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Optimal location of UPFC for voltage profile improvement using particle swarm optimization and fuzzy logic

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ABSTRACT:The objective of this project is to reduce the power loss and to improve the voltage profile in transmission system. Fuzzy is used for placement and Particle Swarm Optimization algorithm is used for sizing of UPFC. The UPFC using Current Injection Model (CIM)**.** The system performance is improved with the use of UPFC and this is demonstrated on IEEE14& 30 bus systems.

KEYWORDS:UPFC, PSO Algorithm, Fuzzy logic.

I. INTRODUCTION

Load flow studies is one of the most important aspects of power system planning and operation. The load flow provides the sinusoidal steady state of the entire system voltages, real and reactive power generated and absorbed and line losses since the load is a static quantity and it is the power that flows through transmission lines.

Load flow solution is a solution of the network under steady state condition subject to inequality constraints under which the system operates. The load flow solution gives the nodal voltages, phase angles and power flow at all the buses interconnecting power channels (transmission lines).

A load flow solution of the power system requires mainly the following steps:

- Formulation or the network equations
- Suitable mathematical technique for solution of the equations

Classification of Buses

In a power system each bus node is associated with four quantities namely real and reactive power, bus voltage magnitude and its phase angle. Nodal analysis (i.e.Y_{bus} based) is almost universally preferred in load flows. The main objective of the load flow is to find the voltage magnitude of each bus and its angle when the powers generated and loads are pre-specified. To facilitate this, the classification of buses in power system is shown in the figure.2.1.

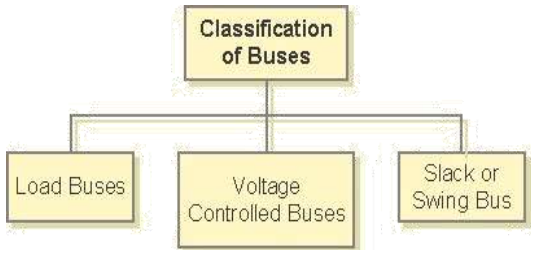

Fig1.1: Classification of buses Load Bus:

This is also called P-Q bus, and at this bus the total injected power is specified i.e., the active and reactive power injected in to the network at this bus. Magnitude and phase angle of the voltage are to be computed.

II. RELATED WORK

The concept of FACTS and FACTS controllers was first defined by N.G. Hingorani, and L. Guygyi in 1988 [1]. FACTS usually refer to the application of high-power semiconductor devices to control different parameters and electrical variables such as voltage, impedance, phase angles, currents, reactive and active power. Since then many researches have taken place in this area by using these FACTS device for power enhancement in the transmission systems.

The different types of modelling techniques have been used for modelling UPFC [2-4]. J. Bian, D. G. Ramey, R. J. Nelson [2], K. K. Sen and E. J. Stacey[3] in their presented papers on suspetance model and firing angle model of SVC [5-6] for the improvement of power system stability

M.Damodar Reddy and K. Dhananjaya babu [7] presented a paper on optimal placement of SVC using Fuzzy and PSO algorithm. In this paper the SVC is modelled as a device which injects the reactive power at the bus to which the device is connected. Here the Fuzzy approach is used for finding the optimal location of SVC.

A. Meta vural and Mehmattumay [8] presented the detailed power injection model along with the modification of the respective elements of the Jacobian matrix in the NR method for the load flow studies. The power injection equations for the UPFC have been derived in this paper.

Ch. Chengaiah, G.V. Marutheswaret.al. [9] presented the paper on control setting of UPFC through load flow calculation. Dr.Shivasharanappa and sunilkumar [8] presented a paper on transmission loss allocation and loss minimization by incorporating UPFC in load flow analysis.

S.V. Ravi Kumar and S. Siva Nagaraju [10] presented a paper for Minimization of losses in transmission networks by incorporating UPFC in load flow studies. In this paper Hale network is taken and the power injection model of UPFC is incorporated and the power flows are studied for different control parameter values of UPFC.

R. Vanitha and M. Sudhakaran [11] presented a differential algorithm approach for loss reduction by optimal location of UPFC and finding the optimal control parameter setting of UPFC. In this paper comparison between differential evolution and genetic algorithm of UPFC is considered.

