OPTIMAL PLACEMENT AND SIZING OF UNIFIED POWER FLOW CONTROLLER USING HEURISTIC TECHNIQUES FOR ELECTRICAL TRANSMISSION SYSTEM

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ABSTRACT

The extensive growth of industrial demand and domestic demand will make the power system more expensive. The increase of demands will also leads to the increase of the losses from generation to the distribution level. To achieve the flexible operation of the power system from generation to the distribution along with the exponential growth of load, Flexible alternating currents transmission system (FACTS) devices are used. The inclusion of FACTS devices in the power system will make the system more reliable. With the advancements in the power electronic devices the design of facts devices will also take more advantageous position to operate the power system with more reliable. There are many types of FACTS devices such as series, shunt, series-shunt and shunt-shunt among these types shunt –shunt FACTS device plays a major role to operate the power system with less power losses and improved voltage profile. Unified power flow controller (UPFC) is one of the types of shunt-shunt FACTS device. In this paper the incorporation of UPFC within the power system which improves the voltage profile and reducing the losses. The placement of FACTS devices and size of the FACTS device is through analytical and soft computing techniques which are Genetic algorithm (GA), particle swarm optimization (PSO) are used.

Keywords: power systems, voltage profile, GA, PSO, losses (KW and MVar).

INTRODUCTION

Power system is the one of the complex systems which consists of thousands of line and hundreds of buses which are inter connected to each other to satisfy the load conditions. With the exponential increasing of load the sources does not able to satisfy the load conditions which turns into block outs at certain parts of the power system. The loss also plays a crucial role to design the generating plants which are connected to the loads to satisfy their need through the transmission lines. The real and reactive behaviour of the load will tends to the real and reactive power losses in the power systems. The increase of load does not tend to rising of the generating plants, but the losses are rising with the increase in load conditions. So, by reducing the losses which will improve the voltage profile of the power system. The inclusion of the capacitive effect at the load and at the transmission system will helping in reduction of the losses in the power system. The inclusion of the capacitive effect will provide the leading MVars to the load and inclusion of the capacitive effect will reduce the inductive nature of the transmission line which reduces overall losses in the power system. The shunt and series FACTS device will perform the above mentioned operations which is UPFC. Stagg and E.i-Abiad introduced the computer methods in power systems analysis to determine the system losses and voltage profile at steady state condition [1]. Gotham and heydt at 1998 proposed the power flow studies of the power system with the incorporation of the FACTS devices which tends to decrease in the losses [2]. Povh. D at 2000 proposed how to model the FACTS devices for power flow studies and implemented in various test cases. [3]. The modeling of

the facts devices with Matlab are proposed by E. Acha [4]. The effect of multiple FACTS device to reduce the losses in the power system is proposed by Radman. G and Raje [5].

The paper in completely divided in to four parts which are introduction, modeling of UPFC optimizing techniques results and conclusion.

Power flow analysis: The complex systems like power systems are analyzed by using one of the mathematical method analyses which is newton-raphson method to give good convergence.

The transmission line in power system can be denoted by a two-bus system "k" and "m" in ordinary form. The active power transmitted between bus nodes k and m is given by:

$$P = \frac{V_k * V_m}{X} \sin(\delta_k - \delta_m) \tag{1}$$

Where $\boldsymbol{\delta_k}$ and $\boldsymbol{\delta_m}$ are the voltages at the nodes, $(\delta_k - \delta m)$ the angle between the voltages and, the line impedance. The power flow can be controlled by altering the voltages at a node, the impedance between the nodes and the angle between the end voltages. The reactive power is given by:

