

## Current Based Model of Upfc and Dg for Loss Reduction and Voltage Profile Improvement

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**Abstract:-** This project shares out with a substitute suggestion for the substantial state modeling of unified power flow controller (UPFC). Since current restrictions are determinant to FACTS apparatus design, the schemed current based model (CBM) assumes the current as variable, allowing easy operation of current restrictions in optimal power flow evaluations. The functioning of the schemed model and of the power injection model (PIM) are compared through a Quasi-Newton escalation approach. Two operating circumstances of a medium size network with 39 busbars were studied from the point of view of escalation and current limits, monitoring the functioning of the UPFC modeling. In general, the electrical power system is a wide variation of a network and it consists of a different equipments such as transmission lines, feeders, transformers, circuit breakers, etc. Due to variations in load or sudden interruption of a network causes to increase in losses and voltage levels of the system are effected. Hence the distributed generation (DG) technology has been paid great attention as far as a potential solution for these problems.

**Index Terms:-** FACTS, Optimal power flow, Quasi-Newton method, UPFC, CBM, DG

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### I. INTRODUCTION

POWER flow studies and escalation techniques are indispensable tools for the safe and economic operation of large electrical systems. The UPFC is one of the most complete apparatus of this new technological family, allowing the regulation of active and reactive powers, substantially enlarging the operative flexibility of the system.[1]-[5]

Substantial state models of UPFC illustrated in the literature employ the power balance equation, resulting in the impartiality of the series and shunt active power of converters  $P_{2n} = P_1$  assuring no internal active power consumption or generation.

One of the first schemed models[6] uses this condition, but only in particular cases, when power and voltage are admittedly known, is the implementation of the model in conventional power flow program viable.

The employed models [7] in represent the active elements through equivalent passive circuits, including the power balance equation. In the passive model consists of a susceptance and an ideal voltage transformer and the fundamental power balance equation is intrinsically included. Voltage source models employed in [8]-[10] consist of series and shunt voltages offered in the equations as control variables.

The model illustrated[11], known as power injection model (PIM), is quite spread in the literature, representing the effect of active elements by equivalent injected powers. In the traditional models, the current is not clearly treated in the equations. As in the design of FACTS converters one of the main limitations lies on current limitation, it is expedient to have a model that uses the current as a variable, which will be the purpose of this paper.

### II. CURRENT BASED MODEL

The developed model signifies the UPFC in substantial state, introducing the current in the series converter as variable

- 1). Series voltage
- 2) Transformer impedance
- 3) Transmission line impedance

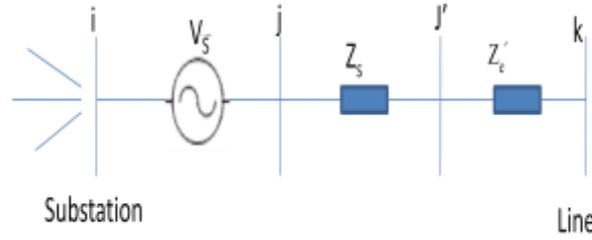


Fig. 1. UPFC and network.

Let us consider busbars  $i$  and  $k$  existent in the transmission line where the UPFC will be located, with impedance. Busbars  $j$  and  $j'$  are created in order to include the UPFC in the system. The series impedance of UPFC coupling transformer and the transmission line are added, resulting in the equivalent impedance connected to the internal node and node is eliminated. This alliance is quite simple, even in case of two port lines reoffered by  $\pi$  circuits.

The equivalent network is offered in Fig. 2, with the series voltage inserted between busbars  $i$  and  $j$

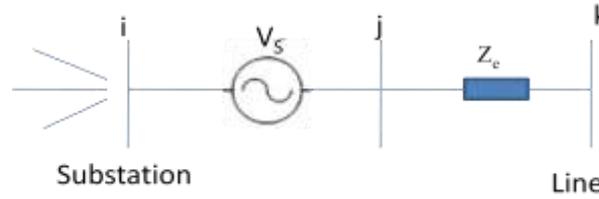


Fig. 2. Equivalent model of UPFC in the electric network.

