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Modeling and unified tuning of distributed power flow controller for damping of power system oscillations

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Abstract A new control scheme to improve the stability of a system by optimal design of distributed power flow controller (DPFC) based stabilizer is presented in this paper. The paper demonstrates the basic module, steady state operation, mathematical analysis, and current injection modeling of the DPFC. The purpose of the work reported in this paper is to design an oscillation damping controller for DPFC to damp low frequency electromechanical oscillations. The optimal design problem is formulated as an optimization problem, and particle swarm optimization (PSO) is employed to search for the damping controller parameters. Results demonstrate that DPFC with the proposed model can more effectively improve the dynamic stability and enhance the transient stability of power system compared to the genetic algorithm based damping controllers. The r and λ are relative magnitude and phase angle of DPFC controller. Moreover, the results show that the λ based controller is superior to the r based controller.

1. Introduction

Because of the power demand grows dramatically, and extension in transmission and generation is restricted with the rigid environmental constraints and the limited availability of resource. However, this causes the power systems to be operated near their stability limits. Moreover, interconnection between remotely power systems results rise to low frequency oscillations in the range of 0.2–3 Hz. These oscillations may keep growing in magnitude until loss of synchronism results, if not well damped [1]. In order to minimize this problem, power system stabilizers (PSSs) have been successfully used to damp these low frequency oscillations. However, PSSs may unfavorably affect on the voltage profile, may result in leading power factor, and may be unable to control oscillations cause by large disturbances [2]. The idea of FACTS technology is to increase controllability and to optimize the utilization of the existing power system capacities using the reliable and high-speed power electronic devices instead of mechanical controllers [3]. The opportunities arise through the ability of FACTS devices to control the parameters of transmission systems, which includes the series/shunt impedances, phase angle and

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Nomenclature

AC	alternating current	SMIB	single machine infinite bus
DC	direct current	SSSC	static synchronous series compensator
D-FACTS	distributed flexible alternating current transmission systems	STATCOM	static synchronous compensator
DPFC	distributed power flow controller	SVC	static var compensator
FACTS	flexible alternating current transmission systems	TCSC	thyristor controlled series capacitor
FD	figure of demerit	T_1	lead time constant of controller
GA	genetic algorithm	T_2	lag time constant of controller
IPFC	interline power flow controller	T_3	lead time constant of controller
ITAE	integral of time multiplied absolute value of the error	T_4	lag time constant of controller
K	proportional gain of the controller	T_s	settling time of speed deviation
OS	overshoot of speed deviation	T_w	washout time constant
POD	power oscillation damping	US	undershoot of speed deviation
PSS	power system stabilizers	UPFC	unified power flow controller
PSO	particle swarm optimization	V	terminal voltage
P_e	electrical output power	v_{ref}	reference voltage
P_m	mechanical input power	ω	rotor speed
		δ	rotor angle
		$\Delta\omega$	speed deviation

damping of oscillations at various frequencies below the rated frequency. These constraints cannot be overcome otherwise, while maintaining the required system stability, by mechanical means without decreasing the transmission capacity [4]. By proving added flexibility, FACTS controllers can enable a line to carry power closer to its ratings. The DPFC recently presented in [5,6] is a powerful device within the FACTS family, which provides much lower cost and higher reliability than conventional FACTS devices. It is derived from the UPFC [7] and has the same capability of simultaneously adjusting all the parameters of the power system: line impedance, transmission angle, and bus voltage magnitude. The DPFC eliminates the common DC link between the shunt and series converters, instead of one large three-phase converter, the DPFC employs multiple single-phase converters (distributed-FACTS concept) as the series compensator, as shown in Fig. 1. This concept reduces the rating of the components and provides a high reliability because of the redundancy [5]. Since the DPFC can instantaneously control the active and reactive power flow and the voltage magnitude, it implies a great potential for power oscillation damping. Ref. [8] presents the capability of the DPFC for damping the low frequency oscillations and the power oscillation damping controller parameters also are calculated by using the residue method. The contribution of this work is that a novel current injection model and dynamic simulation of the DPFC for studying the low frequency oscillations and incorporated in the transmission system model. A new approach for the optimal design of the DPFC damping controller is investigated in this paper, for first time. The problem of damping controller design for DPFC is formulated as an optimization problem, and PSO technique is used to solve it. A problem of interest in the power industry is the mitigation of power system oscillations. These oscillations are related to the dynamics of system power transfer and often exhibit poor damping. Various types of FACTS controller's first and second generations, particularly SVC, TCSC, STATCOM, SSSC, UPFC, and IPFC are being used in literature in order to damp of the power system oscillations. The main motivation of this work is to damp out the electromechanical oscillations using the (new) distributed power flow controller with proposed injection model in a simple power system.

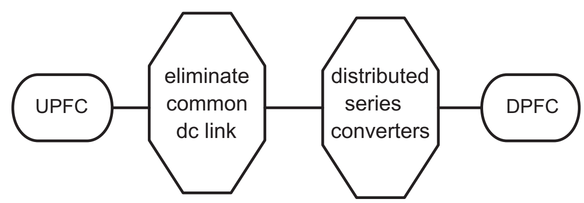

Figure 1 Transformation from the UPFC to the DPFC.

2. DPFC

2.1. Basic module of DPFC

The DPFC consists of one shunt and several series connected converters. The shunt converter is similar as a STATCOM, while the series converters employ the D-FACTS concept. Each converter within the DPFC is independent and has a separate DC link capacitor to provide the required DC voltage. Fig. 2 shows the structure of DPFC that is used in a transformation system with two parallel lines. The control capability of the UPFC is given by the back-to-back connection between the shunt and the series converters with DC link, which allows the active power to exchange freely. To ensure that the DPFC has the same control capability as the UPFC device, a method that allows the exchange of active power between converters without DC link is the prerequisite. In the DPFC, there is a common connection between the AC terminals of the shunt and the series converters, which is the transmission line. Therefore, it is allows to exchange the active power through the AC terminals of the converters [5].

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