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A self-tuning fuzzy PI controller for TCSC to improve power system stability

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ABSTRACT

In this paper, a self-tuning fuzzy PI controller (STFPIC) is proposed for thyristor-controlled series capacitor (TCSC) to improve power system dynamic performance. In a STFPIC controller, the output-scaling factor is adjusted on-line by an updating factor (α). The value of α is determined from a fuzzy rule-base defined on error (e) and change of error (Δe) of the controlled variable. The proposed self-tuning controller is designed using a very simple control rule-base and the most natural and unbiased membership functions (MFs) (symmetric triangles with equal base and 50% overlap with neighboring MFs). The comparative performances of the proposed STFPIC and the standard fuzzy PI controller (FPIC) have been investigated on two multi-machine power systems (namely, 4 machine, 2 area system and 10 machine 39 bus system) through detailed non-linear simulation studies using MATLAB/SIMULINK. From the simulation studies it has been found out that for damping oscillations, the performance of the proposed STFPIC is better than that obtained by the standard FPIC. Moreover, the proposed STFPIC as well as the FPIC have been found to be quite effective in damping oscillations over a wide range of operating conditions and are quite effective in enhancing the power carrying capability of the power system significantly.

1. Introduction

For economic and ecological reasons, the building of new transmission lines and expansion of existing transmission systems are becoming more and more difficult. In this new situation, it is necessary to utilize the existing power transmission system at its maximum capacity to meet increasing demand of electrical energy. However, the power transfer capability of an interregional AC transmission system is usually limited by the stability problems. As a result, power utilities are now placing more emphasis on improving the stability limits of the existing systems to increase the utilization of existing transmission facilities. In this context, it is nowadays well recognized that by applying the flexible AC transmission system (FACTS) controllers, the stability limits can be enhanced significantly [1,2]. Among various FACTS controllers, thyristor-controlled series capacitor (TCSC) is one of the most promising FACTS devices having a few practical installations around the world [3,4] and has attracted a lot of attention for designing an effective control law to enhance the system stability. The various control schemes reported in the literature for TCSC can be classified into two broad categories: (a) linearised, eigenvalue analysis based control system and (b) intelligent technique-based control scheme. Although the effectiveness of the eigenvalue analysis based control scheme has been proven in several publications, as pointed out in [5], it is neither simple to develop the linearised system model nor is absolutely necessary for developing a FACTS damping controller. As a result, different intelligent technique-based controllers for TCSC have been suggested in the literature. Fang et al. [5] have proposed an OTEF descent strategy for designing fuzzy TCSC damping controller. In this work, the TCSC controller actually consists of two TCSC fuzzy controllers and the efficacy of the developed controller has been tested on a four-generator, two area interconnected power system. In Ref. [6], the authors have presented a T–S fuzzy model scheme for TCSC which has been tested on a single machine infinite bus (SMIB) system. Dash et al. have suggested a hybrid fuzzy controller and a non-linear T–S fuzzy controller for TCSC in [7] and [8], respectively. Both these schemes have been tested on a three machine, six bus system with two TCSCs installed in the study system. In Ref. [9], the authors have proposed a new design technique, namely F-HGAPSO, to design the fuzzy controller. The effectiveness of their proposed controller has been tested on a SMIB system. Laiq Khan and Lo [10] have presented a hybrid micro-GA based fuzzy controller for TCSC. The performance of the proposed TCSC controller has been tested on the three machine, nine bus system. However, in this work, both TCSC and UPFC were considered in the study system. In Ref. [11], the authors have proposed a combination of a fuzzy controller and a conventional PI controller for TCSC and the validity of this strategy has been tested on a two area four-machine power system.

From the above discussion it is observed that the different fuzzy control strategies proposed in the literature have been tested on relatively small test systems. This paper aims to extend the work on

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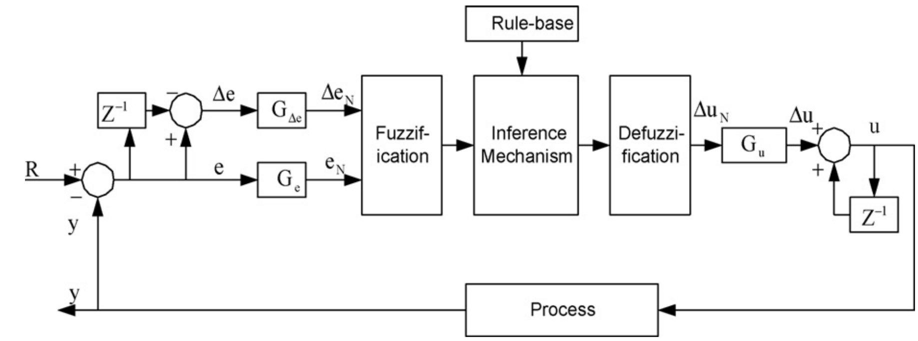

Fig. 1. Block diagram of the PI-type FLC (FPIC).

