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Optimal Location and Parameter Settings of UPFC Device in Transmission System based on Imperialistic Competitive Algorithm

Mehrdad Beykverdi, Soodabeh Soleymani, Babak Mozafari
Department of Electrical Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran,
Email: mehrdad_b2003@yahoo.com; s.soleymani@srbiau.ac.ir, mozafari_babak@yahoo.com

ABSTRACT

In this paper, we present a new method to determine the optimal location and parameter settings of Unified Power Flow Controller (UPFC) for removing voltage violations and transmission lines overloading. UPFC is considered as the most powerful member of the FACTS devices, that it can control shunt and series power flow. This option gives to UPFC the power to control the voltage profile and transmission lines flow simultaneously. We used the Imperialistic Competitive Algorithm (ICA) to determine the optimal location and optimal parameter settings of UPFC to improve the performance of the power system specially removing voltage violations in the buses and solving transmission lines overloading to increase loadability in the power networks. This procedure is proposed to be applied on IEEE 14 bus system to show the validity of the method.

KEYWORDS: Imperialistic Competitive Algorithm (ICA), Loadability, Optimal Location, Optimal settings, Unified Power Flow Controller (UPFC), Voltage Profile.

1. INTRODUCTION

UPFC is applied to control the active and reactive power flow in same time, and voltage magnitude at the UPFC terminals. Also, the controller can be set to control one or more of these parameters in any combination or to control none of them. UPFC allows the combined application of phase angle control with controllable series reactive compensations and voltage regulation, and also the real-time transition from one selected compensation mode into another one to control particular system contingencies more effectively. For example, series reactive compensation may be replaced by phase-angle control or vice versa [1]-[3]. UPFC also maintain operating flexibility by its inherent adaptability in power system in variations without any hard-ware alternations [4, 5]. The mode of UPFC can be adjusted according to the required characteristic where the UPFC can work as Static VAR Compensator (SVC) to improve the network voltage profile by controlling the shunt elements of the UPFC only. And also it can work as Static Synchronous Series Compensator (SSSC) to improve the network lines loadability by controlling the series element of the UPFC only. UPFC has ability to do both of SVC and SSSC performance in a same time in the power systems [6]-[8]. The normal operation of the power system depends on many factors as the loading conditions, the configuration of the network and the current operating point of the system. All the previous factors affect the stability and performance of the system [9, 10]. In [11] optimal placement of UPFC device is determined for enhancing transmission lines overloading issue and survey their impact on reliability of power networks and also in [12] UPFC placement is applied to study the effect of load representation in the static point of view on the performance of the UPFC in the power system.

This paper will concentrate on solving the problems of the network related to overloading of transmission lines and violation of bus voltage profile. This will be performed on the normal configuration of the system with the increasing loading pattern on the system. UPFC in such optimal placement and setting can restore the system operating condition to steady state point.

2. PROBLEM FORMULATION

The normal operation of the power network depends on many factors as the loading conditions, the configuration of the system and the current operating point of the system. All the previous factors affect the stability and the performance of the system. Some indices are used to show lines overloading and bus voltage violations. After determining the performance indices, ICA technique is applied to find the optimal location and parameters setting of UPFC. Installing UPFC in such optimal location with such optimal parameters will remove or minimize the overloaded lines to improve power flows in the lines and bus voltage violations under increasing the loading conditions according to the proposed fitness function.

2.1 ICA Fitness Function

The target is finding the optimal location and the optimal parameters setting of the UPFC in the power system to eliminate the overloaded lines and the bus voltage violations. The main general description of the equations:

$$Min\ Fitness\ Ft(X,U) \tag{1}$$

Subject to:

$$Gt\ (X,U)\ =\ 0.0 \tag{2}$$

$$Ht\ (X,U)\ \leq\ 0.0 \tag{3}$$

Where, $F_t(X,U)$ represents the Fitness function to be minimized;

$G_t(X,U)$ represents the vector of the equality constraints corresponding to UPFC parameter bounds limits, active and reactive power generation limits, bus voltage limits, and phase angles limits;

X represents the vector of the states of the power system consisting of voltage magnitude and phase angles; and

U represents the vector of control variables to be optimized which the output of the process, the location of UPFC and its parameters setting.

