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LOAD-FREQUENCY CONTROL IN TWO AREA POWER SYSTEM

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ABSTRACT

This paper presents a fuzzy application to the area of load frequency control (LFC). The study has been designed for a two-area interconnected power system. Using variable values for proportional and integral gains in the controller units the dynamic performance of the system is improved. The comparison between a conventional PI controller and the proposed controller shows that the proposed controller can genarate the best dynamic response following a step load change.

Key Words: Load-Frequency Control, Power Systems, Fuzzy Logic Controller

İKİ BÖLGELİ GÜÇ SİSTEMLERİNDE YÜK-FREKANS KONTRÜLÜ

ÖZET

Bu makalede, bölge yük-frekans kontrolü için bir bulanık mantık uygulaması araştırılmıştır. Kontrolör, iki bölgeli enterkonnekte güç sistemi için dizayn edilmiştir. Kontrolörde bulunan integral ve oransal kazanç katsayıları için farklı değerler kullanılarak sistemin dinamik performansı arttırılmıştır. Geleneksel PI kontrolör ile önerilen kontrolör arasında yapılan karşılaştırma sonucunda, sistemin basamak yük değişimi dinamik tepkisine önerilen kontrolörün en iyi sonucu verdiği gözlenmiştir.

Anahtar Kelimeler: Yük-Frekans Kontrolü, Güç Sistemleri, Bulanık Mantık Kontrolör

1. INTRODUCTION

The dynamic behaviour of many industrial plants heavily depends on disturbances and in particular on changes in the operating point. This is typically the case for power systems [1]. Load frequency control in power systems is very important in order to supply reliable electric power with good quality. The goal of the LFC is to maintain zero steady state errors in a multi area interconnected power system [2]. In addition, the power system should fulfill the requested dispatch conditions.

A lot of studies have been made in the past about the load frequency control in interconnected power systems. In the literature, some control strategies have been suggested based on the conventional linear control theory [3]. These controllers may be unsuitable in some operating conditions due to the complexity of the power systems such as nonlinear load characteristics and variable operating points. To some authors, variable structure control [3,4] maintains stability of system frequency. However, this method needs some information for system states, which are very difficult to know completely. The dynamic and static properties of the system must be well known to design an efficient controller. On the other hand, to handle such a complex system is complicated [5]. According to [6], conventional PID control schemes will not reach a high performance. Since the dynamics of a power system even for a reduced mathematical model is usually nonlinear, time-invariant and governed by strong cross-couplings of the input variables, the controllers have to be designed with special care. Therefore, a gain scheduling controller can be used. In this method, control parameters can be changed very quickly, since a parameter estimation is not required. However, the transient response can be unstable because of abruptness in system parameters. To solve this problem, a fuzzy gain scheduling of PI (FGPI) controller is proposed in some papers [2,7,8,9,10]. Adjusting the maximum and minimum values of, proportional and integral gains, Kp and Ki respectively, the outputs of the system can be improved. In this paper, the rules for the gains are chosen identical for the proposed FGPI controller. In addition, number of rules in inference mechanism are taken seven. Therefore, system performance is improved. For the conventional PI controller, the gains of proportional and integral are chosen 0.5 and 0.05 respectively. These values are determined experimentally. The comparison between the proposed FGPI controller and a conventional PI controller shows that the overshoots and settling time with the proposed FGPI controller are better than the conventional PI controller's.

2. TWO AREA POWER SYSTEM

Power systems are divided into control areas connected by tie lines. All generators are supposed to constitute a coherent group in each control area. From the experiments on the power system, it can be seen that each area needs its system frequency and tie-line power flow to be controlled [2]. The frequency control is accomplished by two different control actions in interconnected two area power systems: The primary speed control and supplementary or secondary speed control actions. The primary speed control makes the initial vulgar readjustment of the frequency. By its actions the various generators in the control area track a load variation and share it in proportion to their capacities. The speed of response is limited only by the natural time lags of the turbine and the system itself. Depending upon the turbine type the primary loop typically responds within 2 to 20 seconds. The supplementary speed control takes over the fine adjustment of the frequency by resetting the frequency error to zero through an integral action. The relationship between the speed and load can be adjusted by changing load reference setpoint input. In practice, the adjustment of the load reference setpoint is accomplished by operating the speed changer motor. The output of each unit at a given system frequency can be varied only by changing its load reference, which in effect moves the speed-droop characteristic up and down. This control is considerably slower and goes into action only when the primary speed control has done its job. Response time may be of the order of one minute. The speed-governing system is used to adjust the frequency. An isochronous governor adjusts the turbine valve / gate to bring the frequency back to the nominal or scheduled value.