$$Q = \frac{V_k^2}{X} - \frac{V_m * V_k}{X} \cos(\delta_k - \delta m) \tag{2}$$

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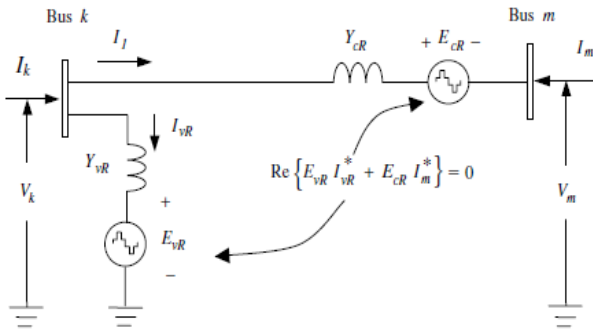
Figure-1. Equivalent circuit diagram of UPFC.

The shunt –series compensators like UPFC controls both wattful power flow, wattless power flow and improving the voltage profile at its terminals. This type of compensator majorly consists of two Voltage source converters which are sharing by a common capacitor. The equivalent circuit is shown in the Figure-1.

The series converter's active power is drawn with the shunt converter from the power system network and supplied to bus m through the DC link. The bus voltage is improved by adding the output voltage of the series converter, here bus 'k' to boost the nodal voltage at bus 'm'. The UPFC equivalent circuit which consists of shunt and series voltage source converter connected with AC system by inductive reactance.

Modeling of UPFC within power flow analysis

The control on the real power flow and reactive power flow and voltage improving is successfully implemented by incorporating the UPFC in the power system network. The modeling of the UPFC is major part of the successful controlling of UPFC on the power system to reduce the losses and improve the voltage profile.

$$E_{vR} = V_{vR}(\cos\delta_{vR} + J\sin\delta_{vR}) \tag{3}$$

$$E_{cR} = V_{cR}(\cos\delta_{cR} + J\sin\delta_{cR}) \tag{4}$$

Where V_{vR} and δ_{vR} are the magnitude of the control voltage $V_{vRmin} \leq V_{vR} \leq V_{vRmax}$ and phase angle $(0 \leq \delta_{vR} \leq 2\pi)$ of the voltage source representing the shunt converter. The magnitude V_{cR} and phase angle δ_{cR} of the voltage source representing the series converter are controlled between limits $V_{cRmin} \leq V_{cR} \leq V_{cRmax}$ and $(0 \leq \delta_{cR} \leq 2\pi)$ respectively. The phase angle of the series-injected voltage determines the mode of power flow control. If δ_{cR} in phase with the nodal voltage angle θ_k, the UPFC regulates the terminal voltage. If δ_{cR} is in quadrature with respect to θ_k it controls active power flow, acting as a phase shifter. If δ_{cR} is in quadrature with the line current angle then it controls active power flow, acting as a variable series compensator. At any other value of δ_{cR}, the UPFC operates as a combination of voltage regulator, variable series compensator, and phase shifter. The magnitude of the series-injected voltage determines the amount of power flow to be controlled.

Based on the equivalent circuit shown in Figure-3 and Equations (5) and (6), the active and reactive power equations are at bus k:

$$P_k = V_k^2 G_{kk} + V_k V_m [G_{km}\cos(\theta_k - \theta_m) + B_{km}\sin(\theta_k - \theta_m)]V_k V_{cR}[G_{km}\cos(\theta_k - \delta_{cR}) + B_{km}\sin(\theta_k - \delta_{cR})] + V_k V_{vR}[G_{vR}\cos(\theta_k - \delta_{vR}) + B_{vR}\sin(\theta_k - \delta_{vR})] \tag{5}$$

$$Q_k = -V_k^2 B_{kk} + V_k V_m [G_{km}\sin(\theta_k - \theta_m) - B_{km}\cos(\theta_k - \theta_m)] + V_k V_{cR}[G_{km}\sin(\theta_k - \delta_{cR}) - B_{km}\cos(\theta_k - \delta_{cR})] + V_{vR}V_k[G_{vR}\sin(\theta_k - \delta_{vR}) - B_{vR}\cos(\theta_k - \delta_{vR})] = \tag{6}$$

