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Automatic Generation Control of Thermal –Thermal Two Area Interconnected System Using Anti Windup Pi Controller

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A B S T R A C T

Anti windup PI controller in automatic generation controls of two area electric power systems is proposed in this paper. The operation of the Anti windup PI controller is based on avoiding the unwanted Windup phenomenon of Proportional Integral controller. The interconnected thermal power plants are proposed in this paper. With the enlargement of power system size and capacity, it is frequently observed that large tie-line power deviations and sustained power oscillations under sudden system load changes cause instability. Conventional controller like PI controller is analyzed for stability in many researchers but it does not satisfy the stability of the system. It necessitates the proposal of advanced controllers like Fuzzy Gain Scheduling controller and Anti windup PI. The operation of the Fuzzy Gain Scheduling controller is based on the online tuning of gains of Proportional Integral controller. Performance of Conventional controller and proposed controllers are compared under small step perturbation using MATLAB / Simulink. Effects of load disturbance on frequency and tie line power are analyzed with governor nonlinearity.

INTRODUCTION

The major expectation of electricity consumer is quality power. Frequency plays vital role in maintaining quality of power. In a large scale power system many power plants are connected together to meet the load. It is done through tie line. When more than one power systems are connected, it is essential to maintain frequency and power flow in tie line without deviations in the case of load disturbance. Load is the device that consumes energy. It varies continuously depending on requirement of the consumer. The sudden change in the load varies the frequency of the power system. Frequency change in power system causes power deviation at different rates in multi system results power flow in tie line. To guarantee the stability of the system Automatic Generation controller is implemented in power generation control (Ibrahim, P.K and Ahmad S., 2004),(Nanda.J *et al*., 2006). During Load variation AGC controls by various control schemes such as PI, improved PI controller regulates the power generation to meet the load. It continuously monitors the status of the load and distributes the load with respect to the rating of the system.

The system can be controlled by using a conventional PI controller. It can reduce the steady state error. But the PI controller produces an overshoot which results frequency variations (Mangla A., and Nanda J., 2004). In this paper Ziegler Nicholas's method of tuning is implemented in PI controller (Cohn N., Feb.1957). To deal with the uncertainties of load disturbance Fuzzy logic controller is analyzed in many researches (Talaq J. and Al-Basri F., 1999) (Indulkar C. and Raj B., 1995) analyzed the performance AGC using a fuzzy logic controller. In this paper Fuzzy Gain Scheduling controller is proposed to control AGC in the interconnected power system. The Fuzzy Gain Scheduling controller was introduced for process control in 1993 (Zhen-Yu Zhao *et al*., 1993). It is analyzed that it is suitable for linear and nonlinear system (Mieczysław .A *et al*., 2002). Many researchers analyzed that fuzzy gain scheduling is suitable for all applications like drives (Ismail Khalil Bousserhane, 2007) and process control (Blanchett T.P *et al*., 2000), (Farzin Piltan *et al*., 2011) . The processing time of the FLC is based on a number of rules. It confines usage of FLC. Apparently no researches in thermal-thermal interconnected system all are hydrothermal interconnected system. So it necessitates simple and efficient controller with less processing time for thermal-thermal interconnected system. The overshoot is high in a conventional PI controller by the phenomenon of Integrator windup. This variance can be overcome by using the Anti windup PI controller (Srikanth Mandarapu *et al*., 2013). Anti windup PI controller is optimum for all applications like drives and positioning etc., (Hwi-Beom Shin *et al*., 2012), (Xin-lan Li *et al*., 2010),(Wahyudi

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et al., 2004). Based on the performance of Anti windup PI controller in early researches it is proposed in this paper to limit the overshoot and to reduce the settling time. Integral windup type anti windup PI controller is proposed in this paper. It has the advantage of less processing time.

2. Thermal-Thermal Interconnected Power System:

The general block diagram of two areas interconnected thermal-thermal system is shown in fig 1. Matlab R2011b (MATLAB User Manuals) has been used to study the system. Performance analysis concentrates on frequency deviation in system 1(Δf1), System 2(Δf2) and tie line power deviation (ΔPtie). To study the system response 1% load disturbance is applied in both areas.

