Improvement of Voltage Stability by Placing UPFC using fuzzy Logic

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ABSTRACT - *Increase in electrical demand due to increase in population and modernization necessitated increase in the power generation with adequate increase in electrical infrastructure. Owing to lack of generation, existing infrastructure, operating power system with large interconnected system becomes more complex causing voltage instability, power loss and unreliable operation of power systems. In this paper, voltage instability is addressed using optimal placement of UPFC using fuzzy logic. The simulation has been conducted on IEEE 14 bus system using Mi Power software package. The results obtained through simulations have ensured the effectiveness of fuzzy logic for UPFC placement to accelerate the significant improvement of voltage stability.*

Keywords: Unified Power Flow Controller (UPFC), Contingency ranking, fuzzy logic, voltage sensitivity index, optimal power flow, voltage stability and Flexible AC transmission Systems (FACTS), optimal placement.

I. INTRODUCTION

Modern electrical power systems are highly complex in nature and aim to meet the increasing power demand with acceptable power quality and affordable electricity price to the consumers. The financial and environmental issues enforce the placement of power generating units at places away from load centers. The restructuring of power system networks has augmented the uncertainties in system operation [1, 4]. The regulatory constraints on the extension of the transmission network has resulted in declining of the stability limits and increased the risks of cascading failures and blackouts. This problem can be sorted out by the introduction of high-power electronic controllers for the regulation of voltages and power flows in AC transmission systems [1-6].

The FACTS is a model depends on the power electronic controllers, which boosts the value of transmission systems by enhancing power transfer capability. These controllers operate at very high speed, leads to safe operating limits of a transmission system with acceptable stability. The evolution in the FACTS was triggered by the development of new solid-state electrical switching devices.

The FACTS devices are mainly classified to three types, Series Devices, Shunt devices and Shunt series devices the effectiveness of FACTS devices in improving the performance of a system depend on

1. The placement of the device in the power system network.
2. The size of the devices.
3. The type of the device, i.e. shunt or series type.
4. The type of control strategy employed.

The main advantages of FACTS devices are,

- Increases 20-30% transfer capacity. Power flow control
- Enhance the stability of power system.
- Efficient use of existing infrastructure.

In this paper, the optimal location of UPFC has been carried out on IEEE 14 bus to boost the voltage stability margin. The load index, voltage and percentage active power loading of the transmission lines are taken into account for deciding the optimal location of the UPFC. To verify the accuracy of the explored optimal location, the enhancement of voltage profile has been tested by connecting UPFC at that transmission line.

II. METHODOLOGY

Standard IEEE-14 bus system is tested with and without incorporation of UPFC to investigate the network behavior. In IEEE 14 bus data, bus number one is considered as slack bus, bus two is voltage control bus and remaining all are load buses. The two buses that consist of synchronous condensers are bus 3 and bus 8. One shunt capacitor connected to bus 9 to inject reactive power. For the incorporation UPFC in the IEEE 14 bus system an additional bus (bus no 15) is required, it is called as dummy bus in network. The UPFC shunt converter is set to maintain bus 13 voltage magnitudes at 1.0502 per unit while series converter regulates the power flow between the two buses i.e., 13 and 14. The power losses in the transmission lines and % loading without UPFC is tabulated in Table-1.

Table-1: Transmission line loss and % loading without UPFC

FROM BUS	TO BUS	LOSSES		% LOADING
		MW	MVAR	
1	2	4.3001	0.2797	74.6
2	3	2.3212	5.1536	35.1
2	4	1.6791	1.1124	26.9
1	5	2.7679	6.1016	35.7
2	5	0.904	-0.8658	19.9
3	4	0.3708	-2.6134	11.9
4	5	0.5165	0.2989	31.2
7	8	0.0324	0.4212	7.7
7	9	0.0983	0.798	13.5
9	10	0.012	0.0319	3.1
6	11	0.058	0.1215	3.9
6	12	0.0723	0.1505	3.8
6	13	0.2142	0.4218	9.0
9	14	0.1139	0.2422	4.7
10	11	0.0137	0.0321	2.0
12	13	0.0065	0.0059	0.9
13	14	0.0561	0.1142	2.9

