Modelling of UPFC (Unified Power Flow Control) to Improve Stability of Power System by Real and Reactive Power Control of Transmission Line

Rakhi Kumari, Prerna and Chitrangada Roy

Abstract Power systems are very complicated, and it needs careful fabrication of recent equipment considering the already existing devices. Flexible AC transmission system (FACTS) devices are introduced to improve the controllability and to raise the power transfer capacity of electric power systems. In this paper, unified power flow controller (UPFC) is opted among various FACTS devices to improve real and reactive power flow in the transmission line. When UPFC is not connected to the system, real and reactive power through transmission line cannot be controlled. In this paper, a UPFC model has been designed and implemented using MATLAB/Simulink. The simulation results obtained from the model show the improvement of power quality and voltage stability in transmission line.

Keywords Flexible AC transmission systems (FACTS)
Unified power flow controller (UPFC)
State space vector pulse width modulation (SVPWM)
Hysteresis current-controlled PWM

1 Introduction

With the increased electrical power demands, complexity of power systems is increasing day by day. Due to inadequate sources of energy, extension of power generation and transmission has been critically affected. As a result, the stressed power systems face stability problems due to disturbances [1]. Therefore, it is

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essential to improve the power transfer capacity of the current transmission systems. FACTS devices are used in order to make the system fast and flexible and to increase the controlling capability. FACTS technology is basically a collection of controllers which works individually or collectively with other devices to achieve better system performance [2].

Among various FACTS devices, UPFC has been used due to its various advantages over other FACTS device. It consists of shunt compensator as Static Synchronous Compensator (i.e. STATCOM) and series compensator as Static Synchronous Series Compensator (i.e. SSSC). These two converters are connected one after another with the help of a DC link. It can simultaneously or selectively control all the parameters such as voltage, phase angle, and impedance, which affects flow of power through the transmission. UPFC inserts voltage in the transmission line; thus, it controls the flow of real and reactive power through transmission line independently [3]. Voltage regulation and transient stability of power system are improved with the help of UPFC. In order to suppress oscillations of power system, UPFC effectively controls damping [4].

In this paper, the capability of UPFC on controlling real and reactive power flow in transmission line to improve stability of the power system is investigated. The simulation results are obtained using MATLAB/Simulink software to analyse the capability of UPFC.

2 Operating Principle of UPFC

Unified power flow controller is a speculated synchronous voltage source (SVC). It is expressed at the fundamental frequency by voltage phasor (V) with adjustable magnitude ($0 \leq V \leq V_{\max}$) and angle α ($0 \leq \alpha \leq 2\pi$). The UPFC consists of two voltage source inverters VSC1 and VSC2 as shown in Fig. 1. These converters are connected back-to-back through a capacitor.

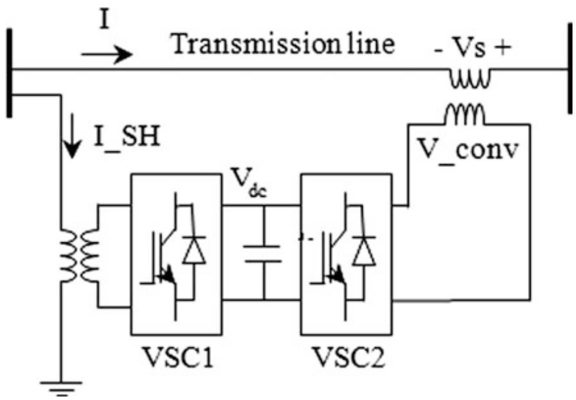

Fig. 1 Block diagram of UPFC connected to transmission line

The VSC2 injects a voltage to the transmission line through a coupling transformer, which is connected in series with the transmission line as shown in Fig. 1. The transmission line current I travels through this voltage source to provide real and reactive power interchange between UPFC and the transmission system. The VSC1 consumes or delivers active power as per the requirement of VSC2 at the DC link. The output voltage of VSC1 is delivered to the transmission line through a coupling transformer which is connected in parallel with the transmission line.

