Analysis of UPFC Impact on Transmission Line Performance

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Abstract--This paper presents an analysis of the dynamic operation of unified power flow controller (UPFC). A two machine-double line power system model is considered for the study. The main objective is to achieve effective independent control of real and reactive power flows with zero dynamic interactions. Towards achieving the objective, PI controller with abc-dqo transformation and space vector pulse width modulation (SV-PWM) technique based scheme is carried to design UPFC controller. The proposed scheme is fully validated through digital simulation. The simulated results show that the shunt converter provides good voltage regulation and series converter influences power flow over the transmission line together with power oscillations damping. Further the results illustrate how the UPFC contributes dynamically to a faster recovery of the system to the pre-fault conditions.

Keywords - Flexible Alternating Current Transmission System (FACTS), Pulse Width Modulation, Space Vector, Unified Power Flow controller, PI, VSC, STATCOM, SSSC.

1 Introduction

In recent years, greater demands have been placed on the transmission network, and this demand will continue to increase. With the increase in electrical power demand, power systems are becoming complex to operate and at the same time less secure. Such a stressed system is continuously under threat of losing stability following a disturbance [1]. Therefore, it has become more difficult to construct new generation facilities and transmission lines due to energy and environment problems. Hence it is advisable to enhance the power transfer capability of the existing transmission lines instead of constructing new one.

In recent times, the availability of high power semiconductor devices for power system applications have led to technologies such as Flexible AC Transmission Systems (FACTS) for secure loading, power flow control and damping of power system oscillations. The main advantage of the power electronics based FACTS controllers over mechanical controllers is their high speed of operation [2].

Of all the FACTS devices, UPFC has been recognized as one of the best featured FACTS devices, is capable of providing simultaneous active and reactive power flow control, as well as voltage magnitude control [2]. In the presently used practical implementation, the UPFC consists of two voltage sourced converters (VSC).

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These VSC's are back-to-back converters, which are connected via a common DC link to allow bi-directional flow of real power between two converters. These two devices are operated from a common DC link provided by a dc storage capacitor [3]. Ratings of this DC link capacitor bank may have a significant impact on the cost and physical size of the UPFC. The capacitor is sized for a specified ripple voltage, typically 10% of the nominal voltage.

This paper presents the detailed model of UPFC installed transmission system. The architecture of the paper in Section 2 describes the structure of UPFC and power system model. In Section 3, the control strategies of UPFC and in Section 4, the simulation results of the SIMULINK transmission model are given. The conclusion is summarized in Section 5.

2 UPFC and Power System Model

2.1 Unified Power Flow Controller

The UPFC is one of the most effective FACTS controller. It provides multifunctional flexibility required to solve many of the problems facing by power industry and able to control, simultaneously or selectively, all the parameters i.e. voltage, impedance, and phase angle, affecting power flow in the transmission line [3]. The schematic of the UPFC is shown in Fig.1. It consists of two VSC's connected back-to-back through a DC link capacitor. One of the VSC-1 perform the function of STATCOM by injecting current in the transmission line through transformer (T1) and other VSC-2 performs the function of SSSC by injecting voltage of controllable magnitude and angle in series through a series insertion transformer (T2).

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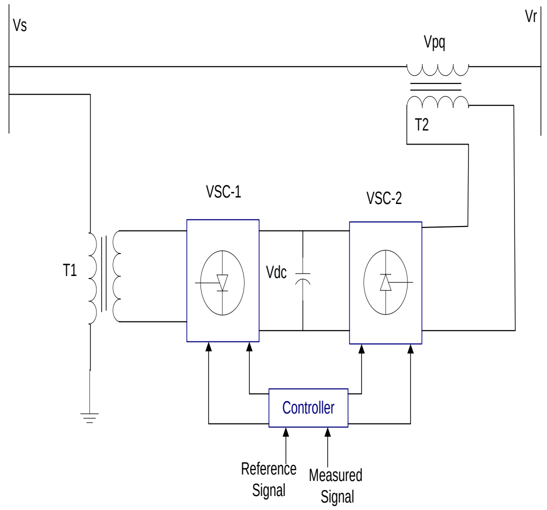

Fig.1. UPFC Schematic Diagram

Therefore, by injecting a voltage of variable magnitude and phase angle, the series converter can exchange real and reactive power with the transmission line. No power is absorbed by UPFC in steady state except the power drawn to compensate for the losses.

