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A novel design of high-sensitive fuzzy PID controller

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ABSTRACT

A hybrid model is designed by combining the genetic algorithm (GA), radial basis function neural network (RBF-NN) and Sugeno fuzzy logic to determine the optimal parameters of a proportional-integral-derivative (PID) controller. Our approach used the rule base of the Sugeno fuzzy system and fuzzy PID controller of the automatic voltage regulator (AVR) to improve the system sensitive response. The rule base is developed by proposing a feature extraction for genetic neural fuzzy PID controller through integrating the GA with radial basis function neural network. The GNFPID controller is found to possess excellent features of easy implementation, stable convergence characteristic, good computational efficiency and high-quality solution. Our simulation provides high sensitive response (∼0.005 s) of an AVR system compared to the real-code genetic algorithm (RGA), a linear-quadratic regulator (LQR) method and GA. We assert that GNFPID is highly efficient and robust in improving the sensitive response of an AVR system.

1. Introduction

The AVR is utilized for controlling the terminal voltage by regulating the exciter voltage of the generator, while the AVR system optimal control is performed by the PID inside the AVR. The AVR system has differential, proportional, and integral coefficients [1]. Minglin proposed a method for designing PID-like fuzzy controller with FPGAV. The feed forward fuzzy PID controller has been used to [2] improve the performance of high pressure common rail system. The performance of current hybrid fuzzy PID controller is somewhat poor and the changes in the system parameters require a new adjustment variable of PID controller. To overcome this difficulty, Sinthipsomboon et al. [3] developed a hybrid system of fuzzy and fuzzy self-tuning PID controller. An improved fuzzy PID controller is employed [4,5] to control brushless DC motor speed. An adaptive-network-based fuzzy logic power system stabilizer (PSS) is proposed by [6,7]. In this research a novel power system stabilizer for damping both local and global modes of an interconnected system based on neuro fuzzy (hybrid) system is developed [8]. This paper is concerned with the application of an adaptive fuzzy logic controller to both single and multi-machine power system simulations. The PLC is further used to develop a fuzzy PID controller for the problem of a set point pressure control in the collecting main pressure system [6]. Jinwook et al. [9] proposed the design and stability analysis of Takagi–Sugeno–Kang (TSK)-type full-scale fuzzy proportional-integral-derivative (PID) controller. The fluctuations in temperature is further improved by self-setting fuzzy PID control algorithm [10]. An improved fuzzy PID controller algorithm based on DSP is introduced [11]. Computational techniques such as GA and fuzzy logic are used for analytic solution [5,9–11] which resulted the control field for implementing the real time manipulation based on the neural network.

The PID is incharge of the optimal control of AVR system possessing differential, proportional and integral coefficients. The real-coded genetic algorithm (RGA) is applied to generate the optimal PID parameters for the formulation of the fuzzy rules [12]. Zhang et al. [13,14] designed a new algorithm of vehicle stability adaptive PID control with single neuron network. Kun et al. [15] used radical basis function (RBF) to develop an optimal PID controller called direct-drive permanent magnet linear synchronous motor (PMSM). It is established that RBF-NN has the ability to approximate any continuous function with any arbitrary accuracy [12–15]. Using bio-inspired and evolutionary methods it is proposed that the optimization of the gains of a PID controller can stabilize the inertia wheel setup (IWP) [16]. Particle swarm optimization and genetic algorithms are employed to find the best gain values of the PID controller. A hybrid PSO-GA optimization

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technique for automatic design of fuzzy logic controllers (FLC) to attenuate the steady state error of a plant's response are proposed [17]. The chase downside for the dynamic model of a unicycle mobile robot is also addressed [18]. A novel optimization technique impressed on the chemical reactions applied to solve this motion problem by integrating a kinematic and a torque controller supported fuzzy logic theory. A novel technique is designed for dynamic parameter adaptation in particle swarm optimization (PSO) IS [19]. PSO may be a metaheuristic impressed in social behaviors that is extremely helpful in optimization issues and improvement to the convergence and variety of the swarm in PSO mistreatment fuzzy logic. A novel hybrid approach is planned for mathematical relation optimization combining Particle Swarm optimization (PSO) and Genetic Algorithms (GAs) using fuzzy logic to integrate the results [20]. Fuzzy logic is employed to mix the results of the PSO and GA within the best approach possible. A new hybrid approach is developed for the improvement combining particle swarm optimization (PSO) and Genetic Algorithms (GAs) exploitation mathematical logic to integrate the results of each ways and for parameters standardization [21]. The new improved methodology combines the benefits of PSO and GA to provide an improved FPSO + FGA hybrid approach. Another hybrid technique is followed for mathematical relation optimization combining particle swarm optimization (PSO) and genetic algorithms (GAs) mistreatment fuzzy logic to integrate the results [22].

