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IMPERIALIST COMPETITIVE ALGORITHM FOR MINIMIZATION OF LOSSES BY OPTIMALLY LOCATING FACTS CONTROLLERS IN POWER SYSTEM

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Abstract: *One of the key tasks to perform in the complicated operation and planning of the power system is the optimal power flow. The Unified Power Flow Controller (UPFC) is one of the Flexible AC Transmission System (FACTS) powerful power electronics device. The UPFC is capable of providing complex control of power systems. This paper focuses on optimally locating the Unified Power Flow Controller (UPFC) device in power system based on Static Voltage Stability Index (SVSI) technique using Imperialist Competitive Algorithm (ICA). The main objective of this paper is to employ ICA optimization technique which is applied to solve the optimal power flow problem in presence of UPFC device. The ICA optimization technique is also used to minimize the power losses and installation cost of UPFC device. Due to this, the voltage profile is improved thereby enhances the stability in power system. This technique is tested in standard IEEE 6-bus system, IEEE 14-bus system, IEEE 30-bus system. The performance of ICA is compared with other optimization techniques like Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Ant Colony Optimization (ACO) and Gravitational Search Algorithm (GSA) to show the effectiveness of the algorithm. The ICA technique has a great ability in faster convergence characteristics.*

Keywords: *Unified Power Flow Controller (UPFC), Static Voltage Stability index (SVSI), Imperialist Competitive Algorithm (ICA), Optimal Power Flow (OPF), Power Loss, Installation Cost, Power System Stability*

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1. Introduction

A challenging concern in a deregulated power system nowadays is the security level of stability and flexibility, during operation and planning of a power system. Generally, the power systems are planned and operated based on the security N-1 criterion. It implies that system security should be maintained under all important contingencies. Hence in order to improve security in power system one solution is a concept of Flexible AC Transmission Systems (FACTS) devices which is proposed by Hingorani in 1988. These FACTS devices can make to operate the power systems in a more flexible, more secure and economic way. The FACTS controllers play a major role by regulating active and reactive power flow in the network and maintain voltage levels in a desired manner at regulated buses. These controllers found to be secured and economical to operate the system [1-2].

One of the FACTS devices Unified Power Flow Controller (UPFC) is used in transmission lines. Several authors investigated the system performance for the benefit of placement of UPFC in power system. UPFC is a versatile FACTS device in controlling load flow (active and reactive power flow along the transmission line [3-4]. But it is highly important to determine the optimal location of this device in the power system to achieve the functionality of the device. Gotham models the flexible AC transmission system (FACTS) devices for power flow studies and also the control of power flow in the study of FACTS devices. Three more generic types of FACTS devices were suggested by Gotham [5].

Puerle-Esquivel and Acha [6] presents the UPFC can be installed in different locations but its effectiveness will be different. However, it is a problem that where the UPFC must be installed. Some performance indices must be satisfied for this reason. Therefore, conventional power flow algorithm should incorporate with UPFC and the optimization should consider for minimizing the active power loss. Several optimization techniques are used to reduce the installation cost of FACTS devices. A number of literature focuses to find the suitable location of FACTS device. Modelling of UPFC device for power

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flow studies and the integration of this device into power flow studies were reported [7].

Sarker, et.al. [8] presents the optimal location of UPFC using GSA technique. This technique is used to find optimum number and location of devices by considering cost of generators and losses in power system. This method establishes the computational ability and robustness. Bakirtzis [9] presents an enhanced genetic algorithm (EGA) by using both continuous and discrete control variables for the solution of the optimal power flow (OPF). The unit active power outputs and generator-bus voltage magnitudes are modeled as continuous control variables while the transformer-tap settings and switchable shunt devices are discrete control variables.

Yujiao [10] presents a novel hybrid multiobjective particle swarm optimization (HMOPSO) algorithm to solve the optimal reactive power dispatch problem. The power losses minimization, voltage profile improvement and voltage stability enhancement is observed simultaneously. Gitizadeh [11] presents the influence of switching losses on Thyristor Controlled Series Compensator (TCSC) optimum allocation in power systems by using Multi—Objective Artificial Bee Colony algorithm. The active power losses, investment cost of devices and active power generation cost are reduced. Allaoua [12] presents the solutions for optimal power flow problem of a power system through ant colony optimization metaheuristic method. It minimizes the total fuel cost of generating units.In order to prevent blackout, the optimal location of installing UPFC enhances the power system security with optimal setting of parameters by using Differential Evolution by Shaheen, et.al. [13].

