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Fuzzy load frequency control in multi area electric power system

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Abstract

The Load Frequency Control (LFC) problem is one of the most important subjects in the electric power system operation and control. In practical systems, the conventional PI type controllers are applied for LFC. In order to overcome the drawbacks of the conventional PI controllers, PI and PID Fuzzy controllers are considered for LFC problem. The parameters of the proposed Fuzzy controllers are tuned using Genetic Algorithms (GA). A multi area electric power system with a wide range of parametric uncertainties is given to illustrate proposed method. The simulation results visibly show the validity of proposed controllers in LFC problem.

Keywords: Multi Area Electric Power System, Load Frequency Control, PID Fuzzy Controller, PI Fuzzy Controller, Genetic Algorithms

Introduction

For large scale electric power systems with interconnected areas, Load Frequency Control (LFC) is important to keep the system frequency and the interarea tie power as near to the scheduled values as possible. The input mechanical power to the generators is used to control the frequency of output electrical power and to maintain the power exchange between the areas as scheduled. A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits.

Many control strategies for Load Frequency Control in electric power systems have been proposed over the past decades. This extensive research is due to fact that LFC constitutes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specifies limits. A unified tuning of PID load frequency controller for power systems via internal mode control has been proposed by Tan (2010). The tuning method is based on the two-degree-of-freedom (TDF) internal model control (IMC) design method and a PID approximation procedure. A new discrete-time sliding mode controller for load-frequency control in areas control of a power system has been presented by Vrdoljak et al. (2010). In this, the full-state feedback is applied for LFC not only in control areas of thermal power plants but also for hydro power plants, in spite of their non minimum phase behaviors. To enable full-state feedback, a state estimation method based on fast sampling of measured output variables has been applied. The applications of artificial neural network, genetic algorithms and optimal control to LFC have been reported (Kocaarslan & Cam, 2005; Rerkpreedapong et al., 2003; Liu et al., 2003). An adaptive decentralized load frequency control of multi-area power systems has been presented by Zribi et al., (2005). Also the application of robust control methods for load frequency control problem has been presented by Shayeghi et al., (2007) and Taher and Hematti (2008).

Our study deals with a design method for LFC in a multi area electric power system using PID and PI Fuzzy controllers. The proposed Fuzzy controllers are tuned using genetic algorithms. In order to show effectiveness of the proposed methods, these two methods are compared with each other. Simulation results show that the proposed methods guarantees robust performance under a wide range of operating conditions and system uncertainties.

Plant model

A four-area electric power system is considered as a test system and shown in Fig. 1. The block diagram for each area of interconnected areas is shown in Fig. 2 (Wood & Wollenberg, 2003).

The parameters in Fig. 2 are defined as follow:

 Δ : Deviation from nominal value

M_i=2H: Constant of inertia of ith area

D_i: Damping constant of ith area

R_i: Gain of speed droop feedback loop of ith area

T_{ti}: Turbine Time constant of ith area

T_{Gi}: Governor Time constant of ith area

G_i: Controller of ith area

 ΔP_{Di} : Load change of ith area u_i: Reference load of ith area

 $B_i=(1/R_i)+D_i$: Frequency bias factor of ith area

 ΔP_{tie} ij: Inter area tie power interchange from ith area to jth area.

Where:

i=1, 2, 3, 4 j=1, 2, 3, 4 and i≠i The inter-area tie power interchange is as (1) (Wood & Wollenberg, 2003).

$$\Delta P_{tie} ij = (\Delta \omega_i - \Delta \omega_j) \times (T_{ij}/S)$$
⁽¹⁾

where:

 $T_{ii}=377 \times (1/X_{tie}ij)$ (for a 60 Hz system); $X_{tie}ij$: impedance of transmission line between i and j areas

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The ΔP_{tie} ij block diagram is shown as Fig. 3.

