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Power loss reduction and voltage stability enhancement by optimal location of UPFC

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The power system is a very complex system. The considerable components of power system are voltage, power flows real and reactive power losses. These components are controlled by compensating the system. The system can be compensated by the various types of devices such as static capacitors, synchronous condensers etc. But the devices which are mentioned are not providing the flexible control of the power system components. The majority of the losses are shared by the transmission system. By controlling the parameters at transmission, the total system is controlled. So the devices with the combination of power electronic devices provide the flexible control on the transmission system of the power system parameters which are called FACTS devices. This paper proposed the combined series-shunt compensation FACTS device called UPFC. This paper mainly concentrated on the suitable placement of the UPFC FACTS device for Loss reduction and enhancement of voltage profile of the power system using Fast Voltage Stability Index (FVSI).

Keywords: *Power Transmission system, FACTS, UPFC, FVSI, MATLAB™.*

1.0 INTRODUCTION

The generated electrical energy can be delivered to distribution is by means of transmission system. The transmission system has low R/X ratio. But majority of the losses of the power system can be occurred at the transmission system. The total power system can be flexibly controlled by controlling the transmission system. The controlling of transmission system is done by using FACTS devices. In this paper the series-shunt compensation using UPFC is introduced by. This paper organized as-part 2 deals with load flow analysis. Part 3 deals with NR load flow iterative method. Part 4 deals with modeling of the UPFC to the load. Part 5 deals with the placement of UPFC by using suitable indices. Part 6 provides Results discussion for both IEEE 30 bus and IEEE 57 bus systems. Conclusion is given in Part 7.

2.0 LOAD FLOW ANALYSIS

The two buses such as bus m and bus k are interconnected by using transmission line of the system. By using system parameters such as bus voltages with its phase angles and line impedance the active power and reactive power can be represented by the following (1) and (2) Equations [1].

$$P = \frac{V_k \times V_m}{X} \sin(\delta_k - \delta_m) \quad ....(1)$$

Where,

V_k and V_m are the voltages at the bus k and bus m respectively

$(\delta_k - \delta_m)$ is the angle between the voltages and, X is the line reactance.

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The power flow can be controlled by altering the voltages at the buses, the impedance between the buses and the angle between the end voltages. The reactive power is given by

$$Q = \frac{V_k^2}{X} - \frac{V_m \times V_k}{X}\cos(\delta_k - \delta_m) \qquad ....(2)$$

Where,

V_m and V_k are the voltages at the bus m and bus k respectively, $(\delta_k - \delta_m)$ is the angle between the voltages and, X is the line reactance.

3.0 NEWTON-RAPHSON POWER FLOW

The selection of Newton Raphson load flow is carried out by considering its advantages such as, selection of slack bus cannot be effect the number of iteration of the algorithm. So it is mainly used for large scale load flow studies. The power flow Newton-Raphson algorithm is expressed by the following relationship [2]

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}\frac{\partial P}{\partial \theta} & V\frac{\partial P}{\partial V}\\ \frac{\partial Q}{\partial \theta} & V\frac{\partial Q}{\partial V}\end{bmatrix}\begin{bmatrix}\Delta \theta\\ \frac{\Delta V}{V}\end{bmatrix} \qquad ....(3)$$

Where,

ΔP and ΔQ are bus active and reactive power mismatches, while θ and V are bus magnitude and angle, respectively.

4.0 MODELING OF UPFC WITH LOAD FLOWS

The electrical circuit model of Unified Power Flow Controller (UPFC) is shown in Figure 1 the UPFC is series-shunt compensating device. The change of the line impedance leads to the change of voltage profile. The change of reactive load can change the power factor of the system. By using UPFC both voltage profile and power factor of the system can be controlled. The modeling of the UPFC is the important tasks for load flow studies the synchronous voltage sources represent the fundamental Fourier series component of the switched voltage waveforms at the AC converter terminals of the UPFC [3].