The fitness function will be depend on some performance indices, the fitness function and the performance indices will be changed according the scope zone of interest as optimizing with overloaded lines and the bus voltage violations:

$$F_t(X,U)= \sum_{i=1}^{No.of\ Lines} L(OL) + \sum_{j=1}^{No.of\ Buses} V(BV) \tag{4}$$

$$L(OL) = \begin{cases} 0, & if\ Si\ operating\ \leq\ Si\ max \\ Log\ (\Psi L(OL).(Si\ operating/Si\ max)^{R}), & if\ Si\ operating\ \geq\ Si\ max \end{cases}$$

$$V(BV) = \begin{cases} 0 & ,if\ 0.95 \le Vi \le 1.05 \\ Log\left(\Psi V(BV).abs\left(\frac{Vj - Vj\,nominal}{Vj}\right)^{Q}\right), & otherwise \end{cases} \quad (5)$$

Where

L(OL) represents the overloaded line function;

$S_{ioperating}$ represents the current volt- ampere power in line *i*;

S_{imax} represents the volt-ampere power rate of line *i*;

$\Psi_{L(OL)}$ represents the weight, is determined in order to have certain weight value for the various percentage of branch loading, also use to adjust the slope of the algorithm;

R represents the coefficient is used to penalize more or less overloads;

Ntl represents the number of lines in the system;

V(BV) represents the Bus Voltage Violation function;

V_j repreents the voltage magnitude at bus j;

$V_{jnominal}$ represents the bus j nominal voltage;

$\Psi_{V(BV)}$ represents the weight is determined in order to have certain weight value for the various percentage of voltage difference, also used to adjust the slope of the algorithm;

Q represents the coefficient is used to penalize more or less and voltage violations;

Nbb represents the number of the buses in the system.

In some cases the log relations can be replaced with linear relations, according to the penalty factor of overloading and voltage violations values [13].

2.2 UPFC modeling for power flow

The UPFC could be seen to consist of two voltage source converters connecting together a common capacitor on their DC side and a unified control system. A simplified schematic representation of the UPFC is given in Figure 1.

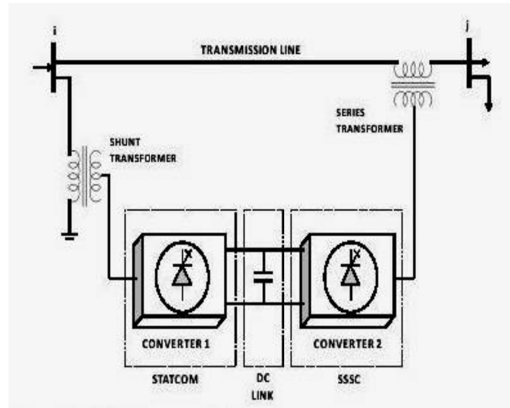

Fig. 1. Block Diagram of the UPFC

The equivalent circuit of UPFC, which will be attached with power system equation and programmed to get the results, is shown in Figure 2. It consists of two synchronous voltage sources (SVS), which are simultaneous coordinated together to achieve the required performance mode.

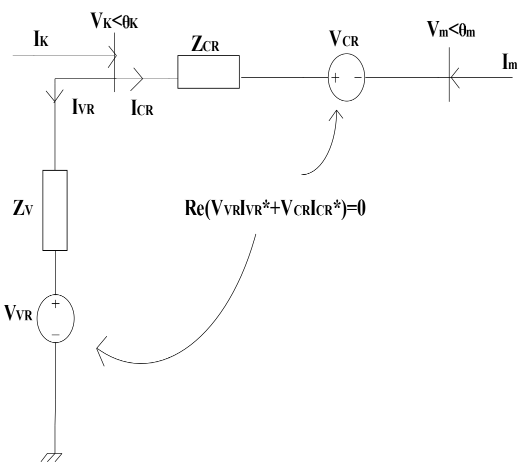

Fig. 2. UPFC equivalent circuit

$$EVR = VVR \times (Cos\delta VR + Sin\delta VR) \quad (5)$$

$$ECR = VCR \times (Cos\delta CR + Sin\delta CR) \quad (6)$$

Where,

V_{VR} the magnitude of the shunt SVS voltage.

δ_{VR} the value of the shunt SVS angle.

