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Optimal Location of UPFC by BFO, MSFL and ICA Algorithms

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Abstract: *This paper presents a finding an optimal location and best parameter setting of Unified Power Flow Controller (UPFC) by Bacterial Foraging Optimization Algorithm (BFOA) and Modified Shuffled Frog Leap Algorithm (MSFLA) and Imperialist Competitive Algorithm(ICA) 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 paper consider a way to find the compromise solution to a problem. Simulations have been implemented in MATLAB software and IEEE 39 bus system is used. Installing the UPFC in the optimal location by ICA Algorithm can significantly minimize the active and reactive power loss in the power system network. The result of the ICA is compared with the BFO and MSFL algorithms.*

Keywords: *Unified Power Flow Controller (UPFC); Optimized Placement; Bacterial Foraging Optimization Algorithm (BFOA), Modified Shuffled Frog Leap Algorithm (MSFLA), Imperialist Competitive Algorithm (ICA).*

I. 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 [1].

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 Passino [5].

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 [4].

II. Problem Formulation

A. UPFC device model

The UPFC device used in this paper 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 [1].

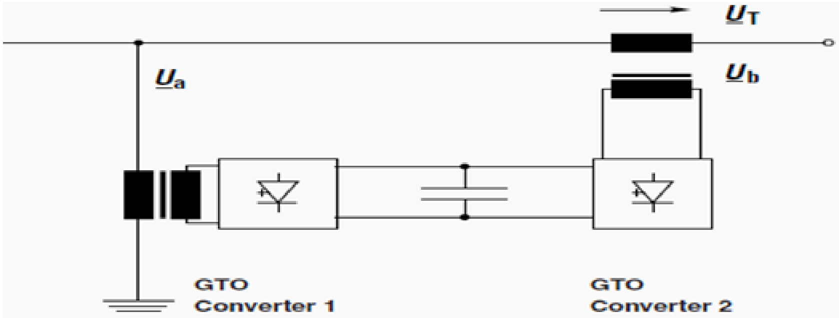

Fig.1. Implementation of UPFC.

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 [8]. 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. 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 an 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).

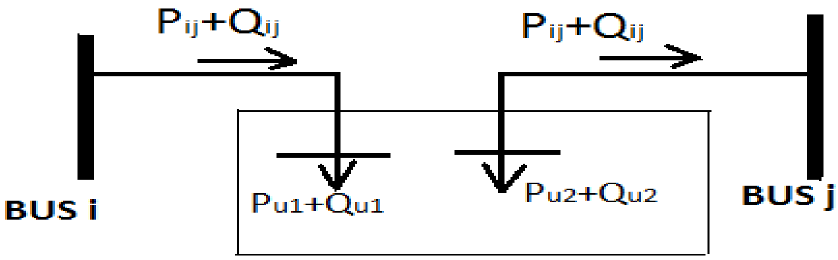

Fig.2.Decoupled method of UPFC.

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 [9]:

$$P_{u1} + P_{u2} = 0 \quad (1)$$

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

B. Objective Function

The objective function of this paper 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. 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 paper is summation of the two terms as shown below [9]:

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

The cost function of the UPFC is shown below:

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

Where F is the objective function, ntl is number of transmission line in the network, PQ_{kloss} are the real and reactive power in the line k, γ is the penalty factor, C_{UPFC} is the cost of the UPFC AND s is the operating range of the UPFC device.

1. Constraints of the System

a) Equality Constraints

For bus k:

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

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

Where P_k *and* Q_k is the real and reactive power in the bus k; P_{dk} *and* Q_{dk} are the real and reactive power load at bus k; P_{gk} and Q_{gk} are the real and reactive power generations at bus k.

b) Inequality Constraints

$$P_{gk}^{min} \le P_{gk} \le P_{gk}^{max} \qquad k=1,\dots,n_g \tag{6}$$

$$Q_{gk}^{min} \le Q_{gk} \le Q_{gk}^{max} \qquad k=1,\dots,n_g \tag{7}$$

$$V_k^{min} \le V_k \le V_k^{max} \qquad k=1,\dots,n_b \tag{8}$$

$$\delta_k^{min} \le \delta_k \le \delta_k^{max} \tag{9}$$

$$V_{sh}^{min} \le V_{sh} \le V_{sh}^{max} \tag{10}$$

$$V_{se}^{min} \le V_{se} \le V_{se}^{max} \tag{11}$$

Where:

n_b and n_g are the set of buses and generation buses indices; and

V_k and δ_k are the voltage magnitude and power angle at bus k.

III. Optimization Methods

I. 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 [3]

i) Chemo taxis
ii) Swarming
iii) Reproduction
iv) Elimination and Dispersal

i) 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.

ii) Swarming:

In this method a group of cells arranged in the travelling ring by moving up of the nutrient gradient.

iii) 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 keeps the swarm size constant.

iv) Elimination and Dispersal:

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

A) 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).

iii. 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)

iv. where, J_{cc} is defined in (2).

