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Research Article

Real and Reactive Power Compensation Using UPFC by Bacterial Foraging Optimization Algorithm (BFOA)

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Abstract: This study presents a finding an optimal location and best parameter setting of Unified Power Flow Controller (UPFC) by Bacterial Foraging Optimization Algorithm (BFOA) for minimizing the active and reactive power loss in power system. The UPFC is one of the important Flexible Alternating Current Transmission System (FACTS) device that control simultaneously voltage magnitude at the sending end and the active and reactive power at the receiving end bus. The FACTS devices have been proposed to be effective for controlling the power flow in transmission lines. However the cost of installing the UPFC is too high. Therefore the objective functions used in this study consider a way to find the compromise solution to a problem. Simulations have been implemented in MATLAB software and IEEE 30 bus system is used. Installing the UPFC in the optimal location by BFO Algorithm can significantly minimize the active and reactive power loss in the power system network.

Keywords: Bacterial Foraging Optimization Algorithm (BFOA), Optimized Placement, Unified Power Flow Controller (UPFC)

INTRODUCTION

Many power systems blackouts, which occurred worldwide over twenty years, are caused by heavily stressed system with large amount of real and reactive power demand and low voltage condition. Besides with electricity market deregulation, increases the number of unplanned power exchanges due to competition among the utilities. While power flow in some of the transmission line was normal condition, the other lines are be overloaded, which effects the voltage profile management and power loss in transmission system. So the fast development technology have introduced as named as FACTS which is the pattern for future power system.

From the above equation it is clear that power flow is a function of transmission line impedance, the magnitude of sending and receiving end voltages and phase angle between the voltages. One of the most important promising devices is the UPFC which have introduced by the Gyugiy in the year 1991. The device UPFC is used to increase the power flow as well as the system through a proper controller design. Hence the functionality of the UPFC is to determine the optimal location placement and the best parameter setting may be the active and reactive power loss reduction, which also increases the power transfer capacity and the system (Ramesh and Damodara Reddy, 2013).

In the last decades, many researchers have been proposed for finding the optimal location and parameter setting of UPFC device. The UPFC can independently or simultaneously controls the active power, reactive power, bus voltage. For optimal location of UPFC in IEEE bus system different techniques have been developed. They are Genetic Algorithm (GA), Practical Swarm Optimization (PSO), Ant Bee Colony (ABC), Differential Evolution (DE) and Firefly algorithms, Bacterial Foraging Optimization Algorithm (BFOA). This BFOA was proposed by Passion (Kirankumar and Suresh Babu, 2012).

In recent days, a new proposed technique called as Bacterial Foraging Algorithm is used for optimization techniques. This BFOA is robust and fast implement techniques. By using UPFC they are many advantages such as eliminating the over loads, reduce the power system loss and also low voltage profiles (Jigar *et al.*, 2012).

PROBLEM FORMULATION

UPFC device model: The UPFC device used in this study is to reduce the power loss in the system. The basic operation of UPFC schematic is shown in Fig. 1. The UPFC normally consists of two converters which are connected to common DC link. The series inverter coupled to transmission line through series transformer.

The Fig. 1 shows the back to back voltage source UPFC converter. The UPFC device is used for reducing loss and as well as maintaining a system stability condition and maintaining the voltage level (Ramesh and Damodara Reddy, 2013).

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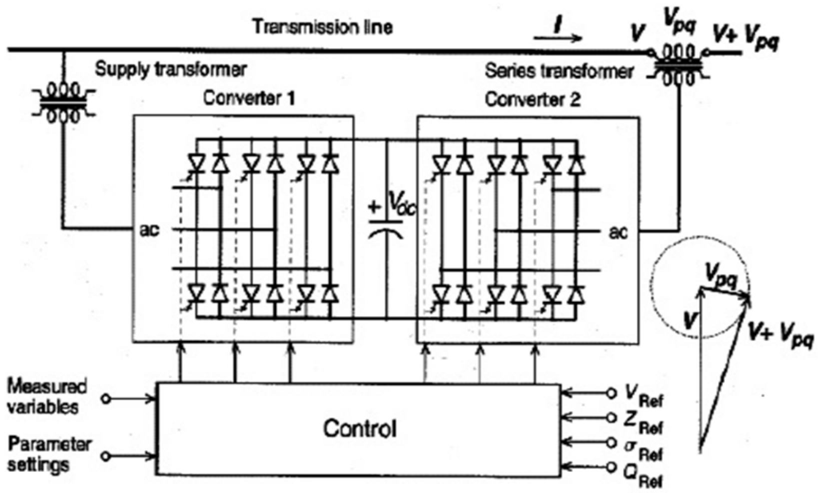

