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Loss reduction through optimal placement of Unified Power-Flow Controller using Firefly Algorithm

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Abstract: The aim of this paper is to reduce power loss and improve the voltage profiles in an electrical system in optimal manner. The flexible AC transmission system (FACTS) controllers such as Unified power flow controller (UPFC) can strongly improve the different parameters in a power system. UPFC can be used to improve voltage profiles, reduce line losses and increase line transmission capabilities. The optimized allocation of FACTS devices is an important issue, so the Voltage stability index (L-index) has been used in order to place UPFC in power system. The advantage of the L-index is to accelerate the optimization process. After placing the UPFC, Firefly optimization method is used for finding the rating of UPFC. The results obtained using Firefly optimization method is compared with Genetic Algorithm. To show the validity of the proposed techniques and for comparison purposes, simulation carried out on an IEEE- 14 Bus and IEEE- 30 Bus test system for normal and 150% loading conditions.

Keywords: Unified power flow controllers (UPFC), Optimized Placement, Voltage stability index (L-index), Firefly optimization method, Genetic algorithm.

I. INTRODUCTION

Most large power system blackouts, which occurred worldwide over the last twenty years, are caused by heavily stressed system with large amount of real and reactive power demand and low voltage condition. When the voltages at the system buses are low, the losses will also be increased. This study is devoted to develop a technique for improving the voltage and minimizing the loss and hence eliminate voltage instability in a power system [1]. Thyristor-Controlled Series Capacitors (TCSC), Thyristor Controlled Phase Shifting Transformer (TCPST) and Static Var Compensator (SVC) can maintain voltage in the power system as well as, can control the active power through a transmission line [2, 16].

Unified Power Flow Controller (UPFC) is a versatile FACTS device which can independently or simultaneously control the active power, the reactive power, and the bus voltage to which it is connected [2]. Following factors can be considered in the optimal installation and the optimal parameter of UPFC, the active power loss reduction, the stability margin improvement, the power transmission capacity increasing and power blackout prevention. UPFC was proposed for real time control and dynamic compensation of AC transmission systems, providing the necessary functional flexibility required to solve many of the problems which are being faced by the industry. Many advantages in power system include UPFC such as minimization of system losses, elimination of line over loads and low voltage profiles.

For last two decades researchers develop algorithms to solve Optimum power flow (OPF) incorporating FACTS devices. For Optimal location of different types of FACTS devices in the power system has been attempted using different techniques such as Genetic Algorithm (GA), Practical Swarm Optimization (PSO), Ant Bee Colony (ABC), Differential Evolution (DE), and Firefly algorithms. Dr. Xin-She Yang [9] have presented Firefly algorithm is to determine the parameters of FACTS devices. In this paper, an approach to find the optimal location of unified power flow controller (UPFC) by using Voltage stability index (L-index) to improve the load ability of the lines, minimize the total losses and improve the voltage profiles using Firefly optimization is presented. The results are compared with the GA optimization. Testing of the proposed approach is carried out on IEEE 14 and IEEE 30-bus system.

II. UPFC DEVICES MODEL

UPFC device have been selected to place in suitable location to reduce the losses improve the voltage profiles in power system. UPFC circuit is shown in Fig. 1.Power flow through the transmission line depend on line reactance, bus voltage magnitudes, and phase angle between sending and receiving end buses .i.e.., $\delta_i - \delta_j$. This is expressed by Eq.1.

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin(\delta_i - \delta_j) - - - - - - - > (1)$$

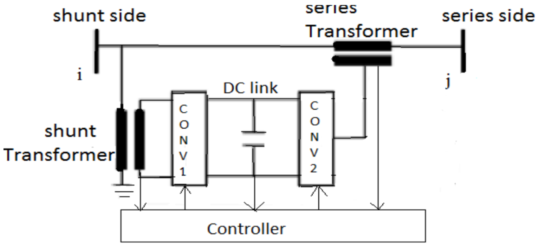

Fig. 1: UPFC schematic diagram

UPFC is capable of both supplying and absorbing real and reactive power and it consists of two ac/dc converters. One converter is connected in series with the transmission line through a series transformer and the other in parallel with the line through a shunt transformer. The dc side of the two converters is connected through a common capacitor, which provides dc voltage for the converter operation. As the series branch of the UPFC injects a voltage of variable Magnitude and phase angle, it can exchange real power with the transmission line and thus improves the power flow capability of the line as well as its transient stability limit. The shunt converter exchanges a current of controllable magnitude and power factor angle with the power system. It is normally controlled to balance the real power absorbed from or injected into the power system by the series converter. Shunt device has the capability of controlling reactive power.

