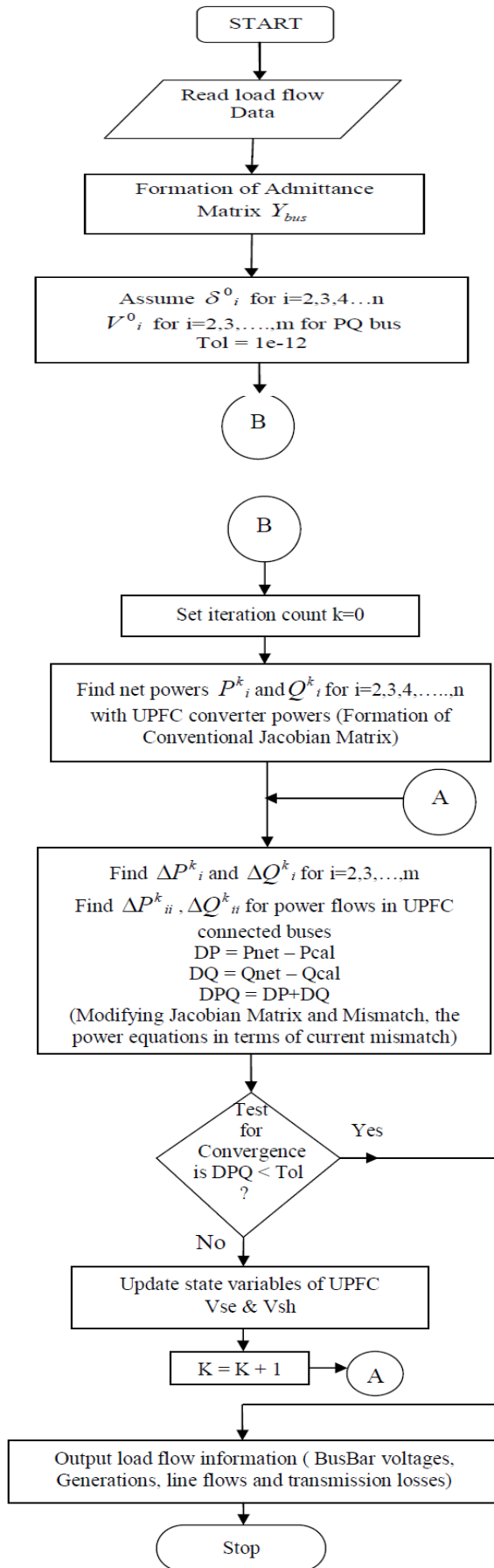


3. Optimization Approach



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 0.95 to 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 for 3 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

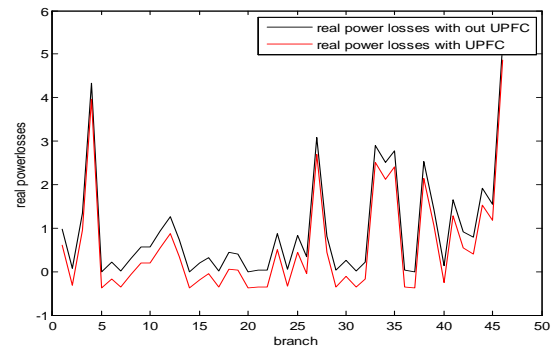
The lines with UPFC and their respective minimum and maximum current limits are presented in Table 4.2. Table 6.4 shows that by increasing the number of UPFCs to 6, the lower convergence time of CBM is still more evident. The results of the variables of the two models are not similar but generation costs 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.

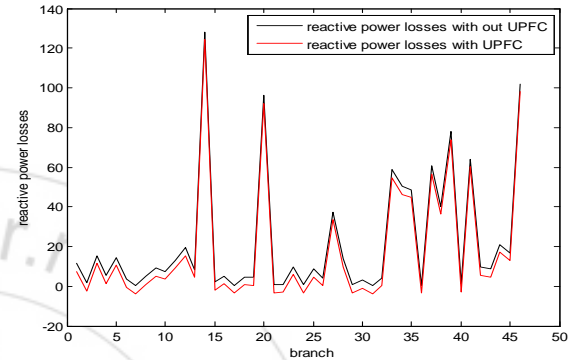
Table 4.2: Current Limits for 6 UPFCs

| 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 |

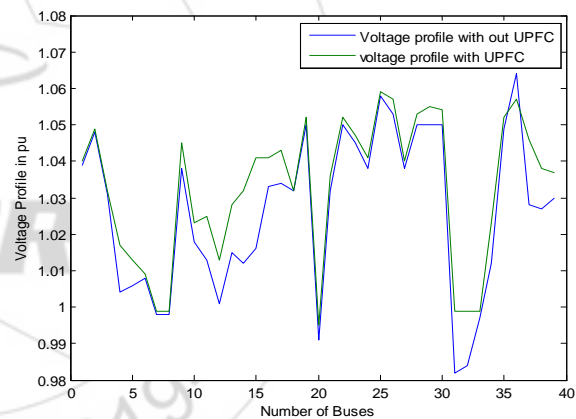
| | PIM | CBM | Differences PIM*CBM (%) |
|-------------------|----------|----------|-------------------------|
| Cost generation | 533.7700 | 533.7541 | 0.0029 |
| Time(sec) | 400.271 | 41.886 | 89.53 |
| | PIM | CBM | Differences PIM*CBM (%) |
| Power 1 | 3.4757 | 3.5153 | 1.13 |
| Power 2 | 2.1070 | 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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