At bus m:

$$P_m = V_m^2 G_{mm} + V_m V_k [G_{mk}\cos(\theta_m - \theta_k) + B_{mk}\sin(\theta_m - \theta_k)] + V_m V_{cR}[G_{mm}\cos(\theta_m - \delta_{cR}) + B_{mm}\sin(\theta_m - \delta_{cR})] \tag{7}$$

$$Q_m = -V_m^2 B_{mm} + V_m V_k [G_{mk}\sin(\theta_m - \theta_k) - B_{mk}\cos(\theta_m - \theta_k)] + V_m V_{cR}[G_{mm}\sin(\theta_m - \delta_{cR}) - B_{mm}\cos(\theta_m - \delta_{cR})] \tag{8}$$

Series converter:

$$P_{cR} = V_{cR}^2 G_{mm} + V_{cR}V_k[G_{km}\cos(\delta_{cR} - \theta_k) + B_{km}\sin(\delta_{cR} - \theta_k)] + V_m V_{cR}[G_{mm}\cos(\delta_{cR} - \theta_m) + B_{mm}\sin(\delta_{cR} - \theta_m)] \tag{9}$$

$$Q_{cR} = -V_{cR}^2 B_{mm} + V_{cR}V_k[G_{km}\sin(\delta_{cR} - \theta_k) - B_{km}\cos(\delta_{cR} - \theta_k)]V_{cR}[G_{mm}\sin(\delta_{cR} - \theta_m) - B_{mm}\cos(\delta_{cR} - \theta_m)] \tag{10}$$

Shunt converter:

$$P_{vR} = -V_{vR}^2 G_{vR} + V_{vR}V_k[G_{vR}\cos(\delta_{vR} - \theta_k) + B_{vR}\sin(\delta_{vR} - \theta_k)] \tag{11}$$

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR}V_k[G_{vR}\sin(\delta_{vR} - \theta_k) - \cos(\delta_{vR} - \theta_k)] \tag{12}$$

Using these power equations, the linear zed UPFC model is given below, where the voltage magnitude V_{vR} and phase angle δ_{vR} are taken to be the state variables [4]

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$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{vR} \\ \Delta Q_{vR} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k}V_k & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}}V_{vR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k}V_k & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}}V_{vR} \\ \frac{\partial P_{vR}}{\partial \theta_k} & \frac{\partial P_{vR}}{\partial V_k}V_k & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}}V_{vR} \\ \frac{\partial Q_{vR}}{\partial \theta_k} & \frac{\partial Q_{vR}}{\partial V_k}V_k & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}}V_{vR} \end{bmatrix} \begin{bmatrix} \Delta \theta_k \\ \frac{\Delta V_k}{V_K} \\ \Delta \delta_{vR} \\ \frac{\Delta V_{vR}}{V_{vR}} \end{bmatrix} \qquad (13)$$

Placement of FACTs device using Optimizing techniques:

The modeling of the UPFC along with the suitable placements give fruitful results in the power system network. The losses are reduced by placing the UPFC in the power system network. But by optimal placement of UPFC in the power system network the losses are greatly reduced. The optimal placement of UPFC is carried by using different optimizing techniques like genetic algorithm (GA), particle swarm optimization (PSO) and differential evolution (DE). The total algorithms are used to place the UPFC to reduce the system losses and improve the voltage profile of the buses.

