SELF-ADAPTIVE FIREFLY ALGORITHM BASED UPFC PLACEMENT WITH MULTI OBJECTIVES

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Abstract: The aim of this work is to improve power system performance through Unified Power Flow Controller (UPFC) placement by the application of Self-Adaptive Firefly Algorithm (SAFA). The SAFA selects the best positions and parameters for UPFC placement. Three single objectives of Real Power Loss (P_{loss}) minimization, Voltage Profile (VP) improvement, Voltage Stability (VS) enhancement and one multi objective of P_{loss}, minimization, simultaneously improve the VP besides enhancing the VS are considered. IEEE 30 bus system is selected to perform the simulation in order to validate the SAFA approach and simulation solutions are conferred.

Key words: *FACTS, Power loss, SAFA, UPFC, Voltage Stability*

1. Introduction

Power system stability is most challenging one for power system engineers due to ever increasing load demand; as a result the power system network falls to stressed condition and leads to voltage instability. Also it's a challenge to widen the existing network to meet the ever increasing power demand by installing new generation and transmission networks due to economical and environmental constraints. An alternate way to overcome this challenge is placing Flexible Alternating Transmission system (FACTs) controllers in transmission network. The series, shunt controlled and combination of both are the classification FACTs devises. Since UPFC has the capability to serve as a series and shunt connected device simultaneously, it is popular one among the FACTs devices. Also it has the capability to control transmission power flow and bus voltages by altering impedance of transmission line, bus voltages and transmission line phase angle in which it is connected [1-3].

The power system researchers are carried out their research work for FACTs device placement on power system network and reported in their publications. They used both conventional and nonconventional method of an optimization algorithm for FACTs placement. Since optimization algorithms has many applications in the field of solving optimization problem, it is generally accepted by most of the power system researchers and they have been considered like Differential Evolution (DE), Genetic Algorithm (GA), Honey Bees Algorithm (HBA), Bacterial Foraging optimization (BFA), Particle Swarm Optimization Algorithm (PSO) Gravitational Search Algorithm (GSA) and Ant Colony Optimization (ACO)[4-15].

Available transfer capability of power system has been improved by the FACTs placement using HBA. [4]. Evolutionary algorithms such as DE and GA have been proposed to choose the suitable locations and parameters of TCSC for increasing the power flow, reduction of losses and enhancement of stability of the system and performances are tested in IEEE 14 bus system [5]. Power flow transmission cost has been reduced with the help of UPFC placement [6]. A Fuzzy lag-lead controller has been proposed to control TCSC and SVC for oscillation damping, stability enhancement and ACO applied for setting of parameters of TCSC and SVC [7]. PSO has been employed to improve power transfer capability and economic power system operation through proper SVC and TCSC placement [8]. A complete review has been reported that the application of PSO for FACTs placement in power system network [9].

Dr. Passino developed BFA to solve optimization problem than later it has been employed for minimizing loss and enhance voltage profile through UPFC placement [10-11]. SVC and TCSC have been considered for security enhancement and the comparative results are presented with BBO, WISPO and PSO [12]. A Gravitational Search Algorithm (GSA) has been proposed for FACTs placement with objectives of power loss minimization and VS enhancement [13-14]. An evolutionary algorithm has been presented for allocating FACTS to improve VS of the system [15]. Recently, Dr. Xin-She Yang has been initiated a Firefly Algorithm (FA) in 2007, for obtaining the solution for optimization problems [16]. The FA has many applications for solving power system optimization problem like economic dispatch and unit commitment etc., [17-18]. Still, due to an unsatisfactory FA parameter selection disturbing convergence and directs to secondary results. Hence SAFA has been presented for SVC and TCSC placement and only loss minimization is considered as an objective [19-20]. Multi objectives have been considered for multiple FACTs placement [21].

In this work single and multi objectives are taken into consideration for optimal position of multiple UPFC in IEEE 30 bus system using SAFA.