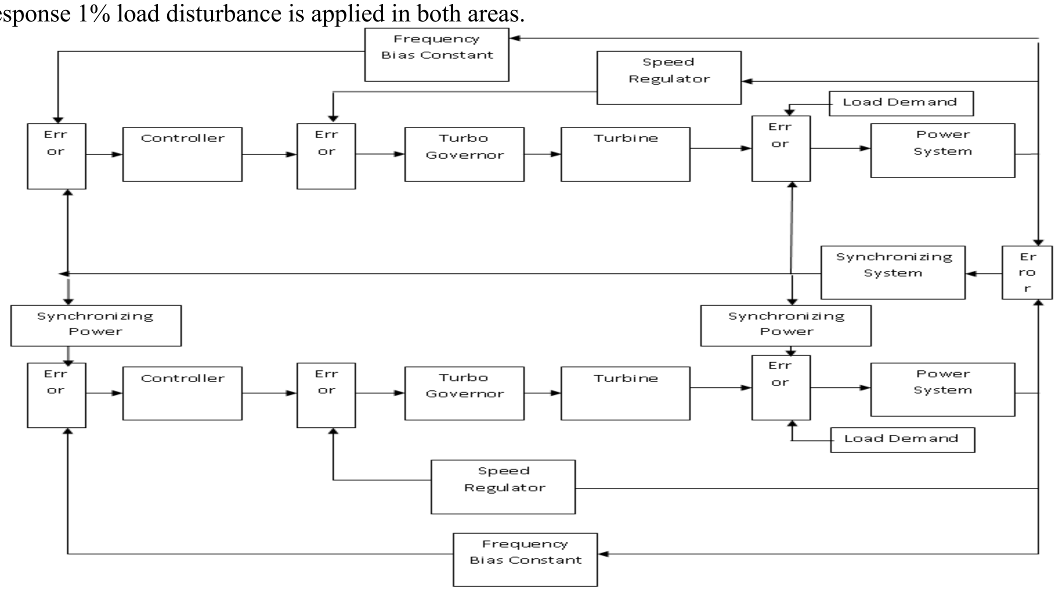


Fig. 1: Two Areas interconnected Thermal-thermal System.

MATLAB Model of the two area system with AGC is shown in fig.2. AGC is the closed loop control system and replaces manual control. The main target of the AGC is to eliminate the steady state frequency error caused by step load perturbation in all areas and tie line. Each system regulates them and supports another system which cannot control its own fluctuations.

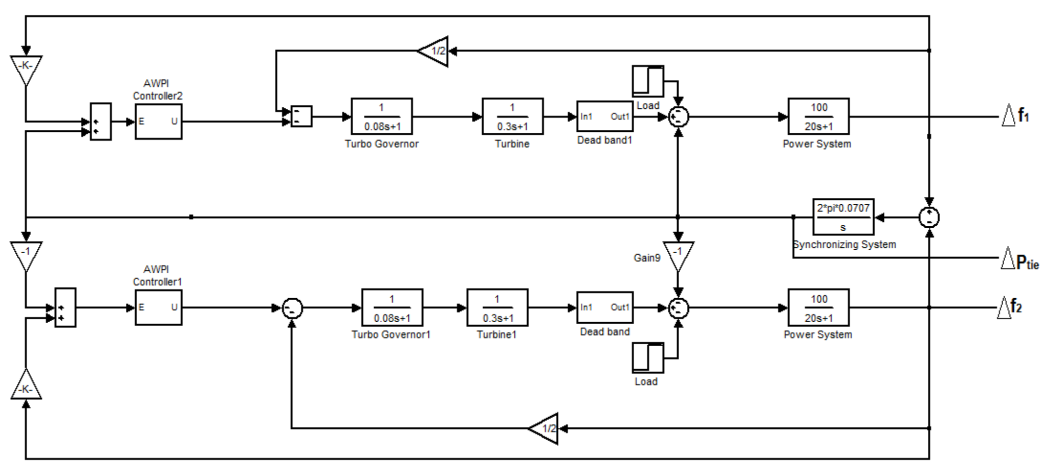


Fig. 2: Two Areas interconnected thermal-thermal System with AGC.