Fig. 1: Implementation of UPFC

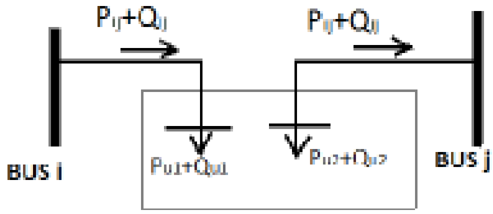

Fig. 2: Decoupled method of UPFC

As well as the shunt inverter is coupled to transmission line through shunt transformer. The shunt inverter can generate or absorbs the reactive power and the series inverter satisfies the operating requirements. The shunt converter is decomposed to two components (Syed and Mohammed, 2011). One component is in phase and other component is quadrature with UPFC bus voltage. It can independently and very rapidly can control the both real and reactive power flows in a transmission line and its configuration is shown in Fig. 1. The dc voltage for the both converter is provided by common capacitor bank which is shown in Fig. 1.

The converter 1 is used mainly for supplying the real power demand of the converter 2; it drives from the transmission line. The net real power which is drawn from ac system is same or equal to the losses of the two converters Basu (2008). The shunt converter which acts like an STATCOM and regulates the terminal voltage. The UPFC has the capabilities of the voltage regulation, series compensation and the phase shifting. The series converter is used for control to inject a voltage phasor in series with the line. Although the reactive power is internally generated/absorbed by the series converter, the real power generation/absorption is made by the dc energy storage device (i.e., capacitor).

The decoupled model circuit of UPFC is shown in Fig. 2. Although the UPFC can control the power flow, but cannot generate the real power. So from reference study (Ghamgeen *et al*., 2011a):

$$P_{u1} + P_{u2} = 0 \tag{1}$$

The range of shunt angle is $0 \leq \theta_{sh} \leq 2\pi, V_{sh}$ and θ_{sh} are the magnitude and angle controllable for the shunt voltage converter the limit of the shunt converter is $V_{sh\,max} \leq V_{sh} \leq V_{sh\,min}$. Likewise, the magnitude and angle controllable for the series voltage converter is in the range is $0 \leq \theta_{se} \leq 2\pi$, the limit of series converter is $V_{se\,max} \leq V_{se} \leq V_{se\,min}$ Janathan and Palaniswami, (2012).

Objective function: The objective function of this study is to minimization of the real and reactive power loss in transmission network which always consider an important issue in planning and operating terms in the power system. The UPFC device must be installed with optimal location and parameter setting to minimizing losses as much as possible Dong *et al*., (2007). By installing the FACTS devices the cost plays an major role and however in the general case the installation cost of the UPFC is too high. So in this objective function is developed according to reduces the cost function. The objective function in this study is summation of the two terms as shown (Ghamgeen *et al*., 2011b):

$$\min F = \sum_{k=1}^{ntl} PQ_{kloss} + \gamma \times 1000 \times C_{UPFC} \times S \tag{2}$$

The cost function of the UPFC is shown below:

$$C_{UPFC} = 0.0003 s_{FACTS}^2 - 0.2691 s_{FACTS} + 188.22 \tag{3}$$

where,

- F = The objective function
- ntl = Number of transmission line in the network
- PQ_{kloss} = The real and reactive power in the line k
- γ = The penalty factor
- C_{UPFC} = The cost of the UPFC AND s is the operating range of the UPFC device

Constraints of the system:

- **Equality constraints:** For bus k:

$$P_k(V,\theta) + P_{dk} - P_{gk} = 0 \quad (4)$$

$$Q_k(V,\theta) + Q_{dk} - Q_{gk} = 0 \quad (5)$$

where,

P_k and Q_k = The real and reactive powers in the bus k

P_{dk} and Q_{dk} = The real and reactive power load at bus k

P_{gk} and Q_{gk} = The real and reactive power generations at bus k Prashant and Yog, (2009)