Genetic algorithm (GA): the basic of the genetic algorithm is given. The population, maximum generations, crossover rate, mutation rate and selection of the genetic algorithm. The population of the genetic algorithm is initialized with branch number and the size of the UPFC. At each generation of the GA, the power system network is incorporated with the UPFC along with the size. The loss at each generation is calculated by using load flow analysis. At each generation the losses are considered as the local minimum losses and if the losses will get lesser than the previous generation. Finally the minimum losses are calculated with optimum location and size of the UPFC. The flowchart of the genetic algorithm with incorporation of the UPFC with the optimum size.
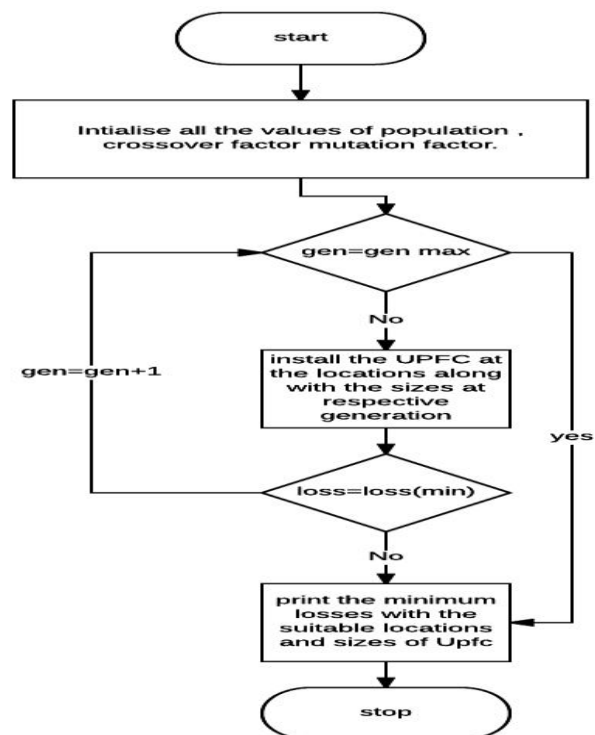

Figure-2. Flowchart of genetic algorithm.

Particle swarm optimization (PSO):

Particle swarm optimization is also one of the optimization techniques which are mainly used for optimizing the engineering problems. In this paper PSO is used to optimize the losses of the power system network by placing the UPFC with optimal size. The basics of the PSO is presented in [] to optimize the many linear and non linear engineering problems. The adoption of PSO with power system by initializing the particles with branch numbers and size of the UPFC. The flowchart of the PSO with placement of UPFC along with size is shown I the Figure-3.

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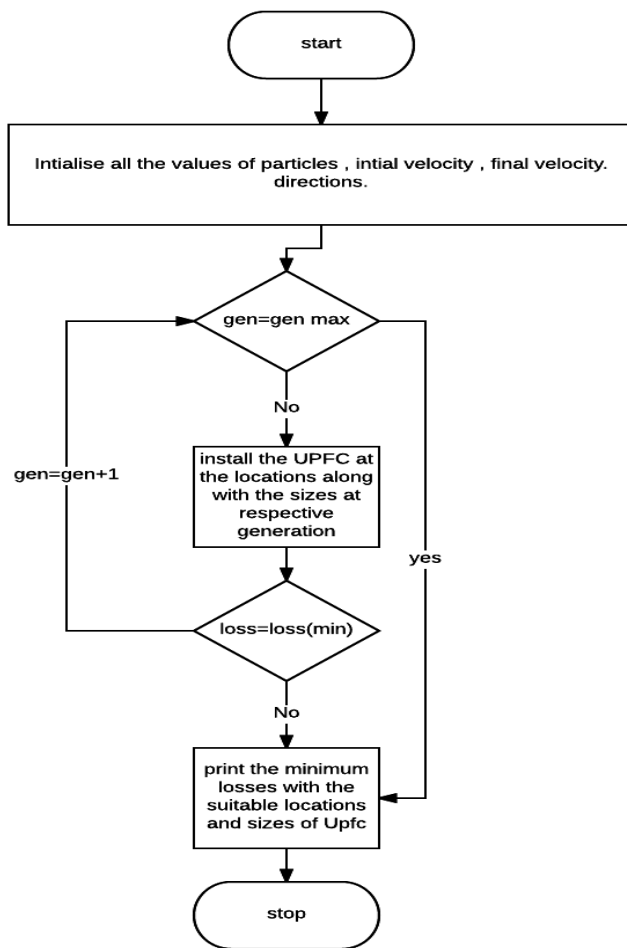
Figure-3. Flowchart of the PSO with the placement of UPFC.