2. Firefly Algorithm

It has many uses of solving power system optimization problem and it belongs to nature inspired meta-heuristic algorithms [16].

The FA employs based on the light intensity among two fireflies. Twenty fireflies are chosen as number of fireflies, nf.

The *r*-th firefly light intensity is represented as

$$LI_r = Fitness\ (x_r) \quad (1)$$

$\beta_{r,s}$ is the absorption coefficient between two fireflies and is represented as

$$\beta_{r,s} = (\beta_{\max} - \beta_{\min})\exp(-\gamma_r {r_{r,s}}^2) \quad (2)$$

In the above, $r_{r,s}$ is the Cartesian distance of fireflies and is presented by

$$r_{r,s} = \|x_r - x_s\| = \sqrt{\sum_{v=1}^{nd}\left(x_r^k - x_s^k\right)^2} \quad (3)$$

The movement between two fireflies takes place, when *r-th* firefly light intensity is less than the *s-th* firefly light intensity and their movement at the *k-th* iteration is as follows

$$x_r(k) = x_r(k-1) + \beta_{r,s}\left(x_s(k-1) - x_r(k-1)\right) + \alpha\left(rand - 0.5\right) \quad (4)$$

2.1. Self-Adaptive Firefly Algorithm (SAFA)

Firefly parameters such as random movement factor (α), Absorption coefficient ($\beta_{\min}$) and attractiveness parameter (γ), are included with each firefly of decision variables. Hence these parameters are controlled over self-adaptive mechanism at each iterative process in SAFA and the firefly is represented as

$$x_r = \left[x_r^1, x_r^2 \cdots, x_r^{nd}, \alpha_r, \beta_{\min,r}, \gamma_r\right] \quad (5)$$

Each firefly with their parameters undergoes whole search process and the equation (2) is thus tailored by the following,

$$\beta_{r,s} = (\beta_{\max} - \beta_{\min})\exp(-\gamma_r {r_{r,s}}^2) + \beta_{\min,r,s} \quad (6)$$

The advantage of SAFA includes less computational effort, avoiding the sub optimal solution and convergence enhancement.

3. Mathematical Modeling of UPFC

The power flow expressions among the buses i and j are as follows [19]

Real power, $$P_{ij} = \frac{V_i V_j}{x_{ij}} \sin\delta_{ij} \quad (7)$$

Reactive Power, $$Q_{ij} = \frac{1}{x_{ij}}(V_i^2 - V_i V_j \cos\delta_{ij}) \quad (8)$$

UPFC is combination of series and shunt FACTs controllers. TCSC is a series connected FACTs device, its reactance is decided by the compensation factor and transmission line reactance in which they are connected. The modeling of TCSC is formed by reactance, X_{tc} and is presented as

$$X_{tc} = \gamma_{tc} X_{line} \quad (9)$$

$$X_{ij} = X_{line} + X_{tc} \quad (10)$$

SVC belongs to shunt connected FACTs device and is used to modify/control bus voltages through reactive power generation/absorption. SVC alter the reactive power of the bus at which they are connected as follows

$$\Delta Q_i = Q_f = -V_i^2 B_{SVC} \quad (11)$$

In order to model the UPFC, the conventional converters of the UPFC are replaced through voltage/current sources, which alter Jacobian elements based on active and reactive power injections in the buses. In this work SVC and TCSC are combined to make UPFC model using equations (9) and (11) to evade alterations in power flow and Jacobian structure.

3.1. Proposed Problem

The placement of multiple UPFC is chosen as an optimization problem and an objective is given by following expression,

Minimize $\Phi(x, y)$ (12)

Subject to $g(x, y) = 0$ (13)

$h(x, y) \le 0$ (14)

In above equations equality constraints denoted as $g(x, y)$, inequality constraints expressed as $h(x, y)$, state variable x comprise slack bus active and reactive power, generator buses reactive power generation and $P_{loss.}$ y is the control variable, which includes FACTs type, UPFC location and parameter of UPFC.

