PERFORMANCE ANALYSIS OF UNIFIED POWER FLOW CONTROLLER (UPFC)

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Abstract : Nowadays, high voltage transmission networks met enormous power demands are very expensive investments in terms of their costs. Because of this, the importance of effective using the existing transmission lines is increasing. In order to benefit more efficiently from the existing transmission lines, the new methods are being developed and applied by making studies related to this area. The rapid developments on the area of power electronics have enabled the development of new equipments to be able to benefit more efficiently from the power systems. The equipments based on the power electronics have been improved under the name of Flexible Alternating Current Transmission Systems (FACTS) in the last years. FACTS devices, are quite efficiently at the power control of the transmission lines and increasing their current capacity, and have rapidly developed. FACTS technology has been used extensively at power control, voltage regulation, increasing the transient stability, and decreasing system oscillations. Unified Power Flow Controller (UPFC) is the more efficient among the FACTS equipments which have the potential to increase the power flow and the stability of the transmission line. In this paper, the modeling and the developing of UPFC were studied in order to make better the steady state works of the power systems. The effect of UPFC on the power flow of transmission lines were analyzed mathematically and graphically in details. The performances of UPFC were examined

***IndexTerms* - FACTS, UPFC, Power Quality**

I. INTRODUCTION

Unified Power Flow Controller (UPFC) is a special arrangement of two VSCs, one of which is connected in series with the AC system and the other is connected in shunt with the AC system with common dc terminal. UPFC is a combination of STATCOM and SSSC, which is coupled via a common DC link. This link allows a bi-directional real power flow between the series output terminals of the SSSC and the shunt output terminals of the STATCOM. The two VSCs, which operate from a common link with a DC storage capacitor, use the technique of power switches. This arrangement functions as an ideal AC to AC power converter in which the real power can freely flow in either direction between the AC terminals of two converters and each converter can independently generate or absorb reactive power at its own AC output terminal. UPFC is able to control concurrently or selectively the transmission line voltage and line impedance, angle or alternatively the real and reactive power flow in the line by means of angularly unconstrained series voltage injection. The additional storage such as DC capacitor connected to the dc link via an electronic interface would provide the means of further enhancing the effectiveness of UPFC. The controlled exchange of real power with an external source, such as storage is much more effective in control of system dynamics than modulation of the power transfer within a power system. UPFC performs not only the functions of the STATCOM, SSSC and the phase angle regulator but also provides additional flexibility by combining some of the functions of these controllers.

In general, the control strategy of UPFC should have preferably the following attributes:

• The steady state objectives (i.e. real and reactive power flows) should be readily achievable by setting the references of the controllers.

• The dynamic and transient stability improvement by using appropriate controller references. To simplify the design procedure, we carry out the design for the series and the shunt branches separately. The design has to be validated when the various subsystems are integrated. The design tasks are given in the following.

• Series voltage control: The power flow will be controlled by using the series voltage injection.

• Shunt voltage control: The controlling of the sending end bus voltage and the regulating of the DC side capacitor voltage will be controlled by using the reactive