III. Conventional method results and after placing UPFC comparison

In the conventional method, Newton Raphson (NR) method load flow analysis was applied to IEEE 14 bus system by installing one UPFC at each transmission line. All transmission lines are considered as contender lines in this test and in all succeeding tests. By using conventional method transmission line 13-14 is found as the optimal place for UPFC considering the improvement in the voltage profile is as shown in Table.2 Effect on voltage profile due to placement of UPFC at different branches of network is as shown in Fig.1.

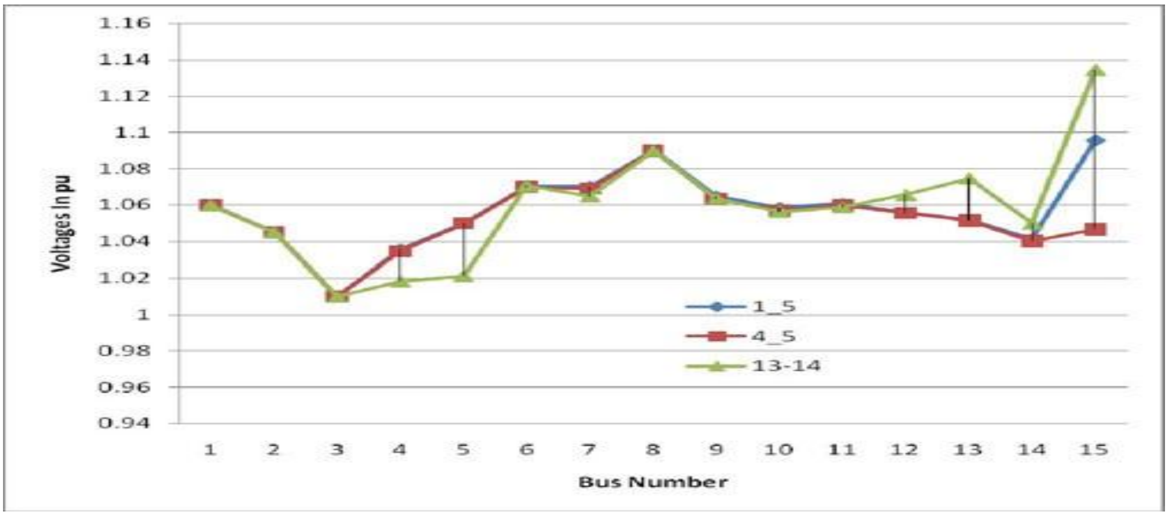

Chart-1: voltage profile with UPFC

Bus. Number	1-5	3-4	4-5	7-8	7-9	12-13	13-14
1	1.06	1.06	1.06	1.06	1.06	1.06	1.06
2	1.04	1.04	1.04	1.04	1.04	1.04	1.04
3	1.01	1.01	1.01	1.01	1.01	1.01	1.01
4	1.03	1.01	1.02	1.02	1.04	1.02	1.02
5	1.05	1.05	1.01	1.02	1.03	1.01	1.02
6	1.07	1.07	1.06	1.08	1.07	1.07	1.07
7	1.07	1.06	1.05	1.06	1.05	1.06	1.06
8	1.09	1.09	1.09	1.09	1.09	1.09	1.09
9	1.06	1.06	1.05	1.07	1.06	1.06	1.06
10	1.05	1.05	1.07	1.06	1.07	1.06	1.06
11	1.06	1.04	1.06	1.05	1.05	1.05	1.06
12	1.05	1.04	1.05	1.05	1.05	1.1	1.05
13	1.05	1.05	1.04	1.02	1.03	1.02	1.05
14	1.04	1.04	1.02	1.03	1.03	1.04	1.08
15	1.09	1.08	1.03	1.02	1.18	1.08	1.14

