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Optimal tunning of type-2 fuzzy logic power system stabilizer based on differential evolution algorithm

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ABSTRACT

In this paper, a type-2 fuzzy logic power system stabilizer with differential evolution algorithm is proposed. As an extension of type-1 fuzzy logic theory, type-2 fuzzy logic theory can effectively improve the control performance by uncertainty of membership function especially when we have to confront with less expert knowledge or unpredicted external disturbances. The corresponding parameters and rule base of type-2 fuzzy logic power system stabilizer are optimally tuned by using differential evolution algorithm for multi-machine power system. Through simulation under different operational conditions, the results demonstrate the effectiveness of the proposed approach for damping the power system electromechanical oscillations.

Introduction

Power system can be termed as a typical multi-variable, nonlinear and dynamical system. It consists of synchronous generators, transformers, transmission lines, switches relays and active/reactive compensators. For maintaining the terminal voltage magnitude of synchronous generator, the automatic voltage regulators (AVRs) are usually adopted in generator excitation system. However, AVRs introduce negative damping torques, which adversely affect stability [1]. Due to disturbances coming from short circuits and operating point variations, power system exhibits electromechanical oscillations. These frequency oscillations needs to be dampened to a desired limitation, otherwise growing amplitude of these oscillations would result in instability. To overcome these problems, the power system stabilizers (PSSs) [2] are used to generate a supplementary stabilizing signal to the excitation system for damping these oscillations.

The conventional PSSs (CPSSs) and dual-input (namely PSS2B, PSS3B and PSS4B) [3–8] are designed based on led-lag phase compensation to provide the damping characteristics. It shows a good control performance in the specific operating point. But it lacks the ability to adapt to changes when the operating point drifts as a result of continuous load changes or unpredictable major disturbances such as three phase fault [9]. In order to improve the dynamic stability of power systems, the fuzzy logic power system stabilizer (FLPSS) [10–13] was developed for adapting to wide ranges of power system operating conditions, and these proposed FLPSSs show better performance in dynamic stability compared with CPSSs. But constructed FLPSSs relies on expert knowledge which usually consists of uncertainties to certain degree. Therefore, the corresponding fuzzy membership functions parameters and rule base needs to be adjusted to obtain the best control performance. The FLPSS combined with intelligent optimal methods have emerged recently. Such as, the design of FLPSS with adaptive neuro fuzzy inference and intelligent optimizing algorithm approaches were proposed in [5,6,8,14–16]; In [17,18], researchers addressed FLPSS and indirect adaptive FLPSS based on particle swarm optimization method; These proposed methods have shown the efficiency to damp out the oscillations compared with CPSSs and FLPSS under different operating conditions. Although these methods have improved a lot in power systems stability. Recent research has shown the limitations of traditional type-1 fuzzy logic theory in treating large uncertainty factors and unexpected disturbances. In order to well compensate these limitations, type-2 fuzzy logic method are developed and applied [19–22] in various fields. Meanwhile, the optimization of type-2 controller are also being considered. In literature [23–26], Oscar Castillo et al. proposed type-2 fuzzy controller based on optimization approaches (GA and PSO). In these works, parameters of type-2

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fuzzy controller are adjusted and the corresponding simulation results demonstrated better performance than conventional type-1 fuzzy controllers.

As one of efficient and powerful global optimization algorithm, differential evolution (DE) algorithm was first proposed by Storn and Price [27]. Recently, the DE algorithm has gradually become more popular and has successfully been applied to diverse domains [28]. It also has shown better performance with good convergence than other optimized algorithms (GA and PSO) [29]. Since the power system is dynamically complicated system which often confront with the changes of operating conditions and disturbances. Type-2 fuzzy theory can be used to deal with uncertainty factors and unexpected disturbances. A power system stabilizer which is based on type-2 fuzzy logic theory (type-2 FLPSS) is proposed and tested in single machine infinite bus system. Moreover, for further enhancement of stability, the parameters and rule base of type-2 FLPSS are adjusted with aid of DE algorithm. Finally, the optimal tunning type-2 FLPSS is evaluated in multi-machine power system under different operating conditions. By simulation and comparisons, the results of the optimized type-2 FLPSS exhibits better performance in damping out the power system oscillations.

This paper is organized as follows. Section 'Type-2 fuzzy logic controller' revisits type-2 fuzzy logic system design. The fundamentals of DE algorithm are presented in section 'DE algorithm'. Type-2 FLPSS design and testing are described in section 'Type-2 FLPSS design and testing'. The approach of type-2 FLPSS optimization is addressed in section 'Type-2 FLPSS optimization'. The optimization results and simulation comparisons are discussed in section 'Optimization results and simulation comparisons'. The conclusions are summarized in the final section of this paper.

Type-2 fuzzy logic controller

General type-2 fuzzy logic are computationally intensive because its inference and type-reduction are very intensive. To simplify, type-2 fuzzy set can be amended to interval type-2 fuzzy set if the secondary memberships are either zero or one. The corresponding fuzzy logic controller (FLC) based on interval type-2 fuzzy set can be constructed, which consists of fuzzifier, inference engine, rule base, type-reducer and defuzzifier.

