Performance Analysis of SVC, TCSC and UPFC When Incorporated in a DTS

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Abstract
Power electronic equipment, named Flexible AC Transmission Systems (FACTS), has been applied on some networks for the control of node voltages and rapid control of power flows on transmission lines or along corridors. The use of FACTS devices increases the electric power system flexibility under variable operating conditions. This paper presents the performance of Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC) and Unified Power Flow Controller (UPFC) in a Dispatcher Training Simulator (DTS). The proposed models are shown to be effective both for maintaining the voltage at a specified load bus and real and reactive power flow through a typically selected transmission line. Finally, the paper presents the effectiveness of the controls for a standard nine bus System.

Keywords
DTS, SVC, TCSC, UPFC

I. Introduction
With increased power transfer, transient and dynamic stability is of increasing importance for secure operation of power systems. FACTS devices with a suitable control strategy have the potential to significantly improve the transient stability margin. This allows increased utilization of existing network closer to its thermal loading capacity, and thus avoiding the need to construct new transmission lines. These opportunities arise through the ability of FACTS controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle and the damping of oscillations at various frequencies below the rated frequency. The FACTS technology is not a single high power controller, but rather a collection of controllers, which can be applied individually or in coordination with others to control one or more of the interrelated system parameters mentioned above. The term FACTS cover all of the power electronics based systems used in AC power transmission. The main systems are: SVC, TCSC, Phase Shifting Transformer (PST), STATic synchronous COMPenser (STATCOM), UPFC and Interline Power Flow Controller (IPFC). This paper presents the performance analysis of few facts devices, SVC, TCSC and UPFC when integrated in the Power System Module (PSM) of a DTS [1-4]. The system taken for simulation is the standard 9-bus system [5]. This paper concludes with the results of simulation for two case studies, Load recovery and Load rejection. The coding is done using C++ language and the simulation processes in PSM, Instructor System Module (ISM) and Operator System Module (OSM) are carried out in VC++ 6.0 environment.

II. Modeling of SVC, TCSC and UPFC
The SVC is a shunt compensation component. It is originally designed for voltage maintenance in power systems. From the difference between the set voltage and the measured voltage, SVC model [6-7] computes equivalent inductive/capacitive current to be injected at the bus to which it is connected so as to maintain the voltage closer to the set value. The SVC is mathematically modeled as an ideal reactive power injection at bus i. The injected power at bus i is, \( Q_i = -[(V_i^2)][B] \). The discretised equations to find BSVC using trapezoidal rule are given in the technical paper [9]. The TCSC is an important component of FACTS. With the precise firing control of the thyristors, it can smoothly and rapidly change its apparent reactance. The TCSC is capable of directly scheduling the real power flow through a typically selected line and allow the system to operate closer to the transmission line limits. More importantly because of its speedy and supple regulation ability, it can improve transient stability and the dynamic performance of the power systems. Particularly, in systems with bulk transfer of power and long transmission lines it can be used to augment the power transfer capability of the transmission line and damp the low frequency oscillations.

In this simulation, the reactance of the transmission line is adjusted by TCSC directly. The reactance of transmission line with TCSC is given by:
\[ X = X_{TCSC} + X_{line} \]
Where, \( X_{TCSC} = \frac{1}{\omega r_{tcsc}} \times X_{tcsc} \)
\[ X_{tcsc} = \text{the reactance of the transmission line and } r_{tcsc} \text{ is the degree of compensation of TCSC.} \]

In the variable reactance model [7] for stability studies, a reference value of power is generated based on power flow specification of the transmission line. The difference between the set reference and actual power flow through the line in which TCSC is connected is computed. Then \( X_{out} \) the proportionate inductive/ capacitive reactance to be added to the line is obtained and presented to the network after a finite delay caused by the firing controls and the natural response of the TCSC. This delay is modeled by a lag network having a time constant \( T_{TCSC} \) This resulting \( X_{TCSC} \) is added to the \( X_{base} \) is the reactance of the TCSC installation’s fixed capacitor component. To obtain per unit values, the TCSC reactance is divided by \( Z_{base} \) where
\[ Z_{base} = \frac{(kV_{TCSC})(MVA_{app})}{MVA_{app}} \]
Where \( kV_{TCSC} \) is the rms line-line voltage of the TCSC in kV and MVA_{app} is the three phase MVA base of the system. The discretised equations to find \( X_{TCSC} \) [8-9] using trapezoidal rule is given in the technical paper [9].

