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Optimal Placement of UPFC to Enhance System Security Using BBO Technique

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Abstract: Nowadays the secure operation of power system has become a critical issue, as they are heavily loaded and are being operated in ways not been originally envisioned. Flexible AC Transmission System (FACTS) devices play a vital role in improving the static as well as dynamic performance of the power systems. UPFC is one of the most effective multifunctional FACTS device, which can control simultaneously or selectively all the parameters affecting the power flow in a transmission line. However the location and ratings of UPFC play a major role in deciding the extent to which the objective of improving the system performance is achieved in a cost effective manner. In this work an objective function comprising of device cost, line loadings and load voltage deviations is proposed to tap maximum benefits and the weights assigned to them decide their relative importance. The optimal placement of UPFC is carried out using PSO, WIPSO and BBO techniques and the results are compared.

Key words: Security enhancement · UPFC placement · Optimal placement of FACTS devices · BBO technique

INTODUCTION

Present day power systems are highly complex interconnected systems, so it becomes necessary to operate the power systems in a secure and reliable manner. Due to the dynamic load pattern and ever increasing load demand, power flows in some of the transmission lines are well above their normal limits, while some of the lines are not loaded up to their full capacity. As a result of this uneven load distribution the voltage profile of the system gets deteriorated which poses a threat for the security of the system. Taking into consideration the factors such as increasing load demand, economical and technical constraints involved in setting up new power generation facilities and limitations faced in purchasing right of ways to realize new transmission corridors, it becomes highly essential to utilize the existing generation and transmission facilities in the most efficient manner. FACTS controllers are found to be an effective alternative for the complex task of building up new transmission corridors [1].

FACTS (Flexible Alternating Current Transmission System) is a concept introduced by N.G.Hingorani [2] which helps to modulate and reverse the power flow through the transmission lines, in a fast, accurate and precise manner. FACTS devices are very effective in improving the voltage profile, reducing the line loadings and line losses, providing reactive power support over a wide range of operating voltages and enhancing the stability of the system. They can as well be used with the existing lines in order to enhance their power transfer capability. The power flow through the network can be controlled without modifying the generation and carrying out any switching operations in the network. [3]. Optimal placement of FACTS devices is essential to tap the maximum benefits in terms of system performance and cost effectiveness. Many researchers had carried out their work on the optimal location of FACTS devices to achieve different objectives using various heuristic techniques. In order to achieve maximum benefits through the installation of the FACTS devices, devices of suitable ratings need to be installed at optimal locations [4].

The type of FACTS device to be installed is determined based on the requirement. It is desirable to install shunt controllers for voltage support and series controllers for line flow control [5]. Proper selection and installation of FACTS devices is necessary to enhance system security under normal and network contingencies [6]. Installation of shunt controller improves bus voltages, series controller maximizes the system loadability and combined series–shunt controllers (UPFC) satisfy both the objectives. The UPFC is one of the best-featured FACTS device with a unique combination of fast shunt and series compensators, so that a flexible power system

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control is provided by its integration [7]. Active and reactive power control, power transfer capability, system stability and power system reliability are improved by the installation of UPFC in a power system. Thus the secure operation of the power system is enhanced by the installation of UPFC. The effectiveness of the optimal installation of UPFC for the enhancement of system security under single line contingencies are investigated in [8] using DE and PSO techniques. But the installation cost of the device is not considered in the analysis. Since the cost of UPFC is very high and also it plays a major role during installation, due to economic reasons it becomes essential to consider cost of the device as one of minimization objective.

The most common objectives reported in the literature for the installation of FACTS devices in power system are static voltage stability enhancement, violation avoidance of line thermal constraints, network loadability enhancement, power loss reduction, voltage profile improvement, fuel cost reduction of power plants using optimal power flow, dynamic stability improvement and efficient damping of power swings [9]. It is worth noting that each of the mentioned objectives improves the performance of the power system network. The power system security is improved by selecting the suitable location of UPFC, after the degree of severity of the considered contingency is evaluated, using voltage stability L-index of load buses and minimum singular value (MSV) [10].

An optimal allocation algorithm for FACTS devices is developed based on a novel particle swarm optimization method considering both power system cost and short circuit level [11]. The optimal location of FACTS devices is suggested with minimum installation cost and maximum system loadability (SL), with the power system constraints such as thermal limit for the lines and voltage limit for the load buses to be satisfied [12]. In this paper TCSC has been modeled as a variable reactance inserted in the line and SVC is modeled as a reactive source added at both ends of the line. UPFC is modeled as combination of a SVC at a bus and a TCSC in the line connected to the same bus. When compared with TCSC & SVC, UPFC gives maximum system loadability.