3 UPFC Controller Design

The equation of series controller is given as below. It injects the voltage V_{sr} in series with transmission line:

$$V_{sr} - V_{sr1} = R_{sr}I_{sr1} + I_{sr}\frac{d}{dt}I_{sr1} \tag{1}$$

$$\begin{bmatrix} P_0 \\ Q_0 \end{bmatrix} = \begin{bmatrix} V_{od} & V_{oq} \\ -V_{oq} & V_{od} \end{bmatrix}\begin{bmatrix} I_{srd} \\ I_{srq} \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} V_{srd} \\ V_{srq} \end{bmatrix} = \begin{bmatrix} \frac{V_{od}-V_{id}}{N_{sr}} + R_{sr}I_{sr}l_d + L_{sr}\frac{d}{d_t}I_{sr}l_d - wL_{sr}I_{sr}l_d \\ \frac{V_{oq}-V_{iq}}{N_{sr}} + R_{sr}I_{sr}l_q + L_{sr}\frac{d}{d_t}I_{sr}l_q - wL_{sr}I_{sr}l_q \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} I_{sr}l_d^* \\ I_{sr}l_q^* \end{bmatrix} = \frac{2}{3}\frac{1}{N_{sr}}\frac{1}{\left(V_{od}^2 + V_{oq}^2\right)}\begin{bmatrix} V_{od} & V_{oq} \\ V_{oq} & V_{od} \end{bmatrix}\begin{bmatrix} P_0^* \\ Q_0^* \end{bmatrix} \tag{4}$$

where V_{sr} and I_{sr} are the series voltage and series current, respectively; L_{sr} is series inductance and N_{sr} is no. of turns of series transformer; w is the angular speed, and P_0 and Q_0 are the active power and reactive power, respectively.

The model of series converter using MATLAB/Simulink is shown in Fig. 2. In series converter, we generate the pulses with the help of Space Vector Pulse Width Modulation (SVPWM) technique [5], and these generated pulses are used to drive the voltage source series converter.

The blocks represent the shunt converter using MATLAB/Simulink as shown in Fig. 3. In case of shunt converter, pulses are generated with the help of Hysteresis Current Control PWM technique [6], and these generated pulses are used to drive the voltage source converter.

Equations (5)–(9) of shunt controller are given as follows:

$$P_{sh} = \frac{2}{3}\left(V_{id}I_{shd} + V_{iq}I_{shq}\right) \tag{5}$$

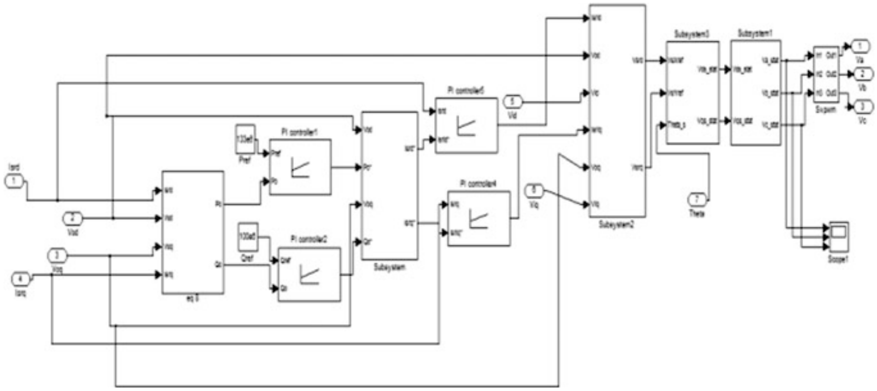

Fig. 2 Series converter using MATLAB/Simulink

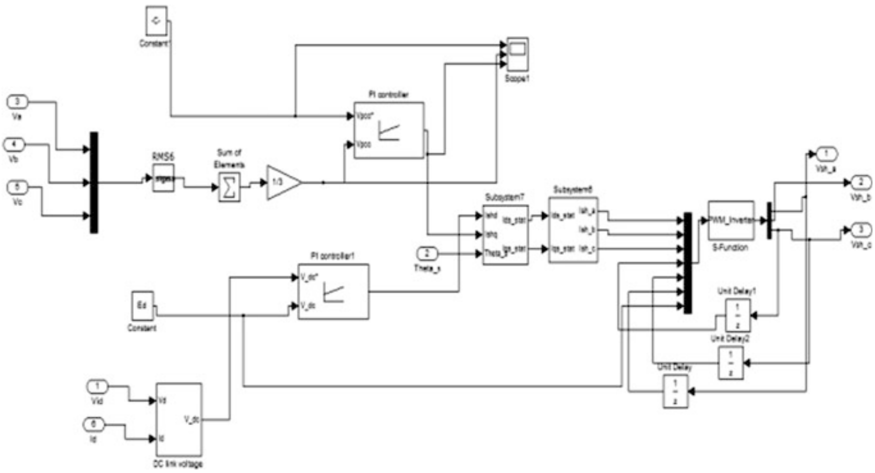

Fig. 3 Simulink model of shunt converter

$$Q_{\mathrm{sh}} = \frac{2}{3}\left(V_{id} I_{\mathrm{sh}q} - V_{iq} I_{\mathrm{sh}d}\right) \tag{6}$$

$$\begin{bmatrix} I_{\mathrm{sh}d} \\ I_{\mathrm{sr}q} \end{bmatrix} = \frac{2}{3}\frac{1}{N_{\mathrm{sh}}}\frac{1}{\left(V_{od}^2 + V_{oq}^2\right)}\begin{bmatrix} V_{id} & -V_{iq} \\ V_{iq} & V_{id} \end{bmatrix}\begin{bmatrix} P_{\mathrm{sh}} \\ Q_{\mathrm{sh}} \end{bmatrix} \tag{7}$$

$$V_{\mathrm{dc\_actual}} = \frac{3}{2}\int \frac{1}{c}\frac{V_d I_d}{V_{\mathrm{dc}}} \tag{8}$$

$$P_{\mathrm{loss}} = \frac{V_{\mathrm{dc}}^2}{R_c} + 3R_{\mathrm{sh}}I_{\mathrm{sh}}^2 + R_{\mathrm{sr}}I_{\mathrm{sh}}^2 \quad (9)$$

where V_{sh} and I_{sh} are the shunt voltage and shunt current, N_{sh} represents the no. of turns of shunt transformer, P_{loss} is the power loss in transmission line, and V_{dc} represents the DC link voltage.

4 Test System Modelling

The three-phase test system has been shown in Fig. 4. The generation voltage is 66 kV at 50 Hz. The length of three-phase 500 kV pi-section line is 60 km. In the receiving end, a RL load of 100 MW at 0.8 power factor lagging is connected.

5 Results and Discussion

In this thesis, active and reactive power control for a UPFC has been discussed. The principle control approach is such that the shunt controller of a UPFC controls the bus voltage and DC link capacitor voltage. The series controller of UPFC regulates the active and reactive power transfer of transmission line. The contribution to the work has been encapsulated as follows.

Figures 5 and 6 show the sending end rms voltage and receiving end rms voltage without UPFC. Sending end rms voltage is 352 kV and receiving end voltage is 347 kV. There is a difference in voltage between sending and receiving end rms voltage due to the losses in the transmission line.

Figures 7 and 8 show the improved sending end rms voltage and receiving end rms voltage in the presence of UPFC. Sending end rms voltage is slightly increased to 352.3 kV, and receiving end voltage is increased to 350 kV. It is observed here that the voltage regulation is improved when UPFC is installed in the transmission line.