The UPFC voltage sources are:

$$E_{vR} = V_{vR}(\cos\delta_{vR} + J\sin\delta_{vR}) \qquad ....(4)$$

$$E_{cR} = V_{cR}(\cos\delta_{cR} + J\sin\delta_{cR}) \qquad ....(5)$$

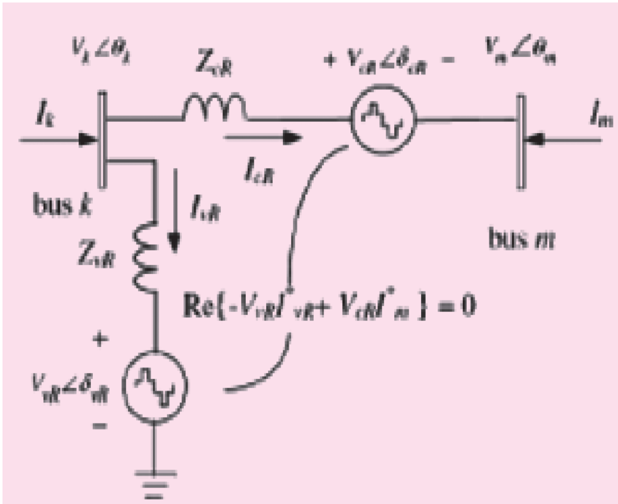

FIG. 1 UPFC EQUIVALENT CIRCUIT

Where V_{vR} and δ_{vR} are the controllable magnitude $V_{vRmin} \leq V_{vR} \leq V_{vRmax}$ 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 [4]. 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 1 and Equations (4) and (5), the active and reactive power equations are at bus k as follows [5].

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

$$Q_k = V_k^2 B_{kk} + V_k V_m [G_{km} \sin(\theta_k - \theta_m) + B_{km} \cos(\theta_k - \theta_m) V_k V_{cR} [G_{km} \sin(\theta_k - \delta_{cR}) + B_{km} \cos(\theta_k - \delta_{cR})] + V_{km} V_{vR} [G_{vR} \sin(\theta_k - \delta_{vR}) + B_{vR} cos(\theta_k - \delta_{vR})] \quad ....(7)$$

At bus m:

$$P_m = V_m^2 G_{mm} + V_m V_k [G_{km} \cos(\theta_k - \theta_m) + B_{km} \sin(\theta_k - \theta_m) V_k V_{cR} [G_{km} \cos(\theta_k - \delta_{cR}) + B_{km} \sin(\theta_k - \delta_{cR})] \quad ....(8)$$

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

For Series converter:

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

$$Q_{cR} = -V_{cR}^2 B_{mm} + V_{cR} V_k [G_{km} \sin(\delta_{cR} - \theta_k) - B_{km} \cos(\delta_{cR} - \theta_k) V_m V_{cR} [G_{mm} \sin(\delta_{cR-} \theta_m) - B_{km} \cos(\delta_{cR-} \theta_m)] \quad ....(11)$$

For Shunt converter:

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

$$Q_{vR} = V_{vR}^2 B_{vR} + V_{vR} V_k [G_{vR} \sin(\delta_{vR} - \theta_k) - \cos(\delta_{vR} - \theta_k)] \quad ....(13)$$

The UPFC power equations, in linearized form, are combined with those of the AC network. For the case when the UPFC controls the following parameters [6].

1. Voltage magnitude at the shunt converter terminal,
2. Active power flow from bus m to bus k,
3. Reactive power injected at bus m, and taking bus m to be a PQ bus.

The linearized system of equation is expressed in equation (14).