The shunt converter (STATCOM) of the bus voltage/shunt reactive power is decomposed into two components. One component is in phase and the other in quadrature with the UPFC bus voltage. Decoupled control system has been employed to active simultaneous control of the UPFC bus voltage and the DC link capacitor voltage.

The series converter (SSSC) provides simultaneous control of real and reactive power flow in the transmission line [11]. To do so, the series converter injected voltage is decomposed into two components. One component of the series injected voltage is in quadrature and the other in phase with the UPFC bus voltage. The quadrature injected components controls the transmission line real power flow. UPFC: Two types of UPFC models are available. One is a coupled model and the other is decoupled model. In the first type, UPFC is modelled with series combination of a voltage source and impedance in the transmission line. In decoupled model, UPFC is modelled with between separated buses. First model is more complex compared with the second one because modification of Jacobian matrix in coupled model is inevitable. While decoupled model can be easily implemented in conventional power flow algorithms without modification of Jacobian matrix elements. Decoupled model has been used for modelling UPFC in power flow study (Fig. 1). To obtain UPFC model in load flow study, it is represented by four variables: P_{u1}, Q_{u1}, P_{u2}, and Q_{u2}. Assuming UPFC to be lossless and real power flow from bus *i* to bus *j* can be expressed as [7]:

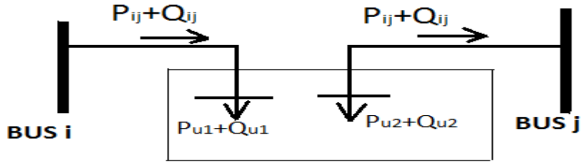

Fig. 2: Decoupled model for UPFC.

$$Pij = Pu1, Pij = Pu2$$

Although UPFC can control the power flow, but cannot generate the real power. So:

$$Pu1 + Pu2 = 0$$

It is assumed that the UPFCs are installed in the middle of lines. Each reactive power output of UPFC Qu1, Qu2 can be set to an arbitrary value depends on rating of UPFC
to maintain bus voltage.

III. OPTIMAL LOCATION FOR UPFC

In order to find the optimal location for the UPFC to be placed the bus which is mostly affected during faults has to be identified. With the increased loading of transmission and distribution lines, voltage instability problem has become a concern and serious issue for power system planners and operators. The main challenge of this problem is to narrow down the locations where voltage instability could be initiated and to understand the origin of the problem. One effective way to narrow down the workspace is to identify weak buses in the systems, which are most likely to face voltage collapse and transmission line losses. [7][3].

Voltage stability index:

Consider a n-bus system having 1, 2, 3 … n, generator buses (g), and g + 1, g + 2…n, the load buses ($r = n - g - s$). The transmission system can be represented by using a hybrid representation, by the following set of equations

$$L_j = \left| 1 - \sum_{i=1}^{g} F_{ij} \frac{|V_i|}{|V_j|} \right| ----------- > (2)$$

Where j=g+1… n and all the terms inside the sigma on the right hand side complex quantities. The complex values of $F_{ij}$are obtained from the Y_{Bus}matrix of power system. For a given operating condition:

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix}$$

WhereI_G, I_L andV_G, I_L represent complex current and voltage vectors at the generator nodes and load nodes $[Y_{GG}], [Y_{GL}], [Y_{LG}], [Y_{LL}]$ are corresponding partitioned portions of the Y_{Bus} matrix.