Equality constraints, $g(x, y)$ are given by the expression as follows

$P(V, \delta) - P^{sp} = 0$ for generator and load buses (15)

$Q(V, \delta) - Q^{sp} = 0$ for bus (16)

Inequality constraints, $h(x, y)$ are defined by the following expressions,

$-100\,MVAR \le Q_f \le +100\,MVAR$ (17)

$-0.8 \le \gamma_{tcsc} \le 0.2$ (18)

$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}$ for generator buses (19)

$V_i^{\min} \le V_i \le V_i^{\max}$ for load buses (20)

An objective function is formed with three single objectives and one multi objective of four cases. Single objectives are $P_{loss,}$ minimization, improvement of VP, and enhancement of VS. Multi objectives includes $P_{loss,}$ minimization, simultaneously improve the VP besides enhancing the VS.

Case 1: Real power loss (P_{loss})

Real power loss minimization expression is as follows [19]

Minimize $J_1(x, y) = P_{loss}$ (21)

Where,

$$P_{loss} = \sum_{k \in \Im} g_{ij} \left(|V_i|^2 + |V_j|^2 - 2\,|V_i|\,|V_j| \cos\delta_{ij} \right) \tag{22}$$

Case 2: Bus voltage profile (VP) improvement

The objective function for improvement of bus VP can be obtained by minimizing Total voltage deviation (TVD) as follows [21]

$$\text{Minimize } J_2(x, y) = \sum_{j \in \Phi} |V_j - 1| \tag{23}$$

Case 3: Voltage stability (VS) enhancement

VS enhancement can be achieved by minimizing L-index and its values are in between 0 and 1. The sum of L-indices represented as follows [21].

$$\text{Minimize } J_3(x, y) = \sum_{j \in \Phi} L_j \tag{24}$$

$$\text{Where, } L_j = \left| 1 - \sum_{i \in \Omega} F_{ij} \frac{V_i}{V_j} \right| \tag{25}$$

Values of F_{ij} are obtained through bus admittance matrix.

Case 4: P_{loss}, VP and VS.

In this case multi objectives are considered for minimizing Ploss at the same time improving the VP also enhancing VS and the objective function as

$$\text{Minimize, } J(x, y) = \sum_{i=1}^{nobj} w_i\, J_i \tag{26}$$

3.2. Illustration of SAFA variables

Table 1 shows the illustration of fireflies. In which the first row indicates the location for the UPFC, representing transmission line numbers L_k where the UPFC to be placed. The subsequent rows are reactive power injection, $Q_f^{\,k}$, compensation factor $\gamma_{tc}^{\,k}$ and parameters of firefly.

3.3. Fitness function

Fitness function is expressed by light intensity function (*LI*), which is maximized to get the optimal solution by the SAFA.

$$\text{Maximize } LI = \frac{1}{1 + \Psi} \tag{27}$$

Where,

$$\Psi = w_1\, J\;(x, u) + w_v \sum_{i=1}^{nload} V_{di} + w_Q \sum_{j=1}^{ngen} \left| Q_{Gi} - Q_{Gi}^{\text{limit}} \right|^2 \tag{28}$$

Table 1

Firefly Illustration for UPFC Placement

L_1	L_2	L_3	$\cdots$	L_{nf}
Q_f^1	Q_f^2	Q_f^3	$\cdots$	Q_f^{nf}
γ_{tc}^1	γ_{tc}^2	γ_{tc}^3	$\cdots$	γ_{tc}^{nf}
α	$\beta_{\min}$	γ		

4. Simulation Results and Discussion

The simulation is performed using Matlab software to analyze feasibility of SAFA for single and multi objectives optimization through UPFC placement in IEEE 30 bus system. Power flow solution is attained using N-R method during the optimization process [22]. The performance of multiple UPFC after their placement is obtained through the SAFA for the four cases, which is described in section 3. The effectiveness of SAFA is compared with the results are attained by HBA and BFA for all considered four cases. The solution for the case 1 is obtained by considering different number UPFCs and is given in Table II, which helps to select the number of UPFC for remaining cases. It is observed from the Table 2 that P_{loss} reduction is 17.1600 MW from 17.5028 MW when four UPFCs are placed. Since the P_{loss} savings less for other number of UPFCs, four UPFCs are selected for remaining cases 2-4.

