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A Lyapunov theory based UPFC controller for power flow control

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ABSTRACT

Unified power flow controller (UPFC) is the most comprehensive multivariable device among the FACTS controllers. Capability of power flow control is the most important responsibility of UPFC. According to high importance of power flow control in transmission lines, the proper controller should be robust against uncertainty and disturbance and also have suitable settling time. For this purpose, a new controller is designed based on the Lyapunov theory and its stability is also evaluated. The Main goal of this paper is to design a controller which enables a power system to track reference signals precisely and to be robust in the presence of uncertainty of system parameters and disturbances. The performance of the proposed controller is simulated on a two bus test system and compared with a conventional PI controller. The simulation results show the power and accuracy of the proposed controller.

1. Introduction

Nowadays the grow of power systems will rely more on increasing capability of existing transmission systems, rather than on building new transmission lines and power stations, for economical and environmental reasons. Due to deregulation electricity markets, the need for new power flow controllers capable of increasing transmission capability, controlling power flows through predefined corridors and ensuring the security of energy transactions will certainly increase.

The potential benefits with the utilization of flexible ac transmission system (FACTS) devices include reduction of operation and transmission investment costs, increasing system security and reliability, and increasing transfer capabilities in a deregulated environment. FACTS devices are able to change, in a fast and effective way, the network parameters to achieve a better system performance [1].

Unified Power Flow Controller (UPFC) is the most comprehensive multivariable device among the FACTS controllers [2]. Simultaneous control of multiple power system variables with UPFC imposes enormous difficulties. In addition, the complexity of the UPFC control increases due to the fact that the controlled and the control variables interact with each other.

UPFC is a power electronic based device which can provide a proper control for impedance, phase angle and reactive power of a transmission line [2]. Each converter of a UPFC can independently generate or absorb reactive power. This arrangement enables free flow of active power in either direction between the ac terminals of the two converters [3]. In the case of the parallel branch of UPFC, the active power exchanged with the system, primarily depends on the phase shift of the converter output voltage with respect to the system voltage, and the reactive power is controlled by varying the amplitude of the converter output voltage. However series branch of UPFC controls active and reactive power flows in the transmission line by amplitude and phase angle of series injected voltage. Therefore active power controller can significantly affect the level of reactive power flow and vice versa.

In recent years a number of investigations have been carried out on various capabilities of UPFC such as power flow control [3–8], voltage control [9,10], transient stability enhancement [11,12], oscillation damping [13–16]. It has been reported in the literatures that there exists a strong dynamic interaction between active and reactive power flows through a transmission line when they are controlled by series injected voltage v_{se} of the UPFC. Zou et al. [17] presented a non-linear index based on normal forms theory to investigate interaction among UPFC controllers (power flow controller, AC voltage controller and DC voltage controller). A P-Q decoupled control scheme based on fuzzy neural network proposed in [18] to improve dynamic control performance. Their proposed controller reduced the inevitable interactions between real and reactive power flow control. It is very difficult to independently control the active/reactive power flow through the line without affecting the reactive/active power flow. Nevertheless, independent control of active and reactive power flows is sometimes necessary to improve the performance of the UPFC. For this reason, a decoupled control strategy based on *d*–*q* axis theory is first proposed in [19].

The performance of the control scheme deteriorates in the presence of uncertainties in system parameters. In this paper, a new controller of UPFC based on Lyapunov theory for power flow control is designed which is able to track reference signals precisely

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and is robust in the presence of uncertainty of system parameters and disturbances The proposed controller is considered as slope changes of energy function which always consists of a set of error terms to provide stability condition in the presence of uncertainty and disturbance.

The remaining section of this paper is set off as follows: Section 2 describes shunt and series branches model of UPFC in the state space. In Section 3, Lyapunov theory based controller is illustrated and simulation results in a typical two bus system are presented in Section 4. Finally Section 5 provides some concluding results.

2. UPFC model

The schematic diagram of a UPFC is shown in Fig. 1. It consists of two back-to-back, self-commutated, voltage source converters connected through a common dc link [8].

As it can be seen in Fig. 1, converter1 is coupled to the AC system through a shunt transformer (excitation transformer) and the converter 2 is coupled through a series transformer (boosting transformer). Note that, subscripts '*s*' and '*r*' are used to represent sending and receiving end buses respectively. By regulating the series injected voltage v_{se}, the complex power flow $(P_r + jQ_r)$ through the transmission line can be controlled. The complex power injected by the converter 2, $(P_{se} + jQ_{se})$ depends on its output voltage and transmission line current. The injected active power P_{se} of the series converter is taken from the dc link, which is in turn drawn from the AC system through the converter 1. On the other hand, both converters are capable of absorbing or supplying reactive power independently. The reactive power of the converter 1 can be used to regulate the voltage magnitude of the bus at which the shunt transformer is connected.

The single-phase representation of a three-phase UPFC system is shown in Fig. 2. In this figure both converters are represented by voltage sources $v_{\rm se}$ and $v_{\rm sh}$, respectively. Also $(R = R_{se} + R_L)$ and $(L = L_{se} + L_L)$ represent the resistance and leakage inductance of series transformer and transmission line respectively, similarly R_{sh} and L_{sh} represent the resistance and leakage inductance of the shunt transformer respectively [8].