A loss sensitivity index with respect to the control parameters of FACTS devices has been suggested and with the computed loss sensitivity index, the FACTS devices are placed on the most sensitive bus or line [13]. The optimal location of a given number of FACTS devices is a problem of combinatorial analysis and to solve such kind of problems, heuristic methods are used [14]. They permit to obtain acceptable solutions within a limited computation time. Sensitivity analysis approach for finding the optimal location and PSO for the optimal parameter setting of TCSC has been suggested in [15] so as to maximize the loadability. The integration of UPFC is mathematically modeled, by the simultaneous placement of several devices in the same line or by a SVC at a bus and another device in an adjacent branch.

Application of Genetic Algorithm for the optimal location of multi type FACTS devices in order to maximize the system loadability is analysed in [16]. A Differential Evolution based algorithm to decide the optimal location and device rating has been suggested in [18] with an objective of enhancing the system security under single line contingencies. The benefits of optimal allocation of FACTS devices in power systems are analysed using GA technique [19]. The study reveals that in a contingency condition after the optimal allocation of FACTS devices, the system recovers its secure state. GA technique is applied for the optimal location of FACTS devices in order to maximize the system loadability, by maintaining thermal and voltage constraints [20]. Here the system loadability is employed as a measure of power system performance. In [21] the optimal location of UPFC is determined based on Voltage Stability Index using Particle Swarm Optimization (PSO) technique. An objective function to minimize the cost of energy loss and cost of UPFC is considered to maximize the net saving per annum. The optimal location and parameter setting of UPFC device is done in reference [22] using DE (Differential Evolution) technique for enhancing system security under single line contingencies through eliminating or minimizing the overloaded lines and the bus voltage limit violations. DE is superior at exploring the search space and locating the area of local optimum, but it is slow in exploitation of the solutions. DE exhibit poor performance in locating the global optimum with limited number of fitness function evaluations [23].

BBO is a new type of heuristic search algorithm based on the species behaviour developed by Dan Simon [24]. Biogeography based optimization, a population based algorithm, which uses the immigration and emigration behaviour of the species based on various natural factors [25]. Literature survey reveals that lot of work has been done for the optimal placement of UPFC. Application of BBO to solve the economic dispatch problem is described in [24], [25] where it has been proved that BBO gives a solution which is comparable with evolutionary programming and differential evolution techniques.

The proposed work applies the recently introduced BBO-Biogeography Based Optimization technique, to find out the optimal location and parameter setting of the UPFC to enhance system security under over loaded conditions. The performance of the algorithm is validated by comparing the results with the results obtained through the application of PSO and WIPSO techniques. Since the proposed work is focused on the enhancement of power system security in cost effective manner, the objective function comprises of line loadings, voltage deviations at the load buses and cost of the device.

Problem Formulation

Objective of the Optimization: The cost of the UPFC is very high and in order to achieve the maximum benefit, the UPFC has to be optimally installed. The objective function is comprised of three terms; the first term represents the installation cost of the UPFC, the second and third terms representing the load bus voltage deviations and line loadings respectively. The minimization of the proposed objective function is expected to lead to a cost effective security oriented UPFC placement.

The objective function is formulated as;

$$MinF = W_1[C_{UPFC} * S] + W_2[LVD] + W_3[LL] \tag{1}$$

Installation Cost (C_{UPFC}): The first term of the objective function is cost function of UPFC, which is obtained from the Siemens data base [26] as reported in [12] [19] is represented in equation 2.

$$C_{UPFC} = 0.0003s^2 - 0.2691s + 188.22 \tag{2}$$

$$S = |Q_1| - |Q_2| \tag{3}$$

Load voltage deviation (*LVD*): Excessive high or low voltages can lead to an unacceptable service quality and can create voltage instability problems. UPFC connected at appropriate locations play a leading role in improving voltage profile thereby avoiding voltage collapse in the power system. The second term considered represents the load voltage deviations in order to prevent the under or over voltages at network buses.

$$LVD = \sum_{m=1}^{nb} \left(\frac{V_{mref} - V_m}{V_{mref}} \right)^n \tag{4}$$

Line Loading (*LL*): In order to remove the overloads and to distribute the load flows uniformly, the UPFC has to be placed optimally. To achieve this, line loading is considered as the third term in the objective function.

$$LL = \sum_{l=1}^{nl} \left(\frac{S_l}{S_{l\max}} \right)^n \tag{5}$$

Mathematical Modeling of UPFC: The UPFC is a multifunctional FACTS device, which can control simultaneously or selectively all the parameters affecting the power flow in a transmission line. The UPFC comprises a series converter and a shunt converter connected with the transmission line via coupling transformers. The shunt converter of UPFC can generate or absorb controllable reactive power and provides reactive power compensation. The series converter injects an AC voltage with controllable magnitude and phase angle in series with the transmission line. A schematic representation of UPFC is shown in Fig. 1.