Table-2: Voltage Profile with UPFC

IV. Voltage stability index(L-index)

For a given system operating condition, using the load-flow analysis results, the load index is calculated by [4],

$$L_i = 1 - \sum F_{ji} \{V_i/V_j\} \qquad (1)$$

The values of F_{ji} are complex in nature and are derived from the Y_{BUS} matrix, for a given system parameters

$$\begin{bmatrix} L_G \\ L_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \qquad (2)$$

$$F_{LG} = -[Y_{LL}]^{-1} [Y_{LG}] \qquad (3)$$

Using equations 1, 2 and 3 the load index of IEEE 14 bus is calculated is as shown in Table.3

Table-3: Bus Voltages and L-index

Bus Number	Voltage in p.u.	L-index
1	1.06	-
2	1.045	-
3	1.01	0.0374
4	1.0186	0.0749
5	1.0202	0.0464
6	1.07	0.0369
7	1.0628	0.0671
8	1.09	0.0055
9	1.0544	0.1069
10	1.049	0.11
11	1.0562	0.079
12	1.0551	0.068
13	1.0502	0.0811
14	1.0345	0.1363

V. Algorithm for UPFC placement

Step-1: For a given power system network run the load flow analysis.

Step-2: Compute the bus voltages, load index and percentage loading of each line in the network

Step-3: Build the fuzzy logic algorithm and train the data.

Step-4: Compute the UPFC placement index using fuzzy logic technique

Step-5: Prepare a table indicating optimal placement of UPFC based on placement index.

Step-6: From the table, identify the highest placement index value of the transmission line as optimal placement of UPFC.

5.1 Fuzzy logic

The Fuzzy logic technique used to determine the optimal placement of UPFC to get better voltage profile in the entire network. The voltage profile, percentage loading and Load index is considered as fuzzy inputs and fuzzy output placement index is considered to list the ranking of transmission lines for UPFC placement is as shown in Fig.2.

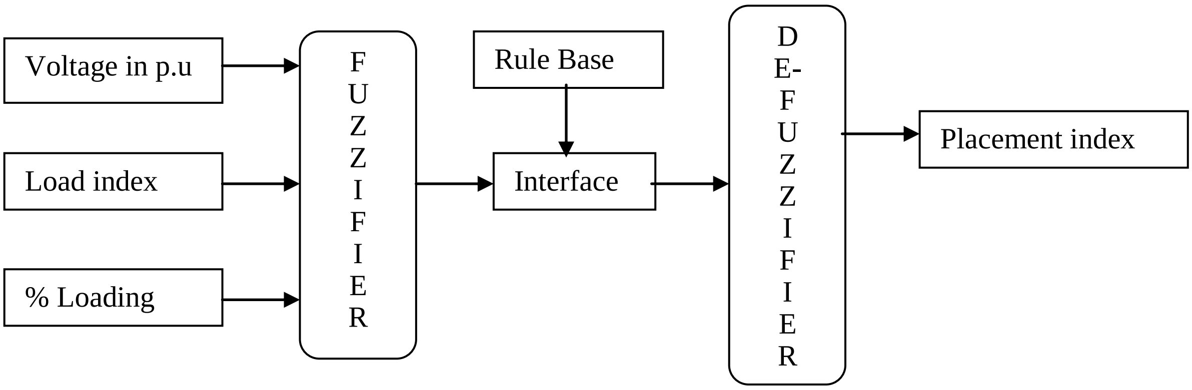

Fig-2: Block diagram of Fuzzy Interface System for UPFC Placement

For the optimal placement of UPFC, fuzzy rules are defined to find the placement index of transmission lines. Twenty-seven rules are formulated out of them two are shown below.

Rule-1: If voltage in p.u. is low and load index is small and % loading is low then placement index is less.

Rule-2: If voltage in p.u. is low and load index is high and % loading is low then placement index is high.

The load flow analysis using NR method is carried out to obtain voltage profile, % loading of transmission lines and for the calculation of L-index. Three membership functions are preferred for the both the input and output of the fuzzy interface system is as shown in Fig.3, To compute the placement index rule viewer is used is as shown in Fig.4. The Fig.5 shows the 3-D structure of all the inputs against the output of fuzzy.