An uncontrolled two area interconnected power system is shown in Figure 1 where, f is system frequency (Hz), R_i is regulation constant (Hz/perunit), T_g is speed governor time constant (sec), T_t is turbine time constant (sec) and T_p is power system time constant (sec).

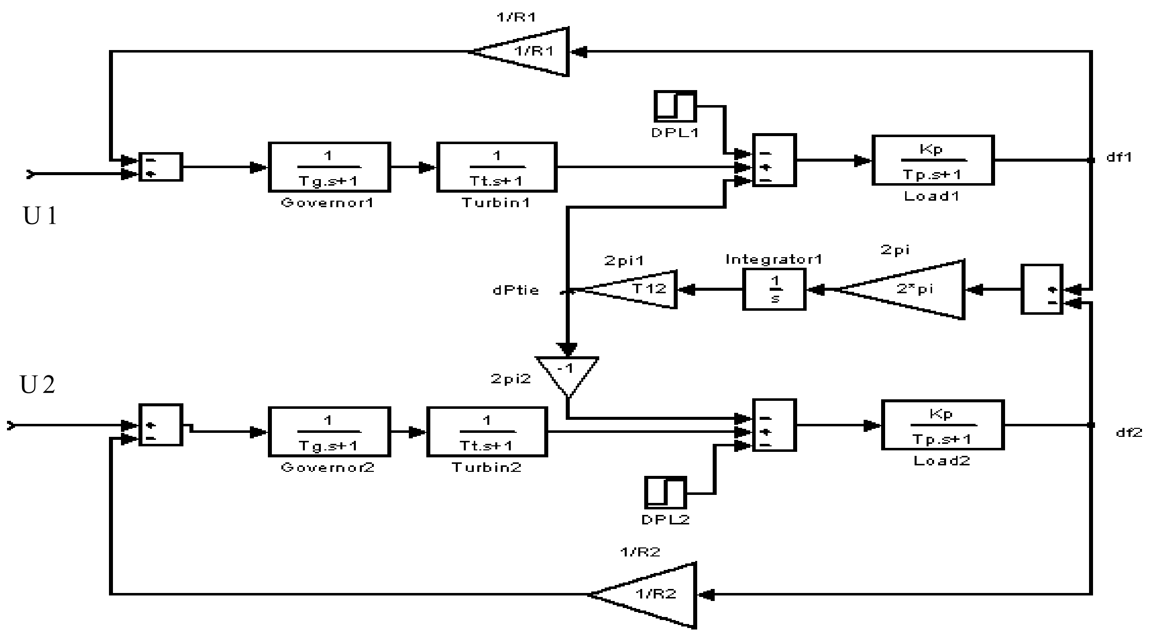


Figure 1. A two area interconnected power system (DP_{L1}, DP_{L2} : Load demand increments) [3]

The overall system can be modelled as multi variable system in the form

$$\dot{x} = Ax(t) + Bu(t) + Ld(t) \quad (1)$$

where A is the system matrix, B and L are input and disturbance distribution matrices, x(t), u(t) and d(t) are state, control and disturbance vectors of load changes respectively.

$$x(t) = \left[\Delta f_1 \quad \Delta P_{g1} \quad \Delta P_{\upsilon 1} \quad \Delta P_{tie12} \quad \Delta f_2 \quad \Delta P_{g2} \quad \Delta P_{\upsilon 2}\right]^T$$

$$u(t) = \left[u_1 \quad u_2\right]^T$$

$$d(t) = \left[\Delta P_{d1} \quad \Delta P_{d2}\right]^T,$$

where Δ denotes deviation from the nominal values. u_1 and u_2 are the controller outputs in Figure 1. The system output, which depends on area control error (ACE) which is shown in Figure 2, is

$$y(t) = \begin{bmatrix} y_1(t) \\ y_2(t) \end{bmatrix} = \begin{bmatrix} ACE_1 \\ ACE_2 \end{bmatrix} \quad (2)$$

