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Optimal Placement of Unified Power Flow Controller by TOPSIS Method for Loss Minimization

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***Abstract:** In order to eliminate active and reactive power losses in the power system, this paper proposes TOPSIS and DE algorithm for determining the best location and parameter settings for the Unified Power Flow Controller (UPFC). To mitigate power losses, the best UPFC allocation can be achieved by re-dispatching load flows in power systems. The cost of incorporating UPFC into the power system. As a consequence, the proposed objective feature in this paper was created to address this problem. The IEEE 14-bus and IEEE 30-bus systems were used as case studies in the MATLAB simulations. When compared to particle swarm optimization, the results show that DE is a simple to use, reliable, and efficient optimization technique than (PSO). The network's active and reactive power losses can be significantly reduced by putting UPFC in the optimum position determined by TOPSIS ranking method.*

***Index Term:** Differential Evolution (DE); Particle Swarm Optimization (PSO); Unified Power Flow Controller (UPFC).*

***Keywords:** The Best Location And Parameter Settings For The Unified Power Flow Controller (UPFC).*

I. INTRODUCTION

Building new generating unit and transmission circuits becomes more tough as the demand for electricity increases due to economic and environmental concerns. As a result, electric utilities must rely on existing generation systems, causing existing transmission lines to become overburdened. Stability, on the other hand, must always be preserved. As a consequence, to operate the power system successfully without risking system security and excellence of supply, a new control plan must be implemented, also in the event of contingency conditions including transmission line and/or generating unit failures, which occur on a regular basis and will be more likely to occur at a higher frequency under deregulation. The Flexible AC Transmission System technology program was started in the late 1980s by the Electric Power Research Institute (EPRI) (FACTS). One of the most hopeful FACTS devices is the UPFC, which Gyugiy established in 1991[2]. The UPFC is designed to optimize power flow and device stability by properly configuring its controller. However, to achieve such UPFC functionality, the best position for this device in the power system, as well as the necessary parameter settings, must be specified.

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When deciding on the best position and parameter settings for UPFC, factors like increased power transmission capacity, efficient power loss decrease, avoiding power blackouts, and increased stability margin, can all be considered.

Various methods for determining the best position and parameter settings for the UPFC system have been proposed by a number of researchers. [4] proposed using an immune algorithm (IA) to determine the best location for a centralized power flow controller (UPFC) to achieve optimal power flow (OPF) and congestion management. [5] investigates the optimal locations for parallel and series FACTS devices. In light of the restructured environment, the STATCOM is chosen as a parallel FACTS device, while the SSSC is chosen as a sequence device, and the optimization issue is reformulated with a new objective function in order to relieve congestion and provide more equitable conditions for power market participants. For determining the best FACTS place, [6-8] proposed a Genetic Algorithm.

Differential Evolution is an Evolutionary Algorithm (EA) technique that is relatively new [11-13]. It's easy to set up, quick, and dependable. This paper proposes a TOPSIS approach for deciding the best position and parameter settings for a UPFC unit. Power systems [14] and [15] are two areas where DE has shown promise to minimize active and reactive power losses in a power system. For various parameter initializations of both techniques, the TOPSIS Method efficiency is compared to PSO.

II. PROBLEM FORMULATION

A. Model of UP FC

1) Equivalent Circuit and Configuration of UPFC:

Figure 1 illustrates a UPFC basic operating principal diagram. Two switching converters based on VSC valves make up the UPFC. A common DC connection connects the two converters. A series transformer connects the transmission line to the series inverter. A shunt attached transformer connects the shunt inverter to a local bus i. To meet operating control requirements, the shunt inverter can produce or absorb controllable reactive power, as well as provide active power exchange to the series inverter.