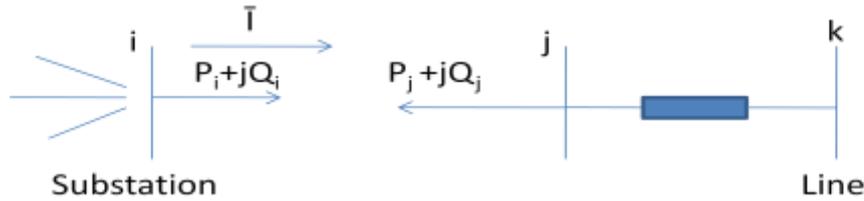


Fig. 3. Injected power due to current in busbars.

#### A. Injected Power Due to Current

The power intake of the system load at bus bar is called  $S_i^0$ . Additional powers, due to current, are easily calculated according to Fig. 3. Current introduces two variables, related to module and phase of the current.

We can write the new power expressions due to current:

$$S_i^c = V_i I^* \quad S_j^c = -V_j I^* \quad (1)$$

$$P_i^c = V_i I \cos(\varphi - \theta_i) \quad P_j^c = -V_j I \cos(\varphi - \theta_j) \quad (2)$$

$$Q_i^c = V_i I \sin(\varphi - \theta_i) \quad Q_j^c = -V_j I \sin(\varphi - \theta_j) \quad (3)$$

We have

$$P_i = P_i^0 + P_i^c \quad P_j = P_j^c \quad (4)$$

$$Q_i = Q_i^0 + Q_i^c \quad Q_j = Q_j^c \quad (5)$$

Placing the new variables and at and position, respectively, the new vector of variables can be written

$$[x^t] = [\theta_1, \theta_2, \dots, \theta_{n-1}, \varphi, V_1, V_2, \dots, V_{n-1}, I] \quad (6)$$

#### B. 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, as a consequence, other apparatus such as IPFC and GIPFC that use series voltage can be modeled as well. Writing the voltage equation between nodes and we obtain

$$V_j - V_i = V_s \quad (7)$$

The series voltage will be treated similarly to the PIM model of:

$$V_s = r v_i e^{j\delta} \quad (8)$$

Where  $r$  is the factor for series voltage and  $\delta$  is the series voltage angle. That equation substituted in (7) results

$$\bar{v}_j - (1 + r e^{j\delta}) \bar{v}_i = 0 \quad (9)$$

If  $r$  and  $\delta$  are constants, in a regular power flow case, calling the complex variable

$$A \angle \alpha = -(1 + r \angle \delta) \quad (10)$$

$$\bar{v}_j + A \angle \alpha \bar{v}_i = 0 \quad (11)$$

We obtain the equations, relative to the real and imaginary parts and, respectively:

$$F_n = A V_i \cos(\alpha + \theta_i) + V_j \cos \theta_j \quad (12)$$

$$G_n = A V_i \sin(\alpha + \theta_i) + V_j \sin \theta_j \quad (13)$$

These equations will be put at the end of the equation system. If  $r$  and  $\delta$  are variables in an escalation case, we have

$$[x^t] = [\theta_1, \theta_2, \dots, \theta_{n-1}, \varphi, \delta, V_1, V_2, \dots, V_{n-1}, I, r] \quad (14)$$

$$F_n = V_j \cos(\theta_j) - V_i [\cos(\theta_i) + \cos(\theta_i + \delta)] \quad (15)$$

$$G_n = V_j \sin(\theta_j) - V_i [\sin(\theta_i) + \sin(\theta_i + \delta)] \quad (16)$$

### C. Power Balance

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 bus bar, similarly (see Fig. 4).

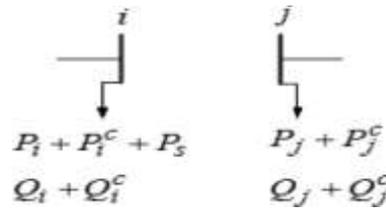


Fig4: Injected powers in the busbars with the inclusion of UPFC.

Let us calculate the power in the series converter:

$$S^s = r e^{j\delta} V_i I \angle -\varphi \quad (17)$$

Splitting the previous expression in active and reactive powers:

$$P^s = r V_i I \cos(\theta_i + \delta - \varphi) \quad (18)$$

$$Q^s = r V_i I \sin(\theta_i + \delta - \varphi) \quad (19)$$

### D. Complete Jacobean

Calling the Jacobean matrix, without UPFC power addition

$$J_c^0 = \begin{bmatrix} H^0 & N^0 \\ J^0 & L^0 \end{bmatrix} \quad (20)$$

Let us add the injected power due to current in busbars and also the voltage equations. The additional correction of the Jacobean matrix, due to the power balance equation, is also included, complementing the formulation

$$[J] = [J_c^0] + [J^c] + [J^s] \quad (21)$$

The elements of the Jacobean matrix are offered in Appendix A.