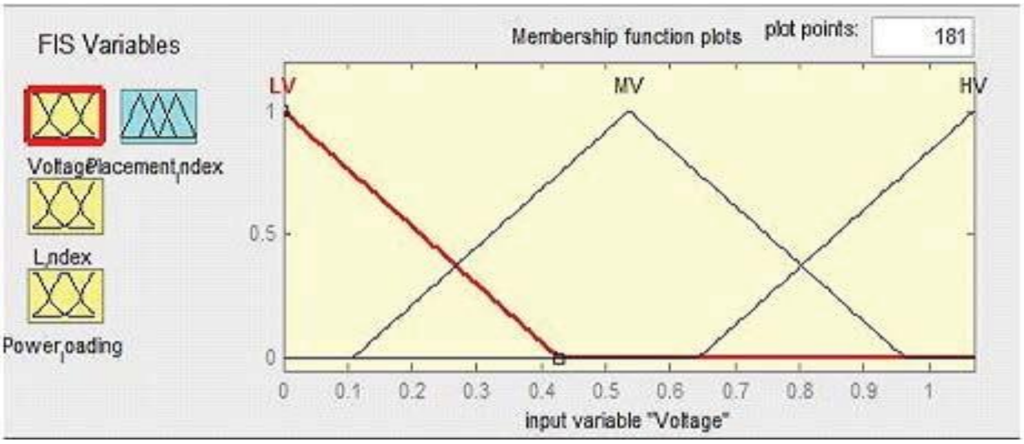

Fig-3: Figure depicting Fuzzy Interface System Input and Output

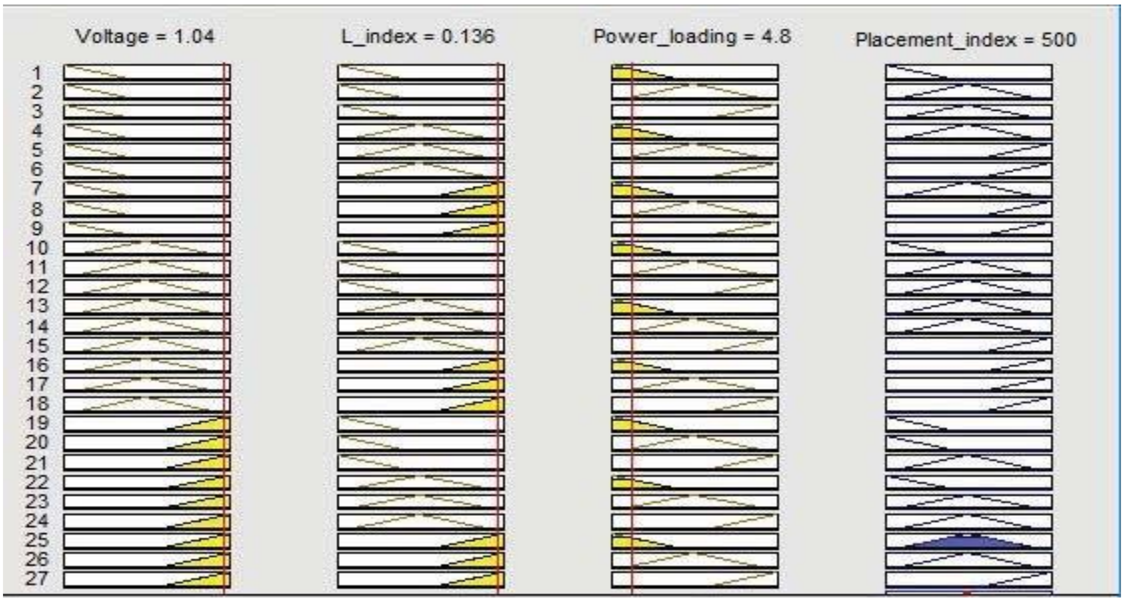

Fig-4: Rule Viewer

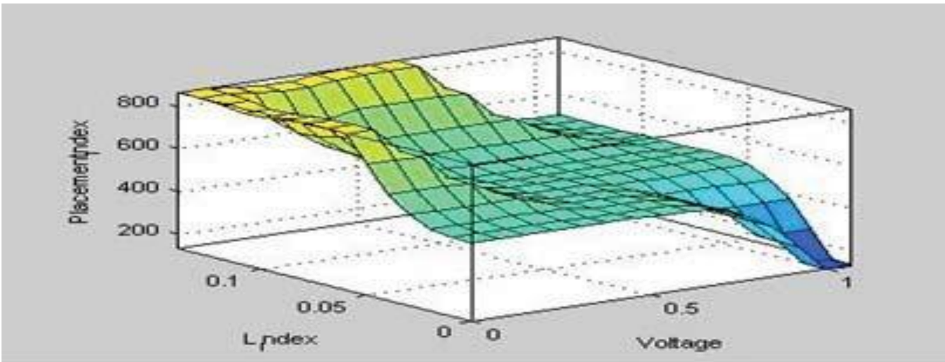

Fig-5: Surface Viewer

The placement index computed from the fuzzy is articulated as shown in Table.4. The highest placement index indicates the very weakest line the network. Depending upon the placement index rank is assigned. Line between bus number 13 and 14 is having highest placement index amongst all transmission lines. With respect to placement index value the severe transmission lines identified. Fig.6 represents the voltage profile of IEEE 14 bus system with and without UPFC

Table-4: Overall Placement index and priority/ranking for UPFC location

Lines	Voltage Profile	L-index	Loading	Placement Index	Priority/Rank
14-13	1.034	0.136	2.9	500	1