- **Inequality constraints:**

$$P_{gk}^{min} \le P_{gk} \le P_{gk}^{max} \ \mathrm{k} = 1,\ldots,n_g \quad (6)$$

$$Q_{gk}^{min} \le Q_{gk} \le Q_{gk}^{max} \ \mathrm{k} = 1,\ldots,n_g \quad (7)$$

$$V_k^{min} \le \mathrm{V_k} \le V_k^{max} \ \mathrm{k} = 1,\ldots.n_b \quad (8)$$

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

$$V_{sh}^{min} \le V_{sh} \le V_{sh}^{max} \quad (10)$$

$$V_{se}^{min} \le V_{se} \le V_{se}^{max} \quad (11)$$

where:

n_b and n_g = The set of buses and generation buses indices

V_k and δ_k = The voltage magnitude and power angle at bus k

OPTIMIZATION METHODS

Bacterial Foraging Optimization algorithm method (BFO): Bacterial Foraging Optimization Algorithm (BFOA) is one of the famous algorithms. It is based on the nature-inspired optimization. This method consists of four types of steps in its operation. They are (Ghamgeen *et al*., 2012):

- Chemo taxis
- Swarming
- Reproduction
- Elimination and dispersal Riya (2013)

Chemo taxis: This process is based on movement of a cell through swimming and tumbling through flagella. The movement of cell consists of two different types of ways. In the same direction of movement it can swim for a period of time or it may tumbles. This alternating two operations is the entire for its lifetime Sajad and Mohammad (2011)

Swarming: In this method a group of cells arranged in the travelling ring by moving up of the nutrient gradient Jahant *et al*. (2010).

Reproduction: In this method the bacteria is splits into two ways and placing in the same location. They least healthy bacteria will die eventually. And healthier bacteria will keep the swarm size constant Bindeshwar *et al*., (2010).

Elimination and Dispersal: In this method sudden change in environmental conditions the bacteria gets killed and dispersed in a new location.

Algorithm of BFOA:

1. Initializing the parameters p, S, N_c, N_s, N_{re}, N_{ed}, P_{ed}, C (i) = (1, 2….S), θ^i
2. Elimination/dispersal loop: *l*=*l*+1.
3. Reproduction loop: *k* = *k*+1.
4. Chemo taxis loop: *j* = *j*+1

i) For *i* =1, 2…S take a chemo taxis step for bacterium *i* as follows.

ii) Compute fitness function, *J (i, j, k, l)*.
Let, $J(i,j,k,l) = J(i,jk,l) + J_{cc}(\theta^i(j,k,l), P(j,k,$ $l)$ (i.e., add on the cell-to cell attractant-repellant profile to simulate the swarming behavior) Jose *et al*., (2007), where, J_{cc} is defined in (2).

iii) Let $J_{last} = J(i,j,k,l)$ to save this value since we may find a better cost via a run.

iv) Tumble: generate a random vector $\Delta(i) \in R^p$ with each element $\Delta_m(i), m = 1,2,\ldots p, a$ random number on [-1, 1]

v) Move: Let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \quad (12)$$

This results in a step of size $C(i)$ in the direction of the tumble for bacterium i.

vi) Compute *J* (*i*, *j* +1, *k*, *l*) and let:

$$J(i,j+1,k,l) = J(i,j,k,l) + J_{cc}\left(\theta^i(j+1,k,l), P(j+1,k,l)\right) \quad (13)$$

vii) Swim process:

a) Let *m* = 0 (counter for swim length)

b) While $m < N_s$ (if have not climbed down too long)

- Let $m = m + 1$
- If $J(i,j+1,k,l) < J_{last}$ (if doing better), $J_{last} = J(i,j+1,k,l)$ and let

$$\theta^i(j+1,k,l) = \theta^i(j,k,l) + C(i)\frac{\Delta(i)}{\sqrt{\Delta^T(i)\Delta(i)}} \quad (14)$$

And use this $\theta^i(j+1,j,k)$ to compute the new $J(i,j+1,k,l)$ as we did in [f].