**E. Escalation Approach**

The behavior of the schemed model was studied with an escalation power flow code based on the Quasi-Newton method. The Quasi-Newton method was used in order to compare time answers of PIM and CBM models, adopting the same initial conditions and trying to obtain similar results as possible, although some differences in the equations of both cases can lead to small discrepancies in some variables of the system. The approximation formula used in the Quasi-Newton method is given by [12] and [14]

$$E_{k+1} = \left[ I_d - \frac{p_k y_k^T}{p_k^T y_k} \right] E_k \left[ I_d - \frac{y_k^T p_k}{p_k^T y_k} \right] + \frac{p_k p_k^T}{p_k^T y_k} \tag{22}$$

Where

$E_{k+1}$  = inverse of approximation of Taylor series expansion of the gradients of f in  $x_{k+1}$

$p_k = E_k + j y_k$  secant relationship or Quasi Newton

$Y_k = \nabla f x_{k+1} - \nabla f x_k$

$I_d$  = Identity matrix

Current restrictions are introduced in the formulation. In the CBM, current module and angle are the variables of the problem, while for PIM current equation is introduced according to

$$\bar{I} = (V_i \angle \theta_i + r V_i \angle (\theta_i + \delta) - V_j \angle \theta_j) (j b_s) \tag{23}$$

Equation (23) would be a little more complex if the series admittance was not simplified to disregarding series impedance losses.

**III. RESULTS**

Several comparative tests performed with CBM and PIM models offered identical results in power flow analysis using a MATLAB code. An additional comparison with the model of was made, using the Power World program.

Some modifications in the New England System of 39 bus-bars were introduced with the purpose of highlighting the optimization results. Generator 2 is the swing bus bar, and the other generators are considered power variable generators and generation costs are also offered. 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 0.95 to 1.05 pu for network busbars. In order to make a fair comparison

By the UPFC the power losses are considerably high so for reducing the power losses introducing the DGs to this network. For the allocation of DG here we are considering the voltage constrains and losses are consider for the size of the DG the improved performance is also presented for both 3 UPFC model and 6 UPFC models.

**A. Network with 3 UPFCs**

With 3 UPFCs, despite the higher Jacobean dimension of CBM, its convergence time is lower since restrictions 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 generation cost offered by the two models and the lower computation time of the CBM model can be verified this is presented in table I.

**TABEL I**

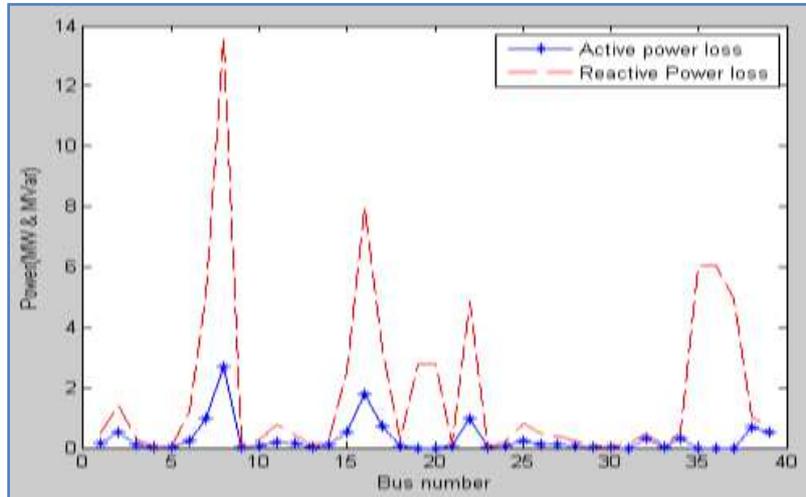
	<b>PIM</b>	<b>CBM</b>	<b>Difference</b>
<b>Cost.gen.</b>	657.762	657.761	0.000289
<b>Time(sec)</b>	100	80	20

With 3 UPFCs, despite the higher Jacobean dimension of CBM, its convergence time is lower since restrictions 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.