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

vi. Tumble: generate a random vector $\Delta(i) \in R^p$ with each element $\Delta_m(i), m = 1,2, \dots p, a$ 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 $J(i,j+1,k,l) = J(i,j,k,l) + J_{cc}\left(\theta^i(j+1,k,l), P(j+1,k,l)\right)$ (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

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

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

- 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

$$J^i_{health} = \sum_{j=1}^{N_c+1} J(i,j,k,l) \quad (14)$$

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 an 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.

B) Flow Chart of BFOA

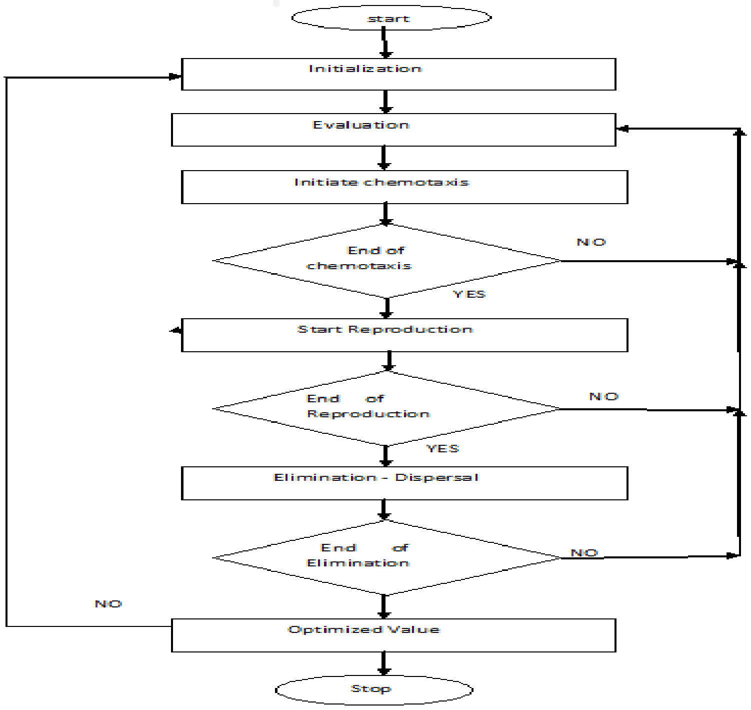

Fig. 3. Flow chart of BFOA

II. Modified Shuffled Frog Leap Algorithm (MSFLA):

Shuffled Frog Leaping Algorithm is a kind of evolutionary computation method based on swarm intelligence. Eusuff and Lansey proposed the algorithm in 2001, which is inspired by the frog prey behavior. Shuffled Frog Leaping Algorithm is similar to Memetic Algorithm, which is based on group cooperative search .At the same time, it is also provided with the advantage similar to Particle Swarm Optimization Algorithm. Shuffled Frog Leaping Algorithm has a lot of strong points,such as few parameters, easy to implement and fast convergence Shuffled Frog Leaping Algorithm was applied by all kinds of intelligent optimization systems. For example, Mgmt made use of the Shuffled Frog Leaping Algorithm in the water distribution optimization system in 2003 and Alireza applied th e SFL algorithm in the mixed linear model series in 2007.

A) Steps for MSFLA

The step by step algorithm are as follows

Step1: Create an initial population of P frogs generated randomly. SFLA Population =[X1,X2,…,Xp] p×n Where, P=m×n,N is the number of distributed generation , m is the no of memplexes and n is the number of frogs .

Step 2: Sort the population increasingly and divide the frogs into m each holding n frogs such that P=m×n.

Step 3: Within each constructed memeplexes, the frogs are effected by other frogs' ideas; hence they experience a metaheuristics evolution. Me-metic evolution improves the equality of the meme of an individual and enhances the individual frog's performance towards a goals. Below which are details of me-metic evolution for each memeplexes

Step 4: Check the convergence. If the convergence criteria are satisfied stop, otherwise consider the new population set as the
initial population and return to the step2. The best solutions is found in the search process is considered as the output
results of the algorithm.