Fig. 2 shows the block diagram of ith area and Fig. 3 shows the method of interconnection between ith and ith areas. The state space model of four-area interconnected power system is as (2) (Wood & Wollenberg, 2003).

$$\begin{cases} \mathbf{\bullet} \\ \mathbf{X} = \mathbf{A}\mathbf{X} + \mathbf{B}\mathbf{U} \\ \mathbf{Y} = \mathbf{C}\mathbf{X} \end{cases}$$
(2)

where:

 $X = \begin{bmatrix} \Delta P_{G1} \ \Delta P_{T1} \ \Delta \omega_1 \ \Delta P_{G2} \ \Delta P_{T2} \ \Delta \omega_2 \ \Delta P_{G3} \end{bmatrix}$ ΔP_{T3} $\Delta \omega_3$ ΔP_{G4} ΔP_{T4} $\Delta \omega_4$ ΔP_{tie} 1,2

 ΔP_{tie} 1,3 ΔP_{tie} 1,4 ΔP_{tie} 2,3 ΔP_{tie} 2,4 ΔP_{tie} 3,4] The matrixes A and B in (2) and the typical values of system parameters for the nominal operating condition are given in appendix. In the controller design for multiarea electric power systems, some areas have more importance than the others for tie-power and also frequency control. But In this paper the importance of areas is considered as equal.

Design methodology

PI-Fuzzy and PID-Fuzzy controllers are considered for LFC problem. The parameters of the proposed Fuzzy controllers are tuned using GA. The structure of these two controllers is shown in Figs. 4-5. In each figure, there are three parameters denoted by K_{in1} , K_{in2} and K_{out} which are defined over an uncertain range and then obtained by genetic algorithms optimization method. Therefore the boundaries of inputs and output signals are tuned on an optimal value.

	0	
Big Positive (BP)	Medium Positive (MP)	Small Positive (SP)
Big Negative	Medium Negative	Small Negative
(BN)	(MN)	(SN)
Zero (ZE)		

Table 1. The linguistic variables for inputs and output

Data base

Data base consists of the membership function for input variables and output variable described by linguistic variables shown in Table 1 (Rajase & Vijay, 2007). The "triangular membership functions" are used as membership functions for the input and output variables. The Fig. 6 illustrates this in detail indicating the range of the variable. This range is defined as default and then tuned via cascade K parameters (K_{in1} , K_{in2} and K_{out}) and adjusted on the optimal value.

Rule base

The other half of the knowledge base is the Rule Base which consists of all the rules formulated by the experts. The Fuzzy rules which are used in this scheme are listed in Table 2.

Genetic algorithms

Genetic algorithms are global search techniques, based on the operations observed in natural selection and genetics (Randy & Sue, 2004). They operate on a

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population of current approximations (the individuals) initially drawn at random, from which improvement is sought. Individuals are encoded as strings (chromosomes) constructed over some particular alphabet, e.g., the binary alphabet {0.1}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the genetic algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance. The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into 3 main categories: reproduction, crossover & mutation (Randy & Sue, 2004).

Fuzzy controller tuning using Genetic Algorithms

The membership functions of the proposed scaled Fuzzy controllers are tuned by K parameters (Kin1, Kin2 and Kout). These K parameters are obtained based on genetic algorithms optimization method. In section 2, the system controllers showed in Fig. 2 as G_i. Here these controllers are substituted by scaled Fuzzy controllers and the optimum values of Kin1, Kin2 and Kout in scaled Fuzzy controllers are accurately computed using genetic algorithms. In genetic algorithms optimization method, the first step is to define a performance index for optimal search. In this study the performance index is considered as (3). In fact, the performance index is the Integral of the Time multiplied Absolute value of the Error (ITAE).

$$ITAE = \int_{0}^{t} t \left| \Delta \omega_{1} \right| dt + \int_{0}^{t} t \left| \Delta \omega_{2} \right| dt + \int_{0}^{t} t \left| \Delta \omega_{3} \right| dt + \int_{0}^{t} t \left| \Delta \omega_{4} \right| dt$$
(3)

The parameter "t" in ITAE is the simulation time. A 100 seconds time period is considered for simulation. To compute the optimum parameter values, a 10 % step change in ΔP_{D1} is assumed and the performance index is minimized using genetic algorithms. The optimum values of the parameters K_{in1}, K_{in2} and K_{out} are obtained using genetic algorithms and summarized in the Tables 3-4. The boundaries of k parameters for optimal search are as follows:

 $0.1 \le K_{in1} \le 5$ $0.1 \le K_{in2} \le 5$ $0.1 \le K_{out} \le 10$

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Fig. 1. Multi-area interconnected power system





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In order to demonstrate the robustness performance of the proposed method, The ITAE is calculated following step change in the second area demand (ΔP_{D2}) at all operating conditions (Nominal, Heavy and Very heavy) and results are shown at Table 5. Following step change, the optimal PID-Fuzzy controller has better performance than the optimized PI-Fuzzy controller at all operating conditions.

Fig. 7 shows $\Delta \omega_1$ at nominal, heavy and very heavy operating conditions following 10 % step change in the demand of second area (ΔP_{D2}). It is seen that the PID-Fuzzy controller has better performance than the other method at all operating conditions.

Conclusions

A new Fuzzy PID and Fuzzy PI controllers have been successfully proposed for Load Frequency Control problem. The proposed method was applied to a typical four-area electric power system containing system parametric uncertainties and various loads conditions. Simulation results demonstrated that the Fuzzy PID controllers capable to guarantee the robust stability and robust performance under a wide range of uncertainties and load conditions. Also, the simulation results showed that the Fuzzy PID controller is robust to change in the system parameters and it has better performance than the optimal Fuzzy PI controller at all operating conditions. Appendix

The typical values of system parameters for the nominal operating condition are as Table 6. The matrixes A and B in (2) are presented as Appendix 1 and 2:

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Appendix 1

	0	0	$\frac{1}{M_{1}}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	$\frac{1}{M_{2}}$	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	$\frac{1}{M_{_3}}$	0	0	0	0	0	0	0	0	0
_	0	0	0	0	0	0	0	0	0	0	0	$\frac{1}{M_{_4}}$	0	0	0	0	0	0
	$\frac{1}{T_{G1}}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	$\frac{1}{T_{G2}}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	$\frac{1}{T_{_{G3}}}$	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	$\frac{1}{T_{C4}}$	0	0	0	0	0	0	0	0
"	PID fu	IZZV	contr	oller"						04			Re	eza	Her	nm	ati e	et al
	http://v	vww.	indjst.c	org										Inc	lian	J.Sc	i.Teo	chno

Table 3. Obtained values K_{in1}, K_{in2} and K_{out} for PID-Fuzzy controllers

	K _{in1}	K _{in2}	K _{out}
First area Fuzzy parameters	1.8119	0.6742	1.3349
Second area Fuzzy parameters	1.0929	0.6410	0.7511
Third area Fuzzy parameters	0.7631	1.3371	1.2099
Fourth area Fuzzy parameters	1.4288	1.2108	1.1237

Table 4. Obtained values Kin1, Kin2 and Kout for PI-Fuzzy controllers

	K _{in1}	K _{in2}	Kout
First area Fuzzy parameters	1.4490	0.7482	1.3677
Second area Fuzzy parameters	1.0136	0.5715	0.8600
Third area Fuzzy parameters	0.5251	1.2349	1.1181
Fourth area Fuzzy parameters	1.1886	1.1297	1.1172

Table 5. 10% Step increase in demand of second area (ΔP_{D2})

	The calculated ITAE						
	PID-Fuzzy	PI-Fuzzy					
Nominal operating condition	0.0305	0.0377					
Heavy operating condition	0.0307	0.0401					
Very heavy operating condition	0.0311	0.0396					

