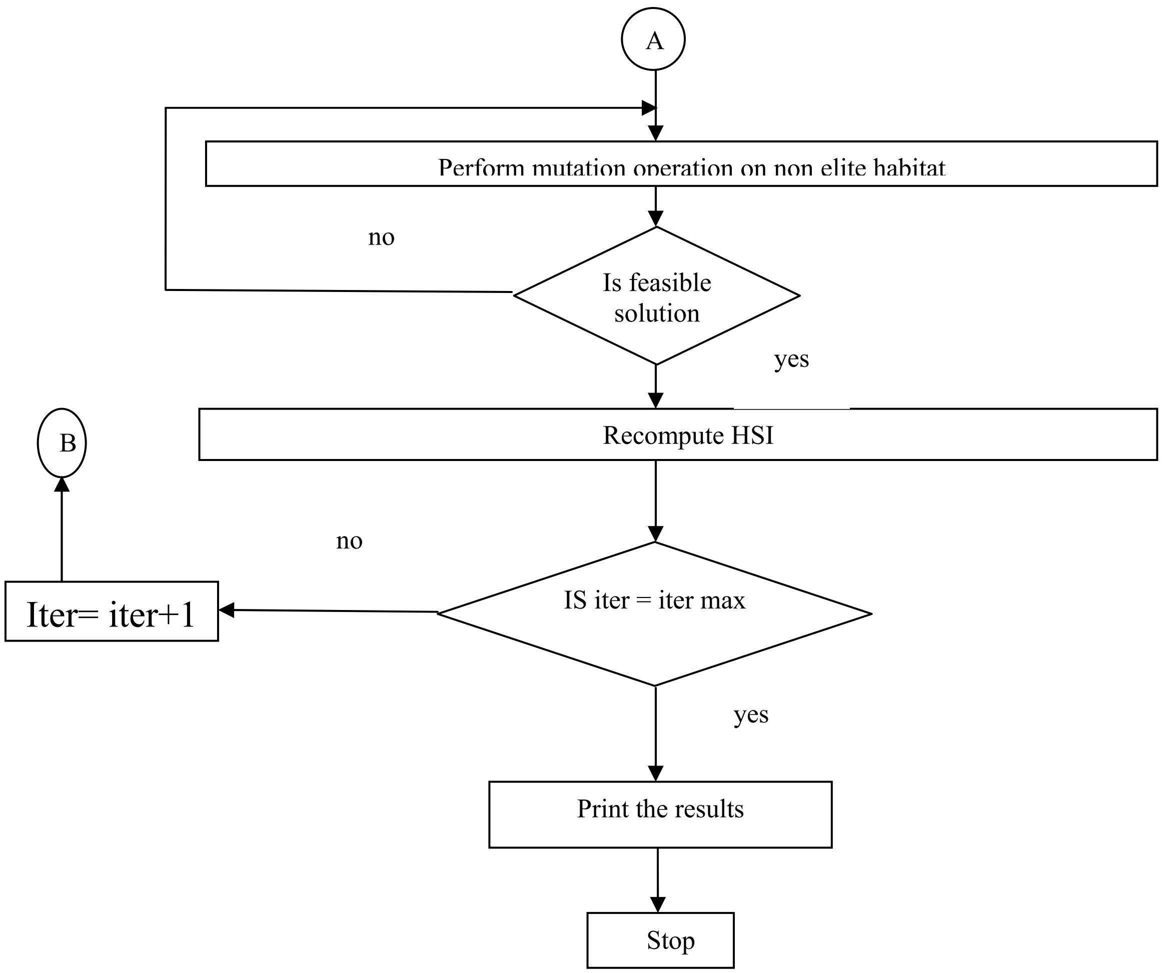
Where

S_k = apparent power in line k.
S_k^{max} = apparent power rate of the line k.