Table 2
P_{loss} with Different Number of UPFC

System	UPFC No	P_{loss}
IEEE 30	0	17.5028
	2	17.2321
	3	17.1919
	4	17.1600
	5	17.1470

The performances obtained through simulation like, P_{loss}, TVD, Maximum Voltage Stability Index (MVSI) and voltage magnitudes limits are shown in Table 3 for all four cases of before and multiple UPFC placement. The case 1 objective is to minimize the P_{loss} and it is noted from this table that P_{loss} minimization is 17.1600 MW by SAFA and concurrently HBA and BFA decrease the P_{loss} to 17.1893 and 17.1916 MW respectively. It is obvious from the solutions that SAFA determines the optimal positions for UPFC placement and suitable VAR support, which reduces the P_{loss} to the minimum feasible amounts than those of HBA and BFA. Fig. 1 shows the P_{loss} savings after UPFC placement of case 1.The percentage of results of P_{loss} saving through HBA is 1.79 % and BFA is 1.78 %, though SAFA directs the P_{loss} savings to 1.96 %. The Fig. shows that SAFA offers higher savings in losses compared to HBA and BFA. The investigation of the Table 3 values also indicates that the SAFA and other algorithms fetch the entire load bus voltages to lie within the considered limits.

In Case 2, objective is improving VP through minimizing the TVD. It is known from Table 3 in case two, the TVD reduced from 0.4562 to 0.1640 by SAFA but the HBA and BFA reduces the TVD to 0.1871 and 0.1974 through multiple UPFC placements. Details of percentage of VP improvement after UPFC placement are presented in Fig. 2. HBA and BFA offers the percentage VP improvements are 58.99 % and 56.73 % respectively, but the SAFA presents the percentage VP improvement of 64.05 %. The results clearly indicate that SAFA offers the optimal placements for UPFC and their VAR support, while minimizing the TVD to improve the VP. It should be noticed that the objective of case 2 is to minimize the TVD, which leads all load bus voltage magnitudes closer to 1.0 per unit by maintaining acceptable voltage magnitude limits.

Table 3
Performance Solutions for Cases 1-4

	Method	**P_{loss} (MW)**	**TVD**	**MVSI**	**V^{low}/V^{hig} (p,u)**
Before UPFC placed		17.5028	0.4562	0.1420	0.989/ 1.082
Case-1	SAFA	17.1600	0.9984	0.1211	1.009/ 1.040
	HBA	17.1893	0.8373	0.1323	0.993 /1.050
	BFA	17.1916	1.0762	0.1237	0.952/ 1.048
Case-2	SAFA	17.8501	0.1640	0.1475	0.985 /1.026
	HBA	18.0404	0.1871	0.1464	0.983/ 1.029
	BFA	17.7850	0.1974	0.1507	0.976/ 1.031
Case-3	SAFA	18.4370	1.3456	0.0772	1.021/ 1.067
	HBA	18.4987	1.2669	0.0832	1.014/ 1.117
	BFA	18.1363	1.3546	0.0844	1.017/ 1.089
Case-4	SAFA	17.5016	0.2553	0.1164	0.986/ 1.020
	HBA	17.5022	0.2561	0.1167	0.986/ 1.020
	BFA	17.5027	0.2617	0.1461	0.978/ 1.04

The objective of case 3 is to enhance VS by minimizing MVSI. It is understatnd from the Table 3 that MVSI is reduced from 0.1420 to 0.0772, 0.0832 and 0.0844 over multiple UPFC placements by the application of self -adaptive firefly algorithm, HBA and BFA respectively. Details of percentage of VS enhancement after UPFC placement are shown in Fig.3. The BFA and HBA show the percentage of VS enhancement as 41.41 % and 40.56 % respectively, whereas the SAFA provides 45.63 % VS enhancement. It can be noticed that SAFA presents optimal locations with suitable VAR support for UPFCs.