Active power generated by the both thermal systems depends upon the speed of the turbine. Speed governor controls the speed of the turbine in thermal systems. The speed governor function is stated by the Equation (1). Change in frequency in a system is caused by lack of power in that system. It is sensed by AGC and it controls the speed of turbine to satisfy the requirement. Flow of steam determines the turbine power. In this paper a single non reheat turbine is used to consider for its flexible and reliable design. Its governing equation is stated as (2). The speed governor dead band has an enormous effect on the dynamic performance of the electric energy system. For more rational analysis the governor dead band has to be included which makes the system non-linear. The proposed method is applied to inspect the effect of dead band on the dynamic performance.

$$\Delta P_g(S) = \Delta P_{ref1}(S) - \frac{1}{R_1}\Delta f_1(S) \quad (1)$$

Where R1 and R2 are Speed regulation of thermal system

$$\Delta P_T(s) = \frac{1}{1+sT_T}\Delta P(s) \quad (2)$$

Where T_T is the Non reheat turbine time constant

Load disturbance changes generator power. Equation (3) shows deviation

$$\Delta P_T(s) - \Delta P_{D1}(s) = \frac{K_P}{1+sTp}\Delta f1(s) \quad (3)$$

Where T_p is the Power system time constant and K_p is the Power system gain constant.

Two Thermal systems are connected through the interconnection called Tie line (Cohn N., Feb.1957). It supports the continuous supply to the load. The equation of tie line is expressed as

$$\Delta P_{tie1,2} = \frac{2\pi T}{s}(\Delta f1(s) - \Delta f2(s)) \quad (4)$$

3. Conventional PI Controller:

The conventional PI controller is the simplest method of control and widely used in industries. Proportional plus Integral Controller increases the speed of response. It produces very low steady state error. In this paper Area Control Error (ACE) is given as input to PI controller and output is taken into the system. General equation of the PI controller is

$$U(s) = K_p E(s) + \frac{K_i}{s}E(s) \quad (5)$$

Where K_p is proportional gain, K_i is the integral gain, E(s) is the controller input and U(s) is the controller output. Fig 3 shows the block diagram of PI controller.

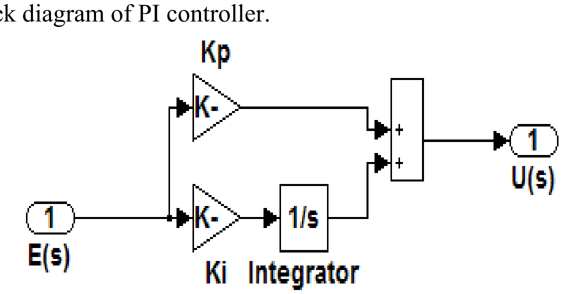


Fig. 3: PI controller.

Ziegler Nichols' method of tuning is adopted to find the optimum value of K_p & K_i values. But the hitch of this controller is, it produces high overshoot and long settling time.

4. Fuzzy Gain Scheduling Controller:

The fixed value of Kp and K_i in a PI controller produces a sudden change in frequency. Online tuning of K_p and K_i in a PI controller can conquer this problem. It necessitates the Fuzzy Gain Scheduling controller for online tuning of K_p and K_i (Zhen-Yu Zhao *et al*., 1993). Fuzzy logic controllers (FLCs) have been an interesting and good alternative in a more power system applications (Indulkar C. and Raj B., 1995), (SwainA.K., 2006). Their advantages are robustness, a non requirement of a mathematical model, and acceptance of non linearity. In order to implement the fuzzy logic control algorithm in an interconnected power system, frequency deviation is sensed and given to the fuzzy gain scheduling controller.

In a Fuzzy Gain Scheduling controller Fuzzy logic module is considered as a self tuning module for parameters K_p and K_i in PI controller. The Fuzzy PI controller considers the major contribution of this research.

The fuzzy inference of fuzzy Gain Scheduling controller is based on the fuzzy associative matrices. The calculation speed of the controller is very quick, which can satisfy the rapid need of the controlled object. The block diagram of control system is shown in Figure 4.

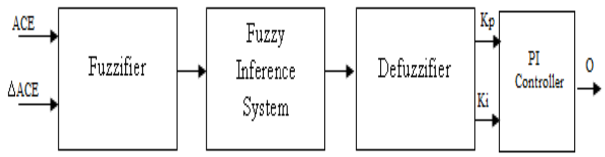


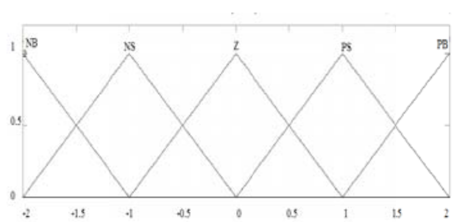
Fig. 4: Fuzzy Gain Scheduling controller block diagram.