IV. PROPOSED FLOWCHART







V. SIMULATION RESULTS AND DISCUSSION

A. IEEE 14 Bus System

Table 1.Line Loading

WITHOUT TCSC						WITH TCSC					
BASE CASE	10	20	30	40	50	BASE CASE	10	20	30	40	50
17.589	19.209	20.932	22.441	24.052	25.777	17.691	19.239	20.989	22.542	24.250	25.989

Table 2. Bus Voltage

WTHOUT TCSC						WITH TCSC					
BASE CASE	10	20	30	40	50	BASE CASE	10	20	30	40	50
1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1
0.96	0.96	0.95	0.95	0.95	0.95	0.99	0.99	0.99	0.99	0.99	0.99
0.9561	0.9531	0.9478	0.9425	0.9372	0.9334	0.9657	0.9629	0.9599	0.9568	0.9534	0.9499
0.9592	0.9564	0.9518	0.9434	0.9407	0.9369	0.9653	0.9628	0.9598	0.9567	0.9538	0.9499
1	1	1	0.98	0.98	0.98	1	1	1	1	1	0.99
0.9753	0.9734	0.9703	0.9658	0.9611	0.9587	0.9796	0.9768	0.9757	0.9739	0.9696	0.969
1	1	1	1	1	1	1	1	1	1	1	1
0.96	0.9579	0.9546	0.9462	0.9431	0.9368	0.9638	0.9656	0.9605	0.9572	0.9643	0.9541
0.9589	0.9568	0.9538	0.9634	0.9385	0.9359	0.9621	0.9632	0.9587	0.9556	0.9612	0.9523
0.9754	0.9741	0.9724	0.9724	0.9542	0.9527	0.9776	0.9774	9749	0.9731	0.9759	0.971
0.9822	0.9811	0.9799	0.9691	0.9582	0.97	0.9825	0.9817	0.9884	0.9792	0.9788	0.9771
0..9752	0.9737	0.9721	0.9611	0.9501	0.9485	0.9758	0.9749	0.9729	0.9712	0.9712	0.9684
0.9469	0.9438	0.94	0.93	0.9199	0.9162	0.9494	0.9488	0.9438	0.9398	0.9427	0.9342

Table 3.Location ,reactance value and cost of installation of TCSC device

	BASE CASE	10	20	30	40	50
L	6 11	7 18	6 11	6 11	6 11	6 16
X	-0.078 0.078	0.134 -0.133	0.117 0.187	0.157 -0.180	0.135 -0.321	0.199 -0.193
COST FUNCTION	75.89	74.89	75.897	75.768	76.898	78.988
OBJECTIVE FUNCTION	13.362	28.1644	36.6986	50.8873	65.8386	97.5485