Y. del Valle, J. C. Hernandezet.al. [12] presented step by step application of theParticle Swarm Optimization (PSO) method to solve the problem of optimal allocation and sizing of unified power flow controller (UPFC). As a part of this study, the optimal setting of PSO parameters is investigated and different power system load conditions are tested to determine the impact over the location and size of each UPFC unit.

III. IMPLEMENTATION OF FUZZY AND PSO FOR OPTIMAL PLACEMENT & SIZING OF UPFC

1) Unified Power Flow Controller (UPFC) Construction and Operation of UPFC

The UPFC can provide simultaneous control of all basic power system parameters (transmission voltage, impedance and phase angle). The controller can full functions of reactive shunt compensation, series compensation and phase shifting meeting multiple control objectives. From a functional per-spective, the objectives are met by applying a boosting transformer injected voltage and exciting transformer reactive current. The injected voltage is inserted by a series transformer. Besides transformers, the general structure of UPFC contains also a "back to back" AC to DC voltage source converters operated from a common DC-link capacitor, Figure 3.2.

First converter (CONV1) is connected in shunt and the second one (CONV2) in series with the line. The shunt converter is primarily used to provide active power demand of the series converter through a common DC link. Converter 1 can also generate or absorb reactive power, if it is desired, and thereby provide independent shunt reactive compensation for the line. Converter 2 provides the main function of the UPFC by injecting a voltage with controllable magnitude and phase angle in series with the line voltage source.

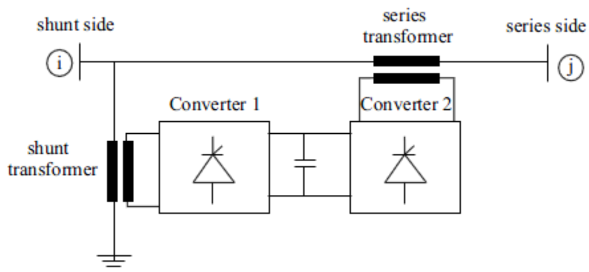

Fig 1.1: Implementation of the UPFC by back-to-back converters

The Unified Power Flow Controller from the stand point of conventional power transmission based on reactive series compensation, shunt compensation, and phase shifting, the UPFC is the only device which can fulfill all these functions and thereby meet multiple control objectives by adding the injected voltage V_{pq}, with appropriate amplitude and phase angle, to the terminal voltage V_0(Using phasor representation, the basic UPFC

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power flow control functions are illustrated in Figure.1.2.

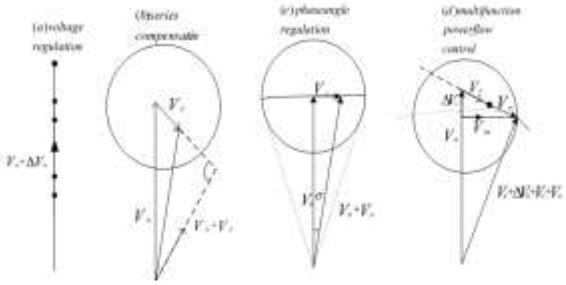

Fig.1.2: Basic UPFC control function. (a)Voltage Regulation (b) Series compensation (c) Angle regulation (d) Multi-function power flow controller

Terminal voltage tap-changer having infinitely little steps is shown at (a) where V_m=ΔV (boldface letters represent phasors) is injected in -phase (or anti -phase) with V). Series capacitive compensation is shown at (b) where $V_m = V_C$ is injected in quadrature with the line current I. Transmission angle regulation (Phase shifting) is shown at (c) where $V_{pq} = V_\sigma$ is injected with an angular relationship with respect to V_0 that achieves the desired σ phase shift (advance or retard) without any change in magnitude. The figure (d) shows that Multi power flow control, executed by simultaneous terminal voltage regulation, series capacitive line compensation, and phase shifting, where $V_{pq}=\Delta V+ V_C+V_\sigma$. The powerful, hither to unattainable, the capability of the UPFC summarized above in terms of conventional transmission control concepts, it can be integrated into a generalized power flow controller which is able to maintain prescribed, and independently controllable, the real power P and reactive power Q in the line.

