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Development of Static Model for a Current Based UPFC

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ABSTRACT- The power system loads are dispersed across the network and generators are concentrated in a few key locations. In between generation and loads, there exist transmission systems. FACTS devices have applications to regulate voltage magnitude and angle, and impedance of the system. In FACTS devices, UPFC is one of its kind. Generally, line outages are occurred due to the faults on the transmission lines. One of the sensitive measures to understand the line outages is Line Outage Distribution Factor (LODF). In this paper, a suitable location is identified for UPFC to place where the line outage distribution factor is quite high in the system through line outage distribution factor.

Keywords: LODF, FACTS, UPFC, line outage distribution factor.

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1. INTRODUCTION

The two basic components of power transfer are active and reactive power is an important aspect to power engineers to address. Power electronic devices may now be used to regulate electrical power systems thanks to the high-power semiconductor industry's ongoing, fast growth [1] [2]. The UPFC [3,4] is one such device to manage the flow control, load sharing, improves stability, reduces oscillations, and regulating voltage. Implementing such equipment necessitates the use of various power electronics controls [5]. The FACTS devices incorporate a variety of power electronics components. These components are rapid to regulate and may be customized with a variety of control algorithms.

High performance management of the power network is necessary in this setting [6–8]. FACTS (flexible ac gearbox system) devices increase controllability and efficient operation [9] [10]. By utilizing controllable parts, the line flows can be altered to guarantee that heat limitations, losses, stability margins, contractual obligations, etc. are all satisfied while maintaining economic dispatch [11]. Quasi-Newton techniques for function reduction speed up the steepest-descent method [12]. The solution for computing power flow is to simulate the steady state behavior of three-phase systems [13]. The voltage can be changed irrespective of its magnitude and phase angle. Power System quick line flow calculations for sensitivity factor-based security control.

2. PROPOSED METHODOLOGY

2.1 Line Outage Distribution Factor LODF

When transmission circuits are disrupted, LODF can be computed as below:

$$d_{l,k} = \frac{\Delta f_l}{f_k^0} \quad (1)$$

Where
$d_{l,k}$ = When monitoring line l that follows a line k outage, use the line outage distribution factor.
Δf_l = active power change in 'l' line
f_k^o = actual line flow before outage

The flow in 'l' line is as below:

$$f_l = f_l^0 + d_{l,k} f_k^0 \quad (2)$$

Where,
f_l^o, f_k^o = power flow in the line
f_l = power flow in line 'l'

2.2 Current Based Model

The model that was developed introduces the series converter's current as a variable and depicts the UPFC in steady state.

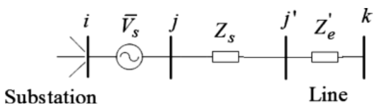

Figure 1: UPFC in the network

Let's assume that the transmission line in which the UPFC will be installed has bus bars i and k and impedance Z_e' To incorporate the UPFC into the system, fictitious bus bars j and j' are made. When the transmission line's series impedance and the UPFC coupling transformer's impedance Z_s are combined, the impedance $Z_e = Z_e' + Z_s$ is removed. *Figure 2* shows the analogous network.

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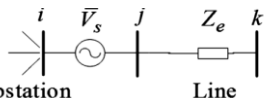

Figure 2: Model of UPFC

2.2.1 Current Model of UPFC

From *figure 3* Current $\bar{I}$ introduces magnitude (I) and angle of current (φ). Additional powers $S_i^c$and S_j^c,

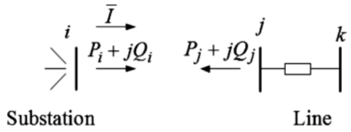

Figure 3: Power in buses *i* & *j*

Powers due to current

$$S_i^c = \bar{V}_i \bar{I}^* S_j^c = -\bar{V}_j \bar{I}^* \tag{3}$$

$$P_i^c = V_i I\cos(\varphi - \theta_i) P_j^c = -V_j I\cos(\varphi - \theta_j) \tag{4}$$

$$Q_i^c = V_i I\sin(\varphi - \theta_i) Q_j^c = -V_j I\sin(\varphi - \theta_j) \quad \text{and} \quad P_i = P_i^0 + P_i^c P_j = P_j^c,\ Q_i = Q_i^0 + Q_i^c Q_j = Q_j^c \tag{5}$$

2.2.2 Injected Series Voltage

For FACTS devices that may make use of this feature, the series voltages for the UPFC are treated in the following manner generally. The SSSC serves as the primary example, and as a result, other devices that employ series voltage, such as IPFC and GIPFC, may also be modeled.