V_{CR} the magnitude of the series SVS voltage.
δ_{CR} the value of the series SVS angle.
The active and reactive power equations for bus k and m can be combined with (5) and (6) to get:

$$PCR = VCR\,Vk \times \left(Gkm\,cos(\delta CR - \theta k) + Bkm\,sin(\delta CR - \theta k)\right) + VCR\,Vm \times \left(Gmm\,cos(\delta CR - \theta m) + Bmm\,sin(\delta CR - \theta m)\right) + VCR2 \times Gm \quad (7)$$

$$QCR = VCR\,Vk\,(Gkm\,sin(\delta CR - \theta k) - Bkm\,sin(\delta CR - \theta k)) + VCR\,Vm\,(Gmm\,sin(\delta CR - \theta m) - Bmm\,cos(\delta CR - \theta m)) - VCR2 \times Bmm \quad (8)$$

$$PVR = -VVR2 \times GVR + VVR\,Vk \times (GVR\,cos(\delta VR - \theta k) + BVR\,sin(\delta VR - \theta k)) \quad (9)$$

$$QVR = VVR2\,GVR + VVR\,Vk(GVR\,sin(\delta VR - \theta k) - BVR\,cos(\delta VR - \theta k)) \quad (10)$$

V_k and V_m: the voltage magnitude at bus k and bus m.
θ_k and θ_m: the voltage angles at bus k and bus m.
P_{CR} and Q_{CR}: the series SVS active and reactive powers.
P_{VR} and Q_{VR}: the shunt SVS active and reactive powers.
G_{mm}, G_{kk}, G_{km} and G_{mk}: the conductance elements, related to lines between buses k and m.
B_{mm}, B_{kk}, B_{km} and B_{mk}: the substance elements, related to lines between buses k and m.
G_{VR}, B_{VR}, G_{CR} and B_{CR}: the substances and conductances for shunt and series SVS.

3. IMPERIALISTIC COMPETITIVE ALGORITHM INTRODUCTION

Atashpaz Gargari and Lucas introduced Imperialistic Competitive Algorithm that is proposed the evolutionary process to optimize which is illustrated by imperialistic competition. Optimization is a process of making something better [14-16]. We want to find the argument x in the way its analogous cost be optimum, which having function in optimization.

In this algorithm all, the countries are divided into two groups: imperialist and colonies. Imperialistic competition is the main part of this algorithm and causes the colonies to converge to the global minimum of the cost function. In continue it will be described how the imperialistic competition is modeled and implemented among empires.

3.1 Flow Chart of Imperialist Competition

Figure 3 shows the flowchart of the Imperialistic Competitive Algorithm, like other evolutionary algorithm starts with an initial population. Some of the best countries in the population are selected to be the imperialist and rests are colonies

All the colonies of initial population are divided among the mentioned imperialists based on their power. After dividing all colonies among imperialists, these colonies start moving toward their relevant imperialist countries. The total power of an empire depends on both the power of the imperialist country and the power of its colonies. We will model this fact by defining the total power of an empire by the power of imperialist country plus a percentage of mean power of its colonies.

The imperialistic competition begins between all the empires. Any empire that is not able to succeed in the competition and cannot increase its power will be eliminated from the competition. The imperialistic competition will gradually result in an increase in the power of powerful empires and a lost in their power and ultimately they will collapse. The movement of colonies to their relevant imperialists along with competition among empires and also the collapse mechanism will hopefully cause all the countries to converge to a state in which there exist just one empire in the world and all the other countries are colonies of that empire. In this ideal new world colonies, have the same position and power as the imperialist [15].

3.2 Generating Initial Empires

The goal of optimization is to find an optimal solution in terms of the variables of the problems. We form an array of variable values to be optimized. In GA terminology, this array is called "Chromosome" and in PSO, it's called "Particle", but here the term "Country" is used for this array. In an N_{var} dimension optimization problem, a country is a $1*N_{var}$ array. This array is defined by:

$$Country = [p1, p2, p3, \ldots, pNvar] \quad (11)$$

The variable values in the country are represented as floating point numbers. The cost of a country is found by evaluating the cost function f at the variables $(p_1, p_2, p_3, \ldots, p_{Nvar})$. Then:

$$Cost = f\,(country) = f\,(p1, p2, p3, \ldots, pNvar) \quad (12)$$

At the first of optimization, we generate the initial population of size N_{pop}. We select N_{imp} of the most powerful countries to form the empires. The remaining N_{col} of the population will be the colonies each of which belongs to an empire. Then we have two types of countries; imperialist and colony.