2. Implementation of Fuzzy

A fuzzy approach is proposed to finding the suitable locations for placement of a UPFC. Two objectives are considered while designing a fuzzy logic for identifying the optimal UPFC locations. The objectives are:

1.To maintain the real power loss and

2.To maintain the voltage within the permissible limits.

Voltages and power loss indices of distribution network nodes are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing a set of rules is then used to find the UPFC placement. UPFC are placed on the nodes with the highest suitability.

For the UPFC placement problem approximate reasoning is employed in the following manner when losses and voltage levels of a distribution system are studied, an experienced planning engineer can choose locations for UPFC installations, which are probably highly suitable. For example, it is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of UPFCs. Whereas low section with good voltage is not ideal for UPFC placement. A set of fuzzy rules has been used to load flow solution for the original system is required to obtain the real and reactive power losses. Again, load flow solutions are required to obtain the power loss reduction by compensating the total reactive load at every node of the distribution system. The loss reduction having a value of 1 and the smallest one having a value of 0. Power loss index value for n^{th} node can be obtained using below equation 4.1

$$PL_{(n)}= \frac{LR(n)-LR(min)}{LR(max)-LR(min)} \quad \ldots (2.1)$$

Where,

$PL_{(n)}$-Power loss index at n^{th} node

Loss reduction (n)-Loss reduction at n^{th} node

Lossreduction(min)-MinimumLossreduction

Loss reduction (max) - Maximum Loss reduction

In MATLAB command window type fuzzy to open the basic FIS Editor. In the FIS Editor, go to File and select either of the following, New Mamdani FIS: to open a new Mamdani-style system with no variables and no rules called untitled.

New Sugeno FIS: to open a new Sugeno-style system with no variables and no rules called untitled.

Select Mamdani type FIS. Five pop-up menus (default) are selected to change the functionality of the following five basic steps in the Fuzzy implication process:

For **And** method : min is selected

For **Or** method : max is selected

For **Implication** method : min is selected

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For **Aggregation** method : max is selected
For **Defuzzification**method: centroid method is selected.

In this project, two input variables such as power loss index (PLI) and per unit nodal voltage (V) and one output variable UPFC suitability index (UPFCSI) are selected. PLI range varies from 0 to 1, V varies from 0.9 to 1.1 and UPFCSI varies from 0 to 1.

These power loss reduction indices along with the p.u. nodal voltages are the inputs to the Fuzzy Inference System (FIS), which determines the node more suitable for UPFC installation. In this present work, Fuzzy Logic toolbox in MATLAB is used for finding the UPFC suitability index.

In this thesis, two input and one output variables are selected. Input variable-1 is the power loss index (PLI) and input variable-2 is the per unit nodal voltage (V). Output variable is UPFC suitability index (CSI).

2.1 Identification of Sensitive Bus for UPFC Placement:

The fuzzy logic is used to identify the optimal location to place the UPFC in a radial distribution system so as to minimize the losses while keeping the voltage at buses within the limit and also by taking the cost of the UPFCs in to account.

The Fuzzy Expert System (FES) contains a set of rules, which are developed from qualitative descriptions. In a FES, rules may be fired with some degree using fuzzy inference, where as in a conventional Expert System, a rule is either fired or not fired. For the UPFC placement problem, rules are defined to determine the suitability of a bus for UPFC placement. Such rules are expressed in the following general form:

IF premise (antecedent), THEN conclusion (Consequent).

For determining the suitability of a particular bus for UPFC placement at a particular bus, sets of multiple-antecedent fuzzy rules have been established. The inputs to the rules are the bus voltages in p.u., power loss indices, and the output consequent is the suitability of a bus for UPFC placement.

2.2 Procedure to Calculate Power Loss Index:

The power loss index at i^{th} bus, PLI (i) is the variable which is given to fuzzy expert system to identify suitable location for the UPFC.

Step 1: Read radial distribution system data

Step 2: Perform the load flows and calculate the base case active power loss

Step 3: By compensating the reactive power injections (Q) at each bus (except source bus)and run the load flows, and calculate the active power loss in each case.

Step 4: Calculate the power loss reduction and power loss indices using the following equation

$$PLI(i)=\frac{X(i)-Y}{Z-Y} \quad \ldots (2.2)$$

Where PLI = power loss index.

X(i)= loss reduction at i^{th}bus. (i=30)

Y= minimum loss reduction.