RESULTS AND CONCLUSIONS

The proposed technique is tested on the IEEE 14 bus and IEEE 30 bus system. The losses of the power system and improvement of the voltage profile can be analyzed by incorporating the UPFC at optimum places with optimum sizes. Finally the losses of the power system
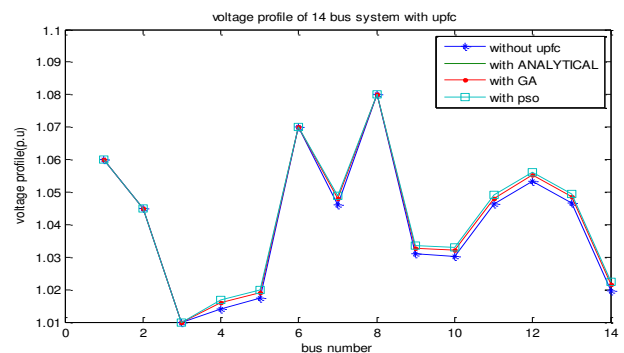
network with the mentioned is optimization networks is detailed in the following section

Test Case 1: IEEE 14 bus system:
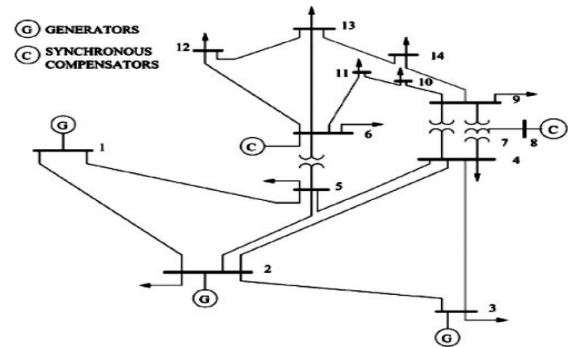
**Figure-4.** Single line diagram of IEEE 14 bus system.

The proposed method is tested on IEEE 14 bus system. The single line diagram and Voltage profile of respective system is shown in the Figure-5 and Figure-6 respectively.
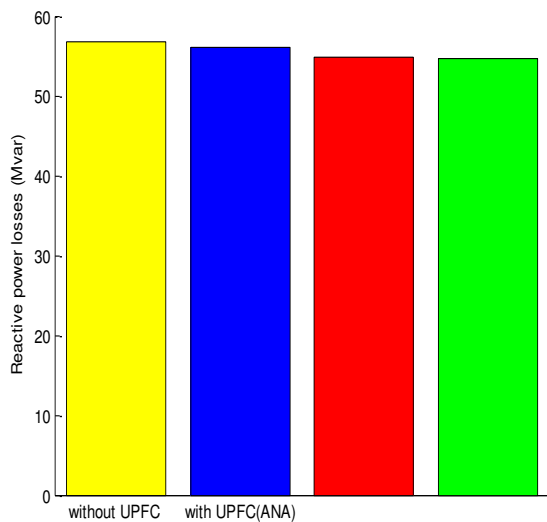

Figure-5. Voltage profile of the IEEE 14 bus with and without UPFC.

Table-1. Comparative analysis of optimising techniques by placing UPFC.