To create the initial empires, we divide the colonies between imperialists based on their power.

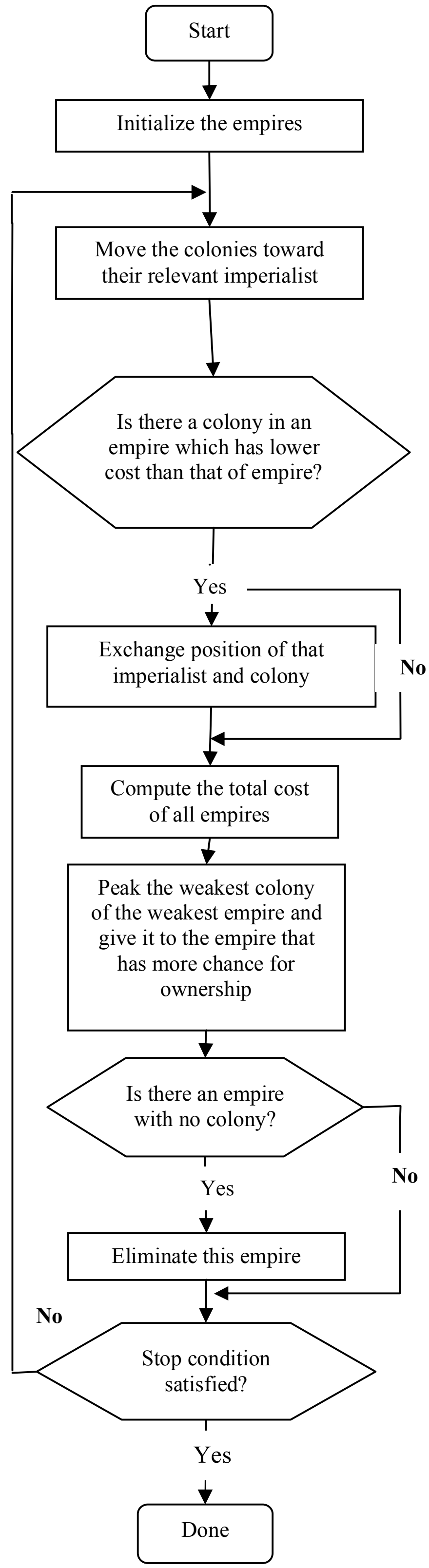

Fig. 3. Flow chart of the ICA

To divide the colonies among imperialists proportionally, we define the normalized cost of an imperialist by:

$$Cn = cn - maxi\{ci\} \tag{13}$$

Where c_n is the cost of nth imperialist and C_n is its normalized cost. Having the normalized cost of all imperialists, the normalized power of each imperialist is defined by:

$$P_n = \left|\frac{Cn}{\sum_{i=1}^{Nimp} Cj}\right| \tag{14}$$

The initial number of colonies of an empire will be:

$$N.C.n = round\{pn\,.Ncol\} \tag{15}$$

Where, $N.\,C._n$ is the initial number of colonies of nth empire and N_{col} is the number of all colonies. To divide the colonies for each imperialist we randomly choose $N.\,C._n$ of the colonies and give them to it. These colonies along with the imperialist will form nth empire. Figure 4 shows the initial population of each empire. As shown in this figure, bigger empires have greater number of colonies while weaker ones have less. In this figure imperialist 1 has formed the most powerful empire and has the greatest number of colonies.

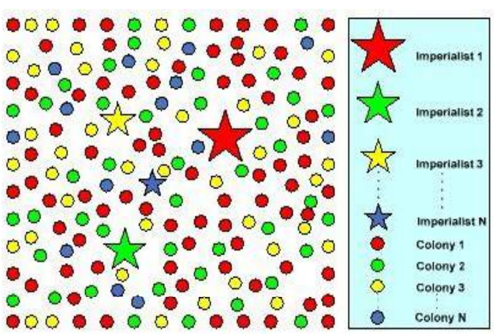

Fig. 4. Initialize the empires: The more colonies an imperialist possess, the bigger one is its relevant Star mark.