The output voltage of the series converter is added to the AC terminal voltage V_0 via the series connected coupling transformer. The injected voltage V_{CR} acts as a series voltage source, changing the effective sending-end voltage as seen from node m. The products of the transmission line current I_m and the series voltage source V_{CR} determines the active and reactive power exchanged between the series converter and the AC system. The real power demanded by the series converter is supplied from the AC power systems by the shunt converter and it is able to generate or absorb controllable reactive power in both operating modes (i.e., rectifier and inverter). The transmission line real or reactive power compensation can be used to maintain the shunt converter terminal AC voltage magnitude at a specific value.

In the literature survey, integration of UPFC is mathemattically modelled in many ways. UPFC is modeled as a combination of series and shunt power injection at both bus i and j [27], the reactive power delivered or absorbed by shunt branch is not considered. Transmission lines real power loss and load buses voltage deviation are minimized simultaneously by tuning the parameters and location of UPFC optimally. UPFC configuration consisting of two shunt converters and a series capacitor is suggested [28] and UPFC is modeled, with two 2-level 3-phase shunt converters and a series capacitor. So, the cost, volume and rated power of UPFC decrease and the control scheme becomes simpler than

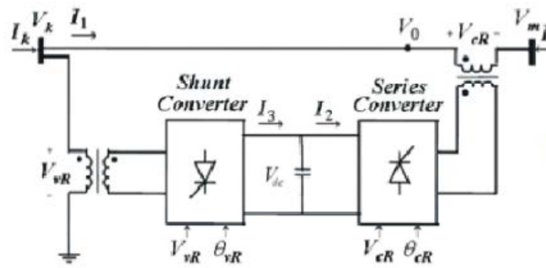

Fig. 1: Structure of UPFC

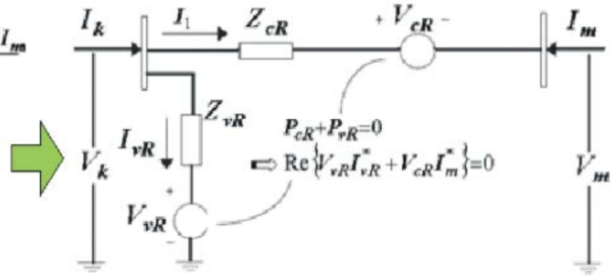

Fig. 2: Voltage source

conventional UPFC configuration. The optimal installation of UPFC is illustrated in [29] by perturbed particle swarm optimization (PPSO) technique to enhance power system security under single line contingencies. UPFC is mathematically incorporated as a complex power injection model with series voltage and the shunt injected current as the control variables. The UPFC model in [30, 20] is represented by a series voltage source and a shunt current source. If the optimal location is assumed at bus-*i,* then the UPFC is placed at bus-*i* and in line connected between bus-*i* and bus-*j*.

The proposed work implements UPFC power flow model as suggested in [8], [10], [19], [20], [30]. The modeling of UPFC is shown in the Fig. 2 which consists of two coordinated synchronous voltage sources. A controllable series voltage source V_{CR} placed between the nodes k and m and in series with the line reactance. The two voltage source converters of the UPFC connected through a DC link are modeled as two ideal voltage source, one controlled in series and other in shunt between the two buses k and m. The output of the series voltage source V_{CR} and θ_{CR} are controllable magnitude and angle between the limits V_{CR} min $\leq V_{CR} \leq V_{CR}$ max and $0 \leq \theta_{CR} \leq 2\pi$ respectively and the shunt voltage source is V_{VR} and θ_{VR} are controllable between the limits V_{VR} min $\leq V_{VR} \leq V_{VR}$ max and $0 \leq \theta_{VR} \leq 2\pi$.

The output voltage of the series converter is added to the AC terminal voltage V_0 via the series connected coupling transformer. The injected voltage V_{CR} acts as an AC series voltage source, changing the effective sending-end voltage from node m. The product of the transmission line current I_M and the series voltage source V_{CR} determines the active and reactive power exchanged between the series converter and the AC system.

The Optimization Variables: The optimization variables considered in this work are;

- The number of UPFC to be installed is taken as the first variable.
- The location of UPFC is considered as the second variable to be optimized. UPFC can be placed in any line in the network, except the lines where the transformers exist.
- The series voltage source magnitude (V_{CR}) and series voltage source phase angle (θ_{CR}) of the UPFC is considered as the third variable to be optimized and the working range for this variables are [0.001,0.2] and [0,2π] respectively.
- The shunt voltage source magnitude and shunt (V_{VR}) voltage source phase angle (θ_{VR}) of the UPFC is considered as the fourth variable to be optimized and the working range for these variables are [0.9,1.1] and [0,2π] respectively.