This analysis will be carried out only for the load buses; hence the index obtained is for load buses only. For stability the index L must not be more than 1 for any of the nodes j. The global index for stability of the given power system is defined to be **L**= maximum of L j for all j (load buses). The index far away from 1 and close to 0 indicates voltage stability. The L index will give the scalar number to each load bus. Among the various indices for voltage stability and voltage collapse prediction (i.e. far away from 1 and close to 1 or >1 respectively), the L index will give more accurate results. The L indices for given loads conditions are calculated for all load buses and the maximum of the L indices gives the proximity of the system to voltage collapse.

IV. FIREFLY OPTIMIZATION METHOD

Firefly Algorithm [12] is a metaheuristic, nature-inspired optimization algorithm which is based on the social flashing behavior of fireflies. It is based on the swarm behavior such as fish, insects or bird schooling in nature. Although the firefly algorithm has many similarities with other algorithms which are based on the so-called swarm intelligence, such as the famous Particle Swarm Optimization (PSO), Artificial Bee Colony optimization (ABC) and Bacterial Foraging (BFA) algorithms, it is indeed much simpler both in concept and implementation. Its main advantage is that it uses mainly real random numbers, and it is based on the global communication among the swarming particles called as fireflies.

A. Attractiveness

In the firefly algorithm, the form of attractiveness function of a firefly is given by the following monotonically decreasing function:

$$\beta(r) = \beta_0 * \exp(-\gamma\, r^m), \quad m \geq 1 --- > (3)$$

Where, r is the distance between any two fireflies,

β_0 is the initial attractiveness at r =0, and γ is an absorption coefficient which controls the decrease of the light intensity.

B. Distance

The distance between any two fireflies i and j at positions xi and xj respectively can be defined as :

$$r_{ij} = \left\| X_i - X_j \right\| = \sqrt{(\sum_{k=1}^{d} X_{i,k} - X_{j,k})^2} ------> (4)$$

Where $X_{i,k}$ is the k^{th}component of the spatial coordinate X_i of the i^{th} firefly and *d* is the number of dimensions.

C. Movement

The movement of a firefly i which is attracted by a more attractive i.e., brighter firefly j is given by:

$$V_{i(new)}=V_{i(old)}+\beta_0*\exp(-\gamma r_{ij}^2)*(X_i-X_j)+\alpha(\text{rand}-\frac{1}{2})----->(5)$$

Where the first term is the current position of a firefly, the second term is used for considering a firefly’s attractiveness to light intensity seen by adjacent fireflies and the third term is used for the random movement of a firefly in case there are no brighter ones. The coefficient α is a randomization parameter determined by the problem of interest, rand is a random number generator uniformly distributed in the space [0, 1].

V. FIREFLY ALGORITHM

Step 1: Read the system data such as, Load bus values, Generator bus, slack bus and all other values.

Step 2: Initialize the parameters and constants of Firefly Algorithm. They are *noff,* αmax, αmin, β0, γmin, γmax and ***itermax*** (maximum number of iterations).

Step 3: Identify the candidate buses for placement of UPFC using L-index**.**

Step 4: Generate randomly ‘n’ number of fireflies. Where each fireflies between ($-V_{imax}$) and ($+V_{imax}$). Each represented as rating of the device. Set iteration count to 1.

Step 5: By placing all the n UPFC of each Firefly at the respective candidate locations and load flow analysis is performed to find the total real power loss (P_L).The same procedure is repeated for the ‘nop’ number of particles to find the total real power losses. Fitness value corresponding to each particle is evaluated using the equation (6) for maximum loss reduction. Fitness function for maximum loss reduction is given by:

$$FV = P_{L,\text{ normal}} - P_{L,\text{ UPFC}} -------> (6)$$

Step 6: P_{best} values for all the fireflies are obtained from the fitness values and the best value among all the P_{best} values (G_{best}) is identified.

Step 7: Error is calculated different between the Maximum fitness and average fitness values are is called the Error.

Error = (maximum fitness - average fitness)

If this error is less than a specified tolerance then go to step 13.

Step 8: Determine the r_{ij}values of each firefly using the following equation:

$$r_{ij} = G_{best}FV - P_{best}FV$$

r_{ij} is obtained by finding the difference between the best fitness value G_{best} **FV and** P_{best} FV of the ith firefly.

