Performance Evaluation of PI and AWPI Controllers Based UPFC for Power Quality Improvement

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Abstract: This paper evaluates the transient and steady state performances of Unified Power Flow Controller for power quality improvement using PI and Anti-Windup PI (AWPI) controllers. UPFC improves the transient stability of the system and so its performance depends upon the fast response to derive the compensation signals. The model of UPFC is developed and the system is simulated using Matlab/Simulink. The control signals needed for compensation in the rectifier and inverter circuits are produced with the help of PI and AWPI controllers. The comparative study is carried out with the open loop, PI and AWPI controller based systems. The simulated results depict that the AWPI controller based system provides better results in terms of reduced peak overshoot and faster switching time.

Key words: UPFC, Power Quality, PI Controller, AWPI Controller, SSSC, STATCOM and Matlab/Simulink.

INTRODUCTION

The power-transfer capability of long transmission lines are usually limited by large signals ability. Economic factors, such as the high cost of long lines and revenue from the delivery of additional power, give strong incentives to explore all economically and technically feasible means of raising the stability limit. On the other hand, the development of effective ways to use transmission systems at their maximum thermal capability has caught much research attention in recent years. Fast progression in the field of power electronics has already started to influence the power industry. This is one direct outcome of the concept of flexible ac transmission systems (FACTS) aspects, which has become feasible due to the improvement realized in power-electronic devices. (Schauder et al 1998, Mihalic et al 1996). In principle, the FACTS devices could provide fast control of active and reactive power through a transmission line. The unified power-flow controller (UPFC) is a member of the FACTS family with very attractive features. This device can independently control many parameter, since it has the combined properties of a static synchronous compensator (STATCOM) and static synchronous series compensator (SSSC) (Schauder et al 1998).

These devices offer an alternative mean to mitigate power system oscillations. Thus, an important question is the selection of the input signals and the adopted control strategy for these devices in order to damp power oscillations in an effective and robust manner. Much research in this domain has been realized (R.Mihalic et al 1996, J.Machowski et al, 1998, M. Noroozian et al 1997). This research shows that UPFC is an effective device for this purpose. The UPFC parameters can be controlled in order to achieve the maximal desired effect in solving first swing stability problem. This problem appears for bulky power systems with long transmission lines. Various methods to reference identification of the series part, in order to improve the transient stability of the system based on: “optimal parameters” R.Mihalic et al 1996) “state variables” (J.Machowski et al, 1998), and also “injection model” were studied. The real and reactive power of the transmission line can be controlled with help of UPFC (Tara Kalyani and Tulasiram Das 2008).

This paper is organized as follows. After this introduction, the principle and operation and of a UPFC connected to a network are presented. In section II, the control strategy for UPFC is introduced. Equivalent circuit of the UPFC system and their simulation are presented in Section III. The open loop and closed loop systems of the UPFC are simulated and their results are presented in Section IV. Section V describes the conclusion.

2. Model of UPFC:

A simplified scheme of a UPFC connected to an infinite bus via a transmission line is shown in Fig.2.1. UPFC consists of a parallel and series branches, each one containing a transformer, power-electric converter with turn-off capable semiconductor devices and DC circuit. Inverter 2 is connected in series with the transmission line by series transformer. The real and reactive power in the transmission line can be quickly regulated by changing the magnitude (Vb) and phase angle (δb) of the injected voltage produced by inverter 2.

The basic function of inverter 1 is to supply the real power demanded by inverter 2 through the common DC link. Inverter 1 can also generate or absorb controllable power (Gyugi 1992, N. G. Hingroani 2000). New method for improving transient stability is given by E. Gholipour and S. Saadate (2003). The modeling, interface, control strategy and case study of the UPFC in interconnected power system is described in Z. Huang et al (2000). Enhancing transient stability using Fuzzy control is also discussed in K. Schoder et al (2000).

Fig. 2.1: UPFC Installed in Transmission Line.