BBO Technique: BBO algorithm tries to solve the optimization problem through the simulation of immigration and emigration behaviour of the species in and out of a habitat. Species move in and out of the habitats depending upon various factors such as availability of food, temperature prevailing in that habitat, already existing species count in that area, diversity of vegetation and species in that area etc. and the process strikes a balance when the rate of immigration is equal to the rate of migration. But these behaviours are probabilistic in nature. BBO algorithm exploits the search of the individuals to find them a suitable habitat to probe into the promising regions of the search space. A habitat is defined as an island that is geographically isolated from other areas. A habitat is formed by a set of integers that form a feasible solution for the problem and an ecosystem consists of a number of such habitats. The areas that are well suited as residents for species are said to have high habitat suitability index (HSI). The variable that characterise habitability are called Suitability index variables (SIVs). The large number of species on high HSI islands have many opportunities to emigrate into neighbouring habitats with less number of species. The immigration and emigration process helps the species in the area with low HSI to gain good features from the

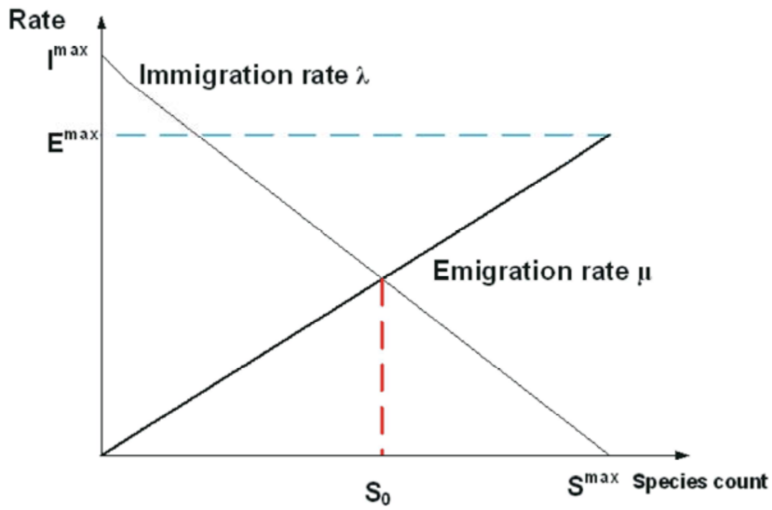

Fig. 3: Species model of single habitat

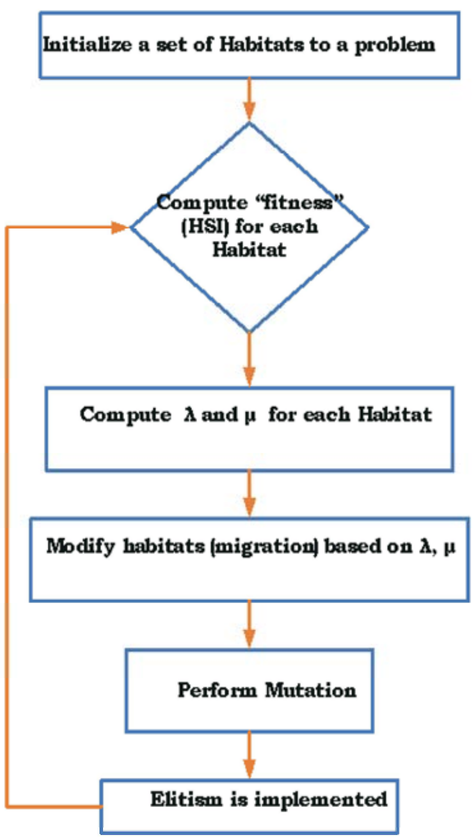

Fig. 4: Generalized algorithm for BBO

species in the area with high HSI and makes the weak elements into strong. Besides it allows retaining good features of species in the area with high HSI . The rate of immigration (λ) and the emigration (μ) are the functions of the number of species in the habitat. Fig. 3 shows the immigration and emigration curves indicating the movements of species in a single habitat. Fig. 4 shows the generalized algorithm for BBO technique.

BBO uses migration operator to share information between solutions which is similar to other biology based algorithms, such as GA and PSO. This feature makes BBO applicable to the problems where GAs and PSO can be applied. Apart from the above mentioned common feature, BBO has a unique feature to maintain its set of best solution throughout the iteration process, when compared with other biology based algorithms.

A set of habitats are generated randomly, satisfying the constraints and their HSI is evaluated. In order to retain elitism, the best habitat having highest HSI is retained without performing migration operation which prevents the best solutions from being corrupted.While the modification operation is performed over the rest of the members, HSI is recalculated for the modified ones thereafter mutation operation is carried out over the extremely good and bad solutions leaving aside the solutions in the middle range. Stopping criteria is similar to any other popular population based algorithm where the algorithm terminates after a pre-defined number of trials or after the elapsing of the stipulated time or where there is no significant change in the solution after several successive trials.

In BBO, a good solution is reffered to an island with high HSI and a poor solution to an island with low HSI. The poor solution in islands with low HSI accept a lot of new features from good solutions in islands with high HSI and improve their quality. However the shared features of the good solutions still remain in the high HSI solutions.

Algorithm:

Step 1: The system data and the load factor are initialized.

Step 2: BBO parameters such as the size of the suitability index variable n, maximum number of iterations, limits of each variable in the habitat are initialized.