The steady-state model [17] is developed using the UPFC equivalent circuit shown in Figure 2. Two ideal voltage sources are represented in the analogous circuit by the fundamental Fourier series portion of the switched voltage waveforms at the AC converter terminals. The power supply for the UPFC is as follows:

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$V_{se} = V_{se}(\cos\theta_{se} + j\sin\theta_{se})$…………….…….….….…1
$V_{sh} = V_{sh}(\cos\theta_{sh} + j\sin\theta_{sh})$…………...……………2
where $0 \le \theta_{sh} \le 2\pi, V_{sh}$ and θ_{sh}
$V_{shmax} \le \theta_{sh} \le 2\pi, V_{shmin}$
$Vse.$ and, $\theta_{se}.$ $V_{shmin} \le \theta_{sh} \le 2\pi, V_{shmax}$
$0 \le \theta_{se} \le 2\pi$ respectively

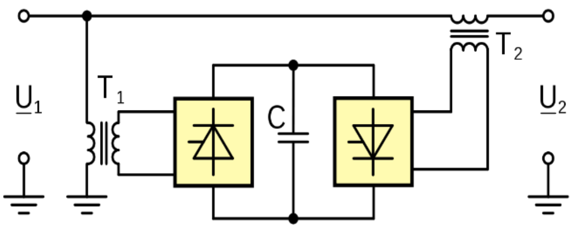

Figure 1: UPFC operating principle

2) UPFC Power Flow Constraints

For the equivalent circuit of the UPFC shown in figure 2 suppose $V_{sh} = V_{sh} < \theta_{sh}$, $V_{se} = V_{se} < \theta_{se}$, $V_{sh} = V_i < \theta_i$, $V_j = V_j < \theta_j$

then the load flow constraints of the UPFC shunt and series branches are:

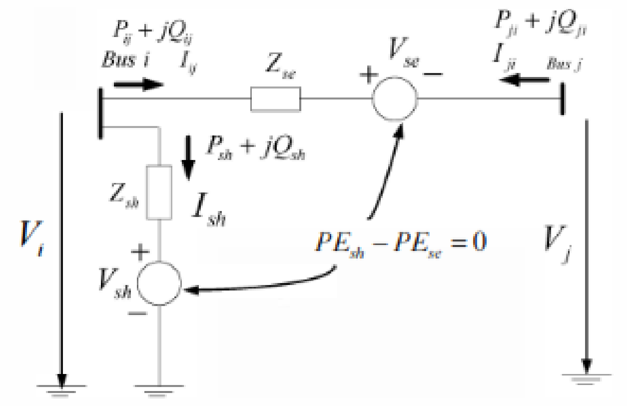

Figure 2: Equivalent circuit of UPFC

$P_{\mathrm{sh}} = V_{\mathrm{i}}^2 G_{\mathrm{sh}} - V_{\mathrm{i}} V_{\mathrm{sh}}[G_{\mathrm{sh}}\cos(\delta_{\mathrm{i}} - \theta_{\mathrm{sh}}) + B_{\mathrm{sh}}\sin(\delta_{\mathrm{i}} - \theta_{\mathrm{sh}})]$ 3
$Q_{\mathrm{sh}} = V_{\mathrm{i}}^2 B_{\mathrm{sh}} - V_{\mathrm{i}} V_{\mathrm{sh}}[G_{\mathrm{sh}}\sin(\delta_{\mathrm{i}} - \theta_{\mathrm{sh}}) - B_{\mathrm{sh}}\cos(\delta_{\mathrm{i}} - \theta_{\mathrm{sh}})]$…….4
$P_{ij} = V_i^2 g_{ij} - V_i V_j(g_{ij}\cos\theta_{ij} + b_{ij}\sin\theta_{ij}) - V_i V_{se}(g_{ij}\cos(\theta_i - \theta_{se}) + b_{ij}\sin(\theta_i - \theta_{se}))$…. ….5
$Q_{ij} = -V_i^2 b_{ij} - V_i V_j(g_{ij}\sin\theta_{ij} - b_{ij}\cos\theta_{ij}) - V_i V_{se}(g_{ij}\sin(\theta_i - \theta_{se}) - b_{ij}\sin(\theta_i - \theta_{se}))$… …6
$P_{ji} = V_j^2 g_{ij} - V_i V_j(g_{ij}\cos\theta_{ji} + b_{ij}\sin\theta_{ji}) + V_j V_{se}(g_{ij}\cos(\theta_j - \theta_{se}) + b_{ij}\sin(\theta_j - \theta_{se}))$………………… …… 7
$Q_{ji} = -V_j^2 b_{ij} - V_i V_j(g_{ij}\sin\theta_{ji} - b_{ij}\cos\theta_{ji}) - V_j V_{se}(g_{ij}\sin(\theta_j - \theta_{se}) - b_{ij}\sin(\theta_j - \theta_{se}))$……..….8
Where: $g_{sh} + jb_{sh} = \frac{1}{Z_{sh}}$, $g_{ij} + jb_{ij} = \frac{1}{Z_{se}}$
, $Q_{ij} = \theta_i - \theta_j$, $Q_{ji} = \theta_j - \theta_i$