The control algorithm of traditional PI controller can be described as

$$u(k) = k_p e(k) + k_i \int e(k) \quad (6)$$

Where, k_p is the proportional gain, k_i is the integral gain and e(k) is the voltage error. The design algorithm of Fuzzy PI controller in this paper is to adjust the k_p and k_i parameters online through fuzzy inference based on the current e and ec to make the control object attain the better transient performance.

Area control error "e" and error change rate "ec" are used as fuzzy input and the proportional gain k_p the integral gain k_i are used as fuzzy outputs. The outputs of the fuzzy controller are given to the PI controller which decides the speed of turbine. The degree of truth of E , EC, k_p and k_i are configured as 5 degrees, all defined as {NB, NS,ZO, PS, PB}, where NB, NS, ZO, PS and PB represent Negative Big, Negative Small, Zero, Positive Small and Positive Big respectively. The membership functions of E, EC, KP and KI are triangular distribution functions. The membership function for all variables is shown in Figure 5.



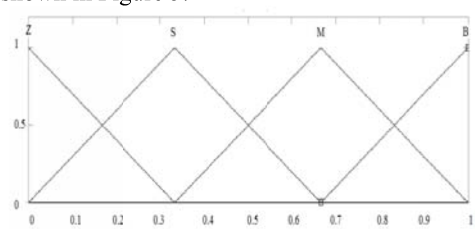


Fig. 5: Fuzzy membership functions of E and EC Figure 6. Fuzzy membership functions of KP and KI.

The principle of designing fuzzy rules is that the output of the controller can make the system output response dynamic and static performances optimal. The fuzzy rules are generalized as Table 1 and Table 2. The Mamdani inference method is used as the fuzzy inference mode. The MIN-MAX method of fuzzification is applied. The centroid method is adopted for defuzzification.

Table 1: The Control Rules for K_p

ec / e	NB	NS	ZO	PS	PB
NB	Z	Z	Z	Z	Z
NS	M	M	M	M	M
ZO	B	B	Z	B	B
PS	S	M	M	M	M
PB	Z	S	B	B	B

Table 2: The Control Rules for K_i

ec / e	NB	NS	ZO	PS	PB
NB	B	B	B	B	M
NS	M	B	S	S	S
ZO	M	B	Z	S	B
PS	S	S	S	S	S
PB	M	B	B	M	B

The fuzzy Gain Scheduling controller reduces the amplitude of oscillations in frequency error. But the settling time to reach zero error is comparatively high. It necessitates a controller to reduce amplitude of oscillation as well as settling time.

5. Anti Windup PI Controller:

Integrator windup phenomenon in a PI controller produces a large overshoot. In order to avoid the unwanted Windup phenomenon, a maximum Integrator output value will be kept within limits; a strategy which is known as Anti-Windup (AW). The anti windup PI controller is proposed in this paper to reduce peak overshoot and settling time. It is similar to the PI controller except that the integral controller has feedback from the output. There are several methods in an anti wind up pi controller such as AWPI with dead zone, AWPI conditioned, AWPI tracking and AWPI tracking with gain. In this study AWPI tracking is proposed which has less overshoot and faster settling time.

Feedback is difference of output from before and after saturation. Feedback gain is referred as (Anirban Ghoshal and Vinod John, 2010).

$$F(s) = \frac{1}{K_P} \quad (7)$$

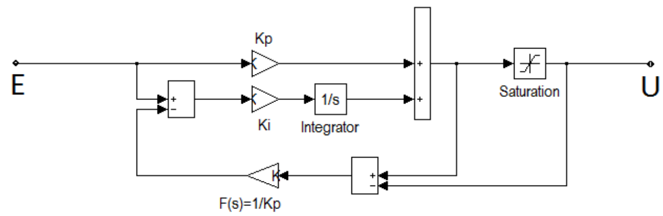


Fig. 7: Anti Wind Up PI controller.

Anti windup PI controller with the effect of saturation improves the system performance by allowing it to operate in the linear region most of the time and recover quickly from nonlinearity. It reduces frequency oscillation as well as settling time.

6. Results and Analysis:

Two area thermal- thermal interconnected system simulations were analyzed using MATLAB R2011b software. First we focus on a conventional PI controller. Then the same system is analyzed using an anti windup PI controller and fuzzy Gain Scheduling controller. The decisive factors considered in this paper are settling time and overshoot. To examine the performance of the plant, in this paper both thermal systems are disturbed by 1% step load. Table 1 shows the parameters of the system considered.

Table 1: Parameters of Power Plant.

