International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Load Flow Studies by CB Model Approach using UPFC

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Abstract: ***This paper deals with steady state modeling of unified power flow controller (UPFC) by an alternative proposition., This paper is focused on the steady-state modeling of UPFC for the direct implementation of the device in the Newton-Raphson (NR) power flow algorithm based on CB (Current Based) model due to current limitations are determinant to FACTS apparatus design, this model due to reduce the complexities of the computer program codes, availability of controlling in active, reactive power and voltage simultaneously or individual, the model overcome on the problem when UPFC is only link between two sub networks, NR power flow based on CB model is considered fast where most Jacobian elements are constant and equal to the terms of the nodal admittance matrix. The proposed UPFC model load flow has been tested using IEEE data test and shows it effectiveness in solving large network containing single or multiple UPFC devices.***

Keywords: CB model, FACTS, optimal power flow, Newton Raphson method, UPFC

1. Introduction

The development of power systems, especially the opening of electric markets, it becomes more and more important to control the power flow along the transmission line, thus to meet the needs of power transfer. Power flow studies and optimization techniques are essential tools for the safe and economic operation of large electrical systems. The UPFC is one of the most complete equipment of FACTS new technological family, allowing the regulation of active and reactive powers, substantially enlarging the operative flexibility of the system [1]–[2]. Steady state models of UPFC described in the literature employ the power balance equation, resulting in the equality of the series and shunt active power of converters $P_{sh}=P_S$ assuring no internal active power consumption or generation. One of the first proposed models [3] uses this condition, but only in particular cases, when power and voltage are admittedly known, is the implementation of the model in traditional power flow program viable. Voltage source models employed in [4]–[7] consist of series and shunt voltages presented in the equations as control variables.

The model described in [7], known as power injection model (PIM), is quite spread in the literature, representing the effect of active elements by equivalent injected powers. In the existing models, , the current is not explicitly treated in the equations. Since in the specification of FACTS converters one of the main restrictions lies on current limitation, It is the convenient to have a model that uses the current as a variable, which will be used explicitly in power mismatching of the line flows and will be the purpose of this paper.

Hence, in Section 2, the equations of a current based model (CBM) are presented in section 3 NR power flow based on CB model using UPFC is presented, seeking to analyze behavior of UPFC

2. Modeling of UPFC

The developed CB model represents the UPFC in steady state, introducing the current in the series converter as variable (see Fig 2.1).
V_S : Series Voltage
Z_S : Series transformer impedance
Z_e : Transmission line impedance

Let us consider busbar and existent in the transmission line where the UPFC will be located, with impedance Z_e. Fictitious busbars j and j' are created in order to include the UPFC in the system. The series impedance of UPFC coupling transformer Z_S and the transmission line are added, resulting in the equivalent impedance Z_e=Z_e+Z_S connected to the internal node j and node j' is eliminated. This association is quite simple, even in case of two port lines represented by Π circuits.

The equivalent network is presented in Fig 2.2, with the series voltage inserted between busbars i and j.

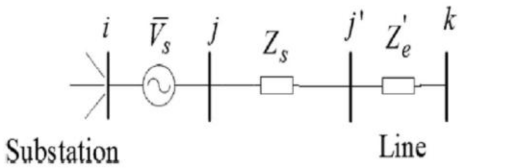


Figure 2.1: UPFC and network

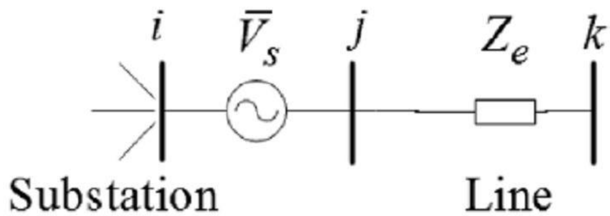


Figure 2.2: Equivalent model of UPFC in the electric network

2.1 Injected Power Due to Current

The power consumption of the system load a at busbar 'i' is called S_i^0 Additional powers and S_i^c, due to current $\bar{I}$ are easily calculated according to Fig 2.3 Current $\bar{I}$ introduces two variables I, ϕ, related to module and phase of the current.