The current through the series and shunt branches of the circuit of Fig. 2 can be expressed by the following differential equations for one phase of the system [8]. These equations can be written for other phases similarly.

$$\frac{di_{sea}}{dt} = \frac{1}{L}(-Ri_{sea} + v_{sea} + v_{sa} - v_{ra}) \tag{1}$$

$$\frac{di_{sha}}{dt} = \frac{1}{L}(-Ri_{sha} + v_{sha} - v_{sa}) \tag{2}$$

The three-phase system differential equations can be transformed into a "*d*, *q*" reference frame using Park's transformation as follows:

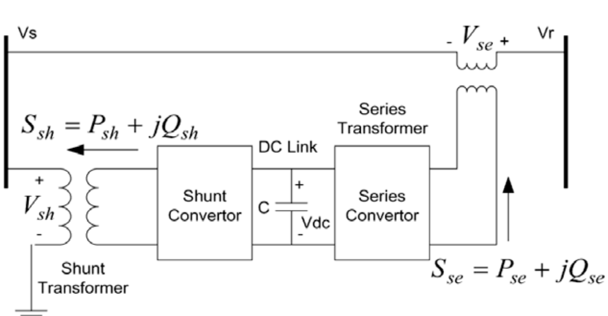

Fig. 1. Schematic diagram of the UPFC system.

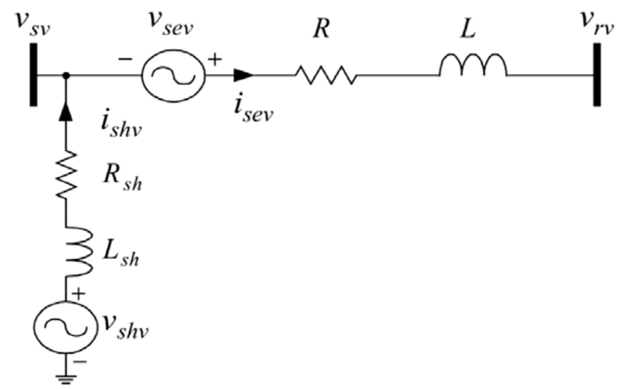

Fig. 2. Single phase representation of the UPFC system.

$$\begin{bmatrix} \dot{i}_{sed} \\ \dot{i}_{seq} \end{bmatrix} = \begin{bmatrix} \frac{-R}{L} & \omega_b \\ -\omega_b & \frac{-R}{L} \end{bmatrix} \cdot \begin{bmatrix} i_{sed} \\ i_{seq} \end{bmatrix} + \frac{1}{L} \begin{bmatrix} v_{sed} + v_{sd} - v_{rd} \\ v_{seq} - v_{rq} \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} \dot{i}_{shd} \\ \dot{i}_{shq} \end{bmatrix} = \begin{bmatrix} \frac{-R_{sh}}{L_{sh}} & -\omega_b \\ -\omega_b & \frac{-R_{sh}}{L_{sh}} \end{bmatrix} \cdot \begin{bmatrix} i_{shd} \\ i_{shq} \end{bmatrix} + \frac{1}{L_{sh}} \begin{bmatrix} v_{shd} + v_{sd} \\ v_{shq} \end{bmatrix} \tag{4}$$

where $\omega_b = 2\pi f_b$, and f_b is the fundamental frequency of the supply voltage. Since the Park's transformation used in finding (3) and (4) keeps the instantaneous power invariant and the *d*-axis lies on the space vector of the sending end voltage v_s, thus $v_s = (v_{sd} + jv_{sq}) = (v_{sd} + j0)$.

Note that in the above equations, subscripts '*d*' and '*q*' are used to represent the direct and quadrature axes components, respectively $(x = x_d + jx_q)$.

Since the dynamic equations of converter 1 are identical to that of converter 2 as described before, both converters should have identical control strategy. Therefore for the sake of brevity in this paper only the technique of designing the controller of converter 2 is described in detail in the form of state space.

$$\begin{aligned} \dot{\mathbf{x}} &= \mathbf{Ax} + \mathbf{Bu} + d \\ \mathbf{y} &= \mathbf{Cx} \end{aligned} \tag{5}$$

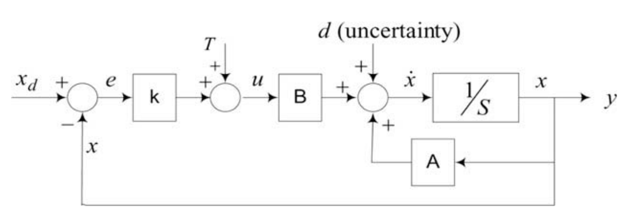

Fig. 3. Schematic of system state space.

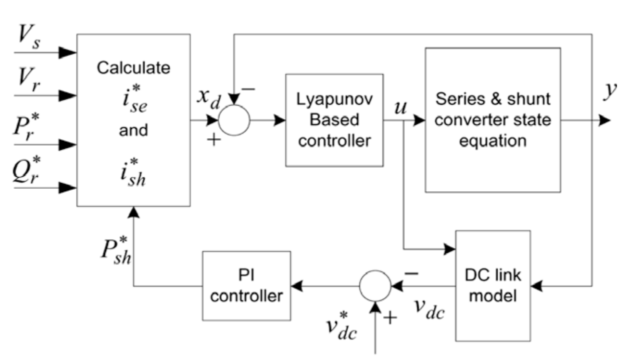

Fig. 4. Block diagram of the overall UPFC control system.