Thus shunt converter is required to compensate for any real power drawn, supplied by the series converter and the losses. Both the converters can independently exchange reactive power with the system through the connected transformer.

2.2 Power System SIMULINK Model

In the study, SimPowerSystem toolbox in MATLAB 2010 is used to model the 132KV parallel transmission system with UPFC installed in the middle of one transmission line and other line is uncompensated. The system built with this tool is shown in Fig.2 [4].

Above model consists of two 200 Km long parallel 132KV transmission lines terminated with voltage source 132KV×0.98 with short-circuit power level of 10,000 MVA and X/R ratio=8 with angle difference of 20⁰ between two voltage sources.

The UPFC consists of two voltage source inverters which are connected through a 2000µF common dc capacitor. The complete system parameters are given in Table. 1.

3 CONTROL STRATEGIES OF UPFC

Control part of UPFC includes series converter control and shunt converter control. For each part, of which the series converter controller controls the transmission line power (real and reactive power), impedance compensation, damp oscillations, whereas the shunt converter controller controls the bus voltage and DC link voltage, to achieve the bus voltage stability and control the power of the line under dynamic conditions.

3.1 Series Control Part

The series control part strategy shown in Fig. 3, is based on automatic power flow control mode. The voltage injected by series converter is determined by a closed-loop control system to ensure that the desired active and reactive powers flowing in the transmission line are maintained under disturbances.

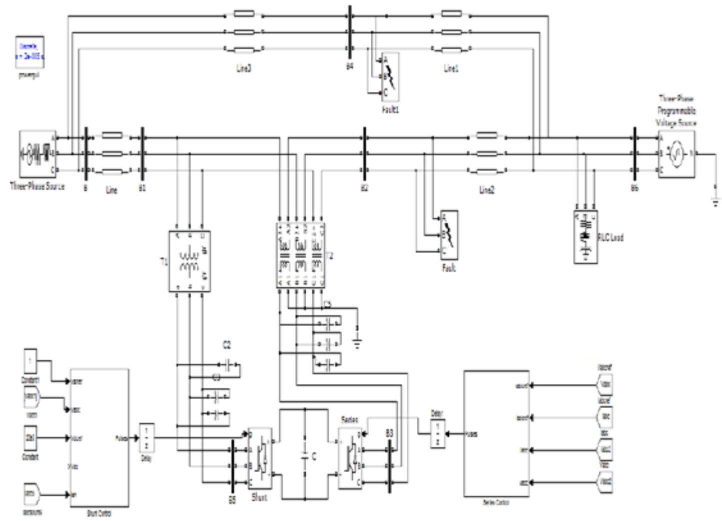

Fig.2. SIMULINK Transmission System Model

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The reference real (Pref) and reactive (Qref) power are compared with the measured positive real (Pm) and reactive (Qm) power flowing in the transmission line, and the error of line power is applied to PI controller to derive the desired direct (V_d) and quadrature (V_q) component of the series inverter voltage. By using V_d and V_q, the magnitude (V_{pq}) and angle (α) of series injected voltage can be calculated as using equation (7) and (8).

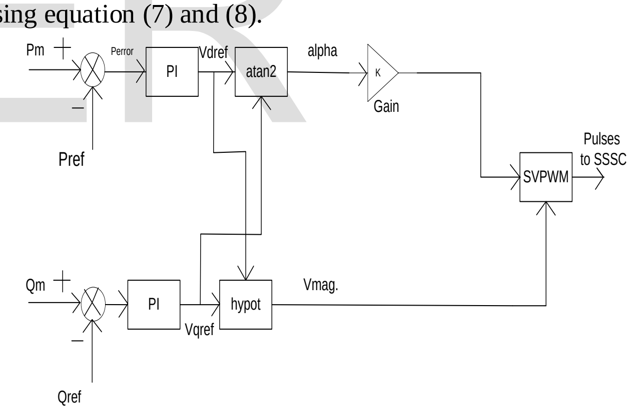

Fig.3 Series control Model

$$V_{pq} = \sqrt{(V_d^2 + V_q^2)} \qquad (7)$$

$$\alpha = \tan^{-1}\frac{Vq}{Vd} \qquad (8)$$

Hence, the magnitude (V_{pq}) and angle (α) together are used by the SV-PWM firing pulse generator to generate the desired pulses for the SSSC voltage source converter.