This paper focuses on applications of ICA to minimize losses, installation cost and to improve voltage profile in power system. This technique is used to determine the optimal location of UPFC based on static voltage stability index. The effectiveness of ICA [14 – 17] validated by comparing other algorithms like PSO, GA, ACO,GSA in standard test bus systems.

2. Problem Formulation

The main objective of this paper is to minimize the power losses in power system by optimally placing the UPFC in transmission lines based on SVSI technique.

2.1 Modeling of UPFC Device

Basically, the UPFC consists of two voltage source inverters (VSI) which shares a common DC storage capacitor. It is connected through two coupling transformers to the system considered. In this paper, an UPFC is designed by incorporating TCSC in the line and SVC at the bus of an adjacent branch. The inductive or capacitive compensation can be obtained by modifying reactance of the transmission line and it is served by means of TCSC. The value of TCSC is a function of the reactance of the transmission line (X_{TL}) where the TCSC is located [18-19].

$$X_{ij} = X_{TL} + jX_{TCSC}, X_{TCSC} = r_{TCSC} \cdot X_{TL} \qquad (1)$$

where X_{TL} is the reactance of the transmission line, r_{TCSC} is the representation of compensation degree of TCSC coefficient.

The constraint limit (in order to avoid over compensation) is [3];

$$r_{TCSC\_\min} = -0.7, r_{TCSC\_\max} = 0.2 \qquad (2)$$

For both inductive and capacitive compensation, SVC can be used. The injected power at bus *i* is given by;

$$\Delta Q_i = Q_{SVC} \qquad (3)$$

The constraint limit of SVC is [20];

$$\begin{aligned} &Q_{SVC\_\min} = -200MVAR, \\ &Q_{SVC\_\max} = 200MVAR \end{aligned} \qquad (4)$$

2.2 Optimal UPFC Placement Allocation

By using the technique Static Voltage Stability Index (SVSI), it is possible to locate the location to place UPFC in transmission line. The constraint considered here to locate the device is, by choosing the weakest bus and also heavily loaded bus. It is considered in order to reduce the stressed condition in the system. Hence the optimal location can be found out while using load flow solution and placing UPFC in every line one at a time and also calculating SVSI at the same time. SVSI can have a value between 0 and 1. In order to obtain stability in a system, the SVSI can be maintained below 1. The concept of the SVSI mathematical calculation [20] can be formulated as:

$$SVSI_{ji} = \frac{2\sqrt{(X_{ji}^2 + R_{ji}^2)(P_{ji}^2 + Q_{ji}^2)}}{\left| |E_i|^2 - 2X_{ji}Q_{ji} - 2R_{ji}P_{ji} \right|} \qquad (5)$$

where, *i* is the sending bus, *j* is the receiving bus, X_{ji} is the reactance of the transmission line, R_{ji} is the Resistance of the transmission line, P_{ji} is the Real Power at the receiving end of the line, Q_{ji} is the Reactive Power at the receiving end of the line.

2.3 Installation Cost Functions

The mathematical formulation of installation cost of UPFC device is given by;

$$IC = C\_UPFC \times S \times 1000 \qquad (6)$$

$$C\_UPFC = 0.0003S^2 - 0.2691S + 188.22 (US\$/KVAR)$$

$$S = |Q_2 - Q_1| \qquad (7)$$

where *IC* is the Installation Cost of the considered device, *C_UPFC* is the cost of the UPFC device and *S* is the operating range of device, Q_1 is the reactive power flow through the line before installation of UPFC and Q_2 is the reactive power flow through the branch after installation of UPFC.

3. Description of Algorithm

3.1 Introduction of Imperialist Competitive Algorithm (ICA)

The ICA is a computational method which is used to solve different types of optimization problems. It is inspired in real world by socio-political process of imperialistic competition.

This algorithm starts initially with random number of population called countries. Some of the countries which are best are chosen to be imperialists and the rest of the countries form colonies of these imperialists. All these colonies with initial population are divided based on their power among imperialists. After distribution of all these colonies among imperialist and creating initial empire they belong to their relevant imperialistic country.