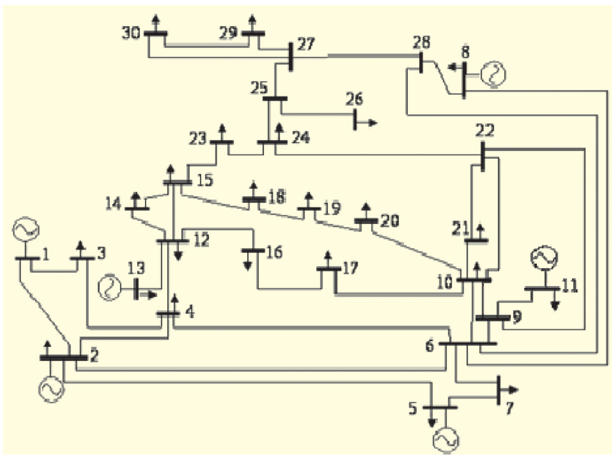

FIG. 2 SINGLE LINE DIAGRAM OF IEEE 30 BUS SYSTEM

$$\begin{bmatrix} \Delta P_a \\ \Delta P_m \\ \Delta Q_k \\ \Delta Q_m \\ \Delta P_{mk} \\ \Delta Q_{mk} \\ \Delta P_{bb} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial \theta_m} & V_{vR}\frac{\partial P_k}{\partial V_{vR}} & V_m\frac{\partial P_k}{\partial V_m} & \frac{\partial P_k}{\partial \delta_{cR}} & V_{cR}\frac{\partial P_k}{\partial V_{cR}} & \frac{\partial P_k}{\partial \delta_{vR}} \\ \frac{\partial P_m}{\partial \theta_k} & \frac{\partial P_m}{\partial \theta_m} & 0 & V_m\frac{\partial P_m}{\partial V_m} & \frac{\partial P_m}{\partial \delta_{cR}} & V_{cR}\frac{\partial P_m}{\partial V_{cR}} & 0 \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial \theta_m} & V_{vR}\frac{\partial Q_k}{\partial V_{vR}} & V_m\frac{\partial Q_k}{\partial V_m} & \frac{\partial Q_k}{\partial \delta_{cR}} & V_{cR}\frac{\partial Q_k}{\partial V_{cR}} & \frac{\partial Q_k}{\partial \delta_{vR}} \\ \frac{\partial Q_m}{\partial \theta_k} & \frac{\partial Q_m}{\partial \theta_m} & 0 & V_m\frac{\partial Q_m}{\partial V_m} & \frac{\partial Q_m}{\partial \delta_{cR}} & V_{cR}\frac{\partial Q_m}{\partial V_{cR}} & 0 \\ \frac{\partial P_{mk}}{\partial \theta_k} & \frac{\partial P_{mk}}{\partial \theta_m} & 0 & V_m\frac{\partial P_{mk}}{\partial V_m} & \frac{\partial P_{mk}}{\partial \delta_{cR}} & V_{cR}\frac{\partial P_{mk}}{\partial V_{cR}} & 0 \\ \frac{\partial Q_{mk}}{\partial \theta_k} & \frac{\partial Q_{mk}}{\partial \theta_m} & 0 & V_m\frac{\partial Q_{mk}}{\partial V_m} & \frac{\partial Q_{mk}}{\partial \delta_{cR}} & V_{cR}\frac{\partial Q_{mk}}{\partial V_{cR}} & 0 \\ \frac{\partial P_{bb}}{\partial \theta_k} & \frac{\partial P_{bb}}{\partial \theta_m} & V_{vR}\frac{\partial P_{bb}}{\partial V_{vR}} & V_m\frac{\partial P_{bb}}{\partial V_m} & \frac{\partial P_{bb}}{\partial \delta_{cR}} & V_{cR}\frac{\partial P_{bb}}{\partial V_{cR}} & \frac{\partial P_{bb}}{\partial \delta_{vR}} \end{bmatrix} \begin{bmatrix} \Delta\theta_k \\ \Delta\theta_m \\ \frac{\Delta V_{vR}}{V_{vR}} \\ \frac{\Delta V_m}{V_m} \\ \Delta\delta_{cR} \\ \frac{\Delta V_{cR}}{V_{cR}} \\ \Delta\delta_{vR} \end{bmatrix} \quad \text{....(14)}$$