S. No	Size of UPFC facts device	UPFC placed bus	Min. voltage (p.u.)	Max. voltage (p.u.)	Real power losses(MW)	Reactive power losses (MVAR)
1	Without		1.010	1.080	13.5770	56.7840
2	With ANA (2.014MVAR)	8	1.0175	1.06	12.5700	56.1400
3	With GA (2.012MVAR)	15	1.0177	1.06	12.1600	54.8240
4	With PSO (2.011MVAR)	17	1.018	1.08	12.0140	54.6040
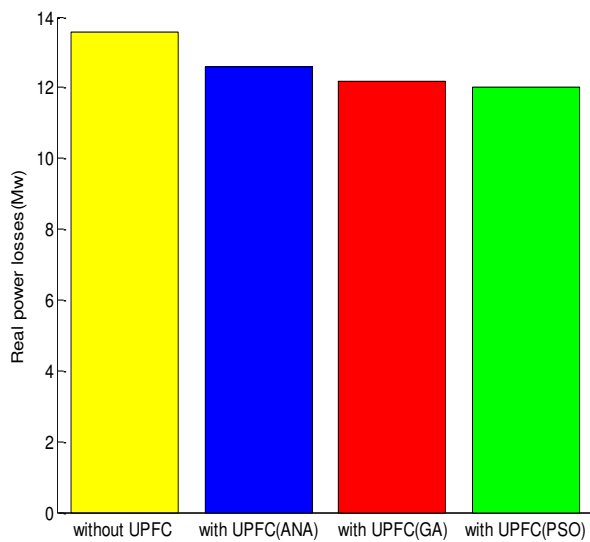
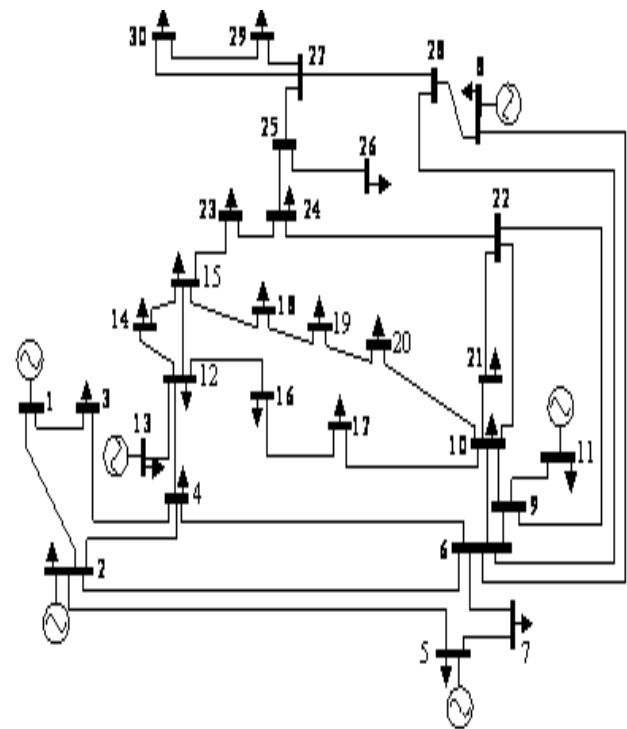**Figure-6.** Real power losses of IEEE 14 bus system with and without UPFC.

Figure-7. Reactive power losses of IEEE 14 bus system with and without UPFC

The proposed optimizing techniques are applied to IEEE 14 bus system. The improvement of the voltage profile is the good impact on the reduction of the reactive

power losses in the system which is greatly improved in pSO optimizing techniques. The analytical methods [] which are used for placement of UPFC has reduce both real and reactive power losses by 12.014 Mw and 54.6040 Mvars. The placement of the UPFC for PSO optimizing techniques is 17th branch with the size of 2.011 MVars. With the inclusion of the UPFC in the transmission system the minimum voltage profile is improved from 1.01p.u to 1.018 p.u. By using the genetic algorithm also [th] size of the UPFC is 2.014 Mvars which is placed at 15th branch. But the losses are reduced by 12.16 Mw and 54.82 Mvars. The minimum voltage profile is improved from 1.01p.u to 1.0177 pu.