The UPFC, by means of angularly unconstrained series voltage injection is able to control concurrently or selectively, the transmission line voltage, impedance and angle or alternatively the real and reactive power flow in the line. The UPFC is implemented practically by using two similar solid-state phase voltage source converters (shunt compensation block and series compensation block) which are connected through a common DC link capacitor. The basic model of UPFC comprises of series and shunt parts [4, 7]. The series part of the UPFC takes care of the real and reactive power flows in a chosen transmission line, and the shunt part of the UPFC takes care of the voltage profile of a chosen node. The discretized equations for UPFC block, using trapezoidal rule are
given in the technical paper [4].

III. Interfacing Algorithm Of SVC and TCSC With Long Term Dynamic Simulation Of DTS

The algorithm [10-11] for interfacing SVC and TCSC model with the PSM of the Dispatcher Training Simulator is well explained in IEEE International conference publication [9].

IV. Simulation Conditions and Results (SVC and TCSC)

The summary of cases considered, the algorithm used for simulation and the disturbance scenarios to illustrate the performance of SVC and TCSC combination are given in Table 1. The results of simulation for the case studies performed are given in fig. 1 to fig. 4.

Table 1: Case Descriptions

<table>
<thead>
<tr>
<th>Case Name</th>
<th>Simulation Algorithm</th>
<th>Disturbance scenario</th>
<th>Fig. No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Long term stability</td>
<td>Load Recovery (30MW, 20MVAR) at BUS8 at 20th Second</td>
<td>1 &amp; 2</td>
</tr>
<tr>
<td>B</td>
<td>Long term stability</td>
<td>Load Rejection (30MW, 20MVAR) at BUS8 at 20th Second</td>
<td>3 &amp; 4</td>
</tr>
</tbody>
</table>

V. Interfacing UPFC With the High Speed Algorithm of DTS

The algorithm [12-14] for interfacing UPFC model with the PSM of the DTS is presented here. The stepwise computations to be performed to advance the simulation by one time step, i.e. from ‘t’ to ‘t+dt’ are as follows. The step width (dt) used in this algorithm is 0.5 sec.