5.0 FAST VOLTAGE STABILITY INDEX (FVSI)

The main aim of the inclusion of the UPFC is to maintain the voltage stability of the system and loss minimization. The best voltage profile of the bus system can be obtained with the suitable placement of UPFC. But the optimal placement of the UPFC can determined by considering the other parameters such as line impedance, reactive power of the receiving bus, voltage profile of the sending bus and line reactance which is called FVSI. The equation 15 indicates the FVS index. Since the voltage profile is in denominator of the equation. The least voltage profile may give highest value of FVSI. So higher value of the FVSI is the suitable placement of the UPFC [6].

$$FVSI_{km} = \frac{4Z_{km}^2 Q_m}{V_k^2 X_{km}} \quad \text{....(15)}$$

Where, Z_{km} is the line impedance between bus k and m

X_{km} is the line reactance between bus k and bus m

Q_m is the reactive power at the receiving end

V_k is the sending end voltage

6.0 RESULTS

6.1 IEEE 30 Bus System

The single line diagram of IEEE 30 bus system is shown in Figure 2, the values of FVSI is calculated at each and every bus in a IEEE 30 bus system and the values are shown in the Table 1, based on the FVSI values we can easily identified the best location of the placement of UPFC in a IEEE 30 bus system, also Figure 3 indicate the FVSI values versus Bus numbers using MATLAB™ programming.

TABLE 1

FVSI OF IEEE 30 BUS SYSTEM

Sl. No.	FROM BUS	TO BUS	FVSI
1	1	2	0.076688
2	1	3	0.024675
3	2	4	0.024818
4	3	4	0.008201
5	2	5	0.064602
6	2	6	0.021907
7	4	6	0.034177
8	5	7	0.066456
9	6	7	0.012822
10	6	8	0.017221
11	6	9	0.129527
12	6	10	0.062732
13	9	11	0.171324

14	9	10	0.065705
15	4	12	0.19599
16	12	13	0.30599
17	12	14	0.036398
18	12	15	0.060147
19	12	16	0.055242
20	14	15	0.0262
21	16	17	0.037526
22	15	18	0.032042
23	18	19	0.013732
24	19	20	0.004171
25	10	20	0.01869
26	10	17	0.00529
27	10	21	0.033618
28	10	22	0.026436
29	21	23	0.001812
30	15	23	0.055927
31	22	24	0.036018
32	23	24	0.034772
33	24	25	0.007322
34	25	26	0.050308
35	25	27	0.030174
36	28	27	0.037347
37	27	29	0.031147
38	27	30	0.040769
39	29	30	0.012739
40	8	28	0.011019
41	6	28	0.006129

And from the above analysis it is conclude that the 16th line of the system i.e., line between 12th and 13th bus is most suitable location for UPFC.

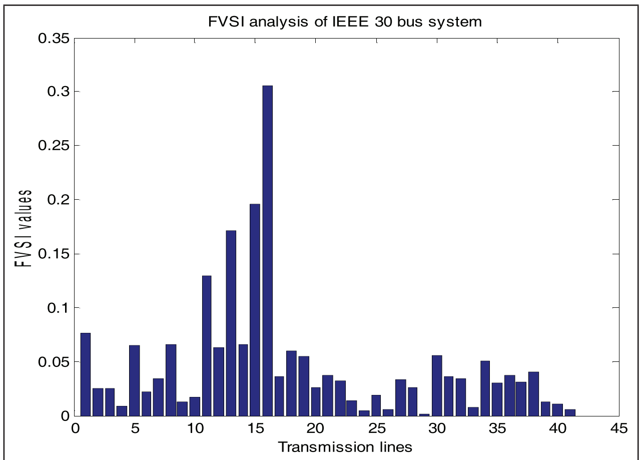

FIG. 3 FVSI ANALYSIS OF IEEE 30 BUS SYSTEMS™

which is highleted in the Table 1, with the effect of UPFC the voltage profile of the system has been improved is shown in Figure 4.