Hence the empire's total power is given by sum of power of the imperialistic country and a percentage of mean power of its colonies to their imperialists. Then, among all the empires the competition begins. Any empire which is not able to succeed and increase its power in imperialistic competition or at least prevent its power from decreasing will be eliminated from the competition. Therefore, this competition process gradually brings about increase in power for powerful empires and decrease in power for weaker empire and ultimately the weaker empires will collapse. Then all empires are collapsed and there is only one remaining empire. All the other countries are colonies of maintained empire.

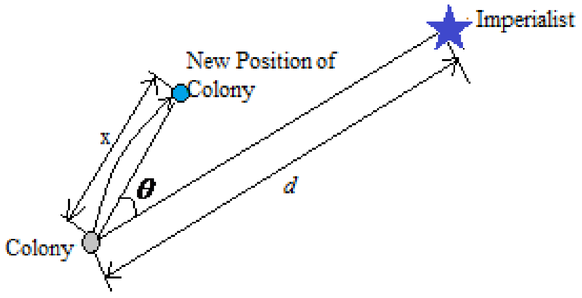

Figure 2. Motion of colonies toward their relevant Imperialist

Fig 2 shows the movement of a colony towards the imperialist. In this movement, θ and x are uniformly distributed random numbers as illustrated in formula (8) and d is the distance between colony and the imperialist.

$$x \sim U(0, \beta \times d), \theta \sim U(-\gamma, \gamma) \quad (8)$$

where; β and γ are parameters that modify the area that colonies randomly search around the imperialist.

3.2 Pseudocode of ICA

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1. Define the Objective Function
2. Random points are selected in search space and the empires are initialized.
3. Assimilation: The colonies are moved towards their relevant imperialist.
4. Revolution: The positions of the some colonies are changed randomly.
5. Exchange the positions of the colony and the imperialist; if the colony in an empire has lower cost than the imperialist.
6. Similar empires are united.
7. The total costs of all empires are computed.
8. Imperialistic Competition: The weakest colonies from weakest empires are picked and give it to one of the empires.
9. The powerless empires are eliminated.
10. Stopping criteria is checked:
    10.1 If conditions are satisfied stop it.
    10.2 Else repeat the steps from 3.
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3.3 Implementation of ICA

Step 1: Initialize Population

In this algorithm, the terminology called country is used. In an N dimensional optimization problem, a country is a 1×N array. This array is defined by;

$$Country = [p_1, p_2, ...p_j]$$

The variable to be optimized is p_j.

Step 2: Assimilation

Based on the absorption policy the imperialist countries absorb the colonies countries toward themselves. Improving the imperialist countries is by improving the colonies. This fact has been modeled by absorbing all the colonies towards the imperialist.

Step 3: Revolution

A random number is generated in all the iteration for every colony which is varying between 0 and 1. This value is then compared with probability of revolution rate. The revolution is performed if random number is lower than probability revolution rate. The new colony will be replaced with previous colony while its cost is improved. The exploration of the algorithm is increased by revolution and prevents the early convergence of countries to local minimum.

Step 4: Exchanging Positions of the Imperialists and their Colonies

A colony might reach a position with lower cost than the imperialist, after assimilation for all colonies and revolution for a percentage of them. In such a case, the positions are exchanged between imperialist and the colony. With the new position of imperialist the colonies start moving towards the new position.