$$ACE_i = \Delta P_{tie,i} + b_i \Delta f_i, \quad (3)$$

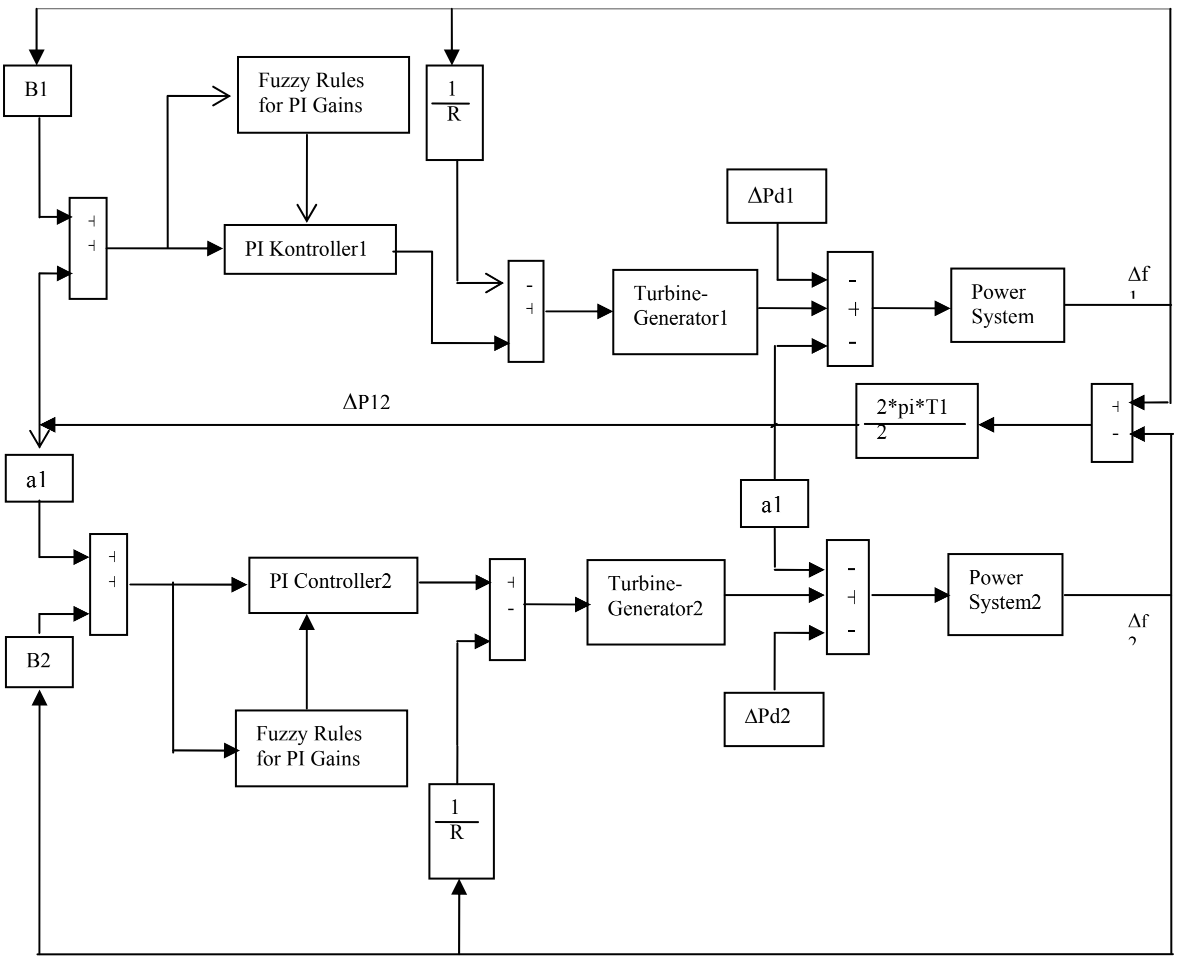


Figure 2. Two area power system with fuzzy logic controller [9]

where b_i is the frequency bias constant, Δf_i is the frequency deviation and $\Delta P_{tie,i}$ is the change in tie-line power for area i [8]. The input vector for a conventional PI controller can be given as

$$u_i = -K_p\,ACE_i - K_i\int(ACE_i)dt = -K_p(\Delta P_{tie,i} + b_i\Delta f_i) - K_i\int(\Delta P_{tie,i} + b_i\Delta f_i)dt \quad (4)$$

The conventional PI controller results in a large overshoot and a long settling time [3]. Also, optimizing time for control parameters is very long.

3. FUZZY LOGIC IN POWER SYSTEMS

The main goal of the load frequency control in interconnected power systems is to protect the balance between production and consumption. Because of complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions. Hence, robustness and reliability make fuzzy controllers useful in solving wide range of control problems [7]. According to many researchers, there are some reasons for the present popularity of fuzzy logic control. First of all, fuzzy logic can be easily applied for most of applications in industry. Besides, it can deal with intrinsic uncertainities by changing controller parameters. Finally, it is appropriate for rapid applications. Human experts prepare linguistic descriptions as fuzzy rules. These rules are obtained based on experiments of the process' step response, error signal, and its time derivative [9]. Determining the controller parameters with these rules a PI controller generates the control signal. For the single-input single-output type of systems, the fuzzy controller shown in Figure 3 [11].