Step 9: New $V_{i(new)}$values are calculated for all the fireflies using the following equation (5):

$V_{i(new)}=V_{i(old)}+\beta_0*\exp(-\gamma r_{ij}^2)*(X_i-X_j)+\alpha(\text{rand}-\frac{1}{2})$ Where, $\beta_0$is the initial attractiveness γ is the absorption co-efficient rij is the difference between the best fitness value G_{best} and fitness value FV of the ith firefly. *α (iter)* is the randomization parameter (In this present work, *α (iter)* value is varied between 0.4and 0.9).

Rand is the random number between 0 and 1.

Step 10: Update the position of firefly by adding the velocity.

$$P_{i,k+1} = P_{i,k} + V_{i(\text{new})} -----> (7)$$

Step 11: New fitness values are calculated for the new positions of all the fireflies. If the new fitness value for any firefly is better than previous P_{best} value then P_{best} value for that firefly is set to present fitness value. Similarly G_{best} value is identified from the latest P_{best} values.

Step 12: The iteration count is incremented and if iteration count is not reached maximum then go to step 3.

Step 13: G_{best} firefly gives the optimal UPFC sizes in n candidate locations and the results are printed.

Data used for Firefly: nop = 100; $V_{min} = -2.05$, $V_{max} = 2.05$,$\gamma_{max} = 0.9$,$\gamma_{min} = 0.4$, β_0=1, T=100.

VI. GENETIC ALGORITHM

Genetic Algorithm (GA) is one of the most famous meta-heuristic optimization algorithms which is based on natural evolution and population. Genetics which is usually used to reach to a near global optimum solution. In each iteration of GA (referred as generation), a new set of string (i.e. chromosomes) with improved fitness is produced using genetic operators (i.e. selection, crossover and mutation)[6].

A. Selection

In proposed GA, method of tournament selection is used for selection. This method chooses each parent by choosing (tournament size) players randomly and choosing the best individual out of that set to be a parent.

B. Cross Over

Cross over allows the genes from different parents to be combined in children by exchanging materials between two parents. Cross over function randomly selects a gene at the same coordinate from one of two parents and assign it to the child. For each chromosome, a random number is selected. If this number is between 0.01 and 0.3, two parents are combined; else chromosome is transferred with no cross over.

C. Mutation

GA creates mutation children by randomly changing the genes of individual parents. In this paper, GA adds a random vector from a Gaussian distribution to the parents. For each chromosome, random number is selected. If this number is between 0.01 and 0.1, mutation process is applied; else chromosome is transferred with no mutation.

Flow chart for Genetic Algorithm:

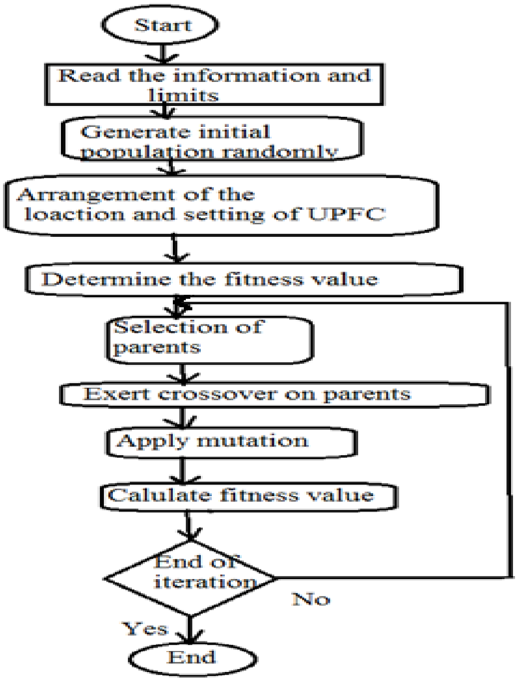

Fig. 3 .Genetic Algorithm flow chart

Table 1.Parameter Values for GA

Parameter Values For GA	
Number of variables	2
Length of variables	2
Number of chromosomes	30
Maximum number of generations	200

VII. SIMULATION RESULTS

A. Results of 14 bus system:

The proposed firefly algorithm is tested for IEEE-14 Bus systems. IEEE 14 bus system [14] contains 5 generator buses (bus numbers: 1,2,3,6 and 8), 9 load buses (bus numbers:4,5,7,9,10,11,12,13 and14) and 20 transmission lines.

