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Fuzzy based controller for dynamic Unified Power Flow Controller to enhance power transfer capability

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ABSTRACT

In this paper, a dynamic model of Unified Power Flow Controller (UPFC) is developed to improve the power transfer capability (PTC) through the transmission line. Improvement of the bus voltages profiles along with the reduction of total power losses is also intended with UPFC's presence. The UPFC shunt and series controllers are developed based on Fuzzy Logic (FL) which has been designed as a stand-alone module in PSCAD environment. Sinusoidal pulse width modulation (SPWM) technique is applied as a modulation technique to generate switching signals for the converter switches. The proposed UPFC controller is tested by using IEEE-5 and 14 bus systems with various case studies. The performance of the proposed controllers is also compared with different control methods. From the test results, significant improvement of PTC has been achieved with the minimization of total power losses.

1. Introduction

The continuous expansion and up-gradation of power system have become essential to satisfy the ever growing power demand due to limited energy resources, and deregulated electricity market. In addition, building new transmission lines to meet the increasing electricity demand has also been restricted by economic and environmental constraints [1]. As a result, utilities are compelled to optimally utilize the existing resources which made the transmission lines overloaded followed by reduced stability, voltage variation increment and looped power flow [2]. These issues have led the system planners to look for the new strategies to improve the power system performance with economic means to transfer bulk power.

As a solution to the mentioned issues, keen attention has been paid to Flexible Alternating Current Transmission System (FACTS) devices which are driven from modern power electronics components. Over last decade FACTS devices have been extensively used to improve PTC through the transmission lines and enhance system controllability resulting in minimizing power losses in transmission network [3]. Among different types of FACTS devices UPFC has got the epic popularity. Since, it comprises with the actions of two FACTS devices which made it capable of voltage regulation, series compensation, and phase angle regulation simultaneously, lead to the discrete control of active and reactive power transmitted together through the line [4,5].

In the past, several steady state model of FACTS devices such as for SVC [6,7], STATCOM [8], TCSC [9–11] and UPFC [12–14] have been proposed. These models were used in power system planning to enhance power transfer capability (PTC), reduce power losses and minimize voltage deviation. The models cannot be used to study real time operation of power system network. Therefore, it is essential to develop dynamic model of FACTS devices so that the real time analysis of power system network can be conducted. However, the biggest challenge of the real time applications of FACTS devices is the design of their internal controllers. Especially control system of UPFC because it is a multi-variable controller. If the control system of the shunt and the series converters of UPFC is such that the shunt converter is not able to meet the real power demand of the series converter, then the DC capacitor voltage might collapse resulting in the removal of the UPFC from the power system [15]. Different control strategies for UPFC have been designed in the literatures. In [16–18], decoupled control method has applied to UPFC to control the active/reactive powers flow. Here, the transmission line current has divided into D-axis and Q-axis currents which control individually the real power and reactive power of the transmission line. However, because of the variation of the power system operating points the transmission parameters change continuously. Therefore, the performance of a decoupling control system may vary significantly depending on the operating

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Nomenclature

K_p	proportional gain of PI controller	K_i	integrator gain of PI controller
Vmag_sh	magnitude of injected shunt voltage	*angle_sh*	angle of injected shunt voltage
Vs_measured	measured value of sending – end voltage	*Vs_reference*	reference value of sending – end voltage
Vdc_measured	measured value of DC link capacitor voltage	*Vdc_reference*	reference value of DC link capacitor voltage
Vs_a, *Vs_b*, *Vs_c*	phase voltages of sending – end	*Vr_a*, *Vr_b*, *Vr_c*	phase voltages of receiving – end
a_s	phase angle of sending-end voltage	$P_{measured}$	measured real power
$Q_{measured}$	measured reactive power	$P_{reference}$	reference real power
$Q_{reference}$	reference reactive power	V_d	direct components of the series injected voltage
V_q	quadrature components of the series injected voltage	*Vmag_se*	magnitude of injected series voltage
a_r	phase angle of receiving – end voltage	sin ()	trigonometric function
FACTS	flexible AC transmission systems	FL	fuzzy logic
PTC	power transfer capability	PI	proportional-integral
PLL	Phase Locked Loop	SPWM	sinusoidal pulse width modulation
VSC	voltage source converter	STATCOM	static synchronous compensator
SVC	static var compensator	TCSC	thyristor controlled series capacitor
SSSC	static synchronous series compensator	EP	evolutionary programming
UPFC	Unified Power Flow Controller	PSO	particle swarm optimization
GA	genetic algorithm	HS	harmony search
ANN	artificial neural network	OPF	optimal power flow