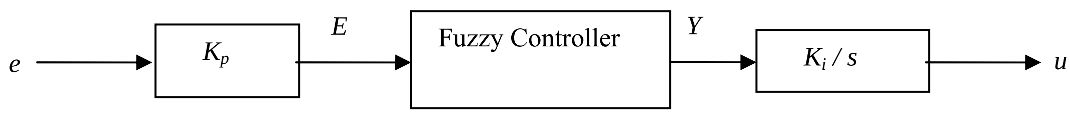


Figure 3. The simple fuzzy controller [11]

In this figure, k_p and k_i are the proportional and the integral gain respectively. The fuzzy controller input can be derivative of e together with signal E. Fuzzy controller block is formed by fuzzification of E, inference mechanism and defuzzification. Therefore, Y is a crisp value and u is a control signal for the system.

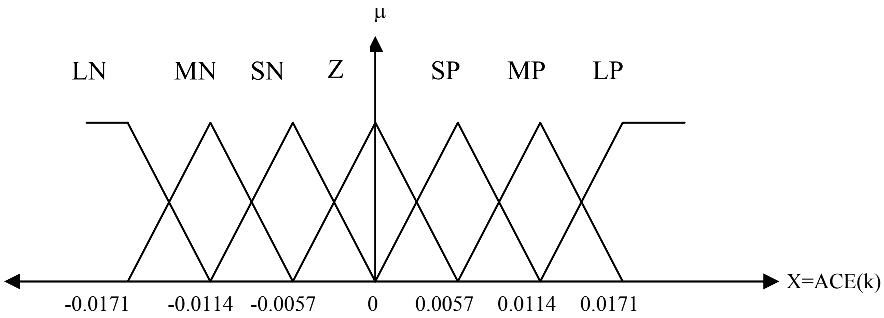
In this work, the appropriate rules are given in Table 1.

Table 1. Fuzzy logic rules for K_p and K_i

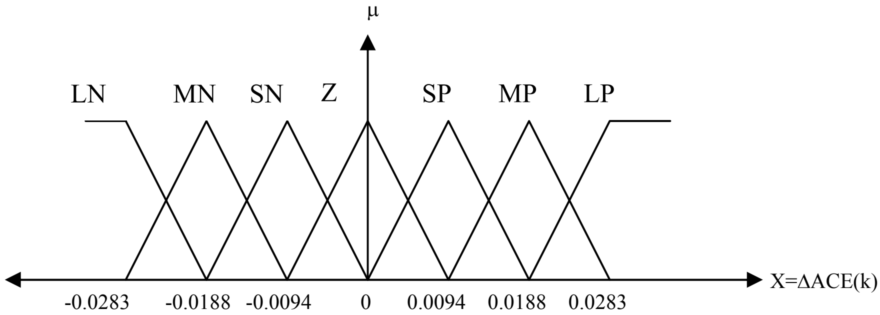
		ΔACE(k)						
		LN	**MN**	**SN**	**Z**	**SP**	**MP**	**LP**
	LN	LP	LP	LP	MP	MP	SP	Z
ACE(k)	**MN**	LP	MP	MP	MP	SP	ZE	SN
	SN	LP	MP	SP	SP	Z	SN	MN
	Z	MP	MP	SP	Z	SN	MN	MN
	SP	MP	SP	Z	SN	SN	MN	LN
	MP	SP	Z	SN	MN	MN	MN	LN
	LP	Z	SN	MN	MN	LN	LN	LN

LN: Large Negative MN: Medium Negative SN: Small Negative Z: Zero SP: Small Positive MP: Medium Positive LP: Large Positive

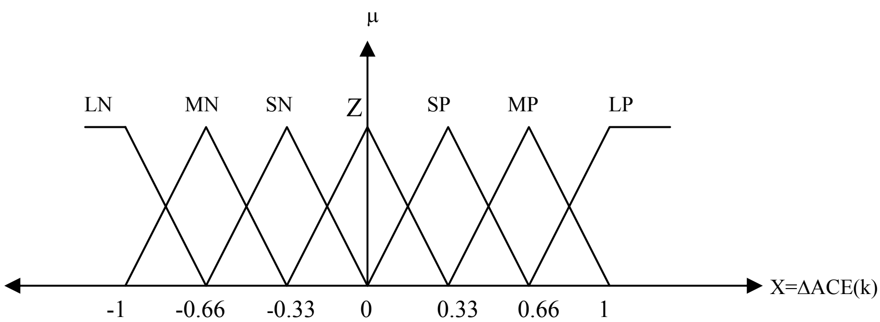
Fuzzy logic shows experience and preference through membership functions. These functions have different shapes depending on system experts' experience [10]. The membership function sets for ACE, ΔACE, K_p and K_i are shown in Figure4.