The above literature does not deal with UPFC system employing closed loop system. Evaluation of shunt and series power conditioning strategies for feeding sensitive loads is given by R. Mohan and R.K. Varma (2000). In this paper, the closed loop system is proposed using PI, AWPI and Fuzzy controllers and the comparison is made between each other and also with open loop system to make examine the switching period and peak value of voltage during the switch period.

3. Equivalent Circuit of UPFC:

Two bus system without compensation is shown in Fig 3.1. Sag is produced when an additional load is added. Voltage across loads 1 and 2 are shown in Fig 3.1(a). The real and reactive power waveforms are shown in figures 3.1(b) and 3.1(c) respectively. Equivalent circuit of UPFC is shown in Fig 3.2. In this equivalent model of unified power flow controller a voltage source is connected in series with the transmission line for representing series converter and a current source is connected in shunt for representing shunt converter. The series capacitive compensation works by increasing the voltage across the impedance of the given physical line which in turn increases the corresponding line current and the transmitted power.

The equations for determining the power is given by,

\[ P = \frac{V^2}{X^2 + R^2} \left[ X \sin \delta - R \cos \delta \right] \]

\[ Q = \frac{V^2}{X^2 + R^2} \left[ R \sin \delta + X \cos \delta \right] \]

Therefore from the equations (1 & 2) it is evident that by altering the value of line voltage, \( V \), and Phase Angle, \( \delta \), the active power (P) and the reactive power (Q) can be controlled.

Table 3.1: Variation of Real and Reactive power with change in phase angle of injected voltage.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>ANGLE OF INJECTED V2 (DEG)</th>
<th>REAL POWER (KW)</th>
<th>REACTIVE POWER (KVAR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>96.82</td>
<td>65.34</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>178.1</td>
<td>111.5</td>
</tr>
<tr>
<td>3</td>
<td>120</td>
<td>310.6</td>
<td>199.9</td>
</tr>
<tr>
<td>4</td>
<td>180</td>
<td>354.1</td>
<td>240.6</td>
</tr>
<tr>
<td>5</td>
<td>240</td>
<td>262.1</td>
<td>194.5</td>
</tr>
<tr>
<td>6</td>
<td>300</td>
<td>139.3</td>
<td>106</td>
</tr>
<tr>
<td>7</td>
<td>360</td>
<td>96.82</td>
<td>65.34</td>
</tr>
</tbody>
</table>

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Fig. 3.1: Line model without compensation circuit.

Fig. 3.1(a): Voltage across Load 2 and Load 1.

Fig. 3.1(b): Real Power.

Fig. 3.1(c): Reactive Power.
Fig. 3.2: Equivalent Model of Unified Power Flow Controller.

Fig. 3.2(a): Load voltage and Load current at $\delta = 0^\circ$

Fig. 3.2(b): Real power and Reactive power at $\delta = 0^\circ$

From the waveforms Fig (3.2a-3.2d) obtained through the simulation of the equivalent model of Unified power flow control and the tabulated results as shown in Table 3.1, it is evident that the real and reactive power of the power system can be controlled by controlling the phase angle of the series injected voltage.

4. UPFC:

i) Conventional Method:

Two bus system with UPFC is shown in Fig 4.1. UPFC is represented as a subsystem. The details of subsystem are shown in Fig 3.2. Voltage across loads 1 and 2 are shown in Fig 4.2a when the firing angle of the inverter is $0^\circ$. Real and reactive powers are shown in Fig 4.2b. Load2 which is initially in OFF condition and it is switched on at $t=0.3$ sec. The shunt branch of UPFC is always in ON condition whereas the series branch of UPFC is switched ON at $t=0.4$ sec. So that time taken for switching period is 0.1 sec.
The above mentioned open loop implementation and has some problems like the UPFC has to be switched ON or OFF manually after monitoring the transmission line parameters and time taken for compensation will be more as the observations have to be done manually. These problems can overcome by using closed loop system.