Table 6. Typical values of system parameter	rs
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1st area parameters			
T _{T1} =0.03	$T_{G1} = 0.08$	M ₁ =0.1667	R ₁ =2.4
D ₁ =0.0083	B ₁ =0.401	T ₁₂ =0.425	T ₁₃ =0.500
$T_{14} = 0.400$	T ₂₃ = 0.455	$T_{24} = 0.523$	T ₃₄ =0.600
2nd area parameters			
T _{T2} =0.025	$T_{G2}=0.091$	M ₂ =0.1552	R ₂ =2.1
D ₂ =0.009	B ₂ =0.300	T ₁₂ =0.425	T ₁₃ =0.500
T ₁₄ = 0.400	T ₂₃ = 0.455	$T_{24} = 0.523$	T ₃₄ =0.600
3rd area parameters			
T _{T3} =0.044	T _{G3} =0.072	M ₃ =0.178	R ₃ =2.9
D ₃ =0.0074	B ₃ =0.480	T ₁₂ =0.425	T ₁₃ =0.500
T ₁₄ = 0.400	T ₂₃ = 0.455	$T_{24} = 0.523$	T ₃₄ =0.600
4th area parameters			
T _{T4} =0.033	$T_{G4} = 0.085$	M ₄ =0.1500	R ₄ =1.995
D ₄ =0.0094	B ₄ =0.3908	T ₁₂ =0.425	T ₁₃ =0.500
$T_{14} = 0.400$	T ₂₃ = 0.455	$T_{24} = 0.523$	T ₃₄ =0.600

Results and discussions

In this section the proposed PID-Fuzzy and PI-Fuzzy controllers are exerted to the system for LFC. In order to comparison and show effectiveness of the proposed method, the results of the proposed methods are compared.

In order to study and analysis system performance under system uncertainties B = robustness), (controller three operating conditions are considered as follow:

i. Nominal operating condition

ii. Heavy operating condition (20% changing parameters from their typical values) iii. Very heavy operating condition (40% changing parameters from their typical values)

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	$\frac{-1}{T_{G1}}$	0	$\frac{-1}{R_1T_{G1}}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	$\frac{1}{T_{mi}}$	$\frac{-1}{T_{mi}}$	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	$\frac{1}{M_1}$	$\frac{-D_1}{M_1}$	0	0	0	0	0	0	0	0	0	$\frac{-1}{M_1}$	$\frac{-1}{M_1}$	$\frac{-1}{M_1}$	0	0	0
	0	0	0	$\frac{-1}{T_{c2}}$	0	$\frac{-1}{R_2T_{C2}}$	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	$\frac{1}{T_{T2}}$	$\frac{-1}{T_{T2}}$	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	$\frac{1}{M_2}$	$\frac{-D_2}{M_2}$	0	0	0	0	0	0	$\frac{1}{M_2}$	0	0	$\frac{-1}{M_2}$	$\frac{-1}{M_2}$	0
	0	0	0	0	0	0	$\frac{-1}{T_{G3}}$	0	$\frac{-1}{R_3T_{G3}}$	0	0	0	0	0	0	0	0	0
. =	0	0	0	0	0	0	$\frac{1}{T_{T3}}$	$\frac{-1}{T_{T3}}$	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	$\frac{1}{M_3}$	$\frac{-D_3}{M_3}$	0	0	0	0	$\frac{1}{M_3}$	0	$\frac{1}{M_3}$	0	$\frac{-1}{M_3}$
	0	0	0	0	0	0	0	0	0	$\frac{-1}{T_{G4}}$	0	$\frac{-1}{R_4T_{G4}}$	0	0	0	0	0	00
	0	0	0	0	0	0	0	0	0	$\frac{1}{T_{T4}}$	$\frac{-1}{T_{T4}}$	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	$\frac{1}{M}$	$\frac{-D_4}{M_4}$	0	0	$\frac{1}{M}$	0	$\frac{1}{M}$	$\frac{1}{M_{4}}$
	0	0	T ₁₂	0	0	$-T_{12}$	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	T ₁₃	0	0	0	0	0	$-T_{13}$	0	0	0	0	0	0	0	0	0
	0	0	T_{14}	0	0	0	0	0	0	0	0	$- T_{14}$	0	0	0	0	0	0
	0	0	0	0	0	T ₂₃	0	0	$-T_{23}$	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	T ₂₄	0	0	0	0	0	$-T_{24}$	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	T ₃₄	0	0	- T ₃₄	0	0	0	0	0	0

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