1. Read the system load curve.
2. Compute the zone loads and individual busloads using the zone and bus distribution factors.
3. Compute the total real power generation required to meet the system load and losses.
4. Distribute the total real power generation to the individual generators in proportion to their real power reference setting made by the instructor. Initially, the real power reference setting is made equal to the power specified for load flow.
5. Set the reactive power generation of the individual generators to the previous time step values. Initially, the reactive power generation, Qgen is set to the value of reactive power output from load flow solution.
6. (a) Compute the Norton current of all generators.\[ I_{or} = \frac{E}{(R_a + jX_d)} \]
   (b) At Bus 5 \[ I_5 = V_5^{\text{old}} (0+j B(t)), \] \[ V_5^{\text{old}} \] is the value of \[ V_5 \] at \( (t-\Delta t) \) for the first iteration.
7. Solve the network equations for bus voltages. This gives the generated voltages \( V \) which includes \( V_5^{\text{approx}} \).
8. Check for generator voltage convergence. This is done by comparing the magnitudes of generator terminal voltages with their earlier values. If they are close enough, go to step 15. Otherwise go to next step.
9. Compute $I_i = \text{Inor}_i - \text{Ynor}_i (V_i)$ and $Q_{\text{gen}_i} = \text{Imaginary part of } (V_i)(I_i)^*$.
10. Calculate the system/island frequency by trapezoidal integration of the aggregate acceleration equation.
11. Update the rotor angle $\delta_i$ using trapezoidal integration of the swing equation. The rotor angle is incremented if $P_{\text{mech}_i} > P_{\text{gen}_i}$ and decremented if $P_{\text{gen}_i} > P_{\text{mech}_i}$.
12. Compute the ‘AVR’ output ($E_{\text{fd}_i}$) proportional to the reference voltages and calculate the internal emf ($E_i$) of all generators.
13. By solving the governor equations compute the mechanical power of the individual units with respect to their $P_{\text{ref}_i}$ settings. If convergence is attained go to next step, else go back to step 6.
14. The system loss during the time step is computed.
15. Correct the individual machine frequency $\omega_{i}$ to match the individual mechanical and electrical power generation, and update the rotor angle accordingly.
16. Check for the convergence of Voltage at Bus5, i.e., check whether $| V_{5}^\text{approx} - V_{5}^\text{old} | \leq \xi V^2$. If yes go to next step. Else compute $B$ with $dV(t) = | V_{\text{set}} - V_{5}^\text{approx} |$. Replace $V_{5}^\text{old}$ by $V_{5}^\text{approx}$ and go to step (6.b). For subsequent iterations the latest value of $B$ and $V_{5}^\text{approx}$ are used in step (6.b).
17. Check for the Real and Reactive Power convergence of the line in which UPFC is connected, i.e., check whether $| P_{75}^\text{old} - P_{75}^\text{approx} | \leq \xi P^2$. If yes go to next step. Else compute $X_{1\text{des}} = X_{1\text{UPFC}} + X_{2\text{UPFC}}$ with $dP = | P_{\text{ref}} - P_{75}^\text{approx} |$. Also check whether $| Q_{75}^\text{old} - Q_{75}^\text{approx} | \leq \xi Q^2$. If yes go to next step. Else compute $X_{2\text{des}} = X_{2\text{UPFC}} + X_{2\text{UPFC}}$ with $dQ = | Q_{\text{ref}} - Q_{75}^\text{approx} |$. Finally compute $X_{\text{UPFC}} = X_{1\text{UPFC}} + X_{2\text{UPFC}}$. Add $X_{\text{UPFC}}$ to the line reactance $X_{75}$ and reconstruct the admittance matrix. Replace $P_{75}^\text{old}$ by $P_{75}^\text{approx}$ and $Q_{75}^\text{old}$ by $Q_{75}^\text{approx}$.
18. Update the past history terms, system/island frequency, rotor angle, AVR, governor and internal emf. Increment the time and go back to step 1.

VI. Simulation Conditions and Results (UPFC)

The summary of cases considered, the algorithm used for simulation and the disturbance scenarios are given in Table 2. The results of simulation for the case studies performed are given in fig. 5 to fig. 10.

<table>
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<td>5, 6, and 7</td>
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<td>B</td>
<td>High speed Algorithm</td>
<td>Load Recovery (30MW,20MVAR) at BUS8 at 20th sec</td>
<td>8, 9, and 10</td>
</tr>
</tbody>
</table>

Fig. 5: Case A. Variation of Voltage at BUS5 With Respect to Time With and Without UPFC

Fig. 6: Case A. Variation of Real Power Flowing Through Line 75 With Respect To Time With And Without UPFC

Fig. 7: Case A. Variation of Reactive Power Flowing Through Line 75 With Respect To Time With And Without UPFC

Fig. 8: Case B. Variation of Voltage at BUS5 With Respect to Time With and Without UPFC
VII. Conclusion

To facilitate the electricity market operation, maintenance of good voltage profile and complete utilization of transmission lines are a must. This paper presented the steps involved in interfacing SVC, TCSC and UPFC with the PSM of the DTS. In the case of abrupt change in system load (load recovery or load rejection), SVC does the job of voltage control whereas TCSC maintains the power flow in the line in which it is installed. SVC too indirectly maintains the power flow in the transmission lines. UPFC, a combinational pack of SVC and TCSC too achieves the same when simulated independently. The Computer simulation results have analyzed the performance of all the three FACTS devices in maintaining both the voltage profile of the network and the real and reactive power flows through selected transmission lines. Two case studies are also presented at the end for both SVC and TCSC combination as well as UPFC.

References


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