3.2 Shunt Part Control

The shunt part control strategy is shown in Fig.4, is used to operate the voltage source converter to inject or absorb reactive power to regulate the connecting point voltage to the desired value. The PLL gives the reference angle which is synchronized to the phase A voltage and this reference angle is used to decompose the three phase voltage of STATCOM into their real (V_d) and reactive part (V_q), via abc to dq0 transformation.

Similarly, the real (I_d) and reactive part (I_q) of currents can be calculated. This V_d is compared with the desired voltage (V_{shref}) and error is applied to PI controller to produce the reference reactive

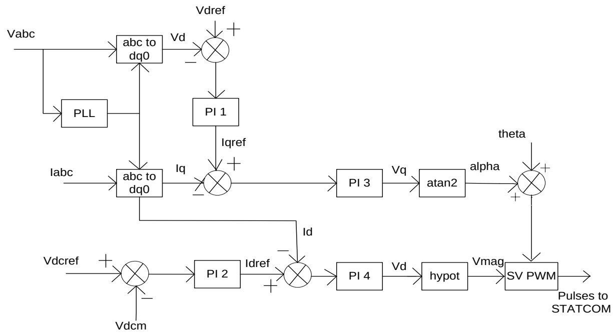

Fig.4 Shunt Control scheme

current (I_{qref}). The reference real current (I_{dref}) can be calculated by comparing reference DC voltage (V_{dcref}) with measured DC capacitor voltage (V_{dcm}) and the error is passed through a PI controller. After comparing the reference and measured values of real (I_{dref}) and reactive current (I_{qref}), the error is passed through a PI controller to obtain real (Vd) and reactive (Vq) voltage magnitude. These voltages are used to calculate V_{pq} and angle (ϴ1). This voltage magnitude and angle are fed to SV-PWM firing pulse generator to generate the desired pulses for the STATCOM.

4 SIMULATION RESULTS

The two machine test system, which is simulated by MATLAB/SIMULINK with parameters as given in Table 1. The inverters consist of IGBT based three phase voltage source converters. As discussed earlier, the UPFC can control line voltage, real and reactive power of transmission line in steady state and dynamic conditions. The disturbance used is a single-phase fault near bus 2 and bus 4 of compensated and uncompensated line respectively, at time t = 0.3 second, and cleared in 0.10 second (i.e. at t=0.4). The receiving and sending end voltages are 1p.u. The simulation results for real, reactive power, voltage and current are discussed below:

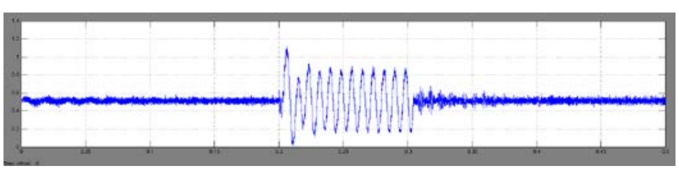

Fig.5.1 Real Power with UPFC

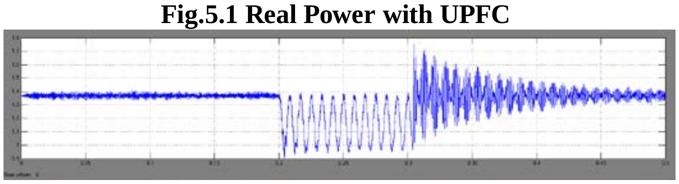

Fig.5.2 Real Power without UPFC

Result 1 Real Power: Fig.5.1 and Fig.5.2 shows the real power flow in compensated and uncompensated transmission line respectively. Transmission of real power in existing transmission line is highly improved with the presence of UPFC under dynamic condition, whereas real power flow in line without UPFC is decreased. This is also clear that after clearing of fault the oscillations in real power is also damped with the UPFC and system recover its pre-fault conditions faster.

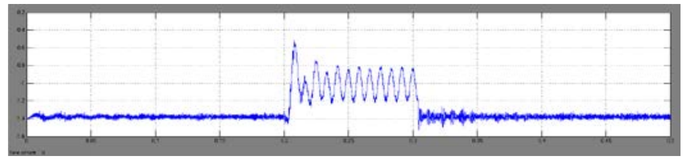

Fig.6.1 Reactive Power with UPFC

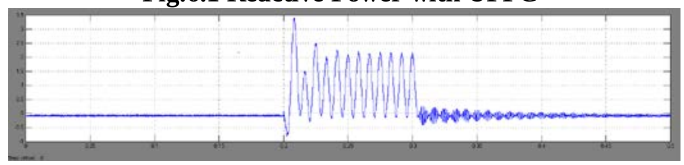

Fig.6.2 Reactive Power without UPFC

Result 2 Reactive Power: The reactive power flow through the transmission line with and without UPFC is shown in Fig.6.1 and Fig.6.2 respectively. It is cleared from figures that the UPFC employed line can be easily control the rise in reactive power by absorbing this excess power and improve the efficiency of transmission line. Similarly, as in real power flow control, the oscillations are also damped for reactive power.