Fuzzifier

The fuzzifier part is used for maping the crisp inputs $x = (x_1, \ldots, x_n)$ into different kinds of fuzzy sets. It includes singleton, type-1 fuzzy set and interval type-2 fuzzy set and so on. Here, singleton fuzzification method is adopted to map the input variables.

Rule base

Rule base is expressed with the form of "if-then" which represents expert knowledge. By considering MISO (multi inputs single output) interval type-2 FLC, the two kinds of "if-then" expressions can be depicted as followed:

$$\text{if } x_1 \text{ is } \widetilde{F}^l_1 \text{ and } x_2 \text{ is } \widetilde{F}^l_2, \ldots, x_p \text{ is } \widetilde{F}^l_p, \text{ then } y^l \text{ is } \widetilde{G}^l$$

$$\text{if } x_1 \text{ is } \widetilde{F}^l_1 \text{ and } x_2 \text{ is } \widetilde{F}^l_2, \ldots, x_p \text{ is } \widetilde{F}^l_p, \text{ then } y^l = f(x_1, x_2, \ldots, x_n)$$

Fuzzy inference

The inference is the key process in fuzzy system. Considering MISO interval type-2 FLC with p antecedents, the expression of lth rule is listed below:

$$R^l: \text{if } x_1 \text{ is } \widetilde{F}^l_1 \text{ and } x_2 \text{ is } \widetilde{F}^l_2, \ldots, x_p \text{ is } \widetilde{F}^l_p, \text{ then } y^l \text{ is } \widetilde{G}^l.$$

where $\widetilde{F}^l_i$ and $\widetilde{G}^l$ are the fuzzy language partition of the input variable and output variable. In addition, the ith input variable and output variable membership functions (MFs) are expressed by the way of $\mu_{\widetilde{F}^l_i}(x_i)$ and $\mu_{\widetilde{G}^l}(y)$. The inference results of lth fired rule is depicted as:

$$\mu_{\widetilde{B}^l}(y) = \mu_{\widetilde{G}^l}(y) \sqcap \{\sqcup_{x \in X}\{[\mu_{\widetilde{X}_1}(x_1) \sqcap \mu_{\widetilde{F}^l_1}(x_1)] \sqcap \cdots \sqcap [\mu_{\widetilde{X}_p}(x_p) \sqcap \mu_{\widetilde{F}^l_p}(x_p)]\}\} \quad (1)$$

where $\mu_{\widetilde{X}_i}(x_i)$ is ith membership function of fuzzification.

By using the singleton fuzzification, the lth fired rule result can be simplified as:

$$\mu_{\widetilde{B}^l}(y) = \mu_{\widetilde{G}^l}(y) \sqcap \{\sqcup_{x \in X}\{\mu_{\widetilde{F}^l_1}(x_1) \sqcap \cdots \sqcap \mu_{\widetilde{F}^l_p}(x_p)\}\} \quad (2)$$

Because the fuzzy sets are interval type-2 fuzzy sets, the inference of antecedents can be addressed as:

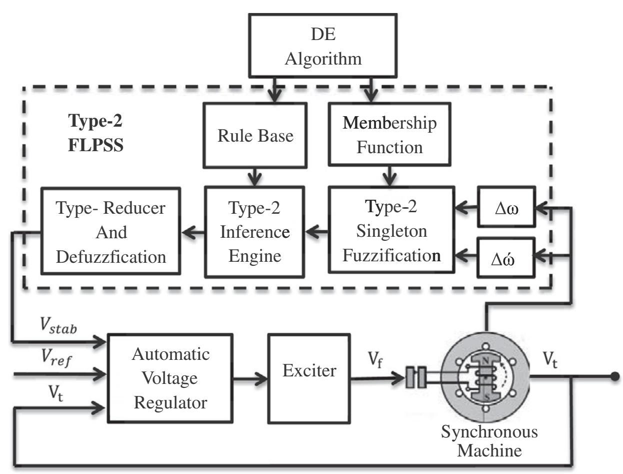

Fig. 1. Structure of type-2 FLPSS.

Table 1
Rule base of type-2 FLPSS.

V_{stab}		$\Delta\omega$				
		NB	NS	ZO	PS	PB
$\Delta\dot{\omega}$	NB	NB	NS	NS	NS	ZO
	NS	NS	NS	ZO	ZO	ZO
	ZO	NS	ZO	ZO	ZO	PS
	PS	ZO	ZO	ZO	PS	PS
	PB	ZO	PS	PS	PS	PB

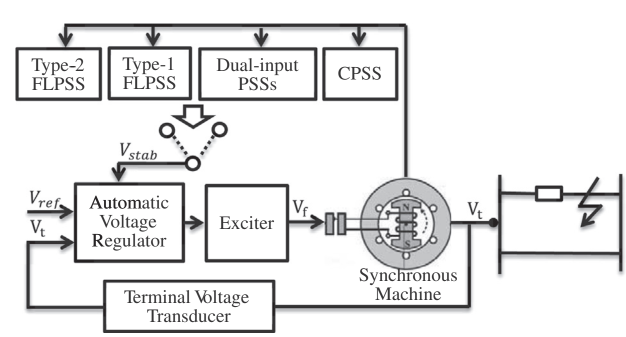

Fig. 2. Single machine infinite bus power system.