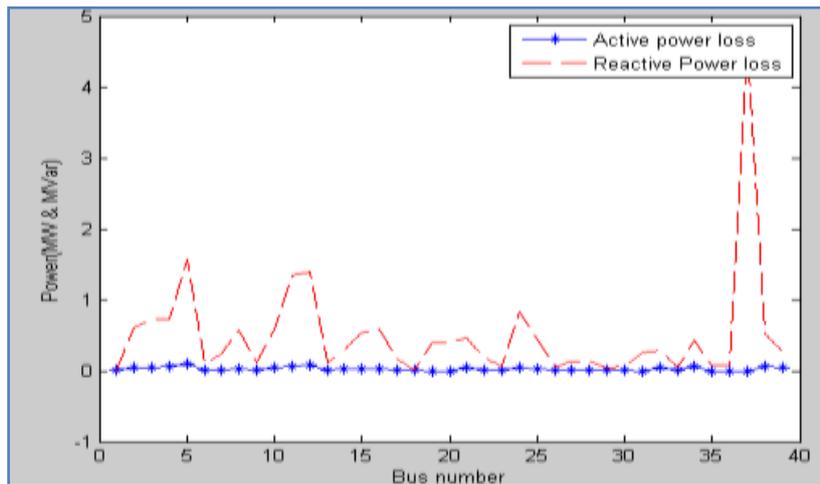
Before placement of DG the active and reactive power losses are 16.552Mw 83.125Mvar. After placement of DG the losses are reduced to 1.395Mw and 25.260 MVAR respectively. The bus wise losses without and with DG placement are shown in in fig.5 and fig.6 respectively.

TABLE II

	With UPFC only	With UPFC and DG
<b>Active power loss(MW)</b>	16.552	1.395
<b>Reactive power loss(MW)</b>	83.125	25.260



**Fig.5. power losses without DG placement**



**Fig.6. power losses with DG placement**

**B. Network with 6 UPFCs**

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. The cost generation with two models are shown in table II.

TABLE III

	PIM	CBM	Difference
<b>Cost.gen.</b>	518.649	518.631	0.003
<b>Time(sec)</b>	100	80	20

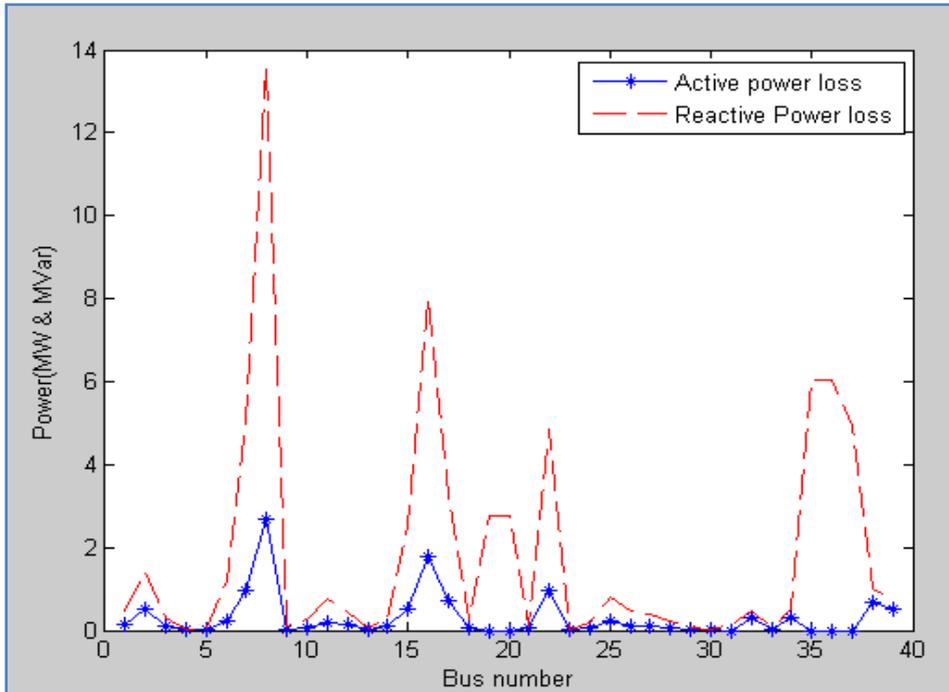
In several cases, it was observed that for all the set of current limits that allow convergence for the PIM models also leads the CBM model to convergence. On the other hand, the inverse is not true, with CBM

presenting a better functioning in cases of difficult convergence due to current restrictions, mainly in cases with narrower current limits.