B) Flow chart of MSFLA

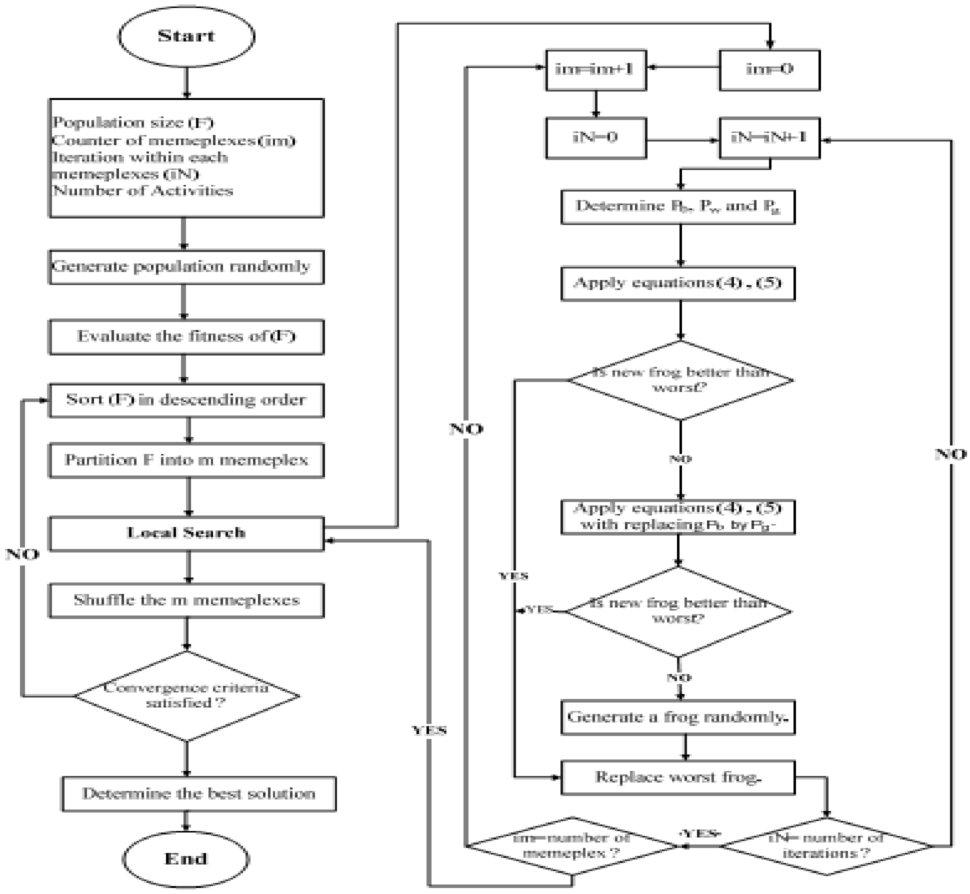

Fig.4. Flow chart of MSFLA

III. Imperialist Competitive Algorithm (ICA)

Imperialist is the term of policy of its extending the power and ruling a government beyond its boundaries. The term imperialism is increasing its number of its colonies and spreading its empire over its world. This results keeps the stronger empires and eliminates the weaker empire ones. In this ICA method they colonies plays an important role for reducing the global optimization and minimizing the cost.

A) Algorithm of ICA

Step 1: Select the random points for the function and initializing the empires.
Step 2: Moving the colonies towards the imperialist.
Step 3: If the colonies of empire has lowest cost than the imperialist, it will exchanges the position of imperialist and colonies.
Step 4: Then computes the overall total power cost.
Step 5: Then analyzing the weakest colonies from the empires and moves to the imperialist competition.
Step 6: Eliminating the powerless empires.
Step 7: If there is only one empire it is stopped, else it goes to the step 2.