Step 3: An initial set of solutions is randomly generated considering the variables such as number of UPFC's, location of UPFC's, rating of UPFC's to be optimized.

Step 4: Fitness function $Min\{C_{UPFC}, LVD, LL)$ is evaluated for the habitats.

Step 5: The immigration rate λ and emigration rate μ are determined for each of the habitats.

Step 6: Elite habitats are identified and they are exempted from modification procedure.

Step 7: A habitat H_i is selected for modification proportional to its immigration rate λ_i and the source for this modification will be from the habitat H_j proportional to its emigration rate μ_j. This represents the migration phenomena of the species wherein the new habitats are formed through migration.

Step 8: The probability of mutation P_i calculated from λ and μ is used to decide the habitat H_i for mutation and its j^{th} SIV is replaced by a randomly generated SIV.

Step 9: Already existing set of elite solutions along with those resulting from the migration and mutation operations result in a new ecosystem over which the steps 4 to 6 are applied until any one of the stopping criteria is reached.

Step 10: The same procedure is repeated for different load factors

Case Study: To study the effect of the installation of UPFC under overload conditions, the loads on the system were increased in a step by step manner; the real and reactive power loads connected at various load buses were increased keeping the load power factor constant. The results were analyzed for base case, 10%, 20% and 30% increase in load from the base case. The proposed method is evaluated by applying the developed algorithm in standard IEEE-14, IEEE- 30 and IEEE-57 bus systems. The bus data, line data and the limits of control variables are estimated from references [23, 25, 31, 32]. The Newton Raphson power flow method is effectively employed to calculate the power flow solution before and after setting UPFC.

Case 1-IEEE 14 Bus System:

Table 1: Line Loading Vs Load Factor for UPFC placement

	Line Loading			
		With FACTS devices		
		Techniques		
Load Factor	Without FACTS	PSO	WIPSO	BBO
Base	17.5892	16.057	15.980	15.704
10%	19.2093	17.594	17.319	17.068
20%	20.9319	18.479	18.376	17.019
30%	22.4464	20.744	20.418	20.187

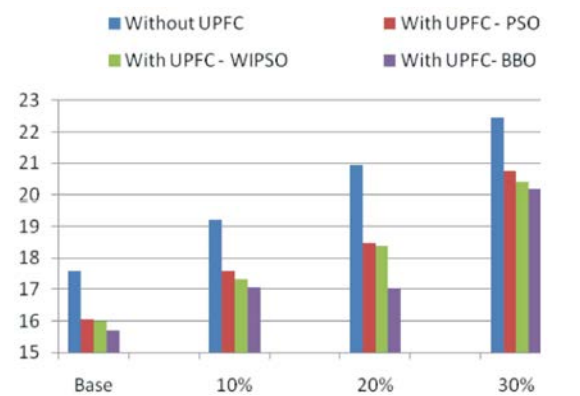

Fig. 5: Line Loading Vs Load Factor for UPFC placement

Table 2: Load Voltage Deviation Vs Load Factor for UPFC placement

	Load Voltage Deviation			
		With FACTS devices		
		Techniques		
Load Factor	Without FACTS	PSO	WIPSO	BBO
Base	0.3509	0.1537	0.1501	0.1471
10%	0.3696	0.1783	0.1746	0.1708
20%	0.4075	0.1891	0.1839	0.1807
30%	0.4875	0.3101	0.2945	0.2852

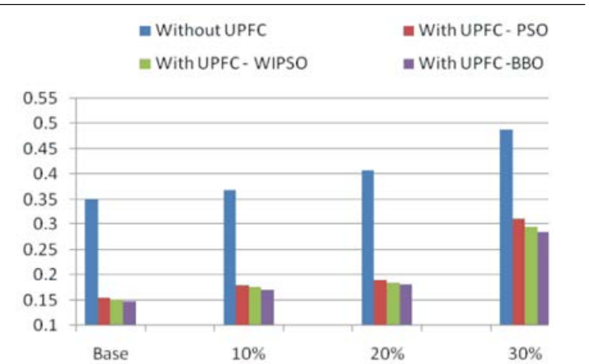

Fig. 6: Load Voltage Deviation Vs Load Factor for UPFC placement

Table 3: UPFC ratings- Shunt Voltage Source

	UPFC ratings								
	Techniques								
	PSO			WIPSO			BBO		
		Shunt Voltage			Shunt Voltage			Shunt Voltage	
Load Factor	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR})*rad*	B-L	(V_{CR}) p.u	(θ_{CR}) rad
Base	9-16	1.022	-1.499	9-16	1.027	-2.453	9-17	1.029	-1.543
10%	9-16	1.024	-2.396	9-16	1.028	-2.172	9-17	1.032	-2.442
20%	7-15	1.026	-2.308	9-16	1.030	-2.917	9-17	1.034	-2.357
30%	7-15	1.010	-2.262	7-15	1.032	-2.447	7-15	1.035	-2.917