Z= maximum loss reduction.

Step 5: Stop.

Five membership functions are selected for PLI. They are L, LM, M, HM and H. all the five membership functions are triangular as shown in figure 2.2.1. Five membership functions are selected for voltage. They are L, LN, N, HN, and H. these membership functions are trapezoidal and triangular as shown in figure 2.2.2. Five membership functions are selected for CSI. They are L, LM, M, HM, and H. these five membership functions are also triangular as shown in fig 2.2.3.

The rule editor is for editing the list of rules that defines the behavior of the system. Constructing rules using the graphical rule editor interface is fairly self-evident. Based on the descriptions of the input and output variables defined with the FIS editor, the rule editor allows us to construct the rule statements

automatically, by clicking on and selecting one item in each input variable box, one item in each output box and one connection item. Choosing none as one of the variable qualities will exclude that variable from a given rule. Choosing not under any variable name will negate the associated quality. Rules may be changed, deleted or added, by clicking on the appropriate button.

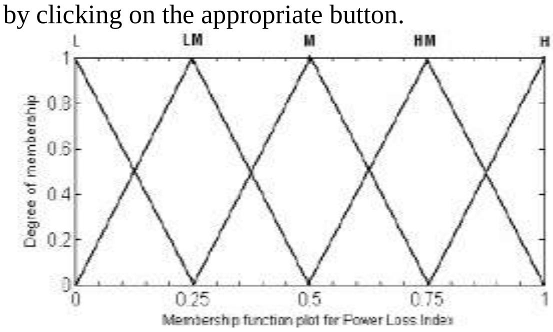


Fig.2.2.1: Membership function plot for power loss index

Fig.2.2.2: Membership function plot for p.u nodal voltage

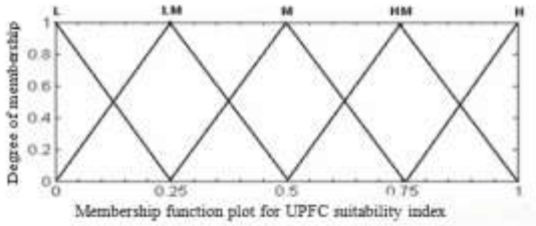


Fig.2.2.3: Membership function plot for UPFC suitability index

For the UPFC allocation problem, rules are defined to determine the suitability of a node for UPFC installation. Such rules are expressed in the below:

IF premise, THEN conclusion. For determining the suitability of UPFC placement at a particular node, a set of multiple-antecedent fuzzy rules has been established. The inputs to the rules are voltage and power loss indices and the output is the suitability of UPFC placement. The rules are summarized in the fuzzy decision matrix in table 2.2.4

Table.2.2.4: Decision matrix for determining the optimal UPFC locations.

AND		Voltage				
		L	**LM**	**M**	**HM**	**H**
PLI	**L**	LM	LM	L	L	L
	LM	M	LM	LM	L	L
	M	HM	M	LM	L	L
	HM	HM	HM	M	LM	L
	H	H	HM	M	LM	LM

In the present work 25 rules are constructed. For example:

- If PLI is H and voltage is L then UPFCSI is H.
- If PLI is M and voltage is M then UPFCSI is LM.
- If PLI is H and voltage is H then UPFCSI is LM.
- Here H is high, L is low and M is medium.

The rule viewer is a MATLAB-based display of the fuzzy inference diagram. Used as a diagnostic, it can show which rules are active, or how individual membership function shapes are influencing the results. Surface viewer can display how one of the outputs depends on any one or two of the inputs –that is, it generates and plots an output surface map of the system, finally to save the current file uses the commands Export to workspace and Export to disk. By calling this file in the main program, the UPFCSI values corresponding to each bus can be obtained. Thereby, find the nodes suitable for UPFC installation.

3. PSO Algorithm

Step 1: Initially [nop x n] number of particles are generated randomly within the limits, where nop is the population size and n is the number of UPFC devices. Each row represents one possible solution to the optimal UPFC-sizing problem.

Step 2: Similarly [nop x n] number of initial velocities is generated randomly between the limits. Iteration count is set to one.