The voltage between *i* and *j* bus is

$$\bar{V}_s = rV_i e^{j\delta} \tag{6}$$

The series voltage factor is *r*, and the series voltage angle is *δ*.

$$\bar{V}_j + A\angle\alpha . \bar{V}_i = 0 \tag{7}$$

2.2.3 Power Balance Equation

The power balancing equation is important to finish the static model. The shunt power of bus bar *i* will have the series power added to it and is shown in *figure 4*.

The series converter power is

$$S_s = re^{j\delta}\bar{V}_i I\angle - \varphi \tag{8}$$

The powers are

$$P_s = rV_i I\cos(\theta_i + \delta - \varphi) \tag{9}$$

$$Q_s = rV_i I\sin(\theta_i + \delta - \varphi) \tag{10}$$

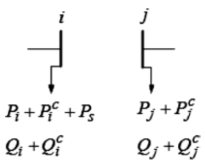

Figure 4: Powers at with UPFC

2.2.4 Complete Jacobian Analysis

The Jacobian matrix, for N-R load flow solution is given below,

$$J_c^0 = \begin{bmatrix} H^0 & N^0 \\ j^0 & L^0 \end{bmatrix} \tag{11}$$

By adding the injected power, the modified Jacobian matrix is as below,

$$[J] = [J_c^0] + [J^c] + [J^s] \tag{12}$$

The sub-matrix elements are H terms:

$$H_{ii}^c = \frac{\partial P_i^c}{\partial \theta_i} = -Q_i^c H_{jj}^c = \frac{\partial P_j^c}{\partial \theta_j} = -Q_j^c,$$

$$H_{in}^c = \frac{\partial P_i^c}{\partial \varphi} = Q_i^c H_{jn}^c = \frac{\partial P_j^c}{\partial \varphi} = Q_j^c,$$

$$H_{ni} = -AV_i \sin(\alpha + \theta_i) H_{nj} = -V_j \sin(\theta_j) \tag{13}$$

N terms:

$$N_{ii}^c = V_i \frac{\partial P_i^c}{\partial V_i} = P_i^c N_{jj}^c = V_j \frac{\partial P_j^c}{\partial \theta_j} = P_j^c,$$

$$N_{in}^c = I\frac{\partial P_i^c}{\partial I} = P_i^c N_{jn}^c = I\frac{\partial P_j^c}{\partial I} = P_j^c,$$

$$N_{ni} = AV_i \cos(\alpha + \theta_i) N_{nj} = V_j \cos(\theta_j) \tag{14}$$

J terms:

$$J_{ii}^c = \frac{\partial Q_i^c}{\partial \theta_i} = P_i^c J_{jj}^c = \frac{\partial Q_j^c}{\partial \theta_j} = P_j^c,$$

$$J_{in}^c = \frac{\partial Q_i^c}{\partial \varphi} = -P_i^c J_{jn}^c = \frac{\partial Q_j^c}{\partial \varphi} = -P_j^c,$$

$$J_{ni} = AV_i \cos(\alpha + \theta_i) J_{nj} = V_j \cos(\theta_j) \tag{15}$$

L terms:

$$L_{ii}^c = V_i \frac{\partial Q_i^c}{\partial Q_j^c} = Q_i^c L_{jj}^c = V_j \frac{\partial Q_j^c}{\partial \theta_j} = Q_j^c,$$

$$L_{in}^c = I\frac{\partial Q_i^c}{\partial I} = Q_i^c L_{jn}^c = I\frac{\partial Q_j^c}{\partial I} = Q_j^c$$

$$L_{ni} = AV_i \sin(\alpha + \theta_i) L_{nj} = V_j \sin(\theta_j) \tag{16}$$

Correction of Jacobian terms due to power balance:

H terms

$$H_{ii}^s = \frac{\partial P_s}{\partial \theta_i} = -rV_i \sin(\theta_i + \delta - \varphi) = -Q_s,$$

$$H_{in}^s = \frac{\partial P_s}{\partial \varphi} = rV_i I\sin(\theta_i + \delta - \varphi) = Q_s \tag{17}$$

N terms

$$N_{ii}^s = V_i \frac{\partial P_s}{\partial V_i} = rV_i I\cos(\theta_i + \delta - \varphi) = P_s,$$

$$N_{in}^s = I\frac{\partial P_s}{\partial I} = rV_i \cos(\theta_i + \delta - \varphi) = P_s \tag{18}$$