point of power system network. By considering the variation of the power system parameters in [19–21] another control algorithm for UPFC has been proposed based on cross-coupled method. The drawbacks of both decoupled and cross-coupled based UPFC controller is the ignorance of the dynamics of the DC link capacitor while designing the control system. Also the interaction between the two converters has not eliminated completely. To eliminate this interaction in [22] another controller for UPFC based on coordination control of real and reactive powers has proposed. Though the problem of interaction has overcome but the shortcoming of this strategy is the complexity of the control system has increased. Two control loops (inner and outer) are required to regulate the real and reactive power flow. Afterwards simplified controllers for UPFC have been developed in [23–25] where only a single loop has used to regulate each power system parameters. There is a common requirement of all the controllers discussed above is the need of output feedback control system for regulating the power system parameters. The problem in the design of an output feedback proportional-integral (PI) control system for UPFC is the presence of low margin of stability associated with the series inductance of the transmission line. Later on intelligent controllers with specific reference to fuzzy logic controllers or artificial neural network have been proposed to overcome the problem. UPFC has employed in [26,27] to damp oscillation and improve transient stability where the controllers of both converters have been designed using ANN. But the difficulty of ANN based controller is to generate the training patterns of the controller for complex power system network.

In contrast, FL controller is capable of solving complex problems whose system behavior is not well understood. Another advantage of FL controller is its robustness to system parameters and operating conditions changes [28]. Different controllers for UPFC have been presented in [29–31], based on FL. However, all the UPFC's control methods are developed for the application of oscillation damping of power system network. Very few literatures are reported on FL based UPFC's application to enhance the power flow and maintain voltage profile of the system dynamically. In [32], dynamic flow of power is analyzed using FL based UPFC where only shunt converter has designed with FL. For series converter rotating orthogonal-coordinate method has used. However, during the shunt converter design, instead of taking sending end voltage as feedback signal it considered receiving end voltage as feedback. Another study [33] proposed controller of UPFC using FL to improve voltage profile.

Different from previous works, in this study a new control system for dynamic UPFC is proposed to enhance PTC and bus voltage profile, as well as to reduce power capacity loss. Both controllers of series and shunt converters of UPFC are developed using FL controller. By using FL controller, the problem of stability that usually occurs with PI controller based feedback control can be overcome. Furthermore, the application of FL controller reduced the complexity of UPFC's internal control system, which commonly occurs in conventional controllers such as decoupled and cross coupled controllers. In this study, PSCAD software is used to model and test the proposed UPFC controller. Since PSCAD doesn't provide FL toolbox, a new module for the FL is developed in C language. By using C, the simulation can be done within the PSCAD environment. The proposed UPFC controller is tested by using IEEE-5 and 14 bus systems. In addition, comparative studies also have been conducted to prove the advantage of the proposed controller over different control methods of UPFC.

The rest of the paper is organized as follows: Section 2 focuses on UPFC model. Section 3discusses about the newly developed shunt and series control systems of UPFC along with the FL tool box design in PSCAD. Section 4presents the simulation results after connecting UPFC in two IEEE case studies including two comparative studies to prove the effectiveness of the proposed controller. The significant points of this paper are summarized in the conclusion.

2. UPFC model

The dynamic model of the UPFC is shown in Fig. 1. UPFC connects to the transmission line with shunt and series voltage source converters (VSC) which are coupled via a common DC link. Normally, the shunt VSC is considered as STATCOM and series one as a static synchronous series compensator (SSSC). Low pass AC filters are connected in each phase to prevent the flow of harmonic currents generated due to switching. The transformers connected at the output of converters to provide the isolation, modify voltage/current levels and also to prevent DC capacitor being shorted due to the operation of various switches. Insulated gate bipolar transis-