3.3 Moving the Colonies of an empire toward the Imperialist

Imperialist countries started to improve their colonies. This movement is shown in figure 5 which the colony moves toward the imperialist by *x* units. The new position of colony is shown in a darker color. The direction of the movement is the vector from colony to imperialist. In this figure *x* is a random variable with uniform (or any proper) distribution. Then for *x* we have:

$$x \sim U\,(0\,,\beta\,\times d\,) \tag{16}$$

Where β is a number greater than 1 and *d* is the distance between colony and imperialist. A β>1 causes the colonies to get closer to the imperialist state from both sides.

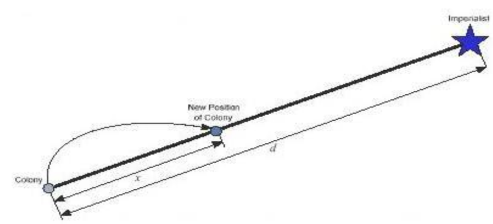

Fig. 5. Moving colonies toward their relevant imperialist

To search different points around the imperialist we add a random amount of deviation to the direction of the movement. Figure 6 shows the new direction. In this figure, the θ is a random number with uniform (or any proper) distribution. Then:

$$\theta \sim U\,(-\gamma\,,\gamma) \tag{17}$$

The γ is a parameter, which adjusts deviation from the original direction.

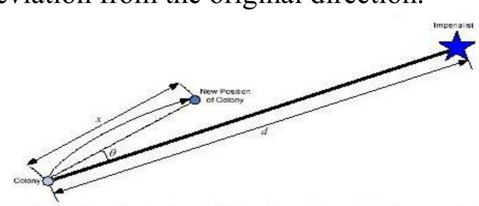

Fig. 6. Moving colonies toward their relevant imperialist in a randomly deviated direction

3.4 Exchanging positions of the Imperialist and Colony

While moving toward the imperialist, a colony may reach to a position with lower cost than that of imperialist. In such a case, the imperialist moves to the position of that colony and vice versa. Then algorithm will continue by the imperialist in a new position and then colonies start moving toward this position. Figure 7a illustrates the position exchange between a colony and the imperialist. In this figure the best colony of the empire is shown in a darker color. This colony has a lower cost than that of imperialist. Figure 7b shows the whole empire after exchanging the position of the imperialist and that colony.

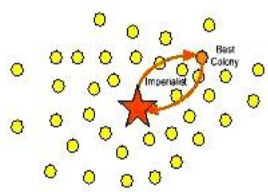

Fig. 7a. Exchanging the positions of a colony and imperialist

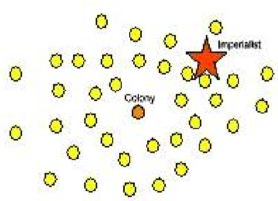

Fig. 7b. Main imperialist after position exchange

3.5 Total Power an Empire

Total power of an empire is mainly affected by the power of imperialist country. But the power of the colonies of an empire has an effect, albeit negligible, on the power of that empire. We have modeled this fact by defining the total cost by:

$$T.C.n = cost(imperialist) + \zeta\ mean\{Cost(colonies\ of\ empiren) \quad (18)$$

Where $T.C._n$ is the total cost of the nth empire and ζ is a positive number which is considered to be less than 1. A little value for ζ causes the total power of the empire to be determined by just the imperialist and increasing it will increase the role of the colonies in determining the total power of an empire.

3.6 Imperialist competition

This competition is modeled by picking some of the weakest colonies of the weakest empires and making a competition between all empires to possess these colonies. Figure 8 shows the modeled imperialist competition each of empires will have a likelihood of taking possession of the mentioned colonies. In other words these colonies will not be possessed by the most powerful empires, but these empires will be more likely to possess them [15].