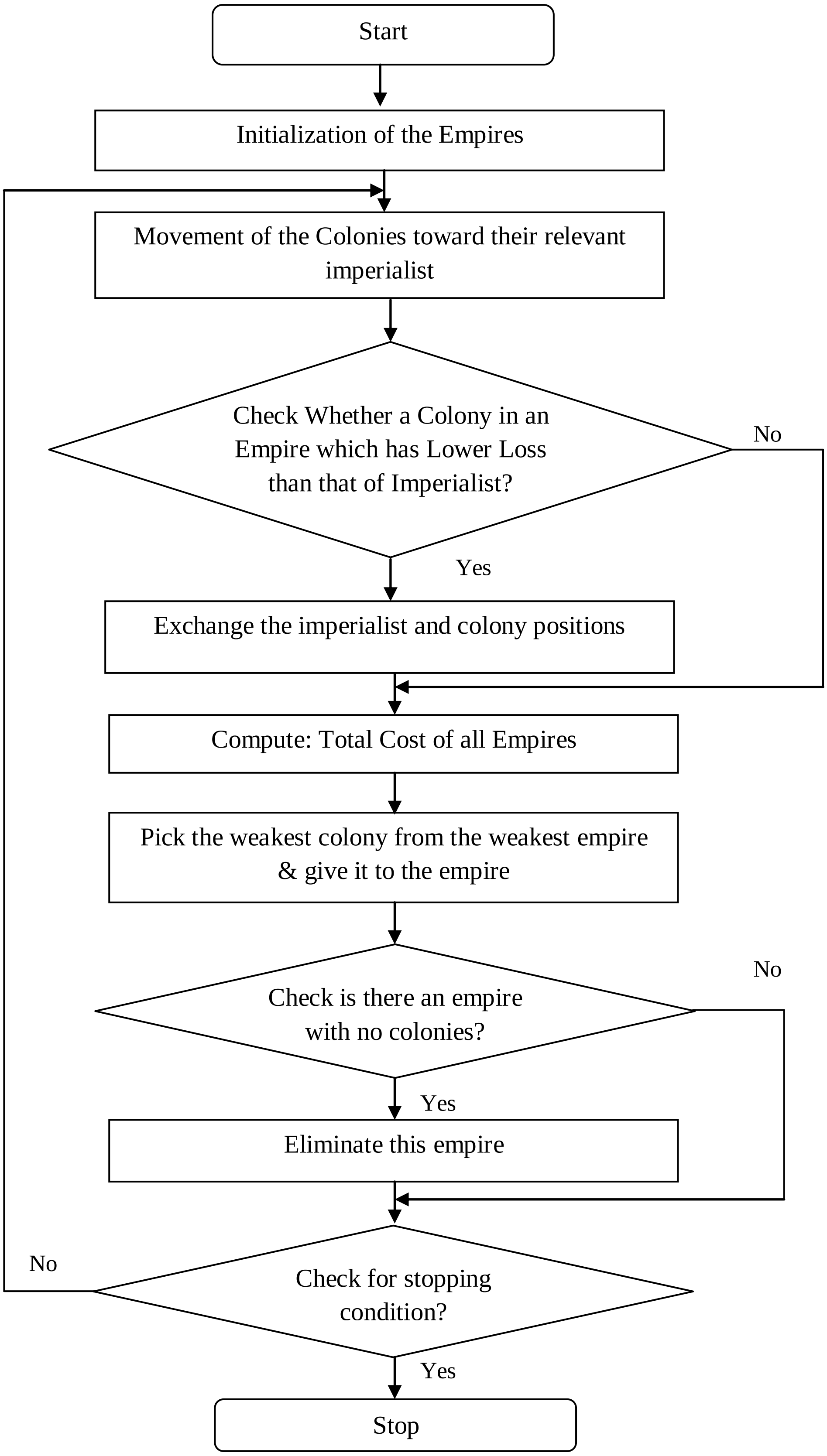

Figure 1. Flowchart of ICA

Step 5: Calculation for Cost of Imperialism

The total power of an empire is affected by the power of both the imperialist power and percent of its average colonies power. The mathematical equation of the total cost is computed by:

$$T.C_n = Cost\left(imperialist_n\right) + \gamma mean\left(Cost\left(Colonies\_imperialist_n\right)\right) \qquad (9)$$

where,

$T.C_n$ is the total cost of the *n*th imperialism.

γ is the positive number which is considered between 0 and 1.

Step 6: Imperialist Competition

The imperialistic competition is modeled by picking the weakest colony from weakest empires and a competition is made among all empires to possess this colony. After selecting a colony, the possession probability of each empire is found.

Step 7: Eliminating the Powerless Empires

When the empire loses all of its colonies the corresponding empire will collapse. In this case, this imperialist is considered as a colony and it assigned to the other empires.

4. Experimental Module of ICA Algorithm

The imperialist competitive algorithm is applied on three different numbers of test cases.

Case 1: Power flow problem without UPFC device and having constant real power generations.