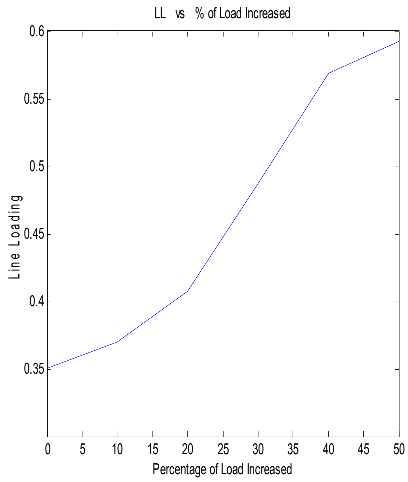


Figure 5.1 .LINE LOADING - WITHOUT TCSC

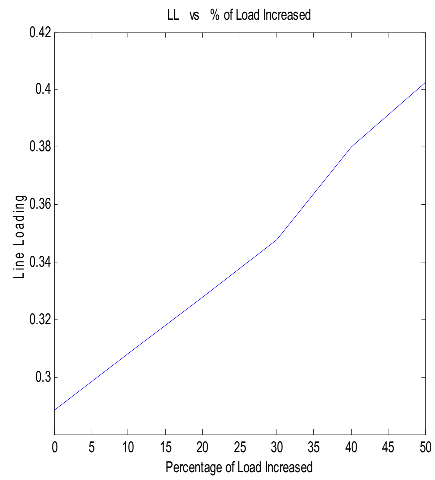


Figure 5.2. LINE LOADING- WITH TCSC

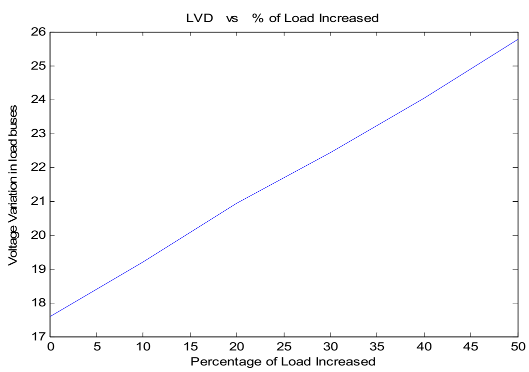


fig:5.3 load voltage deviation without TCSC

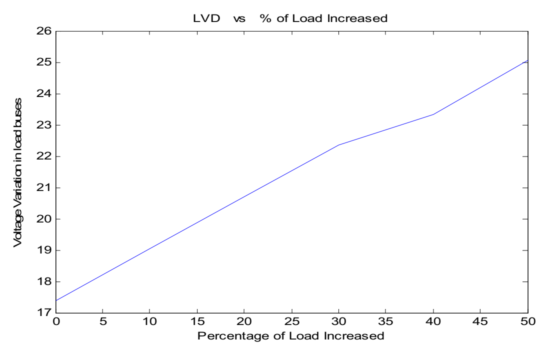


fig:5.4load voltage deviation with TCSC

B. IEEE 30 BUS SYSTEM

Table 4 .Line Loading

WITHOUT TCSC						WITH TCSC					
BASE CASE	10	20	30	40	50	BASE CASE	10	20	30	40	50
14.559	16.212	17.950	19.726	21.535	23.176	14.601	16.158	17.941	19.704	21.541	23.184

Table 5. Bus Voltage(p.u)

BASE CASE	10	20	30	40	50	BASE CASE	10	20	30	40	50
1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
1.0338	1.0338	1.0338	1.0338	1.0338	1.0338	1.0338	1.0338	1.0338	1.0338	1.0338	1.0338
1.0313	1.0298	1.0282	1.0263	1.0243	1.0189	1.0318	1.299	1.0282	1.0263	1.0243	1.019
1.0263	1.0246	1.0228	1.0208	1.0186	1.0125	1.0289	1.0247	1.0227	1.0207	1.0186	1.0125
1.0058	1.0058	1.0058	1.0058	1.0058	1.0058	1.0065	1.0058	1.0058	1.0058	1.0058	1.0058
1.0228	1.0216	1.0203	1.0189	1.0173	1.0101	1.0256	1.0217	1.202	1.0191	1.0172	1.01
1.0081	1.007	1.0058	1.0046	1.0033	0.9985	1.0096	1.0075	1.0055	1.0047	1.0032	0.9984
1.023	1.023	1.023	1.023	1.023	1.013	1.025	1.0235	1.023	1.023	1.023	1.013
1.0357	1.0345	1.0332	1.0317	1.0302	1.0254	1.0467	10349	1.0331	1.0318	1.0301	1.0254
1.0142	1.0126	1.0108	1.0088	1.0067	1.0011	1.021	1.0129	1.0107	1.0089	1.0067	1.0011
1.0913	1.0913	1.0913	1.0913	1.0913	1.0913	1.0989	1.0919	1.0913	1.0913	1.0913	1.0913
1.0417	1.0407	1.0396	1.0383	1.0369	1.0334	1.0497	1.0407	1.0395	1.0383	1.0384	1.0336
1.0883	1.8831	1.0883	1.0883	1.0883	1.0883	1.091	1.0883	1.0883	1.0883	1.0883	1.0883
1.0242	1.0223	1.0202	1.0179	1.0156	1.0108	1.0321	1.1235	1.0222	1.0202	1.018	1.0109
1.0173	1.0151	1.0127	1.0101	1.0074	1.0021	1.0171	1.0159	1.0129	1.0217	1.0089	1.0034
1.0228	1.0211	1.0194	1.0175	1.0154	1.0106	1.0256	1.2229	1.0323	1.0199	1.0179	1.0109
1.0113	1.0095	1.0075	1.0053	1.003	0.9974	1.0213	1.0223	1.0094	1.0074	1.0035	0.9977
1.0038	1.001	0.998	0.9948	0.9915	0.9852	1.0045	1.0138	1.0011	0.9989	0.9954	0.9854
0.999	0.996	0.9929	0.9896	0.9862	0.9795	0.9995	0.9995	0.9969	0.9939	0.9896	0.9865
1.002	0.9993	0.9965	0.9935	0.9903	0.9839	1.0023	0.9997	0.9995	0.9968	0.9912	0.9848
1.0012	0.9984	0.9955	0.9924	0.9911	0.9848	1.0019	0.9986	0.9967	0.9934	0.9934	0.989
1.0016	0.9994	0.9969	0.9944	0.9916	1.9853	1.0021	0.9999	0.9972	0.9929	1.9913	1.9865
1.0012	0.9984	0.9955	0.9924	0.9891	0.9826	1.0024	0.9987	0.9958	0.9894	0.9899	0.9835
0.9883	0.985	0.982	0.972	0.975	0.967	0.9898	9867	0.982	0.976	0.977	0.9754