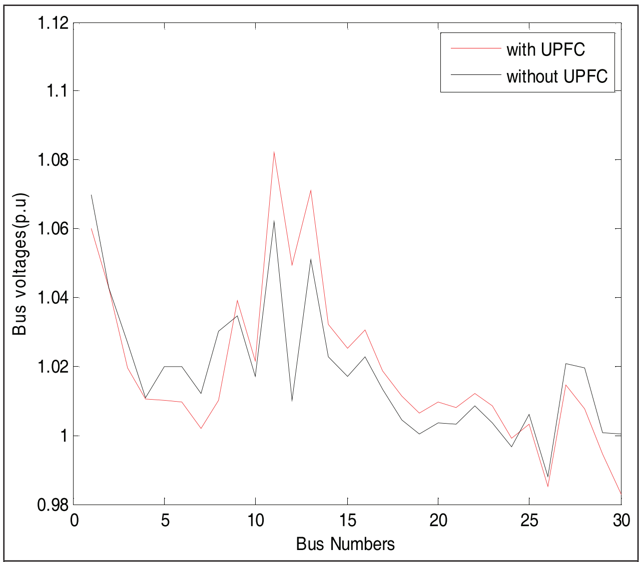

FIG. 4 VOLTAGE PROFILE OF IEEE 30 BUS SYSTEM

The change of real and reactive power losses with and without UPFC is given in Table 2 The real power losses without placement of UPFC are 17.75 MW and the reactive power losses are 69.75 MVAR and By placing UPFC at the suitable location which is determined by FVSI,

TABLE 2

COMPARISON OF IEEE 30 BUS SYSTEM PARAMETERS

Real power losses (MW)		**Reactive power losses (MVAR)**		**Min Voltage (p.u.)**	
Without UPFC	With UPFC	Without UPFC	With UPFC	Without UPFC	With UPFC
17.75	17.02	69.75	62.04	0.9828	0.9901

The real and reactive power losses can be reduced up to 17.02 MW and 62.04 MVAR respectively. The minimum voltage without UPFC is 0.9828 p.u. but by placing the UPFC at the suitable position the voltage profile is stable with 0.9901 p.u.

6.2 IEEE 57 Bus System

The single line diagram of IEEE 57 bus system is shown in the Figure 5.

Sl. No.	TABLE 3					
	COMPARISON OF IEEE 57 BUS SYSTEM PARAMETERS					
	Real power losses(MW)		**Reactive power losses(MVAR)**		**Minimum Voltage (p.u.)**	
1	Without UPFC	With UPFC	Without UPFC	With UPFC	Without UPFC	With UPFC
2	35.219	31.20	236.13	221.132	0.980	0.964