B. Function of the Objective:

The aim of power system planning and operation has long been to reduce active and reactive power losses in transmission networks. To minimize these losses, the UPFC unit should be placed in the best possible location and have optimal parameter settings. Installation of FACTS devices in general, and UPFC in particular, is extremely expensive. As a result, the objective function is set up such that compromise can be used to solve the problem. The problem is reduced to a single objective optimization problem, as is common with multi-criteria constrained optimization. As shown below, the goal's function is defined as the combination of two words:

$$min\ F = \sum_{k=1}^{ml} P\,Q_{kloss} + \lambda x 100 x C_{UPFC} x S$$

The cost function for UPFC in $US\$/kVar$ is [18]

$$C_{UPFC} = 0.0003 S_{FACTS}^2 - 0.2691 S_{FACTS} + 188.2$$

Where F is the objective's optimization function.; PQ_{kloss} are the active and reactive power losses in line k ntl is the number of transmission lines in the system; λ is a penalty
factor; C UFFC is the cost of UPFC device in ($US\$ / kVar$); and, S is the operating range of UPFC.

1) System Constraints:

a) Constraints on equality:

The power flow equations serve as equality constraints, and they are written as follows in general form:

For $bus\ k$: $P_k(V,\theta) + P_{dk} - P_{gk} = 0$
$Q_k(V,\theta) + Q_{dk} - Q_{gk} = 0$
For bus m: $P_m(V,\theta) + P_{dm} - P_{gm} = 0$
$Q_m(V,\theta) + Q_{dm} - Q_{gm} = 0$ -------------14

b) Inequality constraints:

$P_{gk}^{min} \le P_{gk} \le P_{gk}^{max}$ k=1…..n_g ……….…....…..15
$Q_{gk}^{min} \le Q_{gk} \le QP_{gk}^{max}$ k=1…..n_g ….…………..16
$V_k^{min} \le V_k \le V_k^{max}$ k=1…..n_b ..…………………..17
$\delta_k^{min} \le \delta_k \le \delta_k^{max}$…………………….……..……18

$V_{sh}^{min} \le V_{sh} \le V_{sh}^{max}$ ………………….……….…19

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

where: n_b and n_g : are the indices for buses and generation buses; in addition

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

III. OPTIMIZATION METHOD

A. Overview of Differential Evolution

Storn and Price [11] suggested DE as an evolutionary computation method. In the DE technique, difference vectors are used to create perturbations in a vector population. DE algorithms have a high rate of convergence, are stable, conceptually simple, have few parameters, and are simple to implement. The use of this algorithm to solve complex optimization problems has piqued researchers' interest.

B. Finding the Weakest Bus Based on TOPSIS Method

The TOPSIS Procedure or Steps

STEP 1: Establish TOPSIS performance matrix as in figure below

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$$M=\begin{pmatrix}A_1\\A_2\\A_3\end{pmatrix}\begin{array}{c} \begin{array}{ccc} w_1 & w_2\dots & w_n \\ C_1 & C_2\dots & C_n \end{array} \\ \begin{pmatrix} z_{11} & z_{12}\dots & z_{1n} \\ z_{21} & z_{22}\dots & z_{2n} \\ z_{31} & z_{32}\dots & z_{3n} \end{pmatrix} \end{array}$$

STEP 2. Normalize the decision-matrix.

$$n_{ij} = {z_{ij}}\Big/{\sqrt{\sum_{j=1}^{m}\left(z_{ij}\right)^2}} \quad ,j=1\dots,n,i=1\dots,m$$

STEP 3. Calculate the normalized weighted decision matrix.