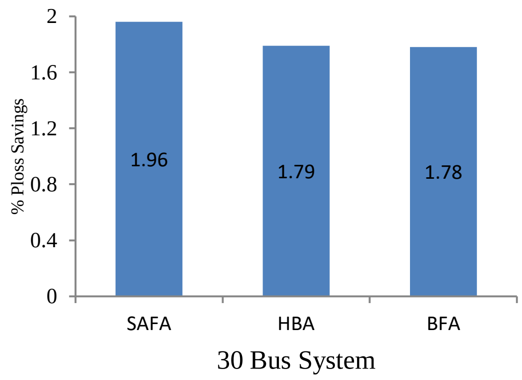

Fig. 1. Comparison of % P_{loss} Savings after UPFC Placement.

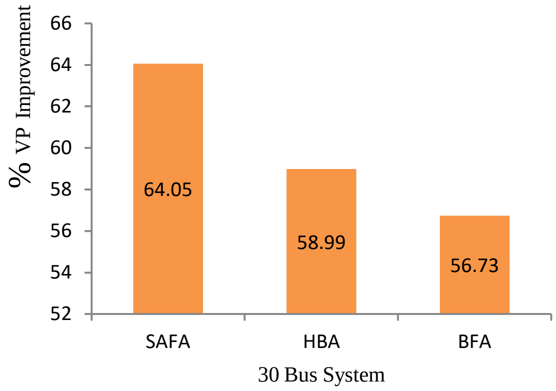

Fig. 2. % VP Improvement Comparison after UPFC Placement

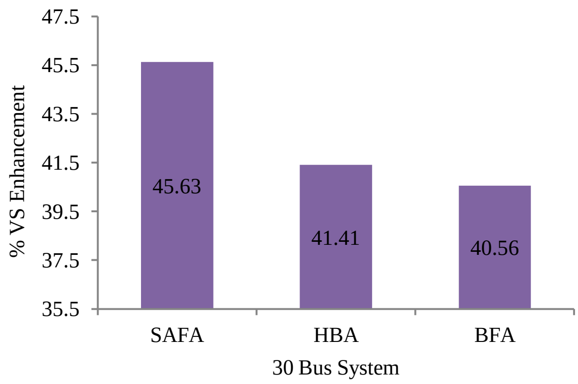

Fig. 3. Comparison of % VS Enhancement after UPFC Placement

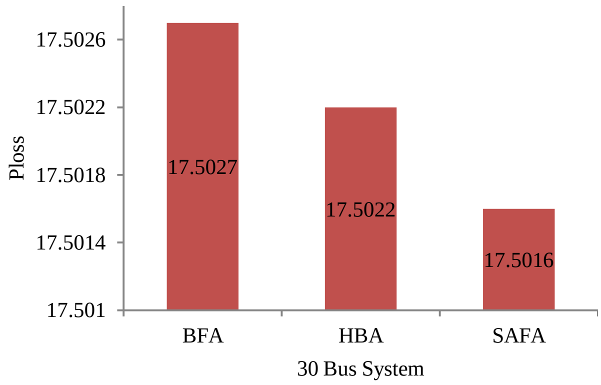

Fig. 4. P_{loss} Comparison Obtained through Case 4 after UPFC Placement

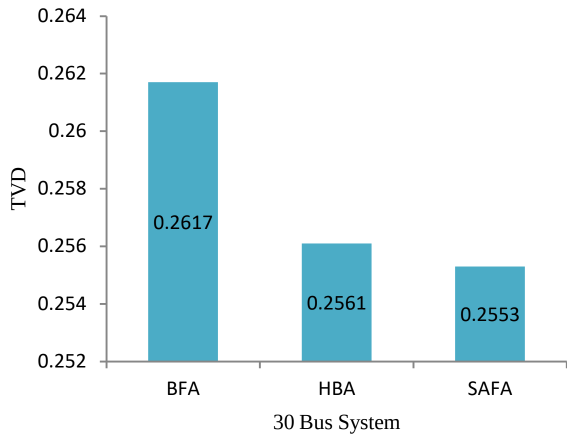

Fig. 5. TVD Comparison Obtained through Case 4 after UPFC Placement

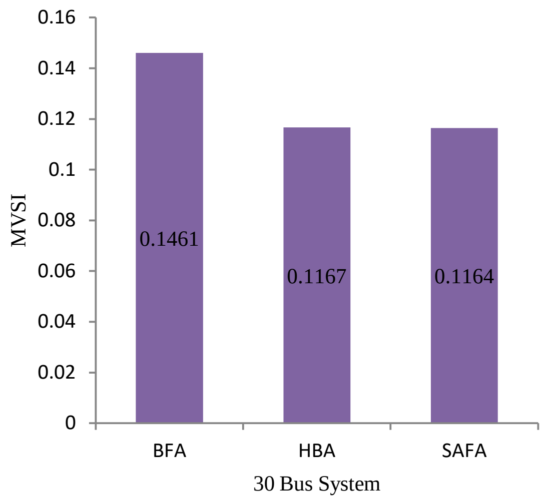

Fig. 6. MVSI Comparison Obtained through Case 4 after UPFC Placement

Table 4
Location and Parameters of UPFC obtained by SAFA

UPFC No.		1	2	3	4
Case 1	Line Location	24	4	29	37
	Injected VAR	7.043	21.718	17.280	7.661
	Compensation factor	-0.398	-0.555	0.101	-0.130
Case 2	Line Location	24	33	28	17
	Injected VAR	12.341	16.716	-27.11	-50.00
	Compensation factor	-0.310	-0.552	0.099	-0.212
Case 3	Line Location	41	12	17	36
	Injected VAR	-38.60	34.941	82.140	45.825
	Compensation factor	-0.420	-0.797	-0.049	-0.800
Case 4	Line Location	24	14	36	18
	Injected VAR	6.589	-15.81	-3.540	-43.31