The results are obtained while calculating power flow problem without any device in transmission line is shown in table 2. The power flow is tested in standard IEEE 6-bus system, IEEE 14-bus system and IEEE 30-bus system. The magnitudes of generator bus voltages are shown in table 1 for IEEE 6-bus system, IEEE 14-bus system and IEEE 30-bus system respectively.

Case 2: UPFC Installation device analysis without using Optimization Techniques

The analysis of Installation cost and Minimization of Losses with the presence of UPFC device and without using any optimization techniques on all test systems are tabulated in table 3.

Case 3: Reduction of Installation cost and Minimization of Losses using ICA Algorithm

The results of the installation cost reduction and loss minimization on all test systems by using Imperialist Competitive Algorithm are tabulated in table 4.

Table 1. Terminal Voltages of Generator (p.u.)

IEEE – 6 Bus System		IEEE – 14 Bus System		IEEE – 30 Bus System	
Notation	**Magnitudes**	**Notation**	**Magnitudes**	**Notation**	**Magnitudes**
V1	1.05	V1	1.060	V1	1.060
V2	1.1	V2	1.045	V2	1.045
		V3	1.010	V5	1.010
		V6	1.070	V8	1.010
		V8	1.090	V11	1.082
				V13	1.071

Table 2. Losses in Systems without using UPFC Device

Control Variables	IEEE – 6 Bus System	IEEE – 14 Bus System	IEEE – 30 Bus System
Real Power Loss (MW)	15.06	13.593	20.3

Table 3. Analysis of UPFC Installation without using Optimization Techniques

Test System	Optimal Location of UPFC Device	Voltage V_m (p.u.)	Real Power Loss (MW)	Installation Cost ($/h)
IEEE – 6 Bus	Device at Bus 6	0.9586	14.9165	4695.65
IEEE – 14 Bus	Device at Bus 5	1.0082	13.38	13769.28
IEEE – 30 Bus	Device at Bus 26	1.04	19.25	10846.00

Table 4. Power Loss and Installation Cost Minimization using ICA Technique

Test System	Optimal Location of UPFC Device	Voltage V_m (p.u.)	Real Power Loss (MW)	Installation Cost ($/h)
IEEE – 6 Bus	Device at Bus 6	0.9962	12.0895	1009.42
IEEE – 14 Bus	Device at Bus 5	1.0189	11.3620	11204.00
IEEE – 30 Bus	Device at Bus 26	1.325	16.48	9188.65

5. Results and Discussions

The Imperialist Competitive Algorithm has been tested on various test systems such as IEEE 6-bus, IEEE 14-bus and IEEE 30-bus system respectively. The total loss should be less than the total loss which was obtained before using any optimization techniques and the loaded bus voltage should be higher than the loaded bus voltage before optimization.

The voltage profile improvement is shown in figure 3-4 for IEEE-14 bus system and IEEE-30 bus system respectively. The optimization problems such as ICA, GSA, PSO, GA and ACO techniques are used to show the effectiveness of the ICA algorithm. The results are compared and are tabulated in table 5.

The convergence characteristics are shown in figure 5-7. The ICA technique proves efficient than other techniques considered while solving for the optimal placement of UPFC device in transmission lines.

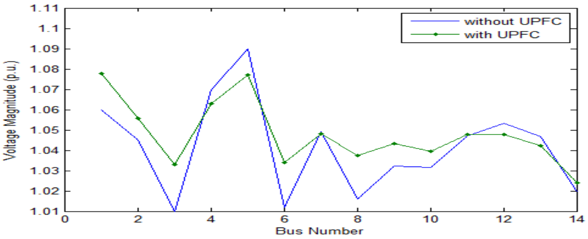

Figure 3. Voltage Profile for IEEE – 14 Bus System

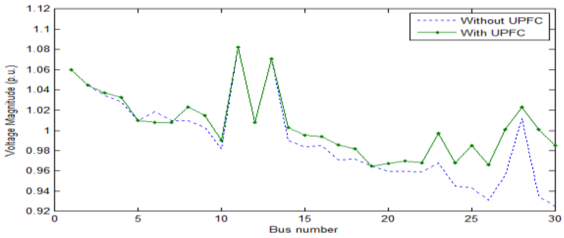

Figure 4. Voltage Profile for IEEE – 30 Bus System

Table 5. Comparison of Power Loss and Installation Cost Minimization using Different Optimization Techniques