$v_{ij} = w_j * n_{ij}$, j=1…, n, i=1…, m $\quad \sum_{j=1}^{m} w_j=1$;

STEP 4: Determine the solutions that are positive ideals and those that are negative ideals. , $V_j^+ \ and \ V_j^-$

STEP 5. Calculate the separation measures.

$$S_i^+ = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_j^+\right)^2\right\}^{1/2}, \text{ j=1…, m}$$

$$S_i^- = \left\{\sum_{j=1}^{n}\left(v_{ij} - v_j^-\right)^2\right\}^{1/2}, \text{ j=1…, m}$$

STEP 6. Determine how similar the solution is to the ideal.

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \ , i = 1,\dots,m$$

If $S_i = 1 \rightarrow S_i = S^+$

If $S_i = 0 \rightarrow S_i = S^-$

STEP 7. Rank the preference order.

The active and reactive power losses in the network are minimized by optimizing these variables. The following is a summary of how the DE algorithm is implemented.

Step 1: Set up power flow data and DE-related parameters like : The size of population (N P), the maximum number of iteration or generation ($Gmax$), the number of variables to be optimized (D), and the DE control parameters CR, and F.

$$X_i(G_0) = X_{i,min} + rand_i[0,1]\left(X_{i,max} - X_{i,min}\right)$$

Step 2: Evaluate the fitness for each individual in the population according to the objective function in equation (9).

Step 3: A new population create by:

Mutation: Three different vectors randomly choose from the current population and generate a trial vector by:

$$U_i(G) = X_{i1}(G) + F\left(X_{i2}(G) - X_{i3}(G)\right)$$

Crossover: From each entity X, (G), and the corresponding trial vector ui, Equation (27) is used to generate a new offspring X/(G) (G).

$$X_{ij}(G) = \begin{cases} U_{ij}(G) & if \ \ j \in J \\ X_{ij}(G) & otherwise \end{cases}$$

Selection: Using equation (28) to pick vectors for the next generation for each, X_i(G) and corresponding,X_i'(G)., and $G = G + 1$.

$$X_{ij}(G+1) = \begin{cases} U_{ij}(G+1) \ \ if \ f\left(X'(G+1) \le f\left(X'(G)\right)\right) & j \in J \\ X_{ij}(G) & otherwise \end{cases}$$

Step 4: If the stopping criterion is met, stop the method and print the best person (optimal position and UPFC parameter setting); otherwise, return to Step 4.

IV. SIMULATION RESULTS

For simulation determinations, this paper develops and integrates MATLAB programming for Differential Evolution and TOPSIS, the weak load flow algorithm with UPFC. The simulation is conducted on a computer with a 2.66 GHz Pentium IV processor and 1 GB of RAM. The initial parameter values for DE and PSG are mentioned in Tables I and II, respectively. The values [11-15], [6], and [9-10] have all been published in peer-reviewed journals. The IEEE-14 bus test system (shown in Figure.3) and the IEEE-30 bus test system data are used to demonstrate the proposed techniques (shown in Figure.4). For simulation purposes, this research develops and integrates MATLAB programming codes for DE, PSG, and an improved power flow algorithm with UPFC. The simulations are performed on a computer with a 2.66 GHz Pentium IV processor and 6 GB of RAM. There are no standard values for the parameters since DE and PSG are both probabilistic and stochastic search techniques. However, as defined in the literature, the accepted values provided the best results in the majority of cases. As a consequence, statistical validation of simulation results obtained with these methods is needed. The following are the results of ten trials used to assess the success of these techniques in this study:

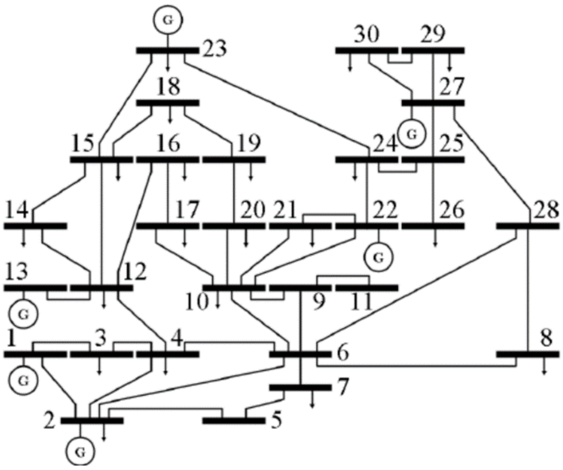

Figure 4: IEEE 30 Bus test system

Table 1: DE initial parameter values

Initial Parameter values of DE	
Population size (NP)	30
Maximum number of	100
Number of variables (NV)	5
Length of individual L_i	5
DE step size F	0.8
Crossover probability constant CR	0.5
DE strategy	DE/rand/1/bin
Termination Criteria	1xe^{-6} or G_{max}