B) Flow Chart of ICA

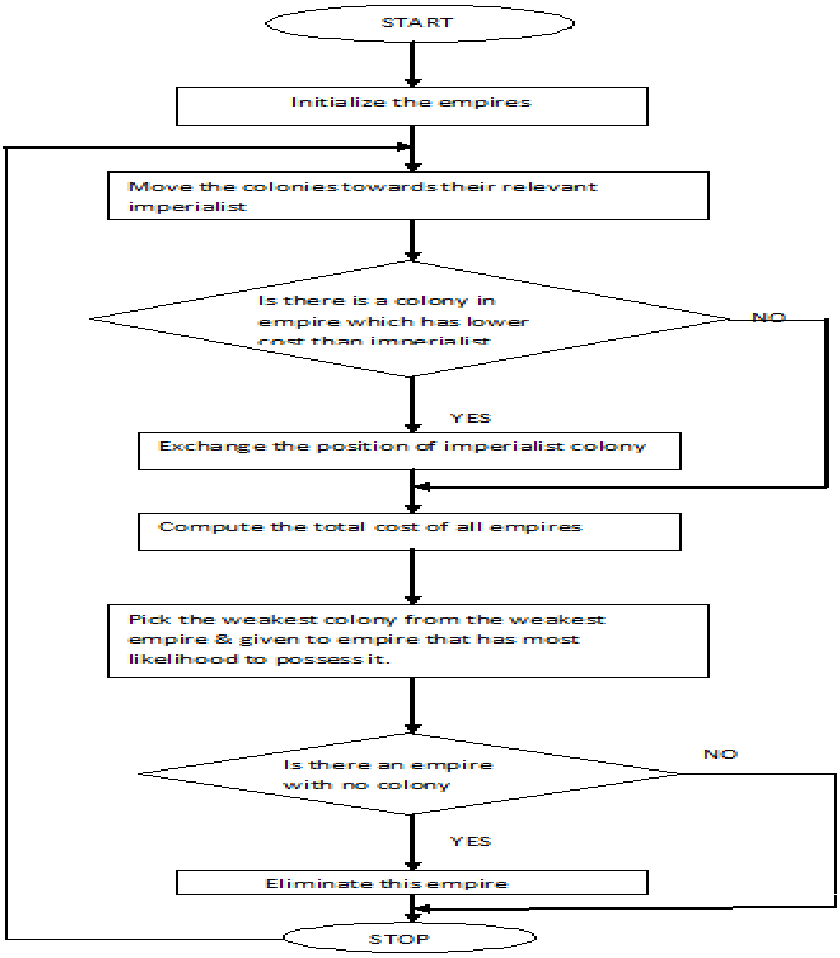

Fig.5. Flow Chart of ICA

IV. Simulation Results

The effectiveness of proposed techniques was illustrated using by IEEE-39 Bus System. Mat lab codlings for BFOA, MSFLA and ICA 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.

a) 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 optimal placement of UPFC achieved from MSFLA technique is in the case is in line two (from 1 to 2) with minimum installation cost of 211.673200 (US $/kvar).

The optimal placement of UPFC achieved from ICA technique is in the case is in line eleven (from 10 to 11) with minimum installation cost of 185.624791 (US $/Kvar).

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

Table-I Optimal Parameter Setting of UPFC in BFOA

UPFC location	2-3
Series Voltage magnitude, V_{se}	0.030000pu
Angle of Series injected voltage, θ_{se}	1.652916
The Real Power loss	0.382444pu

The Table-II shows the optimal parameter setting of UPFC in MSFLA method. In the table consists the voltage and angle of the series converter, and the real power loss.

Table-II Optimal Parameter Setting of UPFC in MSFLA

UPFC location	1-2
Series Voltage magnitude V_{se}	0.060108pu
Angle of Series injected Voltage, θ_{se}	3.126832
The Real Power Loss	0.407468pu

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

Table-III Optimal Parameter Setting of UPFC in ICA

UPFC location	10-11
Series Voltage Magnitude, V_{se}	0.096740pu
Angle of Series injected Voltage, θ_{se}	0.071052
The Real Power Loss	0.432538pu

The Table-IV gives about the details of power loss of IEEE 39 Bus System, After placing the UPFC in BFOA method which is shown below.

Table-IV Power Loss on IEEE 39 Bus System

From Bus	To Bus	Real Power Loss	From Bus	To Bus	Real Power Loss
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

The Table-V gives about the details of power loss of IEEE 39 Bus System, After placing the UPFC in MFSLA method which is shown below.

Table-V Power Loss on IEEE 39 Bus System

From Bus	To Bus	Real Power Loss	From Bus	To Bus	Real Power Loss
2	6	0.256	18	24	0.783
4	35	0.132	19	27	0.067
13	15	0.345	21	34	0.087
11	17	0.638	26	30	0.211
17	20	0.342	22	28	0.134

The Table-VI gives about the details of power loss of IEEE 39 Bus System, After placing the UPFC in ICA method which is shown below.

Table-VI Power Loss on IEEE 39 Bus System

From Bus	To Bus	Real Power Loss	From Bus	To Bus	Real Power Loss
8	9	0.196	13	14	0.546
9	39	0.123	13	12	0.045
10	11	0.756	21	16	0.782
10	13	0.654	21	22	3.543
11	6	0.323	25	2	5.732
11	12	0.028	25	37	2.432
13	10	0.154	39	9	0.002

The Table-VII shows the voltage profile after placing UPFC in both BFOA ,MSFLA and ICA method in IEEE 39 Bus System.

Table-VII Voltage Profile after UPFC placement

Bus No	Voltage in MSFLA (pu)	Voltage in BFOA (pu)	Voltage in ICA (pu)
2	1.065	1.022	1.112
4	1.051	1.001	1.001
6	1.064	1.010	1.005
8	1.053	1.053	1.000
10	1.072	1.034	1.113
29	1.103	1.127	1.110
32	0.9841	0.976	0.999
39	1.03	1.011	1.003

V. 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 includes 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 paper 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 techniques namely Imperialist Competitive Algorithm (ICA) have been made successful for implementing this method than the MFSLA and BFOA method.

For implementing this method the IEEE 39 Bus System has been taken. The obtained results shows that ICA 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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