The terms in the Jacobian matrix [J] is given by

[H] Sub-matrix terms

$$H_{ii} = H_{ii}^0 - Q_i^c - Q_s H_{jj} = H_j^0 - Q_j^c\ ,$$

$$H_{in} = Q_i^c + Q_s H_{jn} = Q_j^c,$$

$$H_{ni} = -AV_i \sin(\alpha + \theta_i) H_{nj} = -V_j \sin\theta_j \tag{19}$$

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[N] Sub-matrix terms

$$N_{ii} = N_{ii}^{0} + P_i^c - P_s N_{jj} = N_{jj}^{0} + P_j^c,$$
$$N_{in} = P_i^c + P_s N_{jn} = P_j^c,$$
$$N_{ni} = AV_i \cos(\alpha + \theta_i)\, N_{nj} = V_j \cos\theta_j \quad (20)$$

[J] Sub-matrix terms

$$J_{ii} = J_{ii}^{0} + P_i^c J_{jj} = J_{jj}^{0} + P_j^c\ ,$$
$$J_{in} = -P_i^c J_{jn} = -P_j^c,$$
$$J_{ni} = AV_i \cos(\alpha + \theta_i)\, J_{nj} = V_j \cos\ \theta_j \quad (21)$$

[L] Sub-matrix terms

$$L_{ii} = L_{ii}^{0} + Q_i^0 L_{jj} = L_{jj}^{0} + Q_j^c,$$
$$L_{in} = Q_i^c L_{jn} = Q_j^c,$$
$$L_{ni} = AV_i \sin(\alpha + \theta_i)\, L_{nj} = V_j \sin\ \theta_j \quad (22)$$

3. ALGORITHM

The research is carried on 5-bus system was carried out and the proposed algorithm is as follows:

1. Read the system's line and bus data; the load (MW & MVAR), generator (MW & MVAR, Q_{min} & Q_{max}), and system angle (MW & MVAR) data are assumed to be constants.
2. Run the power flow without a backup line and use the results as the baseline.
3. Integrate the UPFC into the system and compute the value.
4. Compare using and excluding UPFC.

4. RESULT

The standard-5 bus system is used for simulation and is shown in *figure 5*. Table 1 summarizes active power flow in the pre- and post-contingency states. *Table 2* displays the parameters used to predict line outage distribution. The line linked to the slack bus has a line outage distribution factor of 1.119897, which is the highest number. Even though the slack bus has a greater line outage distribution factor value, it still supplies electricity to offset the loss. Taking into account both load buses for a transmission line linked to buses 3 and 4, which has the second-highest value of the line outage distribution factor, or 1.048109. Given that, following the line 3 - 4, the line 4 - 5 has the next-highest value of the line outage distribution factor. UPFC is installation is near bus number 4.

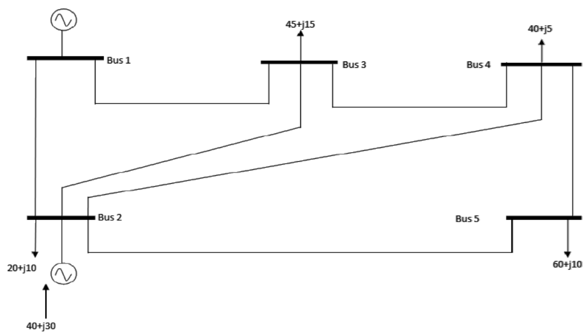

Figure 5: IEEE-5 Bus System

Table 1: Real power flow in the lines before and after outage

Line	Base Case	1 – 2	1 - 3	2 - 3	2 – 4	2 - 5	3 - 4	4 – 5
1 - 2	87.742	0	132.922	81.203	78.673	77.908	95.956	89.23
1 - 3	43.406	141.668	0	50.622	53.395	59.673	35.408	41.96
2 - 3	19.911	-13.664	35.944	0	31.226	36.836	10.73	18.28
2 - 4	29.722	-4.999	47.994	38.692	0	58.831	41.075	26.902
2 - 5	55.66	38.663	65.083	60.204	65.191	0	61.499	61.564
3 - 4	16.472	68.274	-9.887	3.488	36.697	47.547	0	13.554
4 - 5	5.633	22.492	-3.326	1.278	-3.445	63.951	0.051	0

Table 2: Line Outage Distribution factors

Line outage / Line flow	1– 2	1 – 3	2 – 3	2 – 4	2 – 5	3 – 4	4 – 5
1 – 3	1.119897	1.04087	0.328411	0.305128	0.17668	0.498664	0.264158
2 – 3	0.382656	0.369373	0.362413	0.336081	0.292257	0.485551	0.256702
2 – 4	0.395717	0.420956	0.450505	0.380694	0.304078	0.55737	0.289544
2 – 5	0.193716	0.21709	0.228216	0.320672	0.522979	0.68923	0.500621
3 – 4	0.59039	0.607266	0.652102	0.680472	0.5583	0.35448	1.048109
4 – 5	0.192143	0.2064	0.218723	0.30543	1.047754	0.338878	0.518019

The bus voltages and the power flow in the lines are given in *table 3* and *table 4*.