Figure 9 shows the active power through the line without UPFC. Here, active power at the sending side is 28.11 MW and receiving end active power is

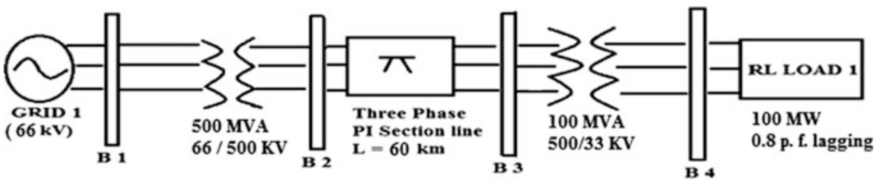

Fig. 4 Block diagram representation of the three-phase test system

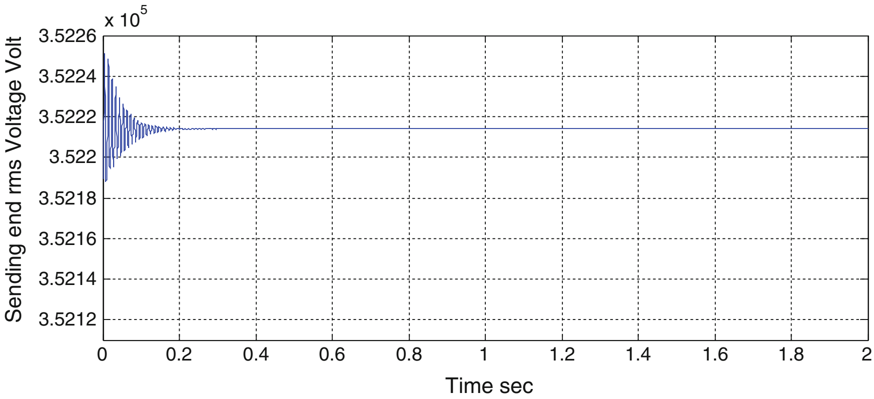

Fig. 5 Sending end rms voltage without UPFC

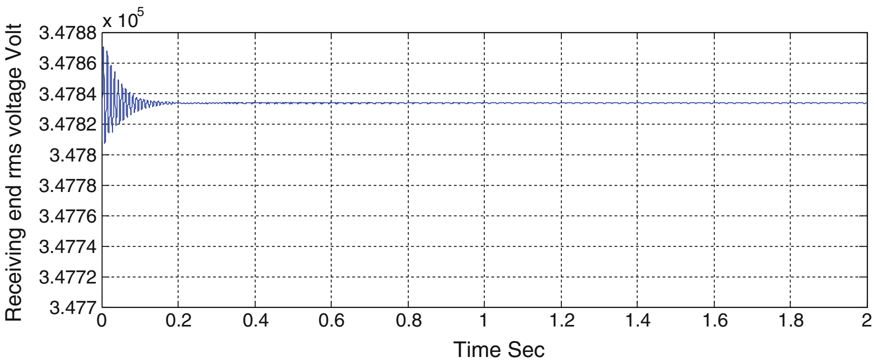

Fig. 6 Receiving end rms voltage without UPFC

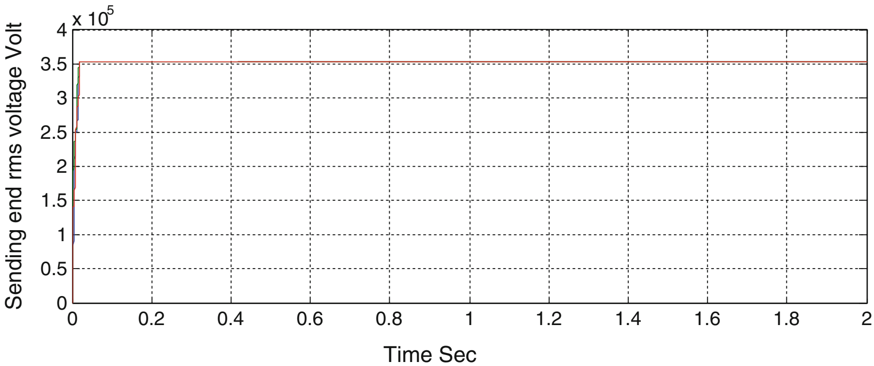

Fig. 7 Sending end rms voltage with UPFC

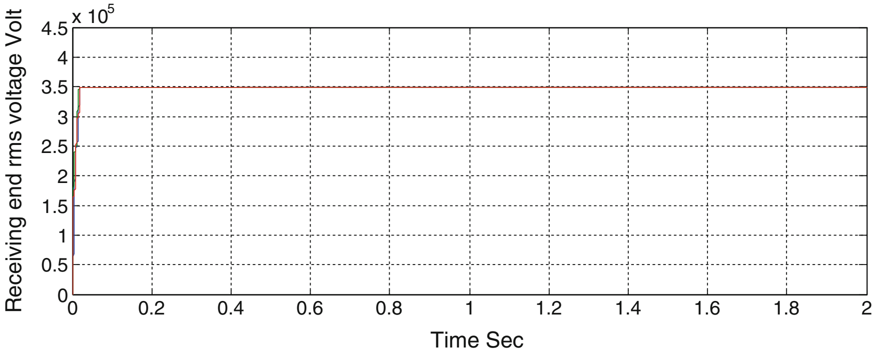

Fig. 8 Receiving end rms voltage with UPFC

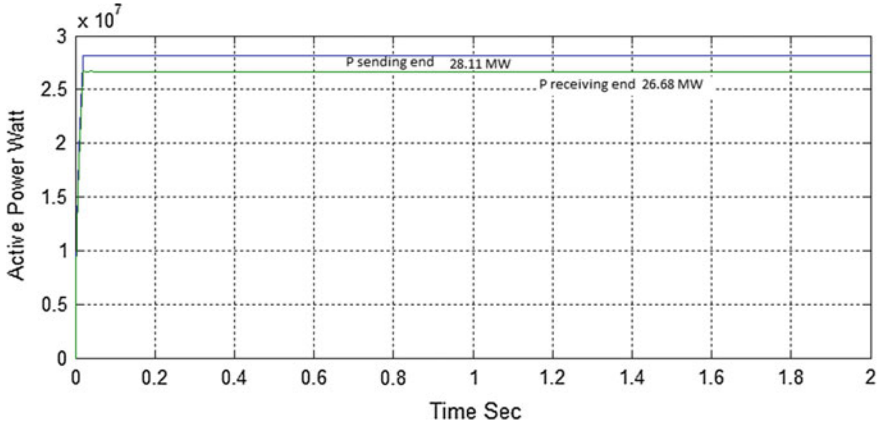

Fig. 9 Active power without UPFC

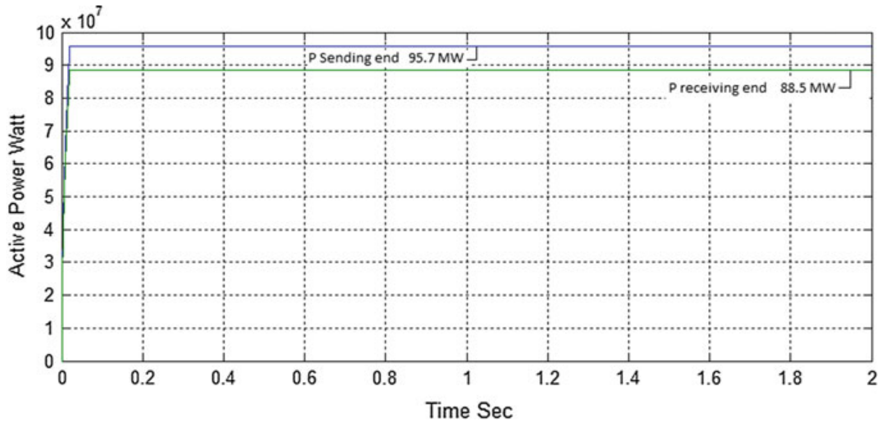

Fig. 10 Active power with UPFC

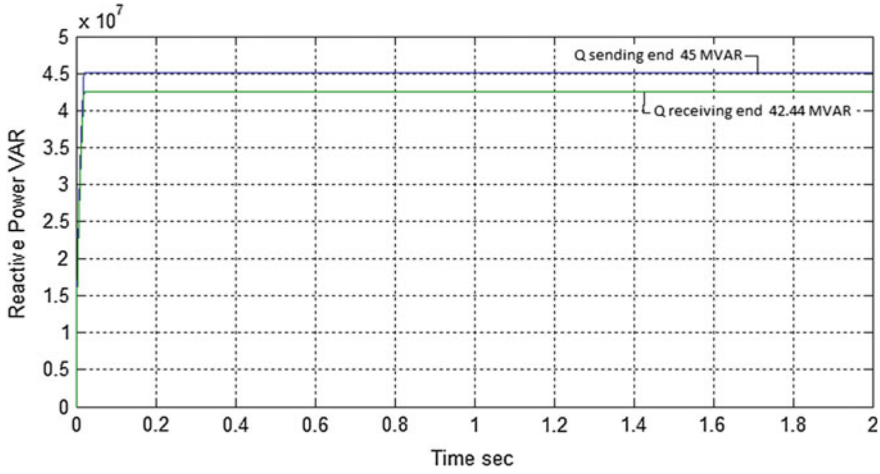

Fig. 11 Reactive power without UPFC

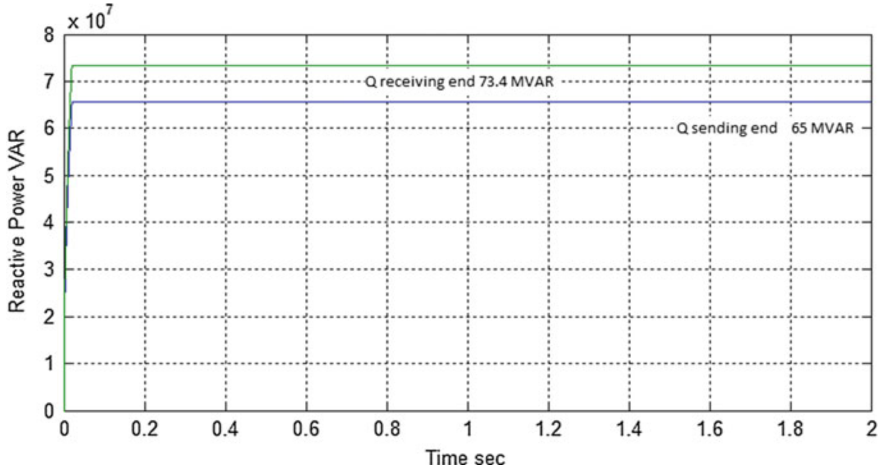

Fig. 12 Reactive power with UPFC