We can write the new power terms due to current:

$$S_i^c = V_i I^*$$
$$P_i = V_i I \cos(\phi - \theta_i)$$
$$Q_i = V_i I \sin(\phi - \theta_i)$$

$$S_i^c = - V_i I^*$$
$$Q_j = -V_j I \cos(\phi - \theta_j)$$
$$P_j = -V_j I \sin(\phi - \theta_j)$$

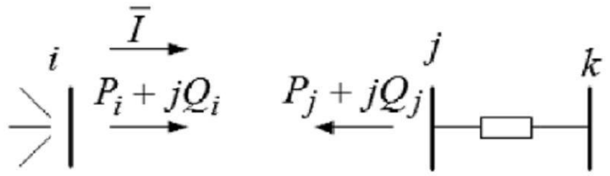


Figure 2.3: Injected power due to current in busbars i and j

2.2 Series Voltage Equations

The following treatment of the series voltages for the UPFC is general for FACTS devices that can employ this feature. The main example is the SSSC and, consequently, other equipment such as IPFC and GIPFC that use series voltage can be modelled as well. Writing the voltage equation between nodes *i* and *j* we obtain

$$V_j - V_i = V_s$$

We obtain the equations, relative to the real and imaginary parts, $F_n=0$ and $G_n=0$,respectively:

$$F_n = AV_i \cos(\alpha+\theta_i) + V_j \cos\theta_j$$
$$G_n = AV_i \sin(\alpha+\theta_i) + V_j \sin\theta_j$$

2.3 Power Balance Equations

In order to complete the UPFC model, it is necessary to introduce the power balance equation between series and shunt converters. The series power will be added to the shunt power of busbar *i*, similar to Fig 2.4.

Let us calculate the power in series converter

$$S^s = re^{j\delta} V_i I \angle -\phi$$

Splitting the previous expression in active and reactive powers:

$$P^S = rV_i I \cos(\theta_i + \delta - \phi)$$
$$Q^S = rV_i I \sin(\theta_i + \delta - \phi)$$

Active power P^S is included in node i (see Fig 2.5).

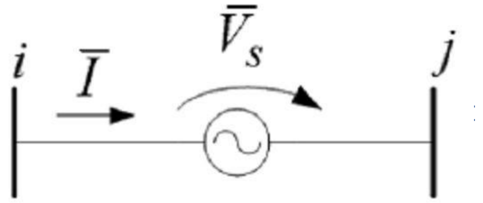


Figure 2.4: UPFC series voltage power

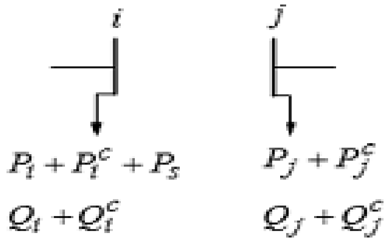


Figure 2.5: Injected powers in the busbars with the inclusion of UPFC.

2.4 Current Injection Mismatches Equations

Case(1):When bus j is PQ type

Real and imaginary parts of current injection mismatches are expressed in terms of power mismatches and voltages at bus j:

$$\Delta I_{rj} = \frac{V_{rj}\Delta P_j + V_{mj}\Delta Q_j}{V_j^2}$$

The calculation of real and imaginary current mismatches is straightforward for PQ buses, because the associated real and reactive power mismatches are known. The current mismatches given in Equations (2.6) and (2.7) are computed to form the vector of mismatches

$$\Delta I_{mj} = \frac{V_{mj}\Delta P_j - V_{rj}\Delta Q_j}{V_j^2}$$

Case (2): When bus j is PV type

$$\Delta I_{rj} = \frac{V_{rj}\Delta P_j}{V_j^2}$$
$$\Delta I_{mj} = \frac{V_{mj}\Delta P_j}{V_j^2}$$
$$\Delta V_j^2 = V_j^{sp} - V_j^{cal}$$