Table 4: UPFC ratings – Series Voltage Source

	UPFC ratings								
	Techniques								
	PSO			WIPSO			BBO		
		Series Voltage			Series Voltage			Series Voltage	
Load Factor	B-L	(V_{VR}) p.u	(θ_{VR}) rad	B-L	(V_{VR}) p.u	(θ_{VR}) rad	B-L	(V_{VR}) p.u	(θ_{VR}) rad
Base	9-16	0.051	-0.436	9-16	0.045	-0.167	9-17	0.064	-1.203
10%	9-16	0.062	-0.330	9-16	0.073	-0.319	9-17	0.075	-1.349
20%	7-15	0.112	-1.494	9-16	0.115	-1.214	9-17	0.112	-1.496
30%	7-15	0.110	-0.588	7-15	0.117	-1.453	7-15	0.125	-2.363

Case 2-IEEE 30 Bus System:

Table 5: Line Loading Vs Load Factor for UPFC placement

	Line Loading			
		With FACTS devices		
		Techniques		
Load Factor	Without FACTS	PSO	WIPSO	BBO
Base	14.5592	14.122	13.923	13.507
10%	16.2116	15.775	15.099	14.815
20%	17.9504	16.807	16.617	16.502
30%	19.7258	18.01	17.902	17.724

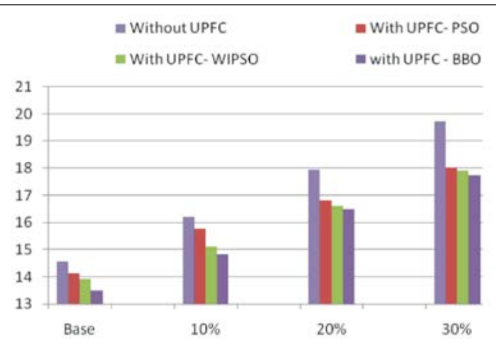

Fig. 7: Line Loading Vs Load Factor for UPFC placement

Table 6: Load Voltage Deviation Vs Load Factor for UPFC placement

	Load Voltage Deviation			
		With FACTS devices		
		Techniques		
Load Factor	Without FACTS	PSO	WIPSO	BBO
Base	0.6967	0.6375	0.6292	0.6117
10%	0.6974	0.6586	0.6515	0.6467
20%	0.7145	0.6752	0.6696	0.6501
30%	0.7342	0.6837	0.6781	0.6574

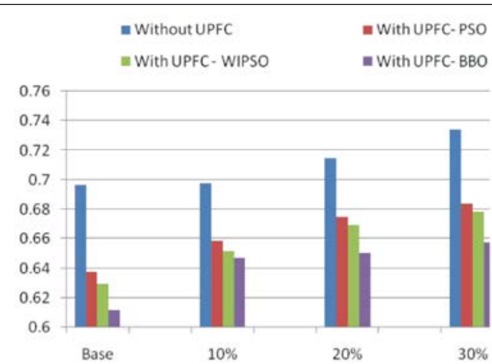

Fig. 8: Load Voltage Deviation Vs Load Factor for UPFC placement

Table 7: UPFC ratings –Shunt Voltage Source

	UPFC ratings								
	Techniques								
	PSO			WIPSO			BBO		
		Shunt Voltage			Shunt Voltage			Shunt Voltage	
Load Factor	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR}) rad
Base	27-37	1.006	-1.210	29-39	0.999	-1.144	24-33	1.004	-1.116
	24-33	0.999	-1.647	24-33	1.009	-1.713	29-39	1.003	-1.293
10%	25-34	1.006	-1.154	25-35	0.994	-1.305	25-34	0.987	-1.382
	24-33	1.002	-1.043	24-33	1.009	-1.279	24-33	1.006	-1.280
20%	24-33	1.007	-2.172	24-31	1.003	-2.244	24-33	1.004	-2.353
	25-35	1.002	-2.998	27-37	1.000	-2.281	29-39	1.007	-2.119
30%	24-33	1.010	-2.264	25-35	1.003	-2.969	24-33	1.003	-2.238
	27-37	1.000	-2.227	24-33	1.002	-2.307	25-35	1.006	-2.045

Table 8: UPFC ratings- Series Voltage Source

	UPFC ratings								
	Techniques								
	PSO			WIPSO			BBO		
		Series Voltage			Series Voltage			Series Voltage	
Load Factor	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR}) rad
Base	27-37	0.020	-1.289	29-39	0.134	-0.457	24-33	0.071	-0.051
	24-33	0.115	-0.156	24-33	0.044	-0.148	29-39	0.016	-0.774
10%	25-34	0.119	-0.513	25-35	0.105	-0.021	25-34	0.019	-0.513
	24-33	0.028	-0.091	24-33	0.142	-0.526	24-33	0.121	-0.528
20%	24-33	0.070	-0.148	24-31	0.014	-0.132	24-33	0.091	-0.184
	25-35	0.095	-0.601	27-37	0.163	-0.564	29-39	0.119	-0.940
30%	24-33	0.126	-0.360	25-35	0.075	-0.315	24-33	0.073	-0.346
	27-37	0.025	-1.739	24-33	0.115	-0.024	25-35	0.104	-0.721