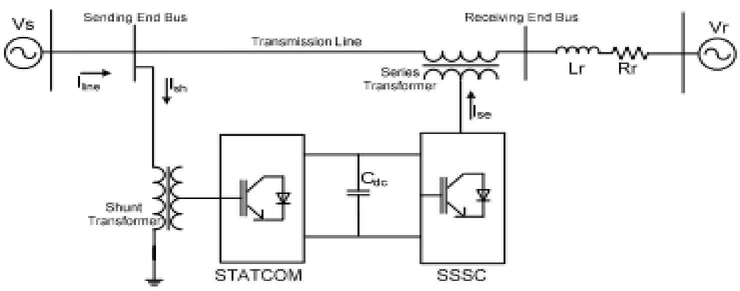


Figure 1. Basic Circuit of UPFC

II. LITERATURE SURVEY

The modeling and the controlling of UPFC have come into intensive investigation in therecent years due to its attractive features. The UPFC, which was proposed by L. Gyugyi in 1992 (Gyugyi et al., 1992) is one of the most complex FACTS devices in a power system today. Several references in technical literature can be found on development of UPFC steady state, dynamic and linearized models.Newton-Rhapson method is used in references (Fuerte et al., 1997; Ambriz et al., 1998). In (Fuerte et al., 1997), this algorithm was improved for UPFC application. It permits instantaneous or independent control of power flow and voltage magnitude. In (Ambriz et al., 1998), Newton-Rhapson algorithm based Nabavi-Niaki and lravani model has been implemented in UPFC-OPF model. This algorithm is very complex and hard to apply. Also, it is quite sensitive to initial condition settings. The order of the Jacobian matrix is increased significantly in the iterative procedure. The selection of suitable initial conditions can solve the oscillations of power system dynamics. In references (Lo K.L et al., 1998; Nabavi-Niaki et al., 1996; Xu et al., 2004), the steady state model, which is necessary for the analysis of the power flow operation of device embedded in a power system, is preferred. In (Lo K.L et al., 1998), Ann based direct control algorithm method is used to compare the simulation results with steady state model. UPFC is modeled as a voltage source in series with line reactance, and the mathematical calculation is incorporated with Jacobian Matrix. The model is simple and helpful at understanding the impact of UPFC in the power system. However, the amplitude modulation and phase angle control signals of the series VSC have to be adjusted manually in order to find the desired load flow solution. In reference (Papic et al., 1997), the basic control method is used. It consists of two control mechanism. One of them is real and reactive power flow control mechanism and the other is sending end bus voltage and DC voltage magnitude control mechanism. The vector-control approach is one of the most used control scheme. It is proposed by Schauder and Metha in 1993 (Schauder et al., 1993). The decoupled control of the real and the reactive powers can be applied easily in this method and it is suitable for UPFC application. The decoupled control can be achieved in this scheme by changing the three-phase balanced system into a synchronously rotating orthogonal system (DQ transform). The D-axis of synchronously rotating orthogonal system corresponds with the instantaneous voltage vector and the Q-axis is orthogonal to it. The D-axis current component coincides with the instantaneous real power and the Q-axis current coincides with the reactive power in this coordinate system. This control scheme can be applied both for series and shunt converters control in references (Yonggao et al.; 2005, Qing et al. 1996; Fujita et al., 2006). Proportional-Integral (PI) controller is used to get dynamic values close to their reference values. The sending end bus voltage magnitude and the dc link voltage are measured to take reference values for components of system As another approach, fuzzy controller and Neural-Network based controller are used with several control methods in UPFC (Eldamaty et al. 2005; Orizondo et al. 2006; Ma et al. 2000; Venayagamoorthy et al. 2005; Mishra et al. 2006). The fuzzy controller is attractive for several control method, because it does not require the mathematical model of the system under study conditions. It can cover wider range of operating conditions, and is simple to implement. The fuzzy models are created by using Sugeno Inference System and used in the series control mechanism of UPFC in this thesis (Eldamaty et al. 2005). Fuzzy is used in the power frequency model of UPFC in reference (Mok et al. 2000). PI and fuzzy controller are used together in the current injection model in references (Orizondo et al. 2006; Ma et al. 2000).Likewise, the fuzzy controller will be used with the PI controller

III. 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 V Vmax) and angle a (0 a 2p). 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 . 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.

3.1 UPFC Controller Design

The equation of series controller is given as below. It injects the voltage Vsr in series with transmission line:

$$V_{sr} - V_{sr1} = R_{sr} I_{sr1} + I_{sr} \frac{\mathrm{d}}{\mathrm{d}t} I_{sr1} \quad \textbf{(1)}$$