	Compensation factor	-0.530	-0.603	-0.502	-0.441

Table 5
Location and Parameters of UPFC obtained by HBA

UPFC No.		1	2	3	4
Case 1	Line Location	29	15	23	34
	Injected VAR	18.281	19.070	5.954	6.173
	Compensation factor	-0.371	-0.072	-0.058	-0.465
Case 2	Line Location	24	12	18	33
	Injected VAR	-3.319	-39.01	-48.10	15.060
	Compensation factor	-0.626	0.097	-0.461	-0.220
Case 3	Line Location	14	23	36	19
	Injected VAR	59.563	-22.16	-11.78	90.908
	Compensation factor	-0.476	-0.224	-0.764	-0.209
Case 4	Line Location	24	14	36	18
	Injected VAR	6.464	-16.33	-3.544	-42.48
	Compensation factor	-0.532	-0.597	-0.499	-0.442

Table 6
Location and Parameters of UPFC obtained by HBA

UPFC No.		1	2	3	4
Case 1	Line Location	32	29	4	24
	Injected VAR	7.144	7.671	21.482	4.634
	Compensation factor	-0.733	-0.483	-0.620	-0.621
Case 2	Line Location	23	18	17	9
	Injected VAR	7.712	-37.91	-6.934	-13.13
	Compensation factor	-0.192	-0.142	0.014	-0.102
Case 3	Line Location	30	36	28	14
	Injected VAR	20.566	-2.307	59.235	-3.279
	Compensation factor	-0.126	-0.718	0.063	-0.491
Case 4	Line Location	27	20	14	17
	Injected VAR	7.709	-7.116	-28.89	-10.94
	Compensation factor	-0.703	-0.059	-0.379	-0.565