This test conducted for optimal location of UPFC on load buses, rating of UPFC and real power losses before and after placement UPFC for normal and 150% loading scenario using Firefly algorithm and compare Genetic algorithm shown in below.

Voltage stability index (L-index) gives weak buses like $9^{th}, 10^{th}, 14^{th}$ So UPFC placed in these buses.

Incorporation of UPFC in IEEE 14 bus system Diagram:

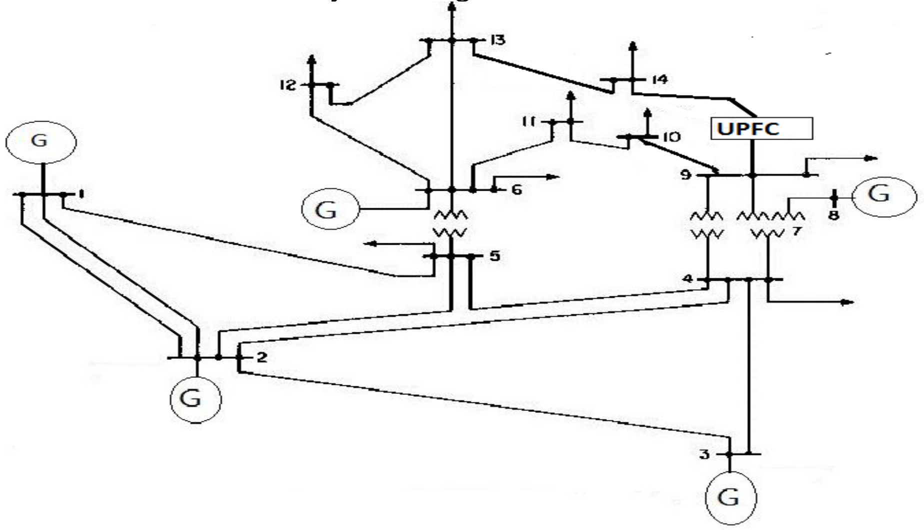

Fig 4: Modified original Network IEEE- 14 Bus system with UPFC.

Table 2: Result for 14 bus system losses without UPFC:

Aspect	Normal loading	150% loading
Total losses without UPFC (M.W)	13.3934	35.011

Table 3: Result for 14 bus system losses with UPFC:

Aspect		UPFC Location	Proposed method	
			Genetic Algorithm	Firefly Algorithm
Total losses with UPFC (M.W)	Normal loading	9-14	13.375	13.375
	150% loading	9-14	34.5747	33.7194

(a) 150% loading condition voltage Profiles:

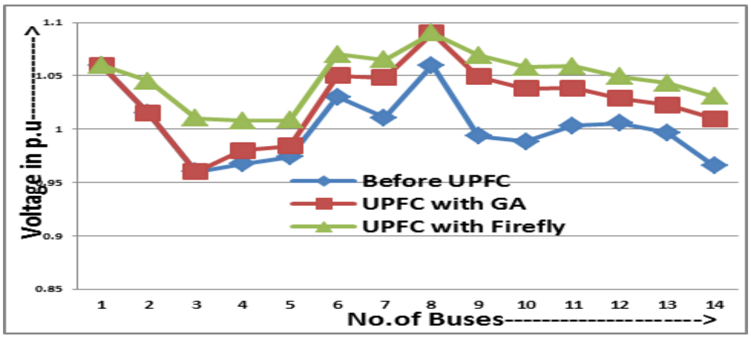

Figure 5: Voltage profile before and after placement of UPFC for 150% loading condition.