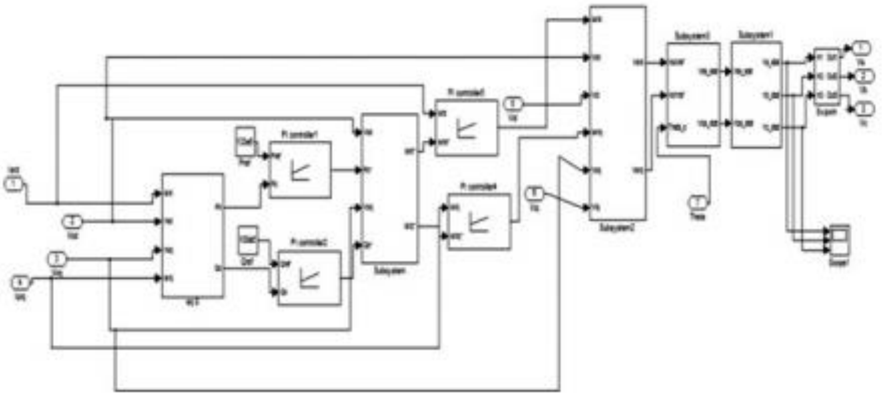
$$\begin{bmatrix} P_0 \\ Q_0 \end{bmatrix} = \begin{bmatrix} V_{od} & V_{oq} \\ -V_{oq} & V_{od} \end{bmatrix} \begin{bmatrix} I_{srd} \\ I_{srq} \end{bmatrix} \quad \textbf{(2)}$$

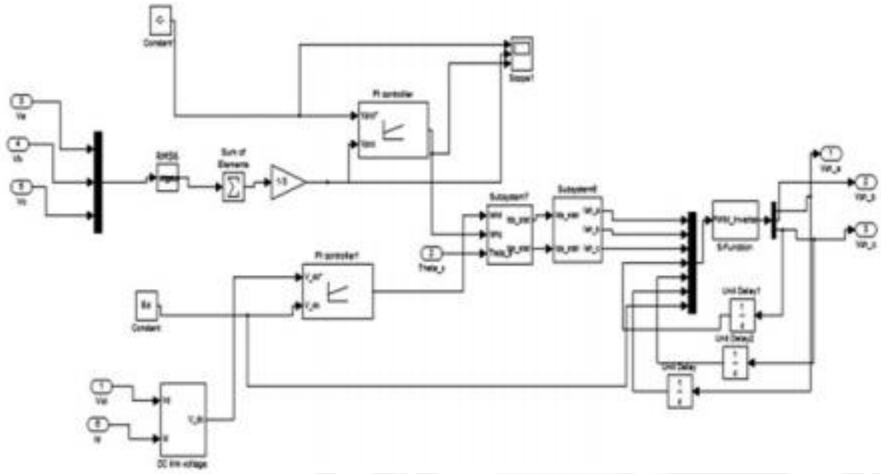
$$\begin{bmatrix} V_{srd} \\ V_{srq} \end{bmatrix} = \begin{bmatrix} \frac{V_{od}-V_{id}}{N_{sr}} + R_{sr} I_{sr} l_d + L_{sr} \frac{\mathrm{d}}{\mathrm{d}_t} I_{sr} l_d - w L_{sr} I_{sr} l_d \\ \frac{V_{oq}-V_{iq}}{N_{sr}} + R_{sr} I_{sr} l_q + L_{sr} \frac{\mathrm{d}}{\mathrm{d}_t} I_{sr} l_q - w L_{sr} I_{sr} l_q \end{bmatrix} \quad \textbf{(3)}$$

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

where Vsr and Isr are the series voltage and series current, respectively; Lsr is series inductance and Nsr is no. of turns of series transformer; w is the angular speed, and P0 and Q0 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:

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





$$Q_{sh} = \frac{2}{3}\left(V_{id}I_{shq} - V_{iq}I_{shd}\right) \quad \textbf{(6)}$$

$$\begin{bmatrix} I_{shd} \\ I_{srq} \end{bmatrix} = \frac{2}{3}\frac{1}{N_{sh}}\frac{1}{\left(V_{od}^2 + V_{oq}^2\right)}\begin{bmatrix} V_{id} & -V_{iq} \\ V_{iq} & V_{id} \end{bmatrix}\begin{bmatrix} P_{sh} \\ Q_{sh} \end{bmatrix} \quad \textbf{(7)}$$

$$V_{dc\_actual} = \frac{3}{2}\int \frac{1}{c}\frac{V_d I_d}{V_{dc}} \quad \textbf{(8)}$$

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

where Vsh and Ish are the shunt voltage and shunt current, Nsh represents the no. of turns of shunt transformer, Ploss is the power loss in transmission line, and Vdc represents the DC link voltage.

IV. RESULTS AND DISCUSSION

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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