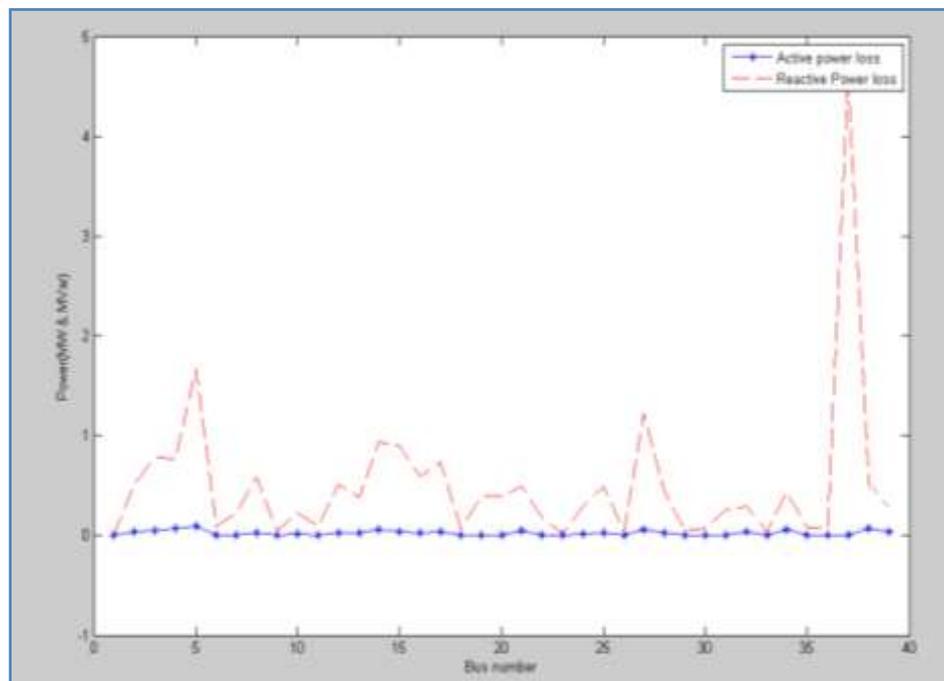
With the 6 upfcs Before placement of DG the active and reactive power losses are 16.552Mw and 83.125 Mvar After placement of DG the losses are reduced to 1.405Mw and 25.576 Mvar. The bus wise losses without and with DG placement are shown in fig.7 and fig.8 respectively

**Table IV**

	<b>With UPFC only</b>	<b>With UPFC and DG</b>
<b>Active power loss(MW)</b>	16.552	1.405
<b>Reactive power loss(MW)</b>	83.125	25.576