The multi objectives are considered in case 4 and they are minimizing P_{loss}, simultaneously improve the VP also enhance VS. It is observed from Table 3 (case 4) that self-adaptive firefly algorithm reduces P_{loss}, TVD and MVSI are 17.5016 MW, 0.2553 and 0.1164 respectively. The comparison of results obtained through SAFA, HBA and BFA for P_{loss} minimization, VP improvement and VS enhancement are given in Figs. 4, 5 and 6 respectively. The presented results obviously shows that the SAFA presents the optimal positions with reactive power values for multiple UPFC placements, which minimizes P_{loss}, improve the VP besides enhancing the VS.

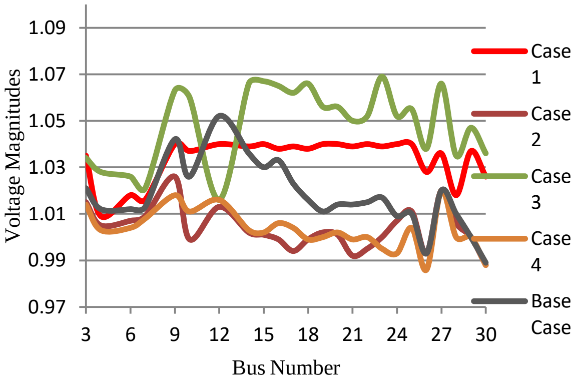

Fig. 7. IEEE 30 Bus Systems VP after UPFC Placement

Load bus voltages of IEEE 30 bus system attained through SAFA for considered all the four cases are presented in Fig. 7. Interestingly the values of voltage magnitudes are found to lie in-between 0.95 and 1.1 p.u. It can be observed from the solutions that SAFA identifies optimal positions for multiple UPFC placements for P_{loss} minimization, VP improvement and VS enhancement of the existing system. Tables 4, 5 and 6 shows the locations for UPFC placement and their parameters attained by SAFA, HBA and BFA.

5. Conclusion

Single and Multi objectives of four cases are considered to seek the optimal positions and parameters of UPFC for their installation in 30 bus system using SAFA. Performances in terms of real power loss, TVD, MVSI and VMs limits are presented and analyzed in terms P_{loss} minimization, VP improvement and VS enhancement. The SAFA identifies the optimal positions and parameter of UPFCs for existing power system performance improvement. It is obvious from the above discussion that the SAFA presents the feasible solutions than those of HBA and BFA.

6. References

[1] C.W. Taylor, "*Power System Voltage Stability*", McGraw-Hill, New Delhi, 1994.

[2] N.G. Hingorani, and L. Gyugyi, "*Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems*", Wiley, IEEE Press, 1999.

[3] R.M. Mathur and R.K. Varma, "*Thyristor-based FACTS Controllers for Electrical Transmission Systems*", IEEE Press, Piscataway, 2002.

[4] R. Mohamid Idris, A. Khairuddin and M. W. Mustafa, "*Optimal allocation of FACTS devices for ATC enhancement using Bees algorithm*", World Academy of science Engineering and Technology, Vol.30: pp.313-320, 2009.

[5] I. Ghamgeen Rashed, Yuanzhang Sun and H.I. Shaheen, "*Optimal location and parameter setting of TCSC for loss minimization based on differential evolution and genetic algorithm*", Physics Procedia, Vol.33, pp.1864-1878, 2012.

[6] Mohammad Mahdi Hosseini-Biyouki, Sajad Jashfar, Behrooz Vahidi, and Hossein Askarian-Abyaneh, "*Impact of Optimal Unified Power Flow Controller in Electrical Transmission Systems in reducing Transmission Cost*", Electric Power Components and Systems, Vol.45, No.16, pp.1762–1772, 2017.