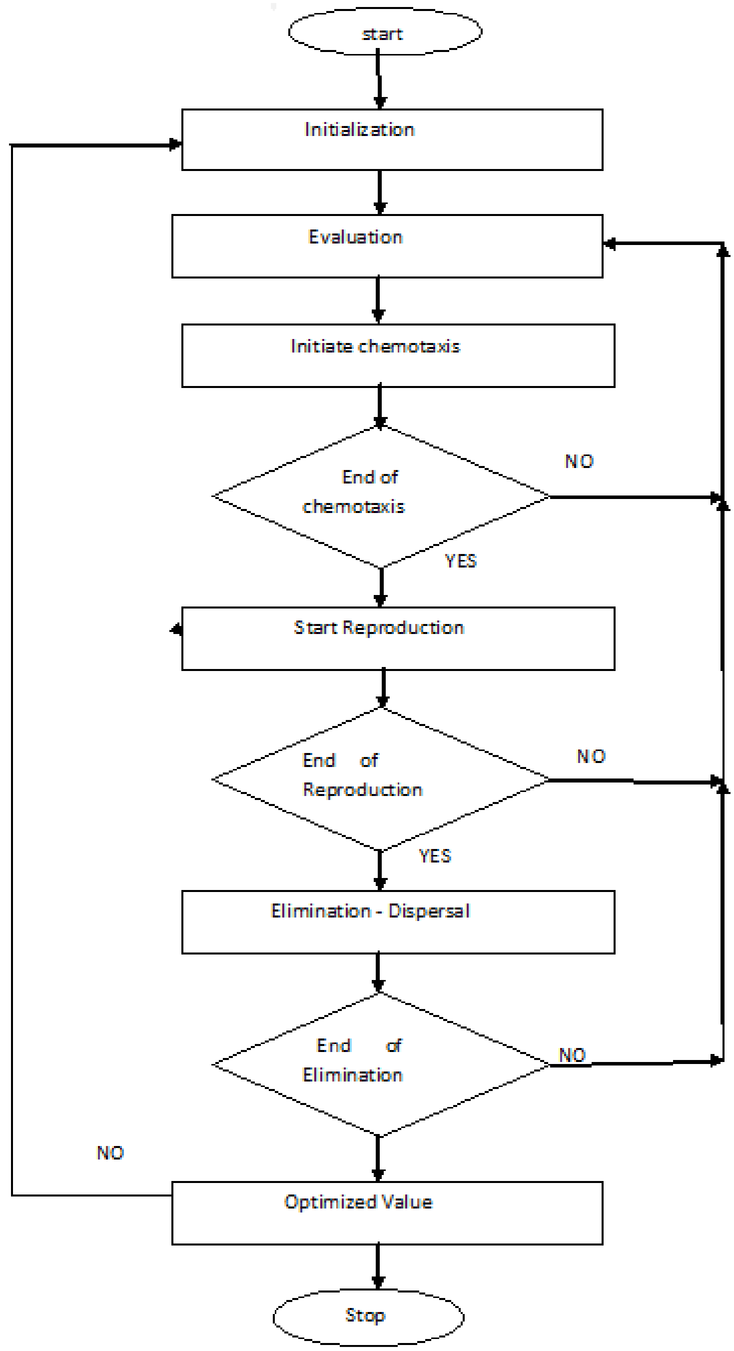

Fig. 3: Flow chart of BFOA

- Else, let $m = N_s$. This is the end of the while statement.

c) Go to next bacterium $(i + 1)$ if $i \neq S$ (i.e., go to [b] to process the next bacterium.

5. If $j < N_c$, go to step 4. In this case continue chemo taxis since the life of the bacteria is not over.
6. Reproduction process.

i) For the given k and l and for each i = 1, 2, ….S, let:

$$J_{health}^{i} = \sum_{j=1}^{N_c+1} J(i, j, k, l) \quad (15)$$

Be the health of the bacterium i (a measure of how many nutrients it got over its lifetime and how successful it was at avoiding noxious substances). Sort bacteria and chemo tactic parameters $C(i)$ in order of ascending cost J_{health} (higher cost means lower health).

ii) The S_r bacteria with the highest J_{helth} values die and the remaining S_r bacteria with the best values split (this process is performed by the copies that are made are placed at the same location as their parent).