**Fig.7. power losses without DG placement**



**Fig.8. power losses with DG placement**

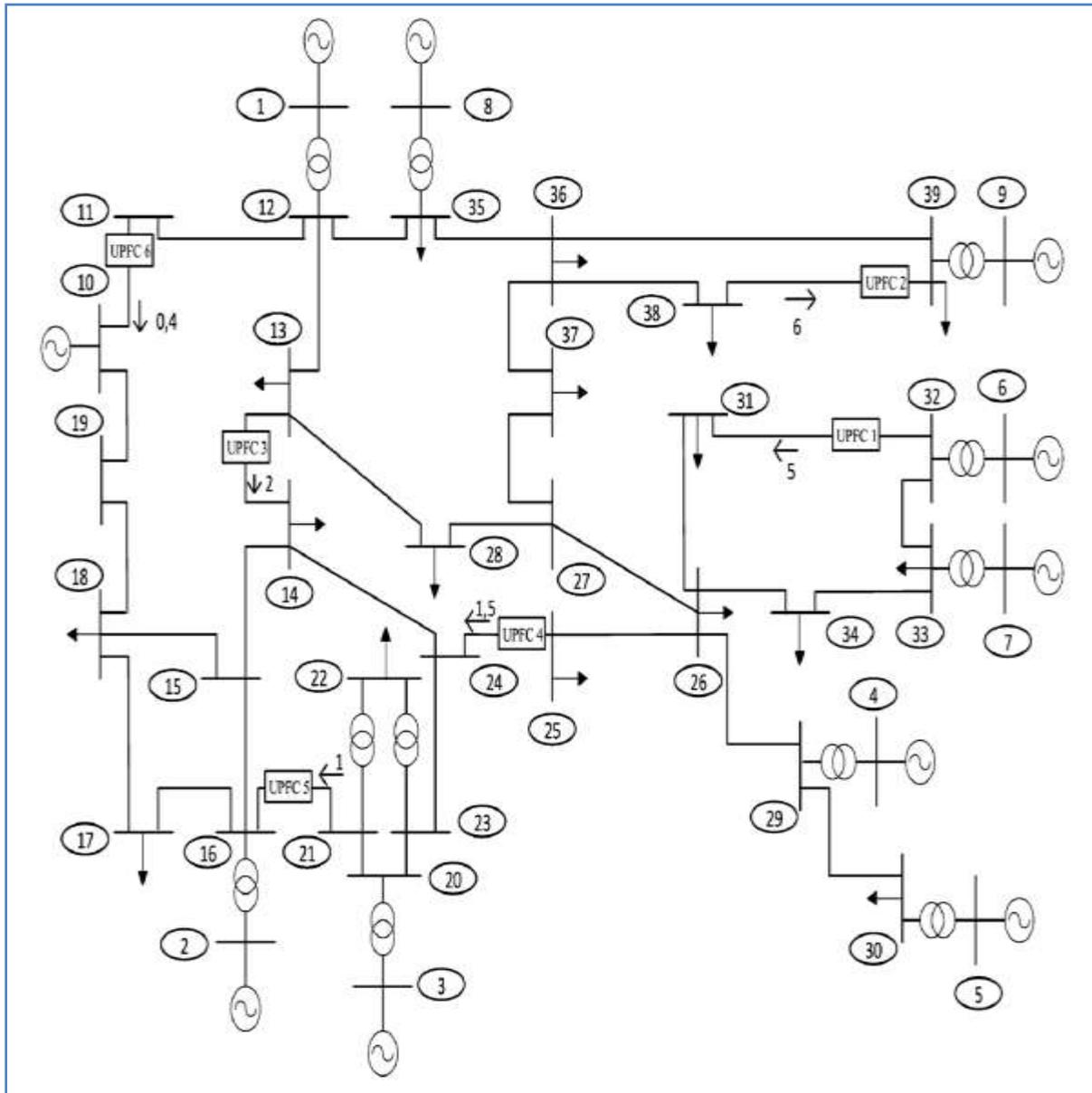


Fig.9 Modified England network with 6 UPFC

#### IV. CONCLUSION

This paper presents the treatment of series voltage converters in power systems and the formulation can be useful to other apparatus of the FACTS family. The suggestion of a substitute formulation for the modeling of UPFC was offered, considering the current in the series converter as a variable. The proposed CBM model was compared with the conventional power injection model PIM, showing coincident results in power flow evaluations.

In an escalation approach, despite carrying out with two additional equations for each UPFC, the CBM model reduces the computational time, when current restrictions are introduced in the series converters, mainly when dealing with several UPFC in the system, which is a very important issue in FACTS design.

Distributed generations (DGs) are placed to minimize the total power loss of system. Depending on the voltage constraints the dg location was found. The proposed procedure based on the UPFC and DG took the only few samples, and therefore reduced the computational requirement dramatically during the optimization process.

#### APPENDIX

Correction terms of the Jacobean matrix due to injection current when  $r$  and  $\delta$  are constants

**H terms :**

$$\begin{aligned}
 H_{ii}^c &= \frac{\partial P_i^c}{\partial \theta_i} = -Q_i^c & H_{jj}^c &= \frac{\partial P_j^c}{\partial \theta_j} = -Q_j^c \\
 H_{in}^c &= \frac{\partial P_i^c}{\partial \varphi} = -Q_i^c & H_{jn}^c &= \frac{\partial P_j^c}{\partial \varphi} = -Q_j^c \\
 H_{ni} &= -AV_i \sin(\alpha + \theta_i) & H_{nj} &= -V_j \sin(\theta_j)
 \end{aligned}$$

