Electrical Power and Energy Systems 67 (2015) 66–75

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

# Optimal design of a robust discrete parallel FP + FI + FD controller for the Automatic Voltage Regulator system

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ARTICLE INFO

*Article history:*
Received 25 January 2014
Received in revised form 9 October 2014
Accepted 15 November 2014

*Keywords:*
AVR
Fuzzy PID
HGAPSO algorithm
PID controllers

ABSTRACT

The purpose of this paper is to design a good tracking controller for the generator Automatic Voltage Regulator (AVR) system. A fuzzy logic-based controller that is called Fuzzy P + Fuzzy I + Fuzzy D (FP + FI + FD) controller has been designed optimally and applied to AVR system. In the proposed method, optimal tuning of controller parameters is very important to achieve the desired level of robust performance. Thus, a hybrid of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) (HGAPSO) technique has been used to find a better fuzzy system control. The motivation for using this hybrid method is to increase disturbance rejection effort, reduce fuzzy system efforts and take large parametric uncertainties into account. The developed FP + FI + FD control strategy leads to a flexible controller with simple structure that is easy to implement. The simulation results have been compared with the conventional Proportional–Integral–Derivative (PID) and fuzzy PID controllers. Three cases of simulation have been performed, case 1: comparing the tracking capability of the controllers, case 2: comparing the disturbance rejection capability of the controller and case 3: evaluating the performance of the controllers assuming that amplifier and exciter system parameters have 50% uncertainty. The simulation results shows that the proposed parallel FP + FI + FD controller has good performance from the perspective of overshoot/undershoot, settling time, and rise time in comparison with both conventional and fuzzy PID controllers.


## Introduction

One of methods for increasing stability and achieving a nominal voltage level in an electric power grid is raising the voltage or employing series capacitors in power transmission lines, but controlling of generator exciter by using of AVR is attracting attention because of its inherent cost advantage. The AVR controls the terminal voltage by adjusting the exciter voltage of the generator [1,2]. During the past decades, the process control techniques in the industry have made great advances. Numerous control methods such as delf-PID controllers and fuzzy control have been studied for AVR system [3].

Due to the complexity of the power system such as nonlinear stochastic load characteristics and variable operating points the usage of artificial intelligence based optimization techniques like PSO, HGA–BF, ABC, ASO, TCGA, simplified PSO [1–6] have been reported for optimal tuning of PID controller in AVR system. Shayeghi and Dadashpour [2] addressed a robust method for tuning PID control of the AVR system by optimizing a time domain based objective function considering model uncertainties using an ASO optimizer. It was shown that the suggested self-tuning PID for AVR system has better performance than the recently Craziness based PSO (CRPSO) and Vector evaluated PSO optimized controllers with respect to reference input and plant parameter changes. In [3] was suggested a PSO based tuned PID type controller for AVR system in comparison with GA via minimizing a objective function composed of overshoot, steady state error, deviation between settling time and rise time. It has better tuning capability than GA. However, its performance is dependent on suitable choice of PSO control parameters. An HGA–BF optimization technique was represented by Kim [4] in order to improve the performance of the self-tuning PID controller for AVR system. Gozde and Taplamacioglu [5] investigated tuning performance of ABC algorithm for AVR control system. The robustness analysis has been compared with PSO and differential evolution (DE) algorithms under different analysis methods such as transient response, root locus, bode and statistically receiver operating characteristic analyses. All analyses results have realized that ABC based optimized PID control of AVR system has better and robust performance than the PSO and DE algorithms. In [6] a simplified PSO method called many optimizing

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http://dx.doi.org/10.1016/j.ijepes.2014.11.013
0142-0615/

**Nomenclature**

| | |
|---|---|
| AVR | Automatic Voltage Regulator |
| PSO | particle swarm optimization |
| TCGA | Taguchi combined genetic algorithm |
| ASO | anarchic society optimization |
| COA | center of area |
| ABC | artificial bee colony |
| HGA–BF | hybrid genetic algorithm–bacterial foraging |
| PID | Proportional–Integral–Derivative |
| PI | proportional–integral |
| PD | proportional–derivative |
| FP + FI + FD | Fuzzy P + Fuzzy I + Fuzzy D |
| BIBO | bounded input bounded output |
| HGAPSO | hybrid of genetic algorithm and particle swarm optimization |

liaisons (MOL) algorithm has reported to determine optimal parameters of PID controller. The superiority of the MOL based self-tuning PID controller performance has been shown using different analysis methods than the modern heuristic optimization algorithms reported in literature review.