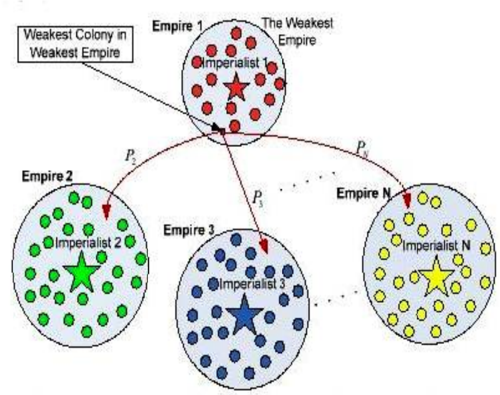

Fig. 8. Imperialist Competition

To start the competition, first we find the possession probability of each empire based on its total power. The normalized total cost is simply obtained by:

$$N.T.Cn. = T.Cn. - maxi\{T.Ci\} \qquad (19)$$

Where $T.C_n$. and $N.T.C_n$. are total cost and normalized total cost of nth empire respectively. Having the normalized total cost, the possession probability of each empire is given by:

$$P_{p0} = \left| \frac{N.T.Cn}{\sum_{i=1}^{Nimp} N.T.Cj} \right| \tag{20}$$

To divide the mentioned colonies among the empires based on the possession probability of them, we form the vector **P** as:

$$P = [pp1, pp2, pp3, \dots, pNimp] \tag{21}$$

Then we create a vector with the same size as P whose elements are uniformly distributed random numbers.

$$R = [r1, r2, r3, \dots, rNimp];$$

$$r1, r2, r3, \dots, rNimp \sim U(0,1) \tag{22}$$

Then we form the vector D by simply subtracting R from P:

$$D = P - R = [D1, D2, D3, \dots, DNimp] = [pp1 - r1, pp2 - r2, \dots, ppNimp - rNimp] \tag{23}$$

Referring to vector D we will hand the mentioned colonies to an empire whose relevant index in D is maximum [17].

3.7 Ignoring the Weak Empires

Weak empires will eliminate in the imperialistic competition and their colonies will be divided between other empires. In this algorithm, it's assumed that an empire will be removed it when it loses all of its colonies.

3.8 Convergence

ICA will run until all the empires except the most powerful one will collapse and all the colonies will be under the rule of this unique empire. In this ideal new world all the colonies will have the same position and same costs and they will be controlled by an empire with the same position and cost as themselves.

3.9 Proposed ICA

In the ICA the colonies are coded to a country that contains variables of the problem. The configuration of the country in order to optimal UPFC consists of two types of parameters: location of UPFC and parameters setting V_{CR}, V_{VR} as decoupled model parameters of UPFC. In the figure 9 the country for the proposed algorithm has been shown.

Number of bus (i)	Number of bus (j)	V_{CR}	V_{VR}

Fig. 9. The country of Proposed ICA

The first set of countries in the colony represents the location of UPFC device in the network. This set contains the number of buses where the UPFC should be located. The second set represents the value of V_{CR} for series SVS. The range for this set is randomly generated according to the working range [0.001, 0.3]. At last, the third set represents the value of V_{VR} for shunt SVS. The range for this set is randomly generated according to the range [0.8, 1.2].

4. SIMULATION RESULTS

Matlab codes for ICA and a power flow program with MatPower to include UPFC are developed. Programmed M-Files are incorporated to include the updates for adjust the algorithm according to the required indices and terms. To show validity of the technique, it will be tested on the IEEE 14 bus system that it's shown in Figure 10. This system consists of five generators, fourteen buses, sixteen lines and eleven loads. Because of economical aspects, we suppose the number of UPFC is set to 1 in IEEE 14 bus system. Figure 11 shows the minimization of objective function achieved by Imperialistic Competitive Algorithm in IEEE 14 bus system.