Table 4: Voltages of 14 bus system for 150% loading Condition:

Bus NO.	Before UPFC	UPFC with GA	UPFC with Firefly	Bus NO.	Before UPFC	UPFC with GA	UPFC with Firefly
1	1.0600	1.0600	1.0600	8	1.0600	1.0900	1.0900
2	1.015	1.015	1.045	9	0.9937	1.0492	1.0690
3	0.960	0.9600	1.0100	10	0.9882	1.0380	1.0581
4	0.9676	0.9801	1.0081	11	1.0033	1.0387	1.0588
5	0.9739	0.9842	1.0086	12	1.0054	1.0286	1.0490
6	1.0300	1.0500	1.0700	13	0.9967	1.0226	1.0432
7	1.0105	1.0483	1.0651	14	0.9659	1.0098	1.0305

(a) 150% loading condition Real power losses:

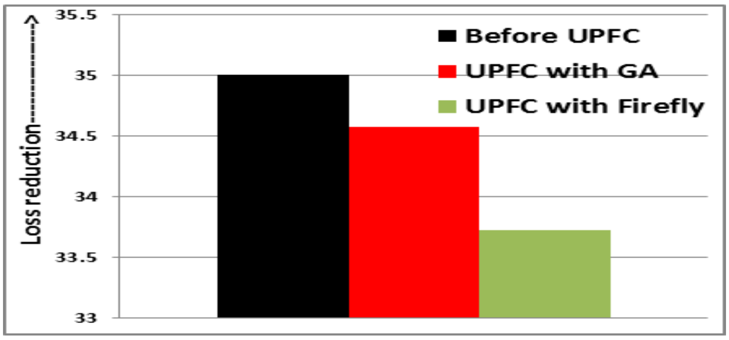

Figure 6: Real power Losses before and after placement of UPFC for 150% loading condition.

Table 5: Result for 14 bus system UPFC ratings:

Aspect		Proposed method	
		Genetic Algorithm	Firefly Algorithm
Normal loading UPFC Rating	Series converter(MVA)	6.522	6.344
	Shunt converter(MVA)	3.966	3.923
150% loading UPFC Rating	Series converter(MVA)	24.563	26.563
	Shunt converter(MVA)	10.498	10.657

Observing from the above results Firefly Algorithm gives better result when compared to Genetic Algorithm.

B. Results of 30 bus system: IEEE 30 bus system[14] contains 6 generator buses (bus numbers: 1, 2, 5 ,8, 11, and 13), 24 load buses (bus numbers : 3, 4, 6, 7, 9, 10, 12, 14 ,15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30) and 41 transmission lines. UPFC is placed in optimal location on load buses, rating of UPFC and real power losses after UPFC placement for normal and 150% loading scenario using Firefly algorithm and comparing with Genetic algorithm is shown.

Table 6: Result for 30 bus system without UPFC with losses:

Aspect	Normal loading	150% loading
Total losses without UPFC(M.W)	17.523	46.9336

Table 7: Result for 30 bus system losses with UPFC:

Aspect		UPFC Location	Proposed method	
			Genetic Algorithm	Firefly Algorithm
Total losses with UPFC (M.W)	Normal loading	27-30	17.4923	17.489
	150% loading	27-30	45.8711	44.5982

(b) 150% loading condition voltage Profiles:

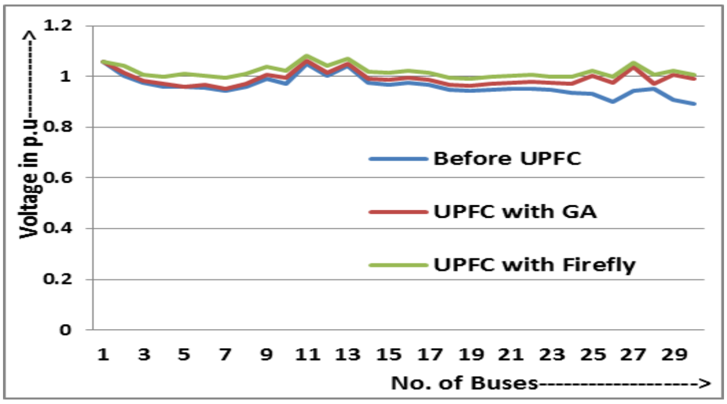

Figure 7: Voltages before and after placement of UPFC for 150% loading condition.