Test System	Control Variables	Using ICA	Using GSA (Jayanthi Sarker, 2013)	Using PSO	Using GA	Using ACO
IEEE 6-Bus	Optimal location of UPFC	At bus 6	At bus 6	At bus 6	At bus 6	At bus 6
	Voltage V_m (p.u.)	0.9962	0.9658	0.9432	0.9378	0.9454
	Real Power Loss (MW)	12.0895	13.0568	14.0561	14.8252	13.3675
	Installation Cost ($/h)	1009.42	1052.80	3325.00	3695.65	2125.20
IEEE 14-Bus	Optimal location of UPFC	At bus 5	At bus 5	At bus 5	At bus 5	At bus 5
	Voltage V_m (p.u.)	1.0189	1.0893	1.0562	1.014	1.0351
	Real Power Loss (MW)	11.3620	11.6250	12.8917	13.1261	12.5423
	Installation Cost ($/h)	11204.00	12622.80	13026.00	13482.65	12815.15
IEEE 30-Bus	Optimal location of UPFC	At bus 26	At bus 26	At bus 26	At bus 26	At bus 26
	Voltage V_m (p.u.)	1.325	1.2486	1.1763	1.081	1.120
	Real Power Loss (MW)	16.48	16.9247	17.6539	18.30	17.7451
	Installation Cost ($/h)	9188.65	9523.29	9982.65	10764.80	9651.00

5.1 Performance Analysis of ICA Optimization Technique with other Soft Computing Techniques

Table 5 depicts the results of comparison of the five different optimization techniques such as ICA, GSA, PSO, GA and ACO.

PSO is similar to GA in the sense that they are both population-based search approaches. They both depend on information sharing among their population members to enhance their search processes using a combination of deterministic and probabilistic rules. PSO proves to be more computationally efficient than GA. PSO and ACO enables the algorithm to retain knowledge of good solutions which means that they both have memory. But GA may destroy previously learned knowledge when producing offspring. It is found that ICA outperforms when compared with the other techniques. Figure 5-10 shows ICA has characteristics of good convergence. ICA avoids local optimum and increases the global search ability. It is efficient and flexible within different search spaces. ICA has faster computations for finding the optimal solutions. Since UPFC device is costly, it can be optimized to reduce the cost by using ICA algorithm. The effectiveness of the algorithm is proved by comparing with various algorithms like GA, PSO, ACO and GSA. ICA prevents premature convergence and also results in cost minimization. The algorithms are tested in various standard systems like IEEE 6-bus, IEEE 14-bus and IEEE 330-bus systems. The output of cost minimization of UPFC device is shown in fig 5-7.