Result 3 Bus Voltage: Fig.7.1 and Fig.7.2 shows the bus voltage of line with and without UPFC installed respectively. During fault, the phase A (or faulted phase) voltage of bus is same as before fault due to UPFC, whereas voltage is reduced to zero of uncompensated line. It is clear that UPFC increase the reliability of line by maintaining the bus voltage.

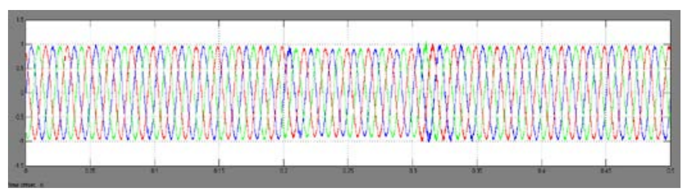

Fig.7.1 Line Voltage with UPFC

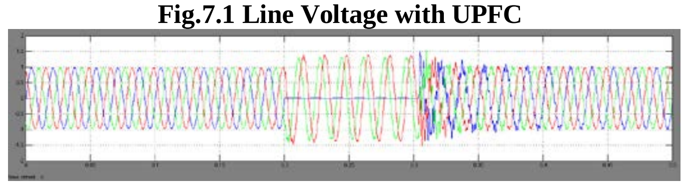

Fig.7.2 Line Voltage without UPFC

Result 4 Line Current: Due to the occurrence of fault, the current in the line is raised to

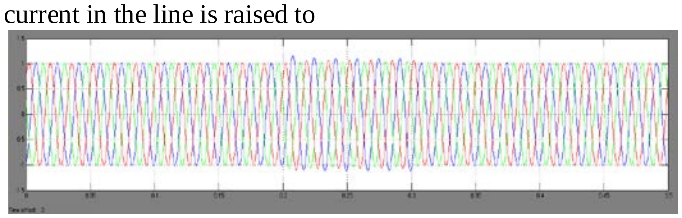

Fig.8.1 Line Current with UPFC

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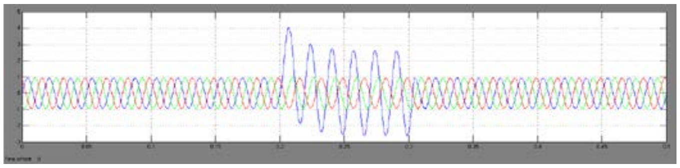

Fig.8.2 Line Current without UPFC

dangerous level. Fig.8.1 and Fig.8.2 shows the current in the line with UPFC and without UPFC respectively. The results show that with the use of UPFC the rise in current is suppressed to safe value. This increase the system security and safety under steady state and dynamic conditions.

5 CONCLUSION

In this study, the MATLAB/SIMULINK environment is used to simulate the model of UPFC to a three phase-three wire transmission system. This paper presents control and performance of UPFC on a transmission line. A control system is simulated with shunt converter in voltage control mode and series converter in power flow control mode. Simulation results show the response of UPFC in controlling real and reactive power through the line. Due to shunt converter, bus voltage regulation is improved. The simulation result shows the fast response and effectiveness of the presented control scheme using PI controller. This paper presents an improvement in the real and reactive power flow through transmission line with UPFC when compared to the system without UPFC.

Table.1 Parameters

Sr. No.	Simulation System Parameters	Set Values
1	**Three-Phase Source**	
	Rated Voltage	132KV
	Frequency	50Hz
	X/R	8
	Short Circuit Capacity	10,000MW
2	**Three-Phase Programmable source**	
	Rated Voltage	132*0.98KV
	Phase Angle(degrees)	20
	Frequency	50Hz
3	DC Link Capacitor	2000µF
4	**Shunt & Series Converter side IGBT**	
	Snubber Resistance	1e5(ohm)
	Snubber Capacitance/resistance	Infinite/1e-3 (ohm)

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