Case 3- IEEE 57 Bus System:

Table 9: Line Loading Vs Load Factor for UPFC placement

	Line Loading			
		With UPFC devices		
		Techniques		
Load Factor	Without UPFC	PSO	WIPSO	BBO
Base	53.33	50.666	49. 761	48.371
10%	61.29	57.921	56. 579	55.465
20%	70.01	67.191	66.246	65.877
30%	79.86	77.060	76.895	74.640

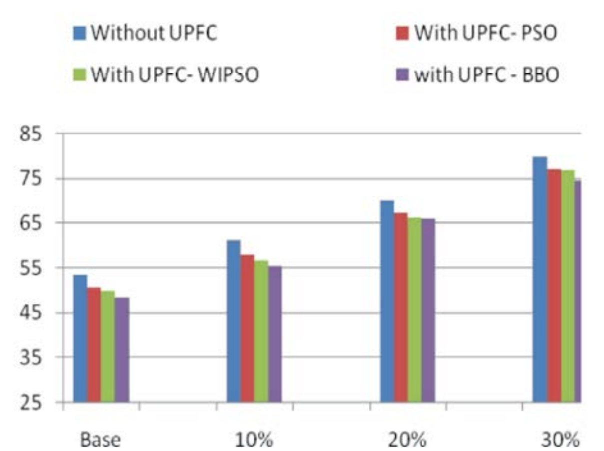

Fig. 9: Line Loading Vs Load Factor for UPFC placement

Table 10: Load voltage deviation Vs Load Factor for UPFC placement

Load Factor	Load Voltage Deviation			
		With UPFC devices		
		Techniques		
	Without UPFC	PSO	WIPSO	BBO
Base	3.98	3.7148	3.6845	3.5125
10%	4.16	3.7407	3.6531	3.5041
20%	4.46	4.0939	3.9019	3.8133
30%	4.46	4.1019	3.9765	3.9464

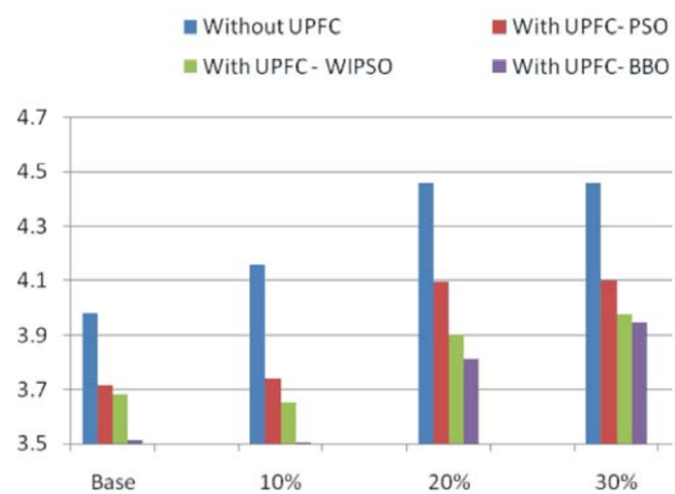

Fig. 10: Load voltage deviation Vs Load Factor for UPFC placement

Table 9: UPFC ratings –Shunt Voltage Source

Load Factor	UPFC ratings								
	Techniques								
	PSO			WIPSO			BBO		
		Shunt Voltage			Shunt Voltage			Shunt Voltage	
	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR}) rad
Base	11-54	0.994	-1.279	29-41	0.886	-1.427	11-54	0.932	-1.774
	31-44	1.013	-2.524	11-54	0.881	-1.482	51-65	0.905	-1.445
	29-67	1.014	-2.921	51-65	1.004	-1.212	29-41	0.933	-1.163
10%	11-24	1.014	-2.875	54-70	1.007	-2.990	54-70	1.007	-2.968
	54-70	1.002	-2.425	31-44	0.995	-1.552	31-44	0.965	-1.008
	29-41	0.930	-1.005	29-67	0.969	-1.065	11-54	1.014	-2.781
20%	54-70	1.014	-1.663	11-24	0.877	-1.525	29-41	0.891	-1.942
	29-41	0.955	-2.163	29-41	1.031	-2.703	11-24	0.952	-1.526
	11-24	1.051	-2.713	54-70	1.013	-2.473	51-65	1.033	-2.106
30%	54-70	1.051	-2.052	29-40	1.022	-2.971	49-62	0.974	-2.613
	29-67	0.990	-2.869	51-65	0.971	-2.500	29-40	1.030	-2.091
	31-44	1.015	-1.091	11-24	1.021	-2.507	51-65	1.103	-2.444