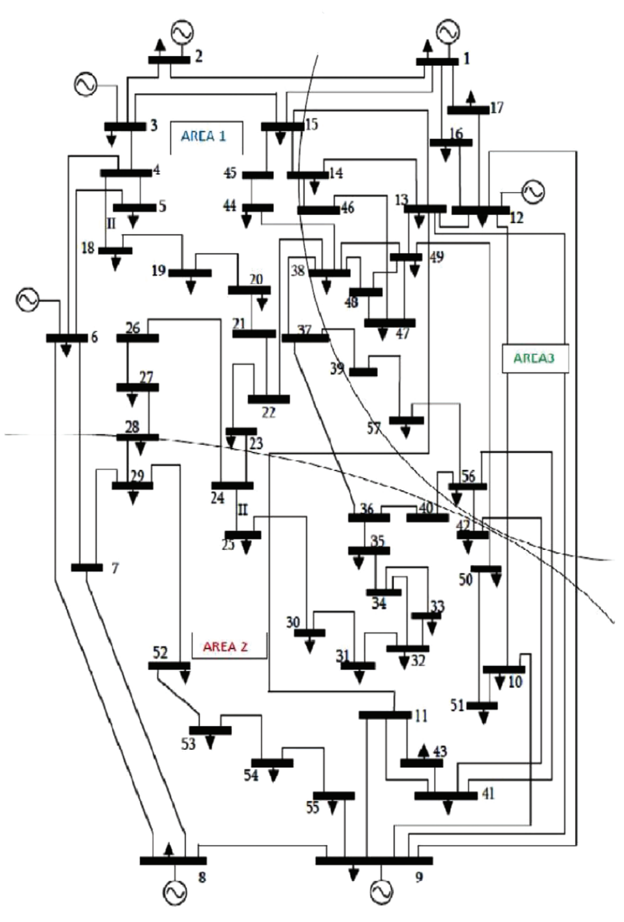

FIG. 5 SINGLE LINE DIAGRAM OF IEEE 57 BUS SYSTEM

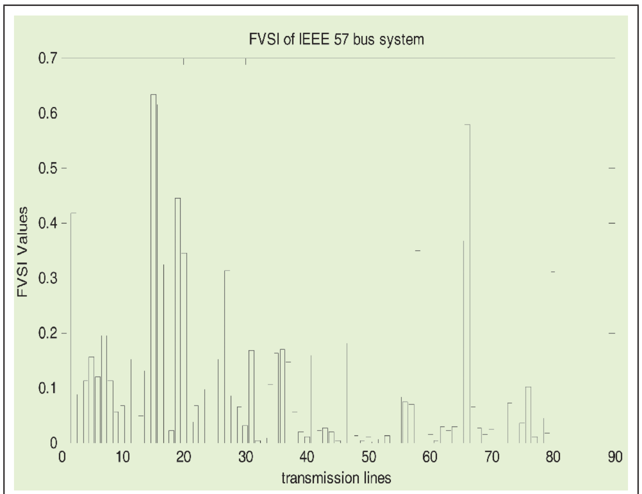

FIG. 6 FVSI OF IEEE 57 BUS SYTEM

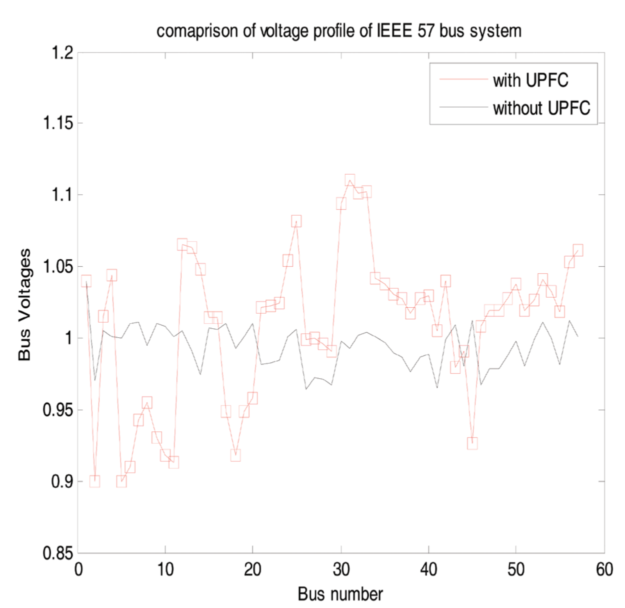

FIG. 7 VOLTAGE PROFILE OF IEEE 57 BUS WITH AND WITHOUT UPFC

Similarly as in the case of IEEE 30 bus system the values of FVSI is calculated for IEEE 57 bus system in Figure 6 and based on the FVSI values the best location is identified for Placement of UPFC. After the placement of UPFC the real and reactive power losses are minimized which are shown in Table 3 and also the voltage Profile of the IEEE 57 system is improved which is shown in Figure 7 and Table 3

7.0 CONCLUSIONS

This paper proposed an unique algorithm for placing the UPFC for improving voltage profile and reduce the transmission losses in the system. In IEEE 30 bus system the placement of UPFC effect on the reduction of power losses. The real power losses are reduced b 4.1% and reactive power losses are reduced by 11.12%. In IEEE 57 bus system on the effect of placement of UPFC the real power losses are reduced by 11.41% and reactive power losses are reduced by 6.35%.In this paper for the both test cases 1 MVA UPFC is used to compensate the system for improving the voltage profile and reduce the transmission losses. By applying the optimizing techniques the exact size of the UPFC can be determined for reducing the maximum losses.

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