Recently, the application of fractional order PID (FOPID) controller optimized by chaotic ant swarm [7] and improved evolutionary non-dominated sorting genetic algorithm (NSGA-II) [8] has been applied for solving AVR system control problem. FOPID controller is a generalization of standard PID controller using fractional calculus. To design FOPID controller minimizing some objective function composed of overshoot, rising time, settling time, steady-state error, integral of the time multiplied squared error and integral of squared controller output was used. They investigated the basic performance and robustness of their controller compared with that of the classical PID controller. It should be noted that, FOPID controller has two extra parameters compare to the standard PID controller. On one hand, it enables people have more degrees of freedom to design FOPID controller, and, on the other hand, it means that it is more complex in the synthesis of FOPID controller.

Although, heuristic optimization techniques based self-tuning PID controller seems to be good methods to solve AVR control system problems. However, there is a problem that how to incorporate knowledge of the plant non-linearity and uncertainty effectively in the above methods.

The real world power system contains different kinds of uncertainties and various disturbances due to complexity, system modeling errors and changing daily power system operating state from full load to null load conditions. As a result, a fixed controller designed by the classical theories is certainly not suitable for solving of AVR system problem. Thus, it is desirable that a flexible controller be developed. Efforts have been made to design fuzzy logic controllers with better performance to cope with model dynamical uncertainties and accommodate strong nonlinear behavior of the plant [9–11]. In view of this, some authors suggested fuzzy PID methods to improve the performance of the AVR control system [12,13]. In [12] a fuzzy controller was developed and implemented in an IBM compatible personal computer to control an industrial size 5 kV A synchronous machine. Mukherjee and Ghoshal [13] presented a CRPSO based search technique for tuning of PID controller gains with off-line, as well as, nominal input conditions. Sugeno Fuzzy Logic (SFL) has been used for on-line input conditions. It was shown that CRPSO–SFL based PID controller has better quality solution for AVR system with less computational effort than binary coded genetic algorithm SFL based PID controller one. Recently, a discrete fuzzy logic based PID excitation controller was developed [14]. It is composed of two parts; a fuzzy PI and a fuzzy D controller; which preserves the simple linear structure of its conventional counterpart and improved the self tuning control capability. It is found that the proposed controller was provided good damping improvement for various operating points in comparison with the conventional PID and the double input fuzzy PID controllers.

This paper presents an optimal design of robust parallel FP + FI + FD controller to maintain the terminal voltage of the generator in its nominal value, which is based on the structure of a conventional parallel PID controller, with analytical formulas. It has variable gains that contain self-tuning feature, i.e., as the process parameters are changed with respect to time, the FP + FI + FD controller adjusts its gains accordingly. Its self-tuning behavior helps the controller to adjust its parameters in a very fast manner as simulation results show this controller is very fast in reference tracking and disturbance rejection. This capability is very useful for controlling output voltage of a generator because of the oscillations in load demand that is always an important problem in power systems. On the other hand, successful design of a rule-based fuzzy control system depends on several factors such as the choice of rule set, membership functions, defuzzification strategy and tuning of controller gains [10,15]. Among these factors the simplest one is to tune the controller gains. It should be noted that the exact tuning of gains in the FP + FI + FD controller has more effect on controller performance. Thus, in this study gains of the FP + FI + FD controller have been tuned using the HGAPSO optimization method to increase disturbance rejection, reduce fuzzy system effort and take large parametric uncertainties into account. The developed FP + FI + FD control strategy combines the advantage of HGAPSO technique and fuzzy theory and leads to a flexible controller with a simple structure that it is easy to implement.

In summary, the main contribution of this paper is as follows:

- Proposing a novel FP + FI + FD controller for the solution of the AVR system control problem.
- Using HGAPSO technique to reduce design effort and cost to optimized controller gains automatically.
- Considering model uncertainties in synthesis procedure and investigation the tracking and disturbance rejection capability of the proposed controllers in comparison with fuzzy-PID and PID controllers.

The robustness of the proposed FP + FI + FD controller is tested by carrying out the simulations under five operating conditions in comparison with fuzzy PID and conventional PID controllers. Three cases of simulations have been performed. In case 1 the tracking capability of the proposed controllers has been compared. In case 2 by creating a disturbance and plotting the results, the disturbance rejection capability of controllers has been illustrated and in case 3 the performance of the proposed FP + FI + FD controller has been evaluated by considering that the amplifier and exciter system parameters have 50% uncertainty.

## AVR system modeling

Excitation control of synchronous alternator is one of the most important factors to improve power system stability and quality of electrical power [16]. Exciter should be regulated in order to match the voltage drop (or rise). There must be a voltage regulator device