Step 3: By placing all the 'n' UPFC devices of each particle at the respective candidate locations and load flow analysis is performed to find the total real power lossPL_{upfc}. The same procedure is repeated for the 'nop' number of particles to find the total real power losses. Fitness value corresponding to each particle is evaluated using the equation (8) for maximum loss reduction.

Fitness function for maximum loss reduction is given by:

Fitness$F_A = P_L P_{Lupfc}$

Where, PL is Original total real loss, P_{Lupfc} is Present total real loss with UPFC.

Step 4: New velocities for all the particles within the limits are calculated using equation (4.7) and the particle positions are updated using equations (4.8)

Step 5: Once the particles are updated, load flow analysis is performed; new-Fitness is calculated using equation (4.10). If the new-fitness is greater than P_{best} -fitness then the corresponding particle is moved to the p_{best}-particle.

Step 6: Maximum of P_{best} -fitness gives the g_{best} -fitness and the corresponding particle is stored as g_{best} -particle.

Step 7: From P_{best} --fitness maximum fitness and average fitness values are calculated. Error is calculated using the below equation.

Error=(max.fitness–avg.fitness)

If this error is less than a specified tolerance then go to step 9.

Step 8: The current iteration count is incremented and if iteration count is not reached maximum then go to step 4.

Step 9: g_{best} -fitness gives maximum loss reduction and g_{best} -particle gives the optimal UPFC sizes.

3.1. PSO Flow Chart

In conventional PSO algorithm, the search velocity v(n) is always clamped within a range, which is denoted by V_{max}. Given an optimization problem, the proper range of V_{max} for good performance is always limited and hard to be predicted. Hence, a PSO with decreasing V_{max} method (PSO) is developed, in which V_{max} is decreasing over time. By using this method, a large scale of searching is expected at the early steps, so that the population can remain in enough diversity profitable to converge to the global optimum. As the searching process continues, the searching scale is reduced to allow the solution to be found.

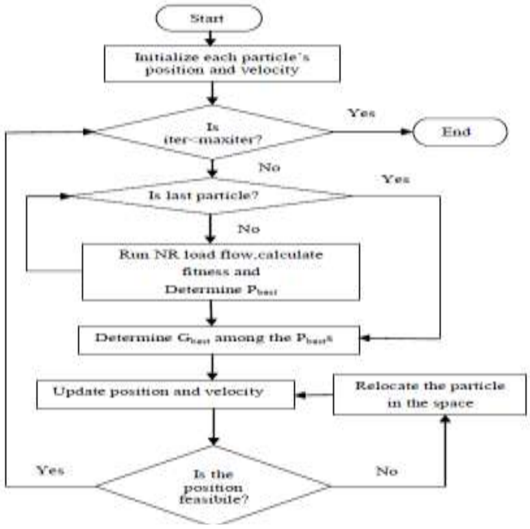
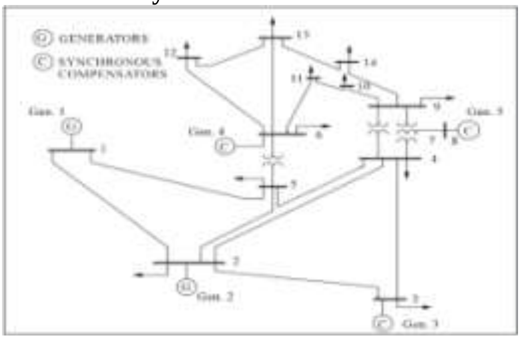


Fig.3.1: Flow chart of PSO.

IV. RESULTS

IEEE 14-Bus System:



The test system consists of 5 generators and 20 transmission lines and one slack bus. Voltage is regulated by the generator. These generator buses do not need a UPFC and are omitted from the PSO search process. The problem to be addressed consists of finding the optimal location (bus number) and rating of UPFC (current in p.u.). with current injection model. In this case the PSO is able to find the rating of the UPFC. Simulation results for voltage magnitudes and power loss reduction before and after placement of UPFC are shown in table. 4.1 and table. 4.2 respectively.

Table.4.1: Results for 14 bus system with UPFCs with PSO for various locations.

Loading condition	Losses without UPFC (MW)	UPFC Location	PSO	
			Rating of UPFC (p.u)	Losses with UPFC (MW)
100% Normal loading	13. 3938	14, 5	4∠8.484 3∠9.256	13.3196
85% loading	8.0728	5, 4	3∠7.582 3∠8.595	8.0488
110% loading	16.7223	14, 9	4∠8.756 3∠7.782	16.6266

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Table.4.2: Voltages of 14 bus system for (100%) normal loading.