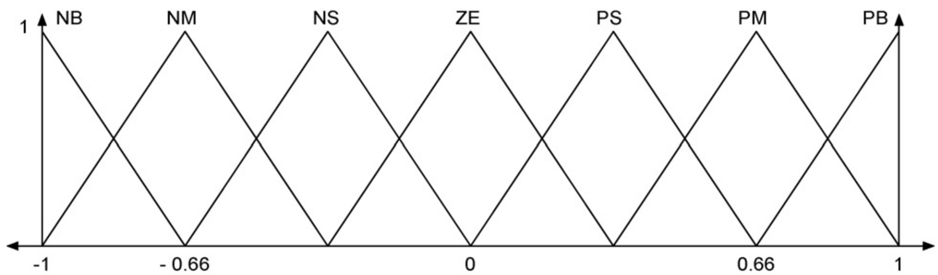

Fig. 2. MFs for e, Δe and Δu. N: negative; P: positive; ZE: zero; B: big; M: medium; S: small.

application of intelligent control technique for TCSC control design further. Specifically, in this paper, a new self-tuning fuzzy PI control for TCSC is proposed to enhance the power system stability. Further, the effectiveness of the developed TCSC controller has been tested on a relatively large 10 machine 39 bus system (which has not been used in earlier publications [5–11]). This paper is organized as follows. Section 2 describes the proposed fuzzy logic controller for TCSC. Section 3 presents the main results of this work. Finally, Section 4 discusses the conclusions of this work.

2. Fuzzy PI controller

The block diagram of the fuzzy PI controller (FPIC) is shown in Fig. 1 [12,13]. In this figure, $e(k)$ is the error at the kth sample and it can be written as $e(k) = y_{sp} - y(k)$ where, $y(k)$ is the actual system output and y_{sp} the set-point or desired system output at kth sample, respectively. The change in error is defined as

$$\Delta e(k) = e(k) - e(k-1) \quad (1)$$

The quantities e and Δe are converted to normalized quantities e_N and Δe_N, respectively by using the scaling factors (SFs) G_e and $G_{\Delta e}$. These normalized quantities e_N and Δe_N are crisp in nature and therefore need to be first converted to their corresponding fuzzy variables. After fuzzification, the fuzzified inputs are given to the fuzzy inference mechanism which, depending on the given fuzzy rule base, gives the normalized incremental change in control output (Δu_N). The output Δu_N is converted into actual incremental change in control output (Δu) by using the scaling factor G_u. For implementing the fuzzy inference engine, the "min" operator for connecting multiple antecedents in a rule, the "min" implication operator, and the "max" aggregation operator have been used. Actually, the output Δu_N from the inference mechanism is fuzzy in nature, hence, to determine the crisp output, these fuzzy outputs need to be defuzzified. The centroid defuzzification scheme has been used here for obtaining the output Δu as shown in Fig. 1.

Finally, the actual value of the controller output (u) is computed by

$$u(k) = u(k-1) + \Delta u(k) \quad (2)$$

The relationships between the SFs (G_e, $G_{\Delta e}$ and G_u) and the input and output variables of the FPIC are as follows:

$$e_N = G_e e$$

$$\Delta e_N = G_{\Delta e}\, \Delta e$$

$$\Delta u = G_u\, \Delta u_N$$

Here G_e, $G_{\Delta e}$ and G_u are the SFs for e, Δe and Δu, respectively and e_N, Δe_N and Δu_N are normalized quantities. The SFs are the main parameters used for tuning any fuzzy logic controller (FLC) because variation of the SFs changes the normalized universe of discourse of input and output variables and their corresponding membership functions. Generally, selection of suitable values for G_e, $G_{\Delta e}$ and G_u are made based on the knowledge about the process to be controlled and sometimes through trial and error to achieve the best possible control performance. This is so because, unlike conventional non-fuzzy controllers, there is no well-defined method for selecting appropriate values of SFs for FLC. However, if required, it is possible to tune these parameters to achieve a given control objective using some optimization techniques. In this work, the appropriate values for G_e, $G_{\Delta e}$ and G_u have been determined

Table 1
Rule base for Δu

$\Delta e/e$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NM	NS	NS	ZE
NM	NB	NM	NM	NM	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PM	PB
PB	ZE	PS	PS	PM	PB	PB	PB