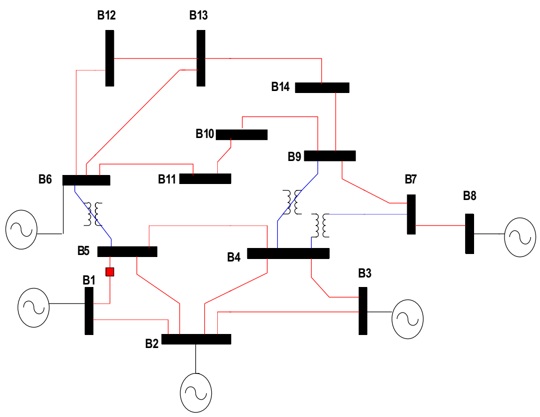

Fig. 10. IEEE 14 bus system

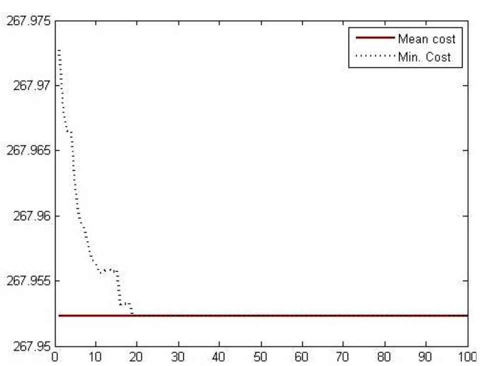

Fig. 11. Convergence characteristics of ICA algorithm for IEEE 14 bus system

Table 1. Optimal location and parameter settings of UPFC in IEEE 14 bus system

Bus Number	Bus Number	V_{CR}	V_{VR}
7	9	0.2899	1.1967

From the Table 2-4, we can find that voltage profile is improved and active and reactive power flow in lines is optimized by placing UPFC in an optimal location with optimal parameters setting by ICA. Also for bus voltage profile, the optimal location and settings of UPFC resulted from the ICA, keep the voltage profile for all the buses in the system inside the required limit ($0.95 \leq V_i \leq 1.05$) and there is not any violation in active and reactive power flow. The results show that the UPFC can significantly improve the performance of power systems with optimal location and settings. Placing UPFC in the system eliminate all of the overloaded lines and improve power flows in the system and also all of the bus voltage violations eliminated or if these violations aren't exits the algorithm able to reach the solution space to eliminate the overloaded lines and at the same time keeping the voltage profile constraint. Increasing of transmission system loadability of power system as an index to evaluate the impact of the UPFC in power system is achieved in some cases with respect to the line flow limits and the bus voltage magnitude limits.

5. CONCLUSION

The UPFC is so efficient device to improve the performance of power networks with optimal location and optimal parameter settings on an unstable power system because of load increasing. Installing UPFC in the optimal location with such optimal parameters in the power network, eliminate the overloading in the lines and removing voltage violations in the buses. ICA applied to detect the optimal location and optimal parameters settings of UPFC in the power systems. This procedure was applied for IEEE 14 bus system. The results show the efficient role of UPFC in enhancing the characteristics of the network operation.

Table 2. Bus Voltages without and with UPFC

Bus No.	Voltage without UPFC	Voltage with UPFC
1	1.05	1.05
2	1.05	1.05
3	1.034	1.032
4	0.982	1.041
5	1.001	1.027
6	1.051	1.057
7	0.953	0.986
8	1.049	1.0499
9	0.903	1.051
10	0.887	0.981
11	0.951	1.079
12	0.949	1.017
13	0.961	1.025
14	0.849	0.991

Table 3. Active power flow without and with UPFC

Line No.	Power flow without UPFC	Power flow with UPFC
1	0.908	0.463
2	0.122	0.147
3	0.037	0.061
4	0.291	0.339
5	0.172	0.258
6	0.117	0.183
7	0.016	-0.05
8	0.089	0.141
9	-0.13	-0.18
10	0.431	0.331
11	-3.68	-0.91
12	-1.25	-0.97
13	-0.03	0.16
14	1.63	0.9
15	1.5	1.021
16	1.3	1.06
17	0.1	0.2
18	0.74	0.9
19	0.4	0.6
20	0.003	0.01

Table 4. Reactive power flow without and with UPFC

Line No.	Power flow without UPFC	Power flow with UPFC
1	0.407	0.591
2	0.05	0.056
3	0.029	0.029
4	0.183	0.19
5	0.206	0.221
6	0.17	0.169
7	-0.09	-0.09
8	-0.02	-0.04
9	-0.11	-0.12
10	0.23	0.217
11	-0.54	-0.46
12	0.29	0.261
13	0.651	0.7
14	0.451	0.572
15	0.3	0.2
16	1.6	1.2
17	-0.07	-0.05
18	-0.17	-0.19
19	-0.3	-0.29
20	0.6	0.7

APPENDIX A

ICA parameters: $N = 100, M = 30, \zeta = 0.1, \beta = 2,$ $\gamma = \pi/4$.

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