7. If $k < N_{re}$, go to step 3. In this case, we have not reached the number of specified reproduction steps, so we start the next generation of the chemo taxis loop.
8. Elimination-dispersal process: For i = 1, 2..., S with probability P_{ed}, eliminate and disperse each bacterium (this keeps the number of bacteria in the population constant). To do this, if a bacterium is eliminated, simply disperse another one to a random location on the optimization domain. If $l < N_{ed}$, then go to step 2; otherwise end.

Let *l* be the elimination-dispersal event. Also let:

p : Dimension of a search space
S : Total number of bacteria in the population
N_c : The number of chemo tactic steps
N_s : The swimming length
N_{re} : The number of reproduction steps
N_{ed} : The number of elimination-dispersal events
P_{ed} : Elimination-dispersal probability
$C(i)$: The size of the step taken in the random direction specified by the tumble

This process is mainly depends on the process to determine the fitness criteria. This process is for the minimizing the objective function. The BFOA is mainly for the research in the field of biological motivation knowledge and the graceful structure. Without the analytical problem description the BFOA is used to find the minimum objective function and gives an exact optimum function. According its four types of steps this BFOA acts its operation and gives an exact objective function. This BFOA is works with the help of the flagella which the bacteria may choose the swim or tumble operation.

Table 1: Initial parameters of BFOA

Dimension of search space, p	03
The number of bacteria, s	08
The number of chemo taxis steps, N_c	04
Limits the length of swim, N_s	02
The number of elimination-dispersal events, N_{ed}	10
The number of reproduction steps	02
The probability that each bacteria will be eliminated/ dispersed	0.3

Table 2: Optimal parameter setting of UPFC

UPFC location	2-3
Series voltage magnitude, V_{se}	0.030000 p.u.
Angle of series injected voltage, θ_{se}	1.652916
The real power loss	0.382444 p.u.

Flow Chart of BFOA: The detailed flow chart of the BFOA algorithm is shown by the Fig. 3.

SIMULATION RESULTS

The effectiveness of proposed techniques was illustrated using by IEEE-39 Bus System. MAT LAB coding for BFOA and the facts device UPFC are incorporated for the simulation process. According to the lowest cost obtaining in the bus system the UPFC have been placed. The Table 1 shows the initial parameters of BFOA.

There are no standard values for BFOA parameters because the techniques are probabilistic and stochastic search techniques, the adopted values were found to give the best performance. Therefore, the simulation results obtained by these techniques should be evaluated statistically. In this research, the performance evaluation of these techniques is performed with 100 trials and the obtained results are presented.