A linear-quadratic regulator (LQR) method is implemented to improve the PID controller for a universal second-order system [23] which required a good selection of weighting functions for accep Table performance. An effective and powerful technique is proposed to appropriately calculate best PID controllers for AVR systems [24]. This is an improved version of the distinct Action Reinforcement Learning Automata (DARLA), where a discrete probability functions (DPF) of the planning variables do not seem to be thought of freelance. A PID controller is also designed for an AVR system in order to quickly settle the rated voltage ensuring the stability[25]. AVR is a closed loop control system compensated with a PID controller. The transient stability enhancement of the power system interconnected with wind farm by generalized unified power flow controller (GUPFC) having grid frequency switching similar multi-pulse converters is demonstrated [26]. The application of fuzzy system proposes a replacement of the PI controller by fuzzy logic controller to improve the transient performance of the DC link under fast load variations [27]. Valizadeh and Gaing [28–30] suggested a new design method for determining the PID controller parameters of the AVR system using the particle swarm optimization (PSO) method. PSO is a population-based optimization technique, which is enthused by social performance patterns of organisms such as bird flocking and fish schooling.

The main objective of the AVR is to control the terminal voltage by adjusting the generator exciter voltage, while the AVR system optimal control is performed by the PID inside the AVR. The drive of the approach is to design of high sensitive fuzzy PID controller and insert instead of traditional PID controller of AVR depends on a hybrid model designed by combining the GA, RBF-NN and Sugeno fuzzy logic. This keeps track of the generator terminal voltage all the time and under any load condition. It maintains the voltage within pre-established limits for enhancing the transient response of synchronous generator under severe disturbances.

We report the design of a novel method by integrating the Sugeno fuzzy system rule base and the AVR system fuzzy PID controller (GNFPID) for enhancing the system sensitive response. The paper is organized as follows. Section "Radial basis function networks" represents the concept of RBF-NN applied to PID parameters K_p, K_d and K_i those are automatically readjusted by on-line learning algorithm of RBF-NN to keep the system error, $e(k)$ zero. Section "Automatic voltage regulator" elucidates the concept of AVR system modeling and optimization of the control parameters. Section "Proposed GA" illustrates the proposed GA for solving the PID controller parameters optimization. The utilization of Sugeno fuzzy system concept for determining the PID controller parameters under various operating conditions is presented in section "Sugeno fuzzy model". Section "Design of PID controller methodology" describes the design methodology of fuzzy PID. Detailed simulation results are presented in section "Simulation results". Transient response calculations and comparison are made in section "Transient response calculations and comparison". The data analysis, validation and comparison with other findings are summarized in section "Comparison with other findings". The conclusion is presented in final section.

2. Radial basis function networks

In a synchronous generator, an AVR is used to keep the terminal voltage constant at different levels. The AVR system comprised of four main components such as amplifier, exciter, generator and sensors. The outer loop is a self-tuning PID voltage controller based on the radial basis function neural network to provide the ability to adapt for uncertain load and system conditions. Moody et al. [31] proposed a feed-forward two-layered RBF neural network with one single hidden layer to mimic the systematic arrangement of restrictive readjustment in the human mind. Whereas the RBF neural network produces the strongest response near the center of the Gaussian kernel function where each hidden node in the input data space can be regarded as a local detector [32–34] and the RBF neural network is deliberative as local estimation model for the controlled processes. Furthermore, the input samples for RBF neural network do not require a special distribution. In addition, RBF possess an on-line learning and quick converges. Consequently, the control field for implementing the real time manipulation concentrates on the neural network. The RBF is exploited to achieve the best parameters of the controller to maintain the system error zero [35]. The schematic of radial-basis function neural network is shown in Fig. 1.

The updating algorithm for the adaptive PID based RBF can be formulated as,

$$\Delta k_p = \mu \cdot e(k) \cdot e_p(k) \cdot \sum_{j=1}^{m} w_j h_j \frac{c_{j3} - u(k)}{\sigma_j^2} \quad (1)$$

$$\Delta k_i = \mu \cdot e(k) \cdot e_i(k) \cdot \sum_{j=1}^{m} w_j h_j \frac{c_{j3} - u(k)}{\sigma_j^2} \quad (2)$$

$$\Delta k_d = \mu \cdot e(k) \cdot e_d(k) \cdot \sum_{j=1}^{m} w_j h_j \frac{c_{j3} - u(k)}{\sigma_j^2} \quad (3)$$

The PID parameters K_p, K_d and K_i are automatically readjusted by RBF on-line learning algorithm to maintain the $e(k) = 0$ (1–3). Two commands offered by Matlab are used to design the RBF neural network viz. Newrb and newrbe. Newrb adds neurons step by step until the goal is hit with long training time with minimal error. While, newrbe designs a network very quickly with zero error [36,37]. In the training process, the achieved steps are: (i) neurons number in the hidden layer, (ii) the coordinates of the center of RBF function (iii) and the radius (spread) of each RBF functions in each dimension.

3. Automatic voltage regulator

3.1. Modeling of AVR system

In a synchronous generator, the terminal voltage is kept constant at different levels by using an AVR. The AVR system consists