2.5 Complete Jacobian

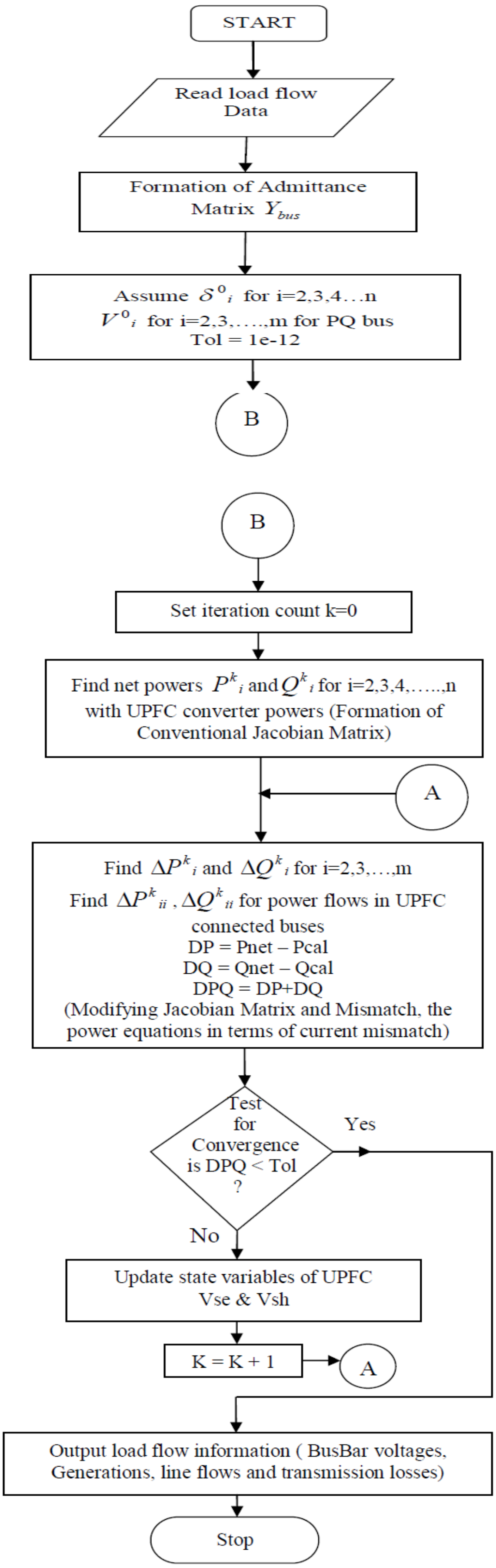
Calling the Jacobian matrix, without UPFC power addition

$$J_c^o = \begin{bmatrix} H^o & N^o \\ J^o & L^o \end{bmatrix}$$

Let us add the injected power due to current in busbars *i* and *j* and the voltage equations F_n and G_n. The additional correction of the Jacobian matrix, due to the power balance equation, is also included completing the formulation

$$[J] = [J_c^0] + [J^c] + [J^S]$$

3. Optimization Approach



4. Simulation Results

Several comparative tests performed with CBM and PIM models presented identical results in power flow analysis using a Matlab code.

Some modifications in the New England System of 39 bus bars were introduced with the purpose of highlighting the optimization results. The modified New England system is represented below. Generator 2 is the swing bus bar, and the other generators are considered power variable generators and generation costs are also presented. In the modified network, the base case does not converge and convergence can only be attained if the power generation cost is optimized. If current restrictions are used in some lines, convergence is only attained with UPFCs in the network. Voltage results were considered inside the range 0.95to 1.05 p.u for network bus bars. In order to make a fair comparison between the two models, the same initial conditions were adopted.

4.1.1 Network with 3 UPFCs

The lines with UPFC and their respective minimum and maximum current limits are presented in Table 4.1 The generation cost and computation time comparison are presented in Table 6.2 showing the critical operative condition, with the currents through the selected lines within range values, which is only possible with the inclusion of UPFCs in the network. The same generation cost presented by the two models and the lower computation time of the CBM model can be verified.

With 3 UPFCs, despite the higher Jacobian dimension of CBM, its convergence time is lower since limitations on current treated as a variable enable fast convergence. Most variables such as voltage, current and angle obtained in the convergence of three UPFCs are identical in both models, but this is not true if current limits are increased. Reducing the current band limits, PIM does not usually converge. The same trend of lower times for CBM was observed, although more analysis should be performed with this system in order to compare numerical values.

Table 4.1: Current Limits for3 UPFCs

Line	UPFC	Current Limits
32-31	1	0-4 pu
39-38	2	0-3 pu
13-14	3	0-2 pu

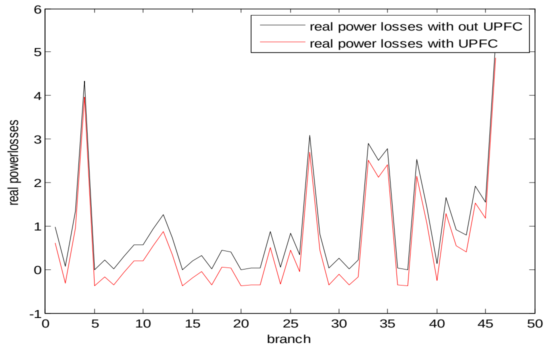
4.1.2 Network with 6 UPFCs

The lines with UPFC and their respective minimum and maximum current limits are presented in Table 4.2. Table 6.4 shows that by increasing the number of UPFCs to 6, the lower convergence time of CBM is still more evident. The results of the variables of the two models are not similar but generation costs are almost the same for these limits. If the limits are increased, different generation costs can be yielded for the models. In several cases, it was observed that for all the set of current limits that allow convergence for the PIM models also leads the CBM model to convergence. On the other hand, the inverse is not true, with CBM presenting a better performance in cases of difficult convergence due to current limitations, mainly in cases with narrower current limits. Here the losses are decreased when compared to 3 UPFCs.