Table 8: Voltages of 30 bus system for 150% loading condition:

Bus NO.	Before UPFC	UPFC with GA	UPFC with Firefly	Bus NO.	Before UPFC	UPFC with GA	UPFC with Firefly
1	1.0600	1.0600	1.0600	16	0.9771	0.9947	1.0217
2	1.003	1.0130	1.0430	17	0.9656	0.98520	1.0133
3	0.9744	0.9838	1.0074	18	0.9487	0.9693	0.9969
4	0.9580	0.9696	0.9986	19	0.9435	0.9642	0.9924
5	0.9600	0.9600	1.010	20	0.9495	0.9702	0.9984
6	0.9553	0.9683	1.003	21	0.9526	0.9763	1.0045
7	0.9438	0.9517	0.9933	22	0.9534	0.9781	1.0006
8	0.9600	0.9700	1.0100	23	0.9466	0.9746	1.0009
9	0.9927	1.0088	1.0368	24	0.9340	0.9721	0.9979
10	0.9729	0.9932	1.0214	25	0.9310	1.004	1.0241
11	1.0520	1.0620	1.082	26	0.9015	0.9768	0.9975
12	1.0020	1.0156	1.0411	27	0.9434	1.0370	1.0532
13	1.041	1.0510	1.071	28	0.9508	0.9724	1.0059
14	0.9749	0.9927	1.0190	29	0.9097	1.0068	1.0236
15	0.9663	0.9863	1.0128	30	0.8903	0.9894	1.0066

From the above tables Firefly Algorithm gives better result when compared to Genetic Algorithm.

(c) 150% loading condition Real power losses:

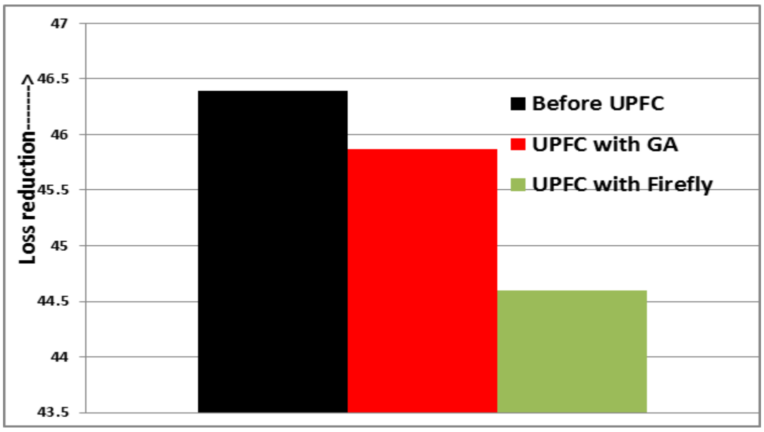

Figure 8: Real power Losses before and after placement of UPFC for 150% loading condition

Table 8: Result for 30 bus system UPFC ratings:

Aspect		Proposed method	
		Genetic Algorithm	Firefly Algorithm
Normal loading UPFC Rating	Series converter(MVA)	7.522	7.0623
	Shunt converter(MVA)	2.0685	1.8994
UPFC Rating 150% loading	Series converter(MVA)	17.622	14.465
	Shunt converter(MVA)	10.395	5.7056

Observing from the above results Firefly Algorithm gives better result when compared to Genetic Algorithm.

VIII. CONCLUSION

A two-stage methodology of finding the optimal location and sizes of Unified Power Flow Controller for Real and Reactive power compensation of standard tested IEEE-14 and IEEE-30 Bus system is presented. Voltage stability index approach is proposed to find the optimal Unified Power Flow Controller locations and firefly and Genetic algorithms is proposed to find the optimal sizes of Unified Power Flow Controller. Based on the simulation results, the following conclusions are drawn: By installing Unified Power Flow Controller at all the potential locations, the total real and reactive power loss of the system has been reduced significantly and at same bus voltages are improved substantially. The proposed Firefly optimization iteratively searches the optimal Unified Power Flow Controller size for the improve the voltage values reduced power losses more compare to the Genetic Algorithm. The coding of Firefly method is simple compare to the GA. Because the Firefly method has no evolution operators such as cross over and mutation, which appears in GA method.

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