Table 2: parameter values of PSO(NP) Number of swarm beings

PSO Technique Parameter	
Number of swarm beings (NP)	30
G_{max},Maximum number of flights	100
(NV),Number of variables	5
L_i, Length of individual	5
C_1, C_2	1.5
w_{max}, w_{min}	0.9,0.4
Termination criteria	1xe^{-6} or G_{max}
Original velocities' deviation	10

A. 14-Bus Test System

There are five generators, twenty transmission cables, fourteen buses, and eleven loads in this technique. The following are the outcomes of the simulation: There are five generators, twenty transmission cables, fourteen buses, and eleven loads in this technique. There are five generators, twenty transmission cables, fourteen buses, and eleven loads in this technique. The following are the outcomes of the simulation: There are five generators, twenty transmission cables, fourteen buses, and eleven loads in this technique. The following are the outcomes of the simulation: Line three (from bus 2 to bus 3) is the best location for UPFC in this situation, with an installation cost of 0.22986 x 10^6 (US $). According to PSO info, line three (from bus 2 to bus 3) is the best location for UPFC, with an installation cost of 0.25001x10^6(US$). Both methods yielded similar findings after ten trials. Table III shows the ideal UPFC array, as well as the magnitude and phase angles of the shunt voltage source obtained with both techniques, after ten trials. After 10 trials, the convergence characteristics of the objective function are shown in Figure 5. The objective function's worst, average, and best values for various DE and PSO parameter settings are shown in Table IV after ten trials.

Table 3: optimal parameter setting UPFC

Techniques of Evolution	$V_{sh}(pu)$	θ_{sh}(rad)	$V_{se}(pu$	θ_{se}(rad)
DE	0.9961	0.06961	0.12171	1.45511
PSO	1.0671	-0.22141	0.13871	1.46191

Table 4: shows the objective function's worst, average, and best values for different DE and PSO parameter settings.

Objective function value	Computational intelligence (CI) Techniques							
	Technique of Evolutionary Algorithm				Technique of Swarm intelligence			
	DE				PSO			
	F=0.5 CR=0.5	F=0.5 CR=0.8	F=0.8 CR=0.5	F=0.8 CR=0.8	c_i, i=1,2 $w_{max} = 0.9, w_{min} = 0.4$			
					0.5	1	1.5	2
worst	312.458	312.587	312.641	312.677	316.84	316.89	315.68	315.97
Average	312.379	312.405	312.524	312.562	315.27	315.48	314.56	314.65
Best	312.321	312.399	312.436	312.488	314.66	314.58	314.22	314.46

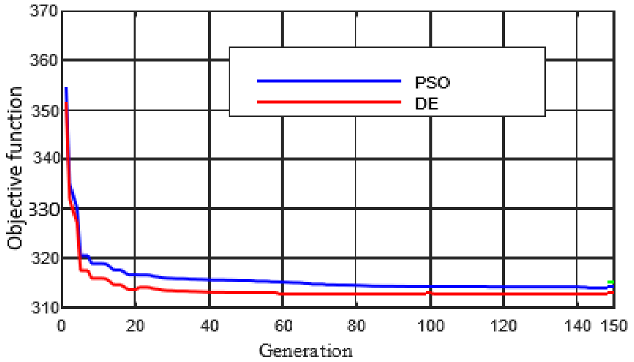

Figure 5: The objective function's convergence characteristics after ten trials

B. Test System for IEEE 30-Bus

There are six generators, 41 transmission cables, thirty buses, and twenty-one loads in this facility. The following are the results of the simulation: This system includes 6 generators, 41 transmission lines, 30 buses, and 21 loads. The simulation results are as follows:

The results of using the DE technique show that the best position for the UPFC in this case is line 7 (from bus 6 to bus 4) with the lowest installation cost of 0.21148xI06(US$).