7-9	1.062	0.067	13.5	489	2
5-2	1.02	0.046	19.9	471	3
10-9	1.049	0.11	3.1	441	4
3-4	1.01	0.037	11	426	5
6-13	1.07	0.036	9	398	6
7-8	1.09	0.005	7.7	153	7
6-11	1.056	0.079	3.9	146	8
6-12	1.055	0.068	3.8	139	9

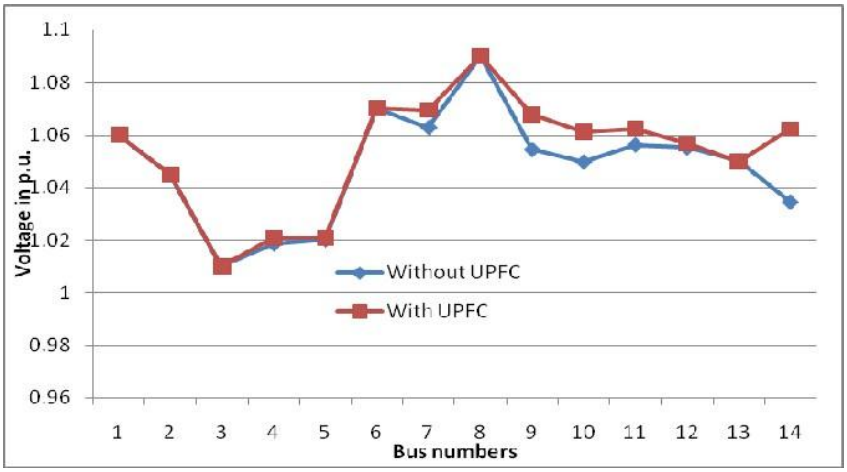

Fig.6: Voltage Profile with and without UPFC

VI. Conclusion

The optimal placement of UPFC is chosen for improvement of voltage stability. The fuzzy logic technique is used to find the contingency ranking of UPFC. The fuzzy results are validated using conventional method. The fuzzy method and conventional methods both are given same location. The conventional method is lengthy and it is complex for large bus system, hence the fuzzy logic is simple and it can be applied for large bus system for UPFC placement for stable, reliable operation of the power system.

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