Table 10: UPFC ratings- Series Voltage Source

	UPFC ratings								
	Techniques								
	PSO			WIPSO			BBO		
		Shunt Voltage			Shunt Voltage			Shunt Voltage	
Load Factor	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR}) rad	B-L	(V_{CR}) p.u	(θ_{CR}) rad
Base	11-54	0.038	-0.112	29-41	0.010	2.210	11-54	0.032	4.343
	31-44	0.103	2.078	11-54	0.036	1.458	51-65	0.106	1.192
	29-67	0.037	6.558	51-65	0.135	2.373	29-41	0.054	1.025
10%	11-24	0.116	-0.448	54-70	0.082	1.287	54-70	0.082	1.312
	54-70	0.025	1.036	31-44	0.097	-1.834	31-44	0.127	-1.826
	29-41	0.125	2.943	29-67	0.140	-1.338	11-54	0.033	1.558
20%	54-70	0.056	-0.433	11-24	0.059	1.945	29-41	0.113	2.515
	29-41	0.138	0.607	29-41	0.103	2.504	11-24	0.016	-1.103
	11-24	0.086	-2.321	54-70	0.117	-1.286	51-65	0.094	-0.848
30%	54-70	0.112	-0.382	29-40	0.032	-0.733	49-62	0.101	0.319
	29-67	0.040	1.182	51-65	0.086	-0.173	29-40	0.032	-0.751
	31-44	0.121	-1.231	11-24	0.130	-0.461	51-65	0.111	-1.266

To simulate the proposed algorithm in IEEE 14 , IEEE 30 and IEEE 57 bus systems, the number of UPFC's considered are 1, 2 and 3 respectively. The algorithm is simulated by developing matlab coding. The system is analyzed by finding out the values of overall Line Loading and Load voltage Deviation before and after placing UPFC in its optimal location using PSO, WIPSO and BBO techniques. The obtained values for Line Loadings and Load Voltage Deviations are tabulated. Tables 1, 5 and 9 compare the Overall Line Loading values of the system before and after UPFC placement for 14, 30 & 57 bus system respectively, under various loading conditions obtained using PSO, WIPSO and BBO techniques. Similarly Tables 2, 6 & 10 show the minimization of Load Voltage Deviations after UPFC placement. The bar charts in Figure 5, 7 & 9 reveal how far the system loading is minimized in BBO compared with other techniques. Similarly the bar charts in Figures 6, 8 & 10 depict the voltage profile improvement after the UPFC placement using BBO. The placement details of UPFC with line number and its rating are shown in Tables 3, 4, 7, 8, 11 & 12. In IEEE 14 bus system the optimal location of UPFC is obtained as bus 9 & line 17 and bus 7 & line 15. In IEEE 30 bus system, obtained locations for two UPFC's are bus 24 & line 33, bus 29 & line 39, bus 25 & line 34 or 35. Similarly for IEEE 57 bus system, the location of 3 UPFC's obtained are bus 11 & line 54 or 24, bus 51 & 65, bus 29 & line 40 or 41, bus 54 & line 70, bus 31 & line 44, bus 49 & line 62.

CONCLUSION

UPFC can be placed at any feasible location in the power system, but its location and rating have to be fixed optimally as they turn out to be costlier. Here the problem of UPFC placement; with comprehensive objective function consisting of cost of the UPFC, load voltage deviations and line loadings is analyzed using BBO algorithm and the obtained results are compared with PSO and WIPSO techniques. The study shows, after the UPFC placement both the load bus voltage deviations and line loadings are minimized hence enhancing the system security. Further Analysis reveals that BBO technique shows best performance compared to PSO and WIPSO techniques. Hence the proposed method yields an efficient solution which considerably reduces load voltage deviations and relieves the lines off their over loads under various loading conditions.

Nomenclature:

BBO	Biogeography Based Optimization
C_{UPFC}	Cost of UPFC in US $/ KVar
F	Objective function
HSI	Habitat Suitability Index
Hi	ith habitat
Iter max	Number of iterations for convergence check
LL	Line loading

LVD	Load voltage deviation;
m	Refers to the load buses, where V_m is less than V_{mref}
P mod	Habitat modification probability
Pm	Mutation probability
Q_1	Reactive power flow in the line before installing UPFC device in MVAR
Q_2	Reactive power flow in the line after installing UPFC device in MVAR
S	Operating range of UPFC
S_l	Apparent power in the line *l*
$S_{l\max}$	Apparent power rating of line *l*
SIV	Suitability Index Variable
S max	Maximum species count
V_{CR}	Magnitude of series voltage source
V_k	Voltage magnitude at bus k
V_m	Voltage magnitude at bus m
V_{mref}	Nominal voltage at bus m
V_{VR}	Magnitude of shunt voltage source
W_1, W_2 & W_3	Weight factors.
θ_{CR}	Phase angle of series voltage source
θ_{VR}	Phase angle of shunt voltage source

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