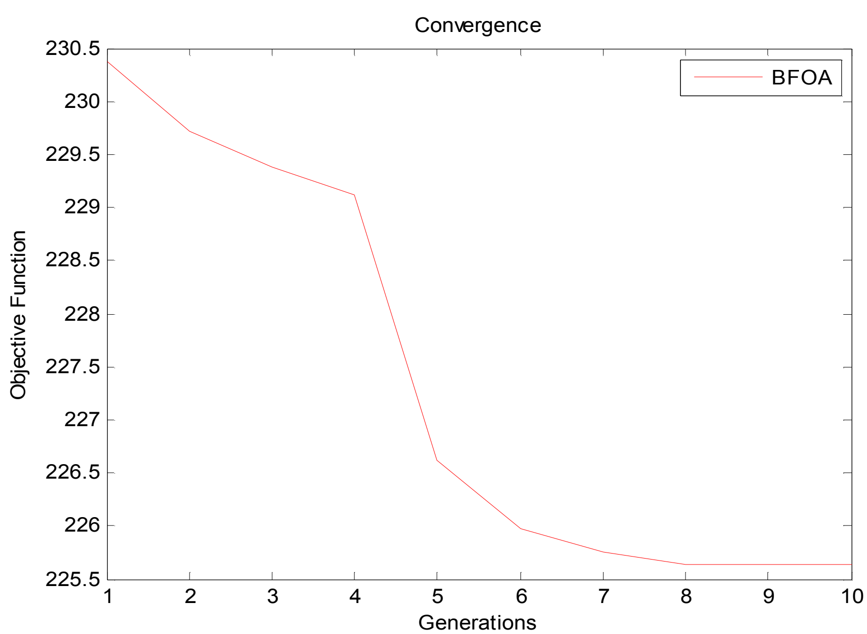

Fig. 4: Convergence speed of BFOA

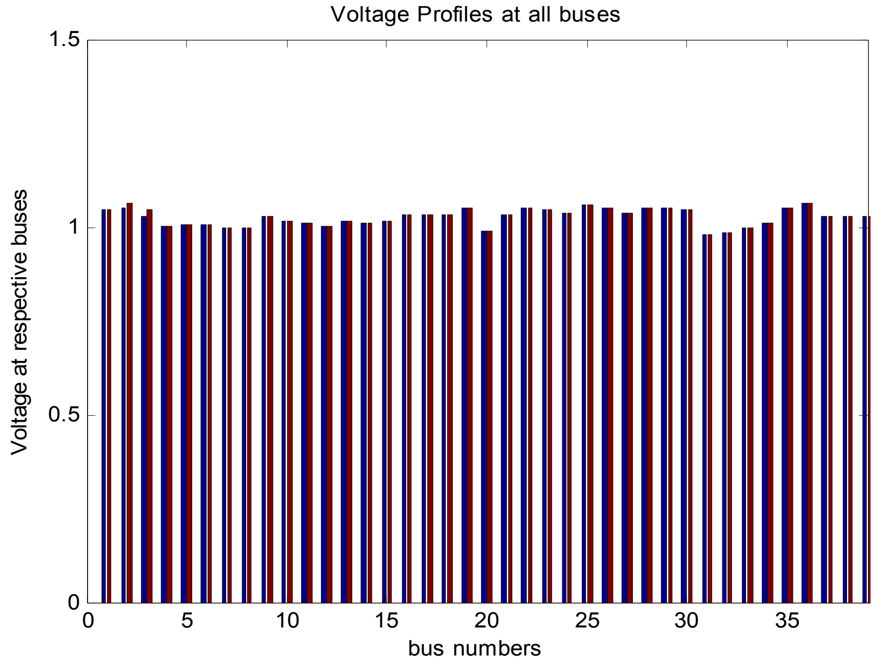

Fig. 5: Voltage profile of 39 Bus System

Table 3: Power loss on IEEE 39 bus system

From Bus	To Bus	Real power loss (MW)	From Bus	To Bus	Real power loss (MW)
8	9	0.184	13	14	0.670
9	39	0.004	13	12	0.035
10	11	0.537	21	16	0.821
10	13	0.320	21	22	2.782
11	6	0.917	25	2	4.161
11	12	0.029	25	37	1.656
13	10	0.320	39	9	0.004

IEEE 39-bus test system: The optimal placement of UPFC which is achieved from implementing BFOA technique in this case is in line number three (from bus 2 to bus 3) with minimum installation cost of 187.395400 (US $/KVAR).

The Table 2 shows the optimal parameter setting of the UPFC for this proposed method. In the table consists the voltage and angle of the series converter and the real power loss.

Convergence speed: The convergence speed of the Bacterial Foraging Optimization Algorithm (BFOA) process for this objective function is shown in the Fig. 4.

The voltage profile for the IEEE 39 Bus System before and after placing the UPFC is shown in Fig. 5.

In the Fig. 5, the bus number 2 and 3 they have voltage profile changes and remaining bus system the voltage profile is same before and after placing the UPFC. According to the cost function the buses 2 and 3 have minimum so the UPFC is placed in between the buses 2 and 3.

The Table 3 gives the details of power loss of IEEE 39 Bus System, after placing the UPFC which is shown below.

CONCLUSION

In the power systems, the facts device UPFC plays an important role for selecting the location and important in implementing the step of UPFC. The benefits of the UPFC device include the improvement of voltage profile management, improvement in system stability, reduction of transmission losses and investment cost. This device is well expert in changing the system parameters in the effective way and provides a better result.

This study is made to find an optimal location and parameter setting of UPFC device which is to minimize the real and reactive power losses of the system with the minimization of UPFC location cost. For implementing this method, a newly inspired technique namely Bacterial Foraging Optimization Algorithm (BFOA) have been made successful for implementing this method.

For implementing this method the IEEE 39 Bus System has been taken. The obtained results shows that BFOA technique is well suits for the optimal location and parameter setting of UPFC device and reduces the real and reactive power loss in the system with minimization of UPFC location cost.

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