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Robust modified GA based multi-stage fuzzy LFC

H. Shayeghi [a,*], A. Jalili [b], H.A. Shayanfar [c]

[a] *Technical Engineering Department, The University of Mohaghegh Ardebili, Daneshkah St., Ardebil, Iran*
[b] *Electrical Engineering Group, Islamic Azad University, Ardebil Branch, Ardebil, Iran*
[c] *Electrical Engineering Department, Iran University of Science and Technology, Tehran, Iran*

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Abstract

In this paper, a robust genetic algorithm (GA) based multi-stage fuzzy (MSF) controller is proposed for solution of the load frequency control (LFC) problem in a restructured power system that operates under deregulation based on the bilateral policy scheme. In this strategy, the control signal is tuned online from the knowledge base and the fuzzy inference, which request fewer sources and has two rule base sets. In the proposed method, for achieving the desired level of robust performance, exact tuning of the membership functions is very important. Thus, to reduce the design effort and find a better fuzzy system control, membership functions are designed automatically by modified genetic algorithms. The classical genetic algorithms are powerful search techniques to find the global optimal area. However, the global optimum value is not guaranteed using this method, and the speed of the algorithm's convergence is extremely reduced too. To overcome this drawback, a modified genetic algorithm is being used to tune the membership functions of the proposed MSF controller. The effectiveness of the proposed method is demonstrated on a three area restructured power system with possible contracted scenarios under large load demand and area disturbances in comparison with the multi-stage fuzzy and classical fuzzy PID controllers through FD and ITAE performance indices. The results evaluation shows that the proposed control strategy achieves good robust performance for a wide range of system parameters and load changes in the presence of system nonlinearities and is superior to the other controllers. Moreover, this newly developed control strategy has a simple structure, does not require an accurate model of the plant and is fairly easy to implement, which can be useful for the real world complex power systems.
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Keywords: LFC; Multi-stage fuzzy controller; Restructured power system; Fuzzy switch; GAs; Power system control

1. Introduction

The dynamic behavior of many industrial plants is heavily influenced by disturbances and, in particular, by changes in the operating point. This is typically the case for restructured power systems. Load frequency control (LFC) is a very important issue in power system operation and control for supplying sufficient and reliable electric power with good quality. The main goal of LFC is to maintain zero steady state errors for frequency deviation and good tracking of load demands in a multi-area power system. In addition, the power system should fulfill the requested dispatch conditions. A lot of studies have been made in the last two decades about LFC in interconnected power systems [1–11].

The real world power system contains different kinds of uncertainties due to load variations, system modeling errors and change of the power system structure. As a result, a fixed controller based on the classical theories is certainly not suitable for solution of the LFC problem. Consequently, it is required that a flexible controller be developed. The conventional control strategy for the LFC problem is to take the integral of the area control error as the control signal. An integral controller provides zero steady state deviation, but it exhibits poor dynamic performance [2]. To improve the transient response, various control strategies, such as linear feedback, optimal

* Corresponding author. Tel.: +98 21 7808022; fax: +98 21 7454055.
E-mail address: hshayeghi@gmail.com (H. Shayeghi).

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Nomenclature

F	area frequency	R	droop characteristic
P_{Tie}	net tie line power flow	B	frequency bias
P_{T}	turbine power	T_{ij}	tie line synchronizing coefficient between areas i and j
P_{V}	governor valve position	P_{d}	area load disturbance
P_{C}	governor set point	P_{Lj-i}	contracted demand of Disco j in area i
ACE	area control error	P_{ULj-i}	un-contracted demand of Disco j in area i
α	ACE participation factor	$P_{m,j-i}$	power generation of GENCO j in area i
Δ	deviation from nominal value	P_{Loc}	total local demand
K_{P}	subsystem equivalent gain	η	area interface
T_{P}	subsystem equivalent time constant	ζ	scheduled power tie line power flow deviation ($\Delta P_{\mathrm{tie,sch.}}$)
T_{T}	turbine time constant		
T_{H}	governor time constant		

control and variable structure control have been proposed [3–5]. However, these methods need some information for the system states, which are very difficult to know completely. There have been continuing efforts in designing LFC with better performance to cope with the plant parameter changes using various adaptive neural networks and robust methods [6–11]. The proposed methods show good dynamical responses, but robustness in the presence of model dynamical uncertainties and system nonlinearities were not considered. Also, some of them suggest complex state feedback or high order dynamical controllers, which are not practical for industry practices.

Research on the LFC problem shows that the fuzzy proportional-integral (PI) controller is simpler and more applicable to remove the steady state error [12]. The fuzzy PI controller is known to give poor performance in the system transient response. In view of this, some authors proposed fuzzy proportional-integral-derivative (PID) methods to improve the performance of the fuzzy PI controller [13–15]. It should be pointed out that it requires a three dimensional rule base. This problem makes the design process more difficult. In order to overcome this drawback and focus on the separated PD part from the integral part, this paper presents a multi-stage fuzzy (MSF) PID controller with a fuzzy switch. This is a form of behavior based control where the PD (proportional-derivative) controller becomes active only when certain conditions are met. The resulting structure is a controller using two dimensional inference engines (rule base) to perform reasonably the task of a three dimensional controller. The proposed method requires fewer resources to operate, and its role in the system response is more apparent, i.e. it is easier to understand the effect of a two dimensional controller than a three dimensional one [16–18]. This newly developed control strategy combines a fuzzy PD controller and an integral controller with a fuzzy switch. The fuzzy PD stage is employed to penalize fast change and large overshoots in the control input due to corresponding practical constraints. The integral stage is also used in order to get disturbance rejection and zero steady state error. Successful design of a rule based fuzzy control system depends on several factors such as the choice of the rule set, membership functions, inference mechanism and the defuzzification strategy. Of these factors, exact tuning of membership functions is more difficult in the proposed MSF controller because it is a computationally expensive combinatorial optimization problem. Usually, the tuning of membership functions is derived from human experts who have acquired their knowledge through experience. However, experts may not always be available. Even where available, extraction of an appropriate set of membership functions from the experts may be tedious, time consuming and process specific. Thus, optimization of membership functions tuning is an important and essential step toward the design of any successful fuzzy controllers. For this reason, a modified genetic algorithm (GA) is being used for tuning the membership functions in the proposed MSF controller to reduce the fuzzy system effort. Classical GAs are powerful search techniques to find the global optimal area. However, the global optimal value is not guaranteed using this method, and the speed of the algorithms convergence is extremely reduced too. To overcome this drawback, the hill climbing method is proposed to improve the speed of the algorithms convergence. Besides, the global optimal value is also guaranteed by this method.

To illustrate the effectiveness of the proposed method a three area restructured power system is considered as a test system. The results of the proposed genetic algorithms based MSF (GAMSF) controller are compared with the MSF [16] and classical fuzzy PID controller (FPID) [13] through some performance indices in the presence of large parametric uncertainties and system nonlinearities under various area load changes. The performance indices are chosen as the integral of the time multiplied absolute value of the error (ITAE) and the figure of demerit (FD). The simulation results show that the proposed controller not only achieves good robust performance for a wide range of system parameters and area load disturbances changes, even

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