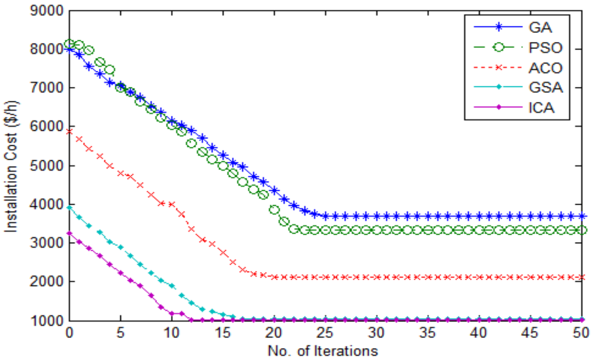

Figure 5. Installation Cost for IEEE 6-Bus System

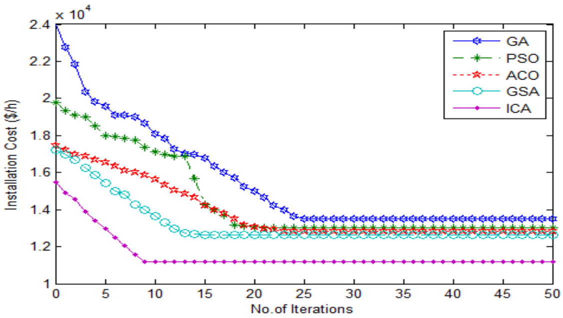

Figure 6. Installation Cost for IEEE 14-Bus System

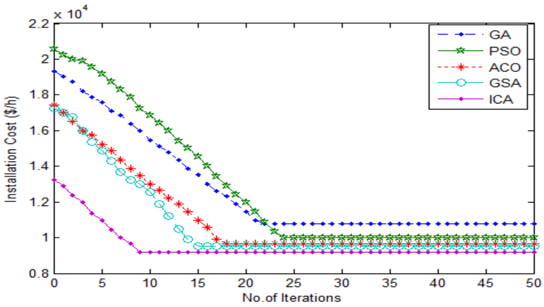

Figure 7. Installation Cost for IEEE 30-Bus System

Figure 5-7 shows the Installation cost for all the test systems with ICA convergence effect.

The application for minimization of losses as the objective function using ICA has significantly reduced the losses and increased the voltage profile value at the loaded bus; hence improving the voltage stability in a system. It is observed that the total losses value decreased accordingly and the voltage profiles for post-UPFC are higher. This implies that with the implementation of UPFC optimization using ICA, voltage has been improved, while total losses have been reduced indicating voltage stability improvement. It is shown in figure 8-10.

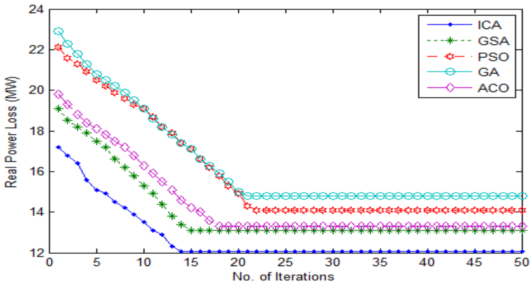

Figure 8. Real Power Loss for IEEE 6-Bus System

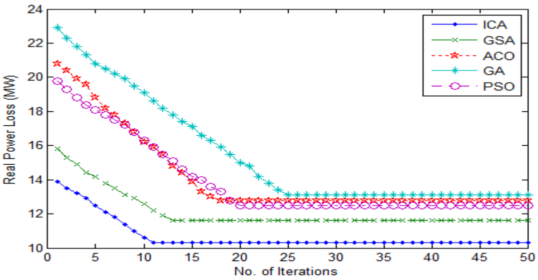

Figure 9. Real Power Loss for IEEE 14-Bus System

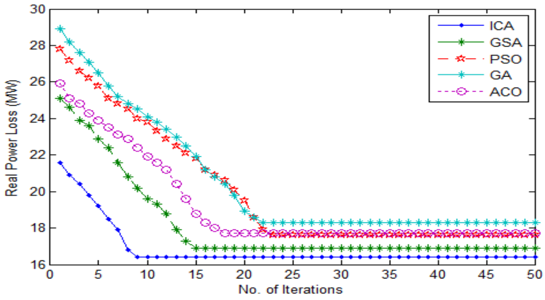

Figure 10. Real Power Loss for IEEE 30-Bus System

Figure 8-10 shows the Real Power Loss for all the test systems with which ICA shows the better performance compared to other optimization techniques.

ICA proves to be more efficient compared to other techniques while optimally placing the UPFC device in transmission lines. By using various optimization techniques, the losses are reduced significantly and the voltage profile has been increased at the load bus. Due to this, the voltage stability can be improved in the system. This concept has been clearly observed in all the cases considered with the implementation of UPFC optimization. Hence the ICA method shows the better results by reducing the losses and improving the voltage profile. As for the installation cost minimization considered, ICA proves well in all cases.

6. Conclusion

This paper uses an optimization technique called Imperialist Competitive Algorithm by which the total losses in the power system are reduced by optimally placing UPFC device in transmission line and minimizing installation cost of the device using ICA technique. The optimal location of UPFC device is carried out by using SVSI technique. Due to this, the voltage profile has been improved at the load bus, thereby maintaining voltage stability in the power system. A good choice for more balanced search and fast convergence by using ICA optimization technique can be observed.

ICA constitutes of increased exploration ability, exhibits robust behavior and requires less number of iterations compared to other competitive variants is the most promising scheme. Considering the table 5 it is proved well that the ICA scheme reduces the losses, reduces the installation cost of the UPFC device, less number of iterations requirement for convergence and improvement in voltage profile when compared to other algorithms.

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