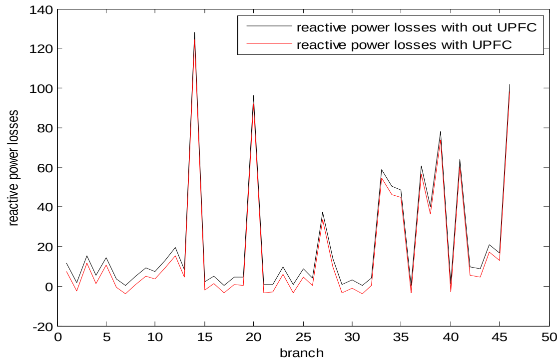
Table 4.2: Current Limits for6 UPFCs

Line	UPFC	Current Limits
39-38	1	0-5 pu
13-14	2	0-6 pu
32-31	3	0-2 pu
25-24	4	0-1.5 pu
16-21	5	0-1 pu
11-10	6	0-0.4 pu

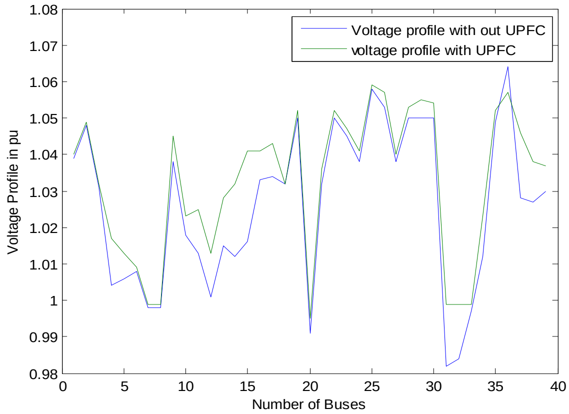
	PIM	CBM	Differences PIM*CBM (%)
Cost generation	533.7700	533.7541	0.0029
Time(sec)	400.271	41.886	89.53
	PIM	CBM	Differences PIM*CBM (%)
Power 1	3.4757	3.5153	1.13
Power 2	2.1070	2.0998	0.341
Power 3	7.0336	7.0466	0.1848
Power 4	9.8240	9.8094	0.1486
Power 5	3.1780	3.7108	16.765
Power 6	2.8237	2.8331	0.332
Power 7	3.2996	3.2843	0.5418
Power 8	14.423	14.847	0.16
Power 9	3.5572	3.5112	1.2931
r1	0.15	0.15	0
δ1	0.45710	0.45767	0.03
r2	0.24340	0.21720	10.7641
δ2	-0.25460	-0.27393	7.07
r3	0.19990	0.24640	18.85
δ3	1.8006	1.7882	0.6886
r4	0.3	0.3	0
δ4	1.6836	1.6813	0.14
r5	0.15	0.15	0
δ5	1.3844	1.3727	0.85
r6	0.24781	0.3	17.40
δ6	1.6751	1.7060	2.05
Current 1	5	5	0
Angle 1	-0.9529	-0.95000	0.05
Current 2	6	6	0
Angle 2	-0.28404	-0.29976	5.24
Current 3	2	2	0
Angle 3	-0.44740	-0.46539	3.86
Current 4	1.5	1.5	0
Angle 4	0.30260	0.30224	0.17
Current 5	1	1	0
Angle 5	0.10672	0.0669	37.25
Current 6	0.2019	0.2019	1.05
Angle 6	-1.4102	-1.1581	17.88
P_{loss}	30.4600	30.1200	1.162
Q_{loss}	832.600	831.471	0.1355



Graph 4.1: Real power losses for 6 UPFCs:



Graph 4.2: Reactive power losses for 6UPFCs:



Graph 4.3: Voltage profile for 6 UPFCs:

5. Conclusion

The CBM model was compared with the traditional power injection model PIM, showing coincident results in power flow evaluations. The proposition of an alternative formulation for the modeling of UPFC was presented, considering the current in the series converter as a variable.

In an optimization approach, despite working with two additional equations for each UPFC, the CBM model reduces the computational time and losses. Where as in 8 UPFC in CBM model the time increases and losses are decreased. In this project mainly reducing the losses .when current limitations are introduced in the series converters, mainly when dealing with several UPFC in the system, which is a very important issue in FACTS design.

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Authors Profile

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