	3	1	7	2	6			6	5	9	
0.988	0.985 1	0.982 1	0.978 8	0.975 3	0.966 6	0.9897	0.986 7	0.983 2	0.987 8	0.981	0.9787
0.9698	0.965 9	0.961 8	0.957 5	0.953	0.943 1	0.9698	0.968 9	0.963 4	0.961 2	0.951 2	0.9439
0.9967	0.994 4	0.991 9	0.989 1	0.986 2	0.977 3	0.9976	0.995 4	0.992 9	0.987 4	0.977 9	0.9787
1.0216	1.020 2	1.018 7	1.017 1	1.015 5	1.007 1	1.0216	1.021 2	1.020 3	1.016 7	1.016 5	1.0083
0.9763	0.972 4	0.968 2	9.963 8	0.959	0.948 2	0.9775	0.978 5	0.972 3	0.959 8	0.959	0.9492
0.9645	0.959 5	0.954 3	0.948 8	0.943	0.930 9	0.9698	0.965 4	0.959 5	0.954 3	0.943 9	0.9315

Table 6. Location ,reactance value and cost of installation of TCSC device

	BASE CASE	10	20	30	40	50
L	19 39	9 11	8 23	6 29	6 29	6 29
X	0.017 -0.0039	0.185 -0.093	0.110 0.015	0.188 -0.038	-0.035 0.196	-0.056 0.036
COST FUNCTION	76.89	75.987	76.980	76.989	76.890	75.890
OBJECTIVE FUNCTION	28.7093	46.7479	54.1758	78.965	97.5485	120.987