**ii) PI controller based System:**
A UPFC is used with PI controller to improve the power quality i.e., to reduce the sag period and peak value of voltage. In a PI Controller, with the proportional band ($K_p$) the controller produces the output proportional to
the error and the integral action produces the output proportional to the amount of time the error is present. Due to the proportional controller offset will be present and increasing the $K_p$ value will make the loop go unstable. The integral action eliminates the offset. The absence of integral term prevents the system from reaching the target value and so PI controllers are used commonly. The PI controller is governed by the equation 1.

$$P_{out} = K_p e(t) + K_i \int e(t)$$

(1)

The schematic model of the PI controller used is shown in Fig. 4.2. The time taken for switching the UPFC is less than 0.02 sec.

![Fig. 4.4: PI controller Schematic Model.](image)

The conventional controllers face several problems in the real time implementation of them. Most of the real systems are non-linear in nature. The presence of saturation in the system will deteriorate the performance of the conventional controllers. They cause the phenomenon of integral wind-up, because of which the peak overshoot increases.

**iii) AWPI Controller:**

The effect caused by real actuators having an input – output characteristic involving saturation or limiting the actuation output is termed as integral wind-up. The integrator term in the controller integrates so that a peak occurs till the long descent after the step has changed sign. This effect is wind-up of the integrator. The integral wind-up phenomenon can be overcome by using anti-wind-up circuits. The anti-wind-up circuits detects when actuator saturation is reached and then switches off the integral action. When the control signal returns to the linear region, then the integral action should be resumed once more. A simple anti-wind-up circuit for PI controller is shown in Fig. 4.5.

![Fig. 4.4: AWPI controller Schematic Model.](image)

**5. Simulation Results:**

The proposed UPFC model is simulated with three controllers, such as open loop controller, PI and AWPI Controller. In the UPFC model with these three controllers, an additional load is switched ON at a time period of 0.3S. Due to the additional load, the output voltage of the system is sagged. The UPFC compensates this sag voltage and recovers back the nominal voltage of the system. The duration of recovery is studied along with the peak voltage occurred during recovery with the above mentioned controllers. In open loop system, the UPFC model is switched ON manually at 0.4 S ie after 0.1S of load disturbance occurrence. In the closed loop systems, the voltage values are fed back to the PI and AWPI controllers and they automatically switch ON the UPFC system. The simulation results of the three systems are shown in Fig. 4.5, 4.6 and 4.7 respectively.

<table>
<thead>
<tr>
<th>Controller</th>
<th>Sag Period in Seconds</th>
<th>Peak Voltage in Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open Loop</td>
<td>0.1 S</td>
<td>$2.28 \times 10^4$</td>
</tr>
<tr>
<td>PI Controller</td>
<td>0.05 S</td>
<td>$2.08 \times 10^4$</td>
</tr>
<tr>
<td>AWPI Controller</td>
<td>0.0178 S</td>
<td>$1.97 \times 10^4$</td>
</tr>
</tbody>
</table>
Fig. 4.5: Response of Open Loop Controller based UPFC Scheme.

Fig. 4.6: Response of PI Controller based UPFC Scheme.

Fig. 4.7: Response of AWPI Controller based UPFC Scheme.

Fig. 4.5: Comparative Analysis of Peak Voltages.
From the comparative analysis shown in Figure 4.5 and 4.6 shows that there is a drastic change in the maximum peak overshoot occurred during the switching ON of the UPFC. The model with AWPI controller scheme has less peak overshoot compared to the PI and Open loop controller models. Also the response time for the clearance of the fault is less in case of AWPI compared to the other two schemes. In the open loop scheme, the UPFC is switched ON manually after 0.1S.

5. Conclusion:

In the simulation study, matlab simulink environment is used to simulate the model of UPFC based on open loop, PI and AWPI controllers. The comparative study is made on these three schemes and the simulation results show the effectiveness of the UPFC to control the real and reactive powers. It is found that there is a reduction in the switching period time and the value of peak voltage during the switching period. It is concluded that, the proposed UPFC system with AWPI controller can be used to get improved transient state performance in the power system to improve the power quality.

REFERENCES


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