The results of using the PSO technique also show that the best position for a UPFC is line 7 (from bus 6 to bus 4) with the lowest installation cost of 0.23324 x 106 (US $). For both methods, the results are obtained after ten trials. Both techniques generated the best UPFC series and shunt voltage source magnitude and phase angles after ten trials. The DE technique's results show that line 7 (from bus 6 to bus 4) is the best place for the UPFC in this situation, with a cost of 0.21148xI06(US$) for installation. The PSO technique also reveals that line 7 (from bus 6 to bus 4) is the best position for a UPFC, with a cost of 0.23324 x 106 (US $) for installation. After ten trials, the results of both methods are obtained. Table 5 shows the ideal UPFC array, as well as the magnitude and phase angles of the shunt voltage source obtained using both techniques, after ten trials. The trial results are shown in Table 5.

Table 5 Optimal parameter setting of UPFC

Evolutionary Techniques	$V_{sh}(pu)$	θ_{sh}(rad)	$V_{se}(pu$	θ_{se}(rad)
DE	0.998	-0.2070	0.1552	-2.1184
PSO	1.0792	-0.2520	0.1627	1.0794

The objective function's worst, average, and best values for various DE and PSO parameter settings are shown in Table 6 after ten trials. The best value for c,' I = 1. 2 in the PSO technique is 1.5, while the best values for W-min. and W-max. are 0.4001 and 0.9001, respectively, according to the findings. F in the DE methodology has a best value of 0.5, and CR has a best value of 0.5. The results in Table 7 show that PSO performs the optimization faster than DE because DE uses mutation, crossover, and selection operations to process the optimization while PSO does not. .

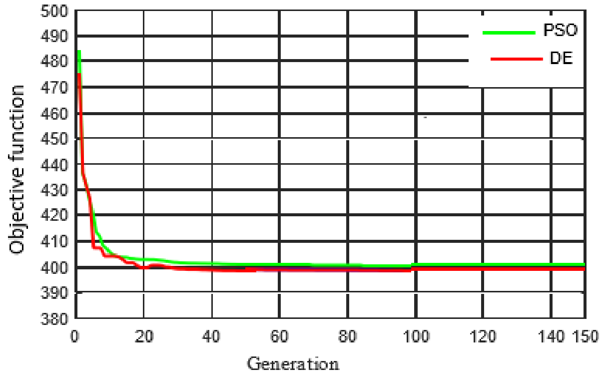

Figure 6: Objective Function Convergence Characteristics

Table 6: With different DE and PSO parameter settings, the objective function's worst, average, and best values are calculated.

Objective function	Techniques of Computational Intelligence (CI)							
	The EAS (Evolutionary Algorithm) technique				Swarm intelligence (SI) Technique			
	DE				PSO			
	F=0.5 CR=0.5	F=0.5 CR=0.8	F=0.8 CR=0.5	F=0.8 CR=0.8	c_i, i=1,2 $w_{max} = 0.9, w_{min} = 0.4$			
					0.5	1	1.5	2
worst	391.216	391.307	391.394	391.408	396.16	395.28	395.07	395.11
Average	391.178	391.248	391.275	391.297	394.10	394.78	394.34	394.48
Best	391.142	391.191	391.241	391.66	394.1	394.17	394.0	394.08

Table 7 for proposed techniques simulation time

system Tested	Simulation time (sec)	
	DE	PSO
14-Bus	76.48721	66.17231
30_Bus	178.54231	114.43851

V. CONCLUSION

The first and most critical step in implementing UPFC in power systems is determining the proper position and parameters for the UPFC unit. This computer has the ability to rapidly and easily adjust system parameters. As a result, the UPFC device clearly provides benefits such as increased system reliability, increased system performance, and lower operating and transmitting investment costs.

In order to eliminate active and reactive power losses in a power system, this paper attempted to determine the best location and parameters for a UPFC unit. DE was successfully applied to the problem at hand, which is one of the most current computational intelligence approaches. This paper contains two case studies, one involving an IEEE 14-bus system and the other involving an IEEE 30-bus system. The findings show that the DE method has a number of advantages, including high-quality solutions, stable convergence, and fast computation speed. Finally, our findings show that active and reactive power losses in a system can be significantly reduced by using the proper parameter settings and installing UPFC in the most optimal position.

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