26.68 MW. When the transmission line is without UPFC, the real and reactive power flow cannot be regulated.

Figure 10 shows the active power flow through line in the presence of UPFC. Here, real power at the sending end side is increased to 95.7 MW (with UPFC) from 28.11 MW (without UPFC) and receiving end active power is improved to 88.5 MW (with UPFC) from 26.68 MW (without UPFC). It is observed that the transmission capacity of the existing transmission line is highly upgraded with the help of UPFC controller.

In the presence of UPFC, the difference between the sending end real power and receiving end real power is high in the transmission line. As a result of increased transmission line losses, it counts losses in the both converters.

The waveform for reactive power at sending and receiving ends without UPFC is shown in Fig. 11; in this case, sending end reactive power (45 MVAR) is greater than the receiving end reactive power (44.44 MVAR). When the transmission line is connected with the UPFC as shown in Fig. 12, the reactive power of receiving end is increased to 73.4 MVAR and the reactive power of sending end is increased to 65 MVAR. So here, it is observed that power quality of the transmission line gets improved in the presence of UPFC.

6 Conclusion

This paper clearly shows that UPFC used in this case has improved the real and reactive power flow and voltage stability in transmission line. The simulation results show that real power and reactive power at both sides, i.e. at receiving end and at sending end, are improved when UPFC is introduced in the transmission line. Voltage regulation is also improved when UPFC is placed in the transmission line. Thus, these results illustrate the performance of UPFC to improve stability of power system effectively.

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