Test case II IEEE 30 bus system:

Figure-8. Single line diagram of IEEE 30 bus system.
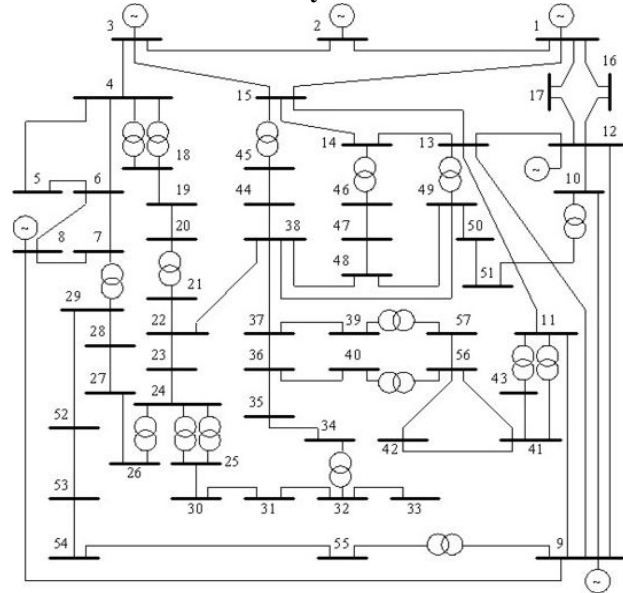
Table-2. Comparative analysis of IEEE 30 bus system with optimizing techniques by placing UPFC.

Method	Min voltage(P.U) (Bus)	UPFC placed bus	Real power losses(Mw)	Reactive power losses(MVar)
Without UPFC	0.9828(30)	_____	17.759	69.759
GA	0.9950(24)	21-22	16.259	62.612
PSO	1.020(24)	21-22	16.152	61.213

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The minimum voltage of the IEEE 30 bus system without UPFC is 0.9828p.u. The real and reactive power losses of the system are 17.759 Mw and 69.759 MVar. The UPFC is placed by using the optimizing techniques. By GA the UPFC is placed at the 5th bus the voltage profile is improved .The minimum voltage is improved to 0.9950 at 24th bus. The real and reactive power losses are reduced to 16.259 Mw and 62.612 MVar which is shown in the table 6.But by using DE the UPFC is placed between 21 and 22 buses. But the voltage injected at 1.024 p.u unlike in GA. The voltage profile and real power losses and reactive power losses are similar to the GA. The improved voltage profile by placing UPFC using PSO is shown in the Figure-5. The minimum voltage is 1.020 p.u at 24th bus by placing the UPFC at 21-22 buses. The real and reactive power losses are 16.152 Mw and 61.213 MVar.

Test case III IEEE 57 bus system

Figure-9. IEEE 57 bus transmission system.

Table-3. Comparative analysis of IEEE 57 bus system with optimizing techniques by placing UPFC.

Method	Min voltage(P.U) (Bus)	UPFC Placed bus	Real power losses(Mw)	Reactive power losses(MVar)
Without UPFC	0.899(57)	_____	35.219	236.136
GA	0.964(46)	52-53	31.132	221.003
PSO	0.9812(45)	51-52	31.112	220.832

The minimum voltage of the IEEE 57 bus system without UPFC is 0.899p.u. The real and reactive power losses of the system are 35.219 Mw and 236.136 MVar. The UPFC is placed by using the optimizing techniques. By GA the UPFC is placed at the 53rd bus the voltage profile is improved which. The minimum voltage is improved to 0.964 at 46th bus. The real and reactive power losses are reduced to 31.132 Mw and 221.003 MVar which is shown in the table 4.But by using DE the UPFC is placed at 53rd bus. But the voltage injected at 1.024 p.u unlike in GA. The voltage profile and real power losses and reactive power losses are similar to the GA.The improved voltage profile by placing UPFC using PSO. The minimum voltage is 0.9812 p.u at 45th bus by placing the UPFC at 52nd bus. The real and reactive power losses are 31.112 Mw and 220.832 MVar.

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