**N terms:**

$$\begin{aligned}
 N_{ii}^c &= V_i \frac{\partial P_i^c}{\partial V_i} = P_i^c & N_{jj}^c &= V_j \frac{\partial P_j^c}{\partial V_j} = P_j^c \\
 N_{in}^c &= I \frac{\partial P_i^c}{\partial I} = P_i^c & N_{nj}^c &= I \frac{\partial P_j^c}{\partial \varphi} = P_j^c \\
 N_{ni} &= AV_i \cos(\alpha + \theta_i) & N_{nj} &= V_j \cos(\theta_j)
 \end{aligned}$$

**J terms:**

$$\begin{aligned}
 J_{ii}^c &= \frac{\partial Q_i^c}{\partial \theta_i} = P_i^c & J_{jj}^c &= \frac{\partial Q_j^c}{\partial \theta_j} = P_j^c \\
 J_{in}^c &= \frac{\partial Q_i^c}{\partial \varphi} = -P_i^c & J_{jn}^c &= \frac{\partial Q_j^c}{\partial \varphi} = -P_j^c \\
 J_{ni} &= AV_i \cos(\alpha + \theta_i) & J_{nj} &= V_j \cos(\theta_j)
 \end{aligned}$$

**L terms:**

$$\begin{aligned}
 L_{ii}^c &= V_i \frac{\partial Q_i^c}{\partial \theta_i} = Q_i^c & L_{jj}^c &= V_j \frac{\partial Q_j^c}{\partial \theta_j} = Q_j^c \\
 L_{in}^c &= I \frac{\partial Q_i^c}{\partial I} = Q_i^c & L_{jn}^c &= I \frac{\partial Q_j^c}{\partial \varphi} = Q_j^c \\
 L_{ni} &= AV_i \sin(\alpha + \theta_i) & L_{nj} &= V_j \sin(\theta_j)
 \end{aligned}$$

Correction in Jacobean terms due to power balance

**H terms:**

$$\begin{aligned}
 H_{ii}^s &= \frac{\partial P_s}{\partial \theta_i} = -rV_i \sin(\theta_i + \delta - \varphi) = -Q^s \\
 H_{in}^s &= \frac{\partial P_s}{\partial \varphi} = rV_i \sin(\theta_i + \delta - \varphi) = Q^s
 \end{aligned}$$

**N terms:**

$$\begin{aligned}
 N_{ii}^s &= V_i \frac{\partial P_s}{\partial V_i} = rV_i I \cos(\theta_i + \delta - \varphi) = P_s \\
 N_{in}^s &= I \frac{\partial P_s}{\partial I} = rV_i I \cos(\theta_i + \delta - \varphi) = P_s
 \end{aligned}$$

**[H] sub -matrix terms**

$$\begin{aligned}
 H_{ii} &= H_{ii}^0 - Q_i^c - Q^s & H_{jj} &= H_{jj}^0 - Q_j^c \\
 H_{in} &= Q_i^c + Q^s & H_{jn} &= Q_j^c \\
 H_{ni} &= -AV_i \sin(\alpha + \theta_i) & N_{nj} &= -V_j \sin(\theta_j)
 \end{aligned}$$

**[N] sub matrix terms**

$$\begin{aligned}
 N_{ii} &= N_{ii}^0 + P_i^c + P^s & N_{jj} &= N_{jj}^0 + P_j^c \\
 N_{in} &= P_i^c + P^s & N_{jn} &= P_j^c \\
 N_{ni} &= AV_i \cos(\alpha + \theta_i) & N_{nj} &= V_j \cos \theta_j
 \end{aligned}$$

**[J] Sub matrix terms**

$$\begin{aligned}
 J_{ii} &= P_i^0 + P_i^c & J_{jj} &= J_{jj}^0 + P_j^c \\
 J_{in} &= -P_i^c & J_{jn} &= -P_j^c \\
 J_{ni} &= AV_i \cos(\alpha + \theta_i) & J_{nj} &= V_j \cos \theta_j
 \end{aligned}$$

**[L] Sub matrix terms**

$$\begin{aligned} L_{ii} &= L_{ii}^0 + Q_i^c & L_{jj} &= L_{jj}^0 + Q_j^c \\ L_{in} &= Q_i^c & L_{jn} &= Q_j^c \\ L_{ni} &= AV_j \sin(\alpha + \theta_j) & L_{nj} &= V_j \sin(\theta_j) \end{aligned}$$

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