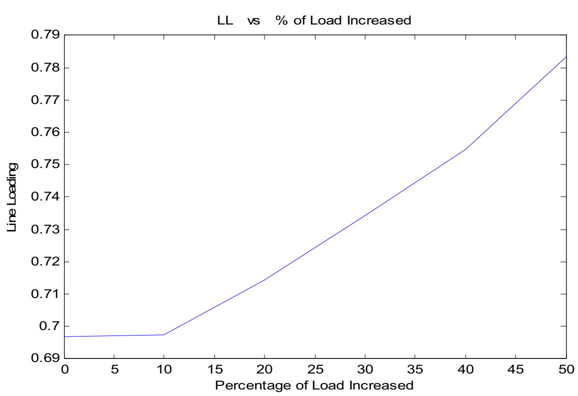


Figure 5.5 line loading – without TCSC

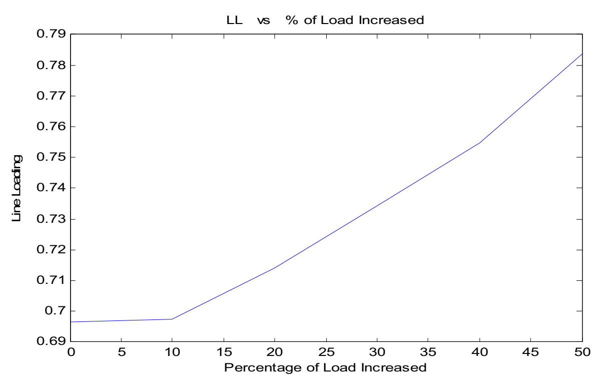


Figure5.6 line loading- with TCSC

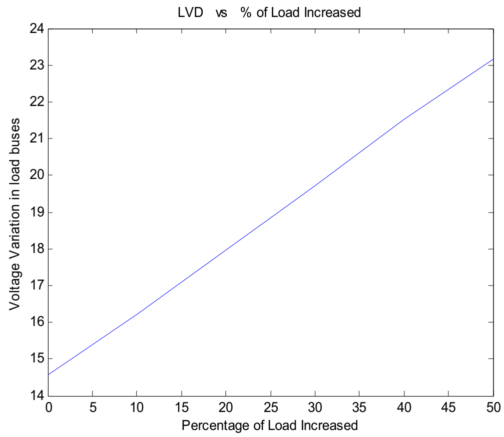


Figure 5.7 LVD without TCSC

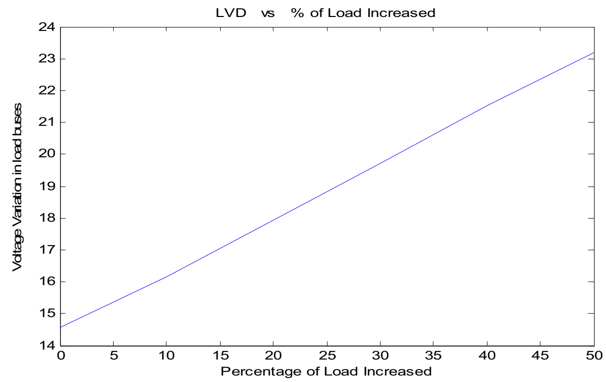


Figure5.8 bus-LVD with TCSC

From the results obtained it can be observed that the voltage profile and line loading has been improved by incorporating TCSC device with minimum installation cost .

VI. CONCLUSION

In this thesis one of the most efficient evolutionary optimization technique ,BBO were proposed and has been implemented to solve the optimization problem under consideration.

The minimization of the installation cost of TCSC devices, voltage profile improvement and elimination of line overloads were considered as the optimization criteria. This approach has been tested and examined on IEEE 14−bus,and IEEE 30 -bus systems to demonstrate its effectiveness. The simulation results indicate that the proposed technique performed well and can successfully applied to the optimal location of multiple TCSC problem

REFERENCES

[1] Aniruddha Bhattacharya and Pranab Kumar Chattopadhyay "Solution of Optimal Reactive Power Flow using Biogeography-Based Optimization" World Academy of Science, Engineering and Technology 63 2010,pp 56-62.

[2] Dan Simon ,"Biogeography–Based Optimization"IEEE Trans on Evolutionary Computation,Vol .12 ,No 6,December 2008,pp 702-713.

[3] Rick Rarick ,Dan Simon ,Eugenio Villaseca.F ,and Bharat Vyakaranam, "Biogeography–Based Optimization and the solution of the power flow problem "Proceedings of the 2009 IEEE international conference on systems ,man and cybernetics, San Antonio TX ,USA –october 2009,pp 1029-1034.

[4] N.G Hingorani,"Power electronics in electrical utilities:role of power electronics in future power systems",proceedings of the IEEE ,vol 76 No 4,april 1988,pp.481-482

[5] C.R Fuerte-Esquivel ,E-Acha and H.Ambriz-perez."A thyristor controlled series compensater model for the powerflow solution", IEEE Trans.powersytem ,vol 15,No.1,February 2000,pp 58-64.

[6] M.A Abdel Moamen,P.P Narayana,"Newton Raphson TCSC model for the power flow solution of practical power networks",IEEE power engineering society summer meeting ,vol 3,2002,pp.1488-1493.