[7] Chun-Feng Lu, Chia-Hung Hsu. and Chia-Feng Juang, "*Coordinated control of flexible AC transmission system devices using an evolutionary Fuzzy lead-lag controller with advanced continuous Ant colony optimization*", IEEE Transactions on Power System, Vol.28, No. 1, pp.385-392, 2012.

[8] B. Bhattacharyya and Vikash Kumar Gupta, "*Application of DE & PSO algorithm for the placement of FACTs devices for economic operation of a power system*", WSEAS Transactions on Power system, Vol.7, No. 4, pp.209-2016, 2012.

[9] A. Rezaee Jordehi, "*Particle swarm optimization for allocation of FACTS devices in electric transmission systems: A review*", Renewable and Sustainable Energy Reviews, Vol.52, No. C, pp.1260-1267, 2015.

[10] K.M. Passino, 'Biomimicry of bacterial foraging for distributed optimization and control", IEEE Control Systems Magazine, Vol.22, No. 3, pp.52–67, 2002.

[11] M. Senthil Kumar and P. Renuga, "*Application of UPFC for voltage stability improvement and loss minimization using Fast Voltage Stability Index (FVSI)*", Archives of Electrical Engineering, Vol.61, No. (2): pp.239-250,2012.

[12] K. Kavitha and R. Neela, "*Comparison of BBO, WIPSO & PSO techniques for the optimal placement of FACTS devices to enhance system security*", Procedia Technologies, Vol.25, pp.824-837, 2016.

[13] Jayanti Sarker and S.K. Goswami, "*Solution of multiple UPFC placement problems using Gravitational Search Algorithm*", Electrical Power and Energy Systems Vol.55, pp.531–541, 2014.

[14] M. Packiasudha, S. Suja and Jovitha Jerome, "*A new cumulative gravitational search algorithm for optimal placement of FACT device to minimize system loss in the deregulated electrical power environment*", International Journal of Electrical Power Energy and System, Vol.84, pp.34–46, 2017.

[15] Sidneo do Nascimento and Maury M, Gouvea, Jr. "*Voltage stability enhancement in power systems with automatic facts devices allocation*", Energy Procedia, Vol.107: pp.60-67. 2017.

[16] X.S. Yang, "Nature-inspired meta-heuristic algorithms", 2 nd ed., Luniver Press, Beckington, 2010.

[17] X.S. Yang, S.S. Hosseini, and A.H. Gandomi, "*Firefly Algorithm for solving non-convex economic dispatch problems with valve loading effect*", Applied Soft Computing, Vol.12, No. 3, pp.180–186, 2012.

[18] K. Chandrasekaran and P. Sishaj Simon, "*Network and reliability constrained unit commitment problem using binary real coded firefly algorithm*", International Journal of Electrical Power and Energy System, Vol.43, No. 1, pp. 921–932, 2012.

[19] R. Selvarasu, M. Surya Kalavathi and C. Christober Asir Rajan, "*SVC placement for voltage constrained loss minimization using self-adaptive Firefly algorithm*", Achieves of Electrical. Engineering, Vol.62, No. 4, pp.649–661, 2013.

[20] R. Selvarasu, and M. Surya Kalavathi, "*TCSC Placement for loss minimization using self-adaptive firefly algorithm*", Journal of Engineering Science and Technology. Vol.10, No. 3, pp.291–306, 2015.

[21] Selvarasu Ranganathan., M Surya Kalavathi. and C. Christober Asir Rajan. "*Self-adaptive firefly algorithm based multi-objectives for multi-type FACTS placement*", IET Generation, Transmission and Distribution, Vol.10, No. 11, pp.2576-2584, 2016.

[22] H. Saadat, "*Power system analysis*", 2 nd ed., McGraw-Hill, New Delhi, 2004.