(a)



(b)



(c)

Figure 4. Membership functions of a- ACE, b- ΔACE, c- K_p, K_i

These membership functions are chosen triangular functions, since load-frequency control is a rapid application. Also, the number of rules in inference mechanism are taken seven. Therefore, 49 fuzzy logic rules are used for this study. The ranges of X are chosen from simulation by experimentally.

4. SIMULATION STUDY AND CONCLUSIONS

In this paper, a new fuzzy gain scheduling of PI controller has been investigated for automatic load frequency control of interconnected power systems. System parameters [12] are given in Table 2.

Table 2. System parameters

Tg = 0.08	B1 = 0.425
R1 = 2.4	B2 = 0.425
R2 = 2.4	T12 = 0.086
Tp = 20	Kp = 120
Tt = 0.3	a12 = -1

Simulation results for the systems are shown in Table 3 and Figures 5 - 6. Performance comparison of the proposed controller versus the conventional PI controller indicates that the system response with the proposed controller has approximately equal overshoots but its setling time is quite shorter. From the Table 3, it is shown that the settling time of PI controller is 60% longer than the proposed controller's.

Table 3. System performances for conventional PI controller and fuzzy gain scheduling of PI controller (Settling time for 5% band of the step change)

	Δf1	
	Settling times (sec)	Overshoots (Hz)
The proposed study (T_a)	4.26	- 0.027
Conventional PI (T_b)	6.92	- 0.028

It has been shown that the proposed control algorithm is effective and provides significant improvement in system performance. In addition, the proposed controller is very simple and easy to implement since it does not require any information about system parameters. Therefore, the proposed controller fulfills the demand for the two area interconnected power system. Hence, the proposed FGPI controller is recommended to generate good quality and reliable electric energy.

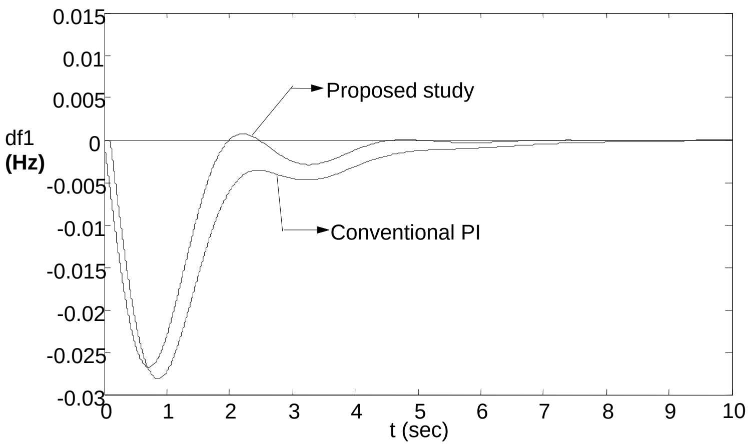


Figure 5. Deviation of frequency of area 1 ($DP_{d,1,2}$=0.01 p.u.)

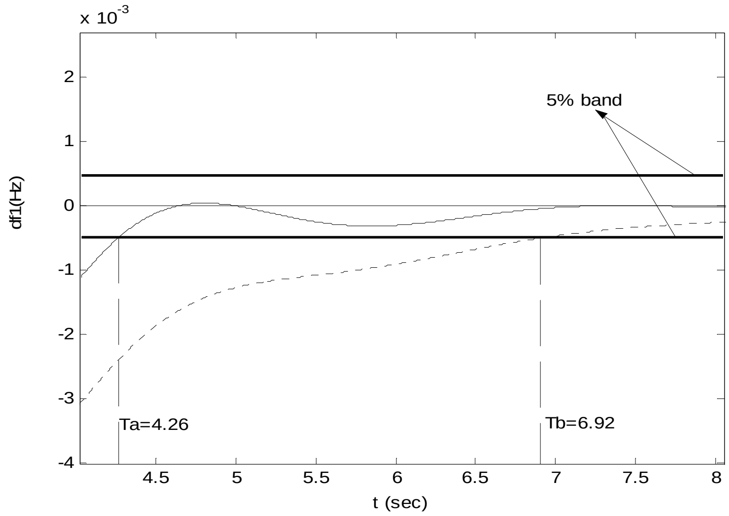


Figure 6. Deviation of frequency of area 1 in a larger scale and settlings times for proposed controller (T_a), Conventional PI controller (T_b)

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