Table 3: Comparison of bus voltage magnitude and angles

Bus No.	UPFC0		UPFC3-4	
	Magnitude	Angle	Magnitude	Angle
1	1.060	0.000	1.0600	0.000
2	1.000	-2.005	1.0290	-2.4749
3	0.987	-4.864	1.0057	-5.0760
4	0.984	-5.128	1.0039	-5.3491
5	0.972	-5.784	0.9951	-6.0187

Table 4: P & Q flow in the lines with UPFC

Line	P_{loss}(MW)	Q_{loss}(MW)
1 - 2	1.468	4.405
1 - 3	1.366	4.098
2 - 3	0.232	0.967
2 – 4	0.514	1.542
2 – 5	1.201	3.602
3 – 4	0.025	0.075
4 – 5	0.025	0.074

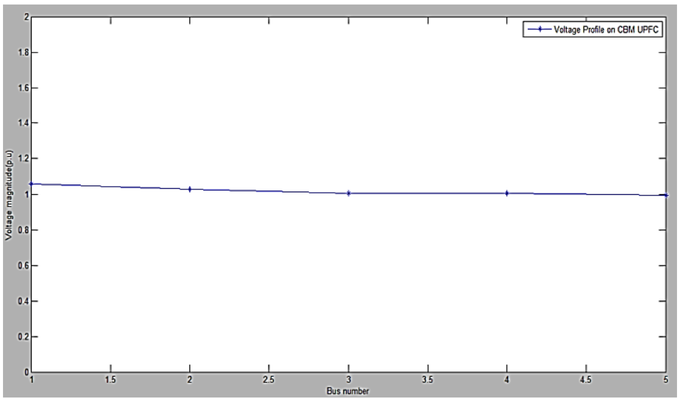

Figure 6: Voltage magnitude at each bus on current based model UPFC

Plotting the two distinct plots demonstrates how active and reactive power losses vary with bus number as well as how voltage magnitude varies with bus number. *Figure 7* shows active and reactive power loss in relation to bus number. *Figure 7* illustrates what happens when the UPFC is included into line 3–4 and the active and reactive power losses between buses 3 and 4 are decreased. As seen in *figure 6*, the bus voltage of all buses increases when the UPFC is added to Lines 3 and 4.

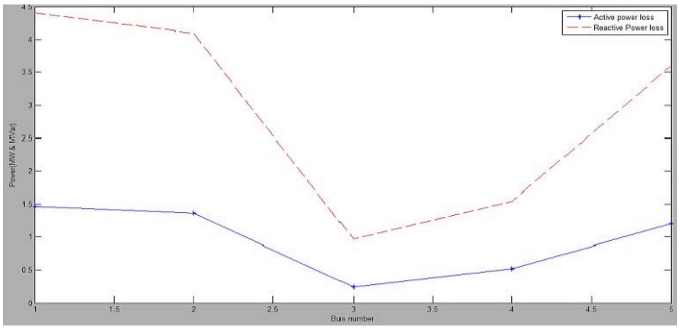

Figure 7: Active and Reactive Power loss at each bus

The bus voltages are raised when UPFC is added between buses 3 and 4. Due to the introduction of UPFC in a line identical to this one, the voltage profile of some buses reduces. It explains that while the UPFC may theoretically be implemented everywhere in the system, it is not possible to do so in practice for the transmission line.

5. CONCLUSION

The static current based UPFC model has been developed and has been included into the traditional NR power flow method in this work using a MATLAB program. Different systems have demonstrated how UPFC works in steady state. It is demonstrated that the active and reactive power losses are decreased for various lines when UPFC is implemented between two buses in the system. It is also demonstrated that after including UPFC, the voltage profile of each bus is enhanced in addition to the reduction in power losses.

Author Contributions

Vasudha D is contributed to resource data and analysis data, implementation of proposed method algorithms, the conduct of experiments and N.C Kotaiah and RadhaRani. K, guided to frame the paper and concept.

Conflicts of Interest

The author declares no conflict of interest

Annexure: Line data of 5- Bus system is given in *table-5.*

Table 5: Impedances and Line charging admittance for the IEEE 5-bus system

Bus Code p-q	Impedance Zpq	Line Charging Ypq/2	Off nominal Tap setting
1-2	0.02+j0.06	0.0+j0.030	1
1-3	0.08+j0.24	0.0+j0.025	1
2-3	0.06+j0.18	0.0+j0.020	1
2-4	0.06+j0.18	0.0+j0.020	1
2-5	0.04+j0.12	0.0+j0.015	1
3-4	0.01+j0.03	0.0+j0.010	1
4-5	0.08+0.24	0.0+j0.025	1

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