Bus no	Voltages (p.u)	
	Before UPFC	After UPFC
1	1.060000	1.0600
2	1.045000	1.0450
3	1.010000	1.0100
4	1.018275	1.0190
5	1.020034	1.0205
6	1.070000	1.0700
7	1.060813	1.0633
8	1.090000	1.0900
9	1.054083	1.0590
10	1.049452	1.0535
11	1.056123	1.0582
12	1.055048	1.0597
13	1.050109	1.0587
14	1.034347	1.0498

(a) Normal loading.

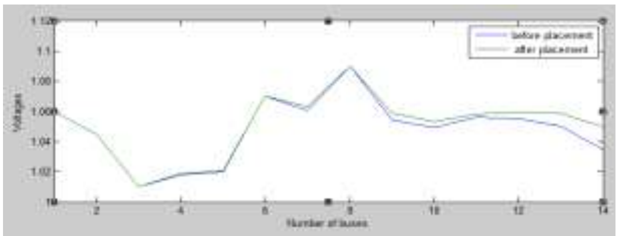

Fig.4.3: Voltage profile before and after placement of UPFC for normal loading (100%).

(b) 85% loading.

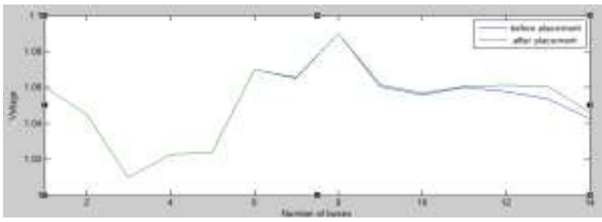

Fig 4.4: Voltage profile before and after placement of UPFC for under loading (85%).

(c) 110% loading.

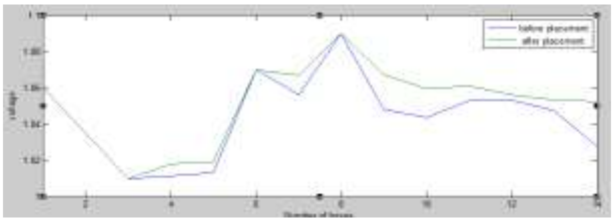

Fig 4.5: Voltage profile before and after placement of UPFC for heavy loading (110%).

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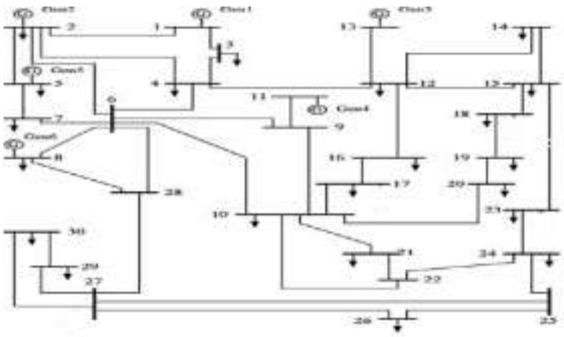
IEEE 30-Bus System:



The test system consists of 5 generators and 41 transmission lines and one slack bus. Voltage is regulated by the generator. These generator buses do not need a UPFC and are omitted from the PSO searchprocess. The problem to be addressed consists of finding the optimal location (busnumber) andratingof UPFC (current in p.u.). With current injection model. In this case the PSO is able to find the rating of the UPFC.
Simulation results for voltage magnitudes and power loss reduction before and after placement of UPFC are shown in Table. 4.5 and Table. 4.6 respectively.

Table.4.5: Results for 30 bus system with UPFCs with PSO for various locations.

Loading condition	Losses without UPFC (MW)	UPFC Location	PSO	
			Rating of UPFC (p.u)	Losses with UPFC (MW)
Normal loading	17.528	21, 24, 30	5∠2.852, 3∠1.298, 1∠0.565	17.3568
85% loading	12.1131	26 21, 7	4∠1.825, 3∠1.296, 1∠0.425	12.0155
110% loading	21.9318	21, 24, 26	5∠2.992, 2∠0.942 1∠0.956	21.7544

Table.4.6: Voltages of 30 bus system for (100%) normal loading.

Bus no	Voltages (p.u)	
	Before UPFC	After UPFC
1	1.060000	1.0600
2	1.043000	1.0430
3	1.021675	1.0237
4	1.012920	1.0154
5	1.010000	1.0100
6	1.012084	1.0146
7	1.003468	1.0050
8	1.010000	1.0100
9	1.050724	1.0600
10	1.043758	1.0615
11	1.082000	1.0820

12	1.057605	1.0655
13	1.071000	1.0710
14	1.042879	1.0541
15	1.038445	1.0525
16	1.044520	1.0566
17	1.038654	1.0548
18	1.028158	1.0437
19	1.025210	1.0416
20	1.029062	1.0458
21	1.029261	1.0549
22	1.035288	1.0572
23	1.029134	1.0537
24	1.023652	1.0507
25	1.020157	1.0450
26	1.002530	1.0278
27	1.026518	1.0497
28	1.010864	1.0151
29	1.006749	1.0369
30	0.995315	1.0329

(a) 85% loading.

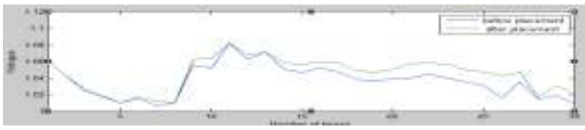


Fig 4.7: Voltage profile before and after placement of UPFC for under loading (85%).

(b) 100% normal loading.

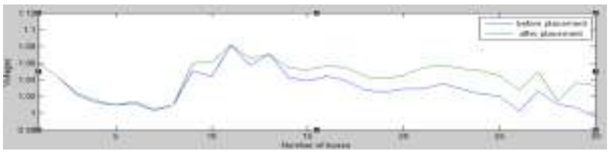
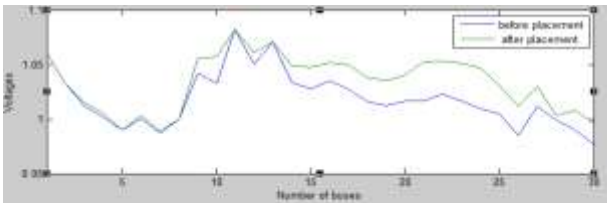


Fig.4.8:Voltage profile before and after placement of UPFC for normal loading(100%).



(c) 110% loading

Fig 4.9: Voltage profile before and after placement of UPFC for heavy loading (110%).

Comparison of PSO and Genetic algorithm results

Table 4.10: Comparison of PSO result with G.A algorithm results for IEEE-14 bus system

LOADING CONDITION	LOSSES WITHOUT UPFC (MW)	LOSSES WITH UPFC (MW)	
		G.A [9]	PSO
100% Normal loading	13. 3938	13.3289	13.3196

Table 4.11: Comparison of PSO result with G.A algorithm results for IEEE-30 bus system

LOADING CONDITION	LOSSES WITHOUT UPFC (MW)	LOSSES WITH UPFC (MW)	
		G.A [9]	PSO
100% Normal loading	17.528	17.5046	17.3568

IV. CONCLUSION

In this thesis, the power loss reduction and voltage profile improvement in the transmission network is done with the help of UPFC device which has been incorporated with the help of two techniques namely fuzzy approach and particle swarm optimization. The optimal locations of UPFC are obtained using fuzzy approach and optimal ratings for the respective locations are obtained using PSO algorithm.

The proposed method is tested on IEEE-14 bus system where power loss reduction before and after placement of UPFC for different loading conditions are considered. The total active power loss for normal loading condition is reduced from 13.3938 MW to13.3196 MW, under loading condition loss is reduced from 8.0728 MW to 8.0488 MW and over loading condition from 16.7223 MW to 16.6266 MW with simultaneous improvement of the voltages at buses.

The proposed method is tested on IEEE-30 bus system where power loss reduction before and after placement of UPFC for different loading condition are considered. The total active power loss for normal loading condition is reduced from 17.528 MW to 17.3568 MW, under loadingcondition loss is reduced from 12.1131MW to 12.0155 MW and over loading condition from 21.9318MW to 21.7544MW.with simultaneous improvement of the voltages at buses.

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