R1, R2	2Hz/p.u.M.W
T_T	0.3 Sec
T_H	0.08 Sec
K_p	100
T_p	20 Sec
A_{12}	-1
T	0.0707
B	0.425 p.u.M.W / Hz

Figure 8, Figure 9 & Figure 10 shows the frequency deviation in system1, system2 and Tie line of the two areas under PI control. Figure 11, Figure 12 & Figure 13 shows the frequency deviation in system1, system2 and Tie line of the two areas under fuzzy gain scheduling controller. Figure 14, Figure 15 & Figure 16 shows the frequency deviation in system1, system2 and Tie line of the two areas under Anti windup PI control.

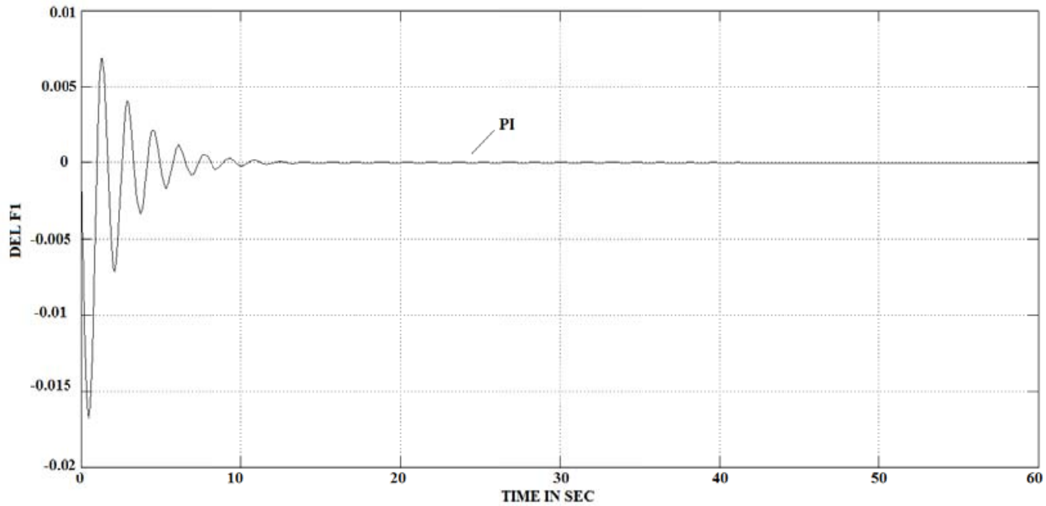


Fig. 8: Frequency deviations in system 1 using PI.

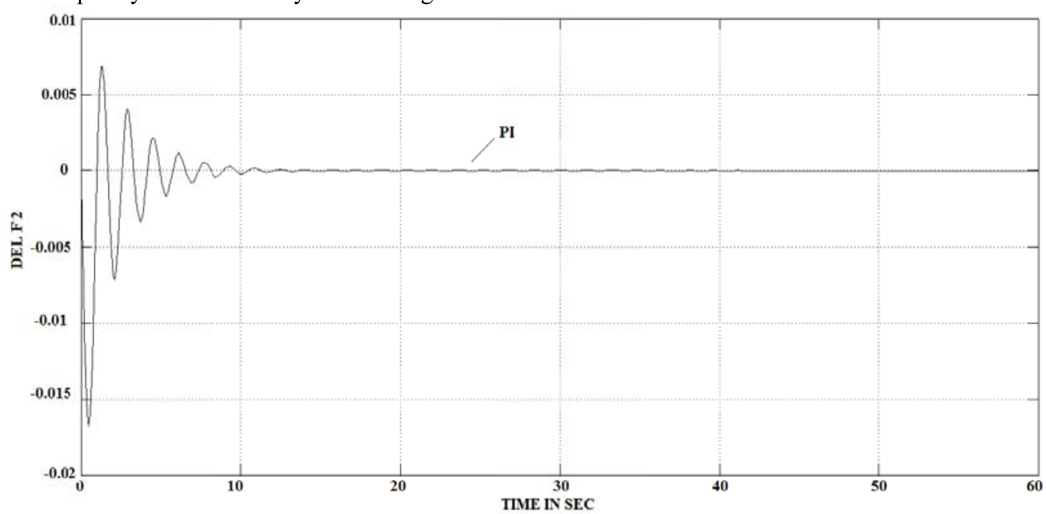


Fig. 9: Frequency deviation in system 2 using PI.

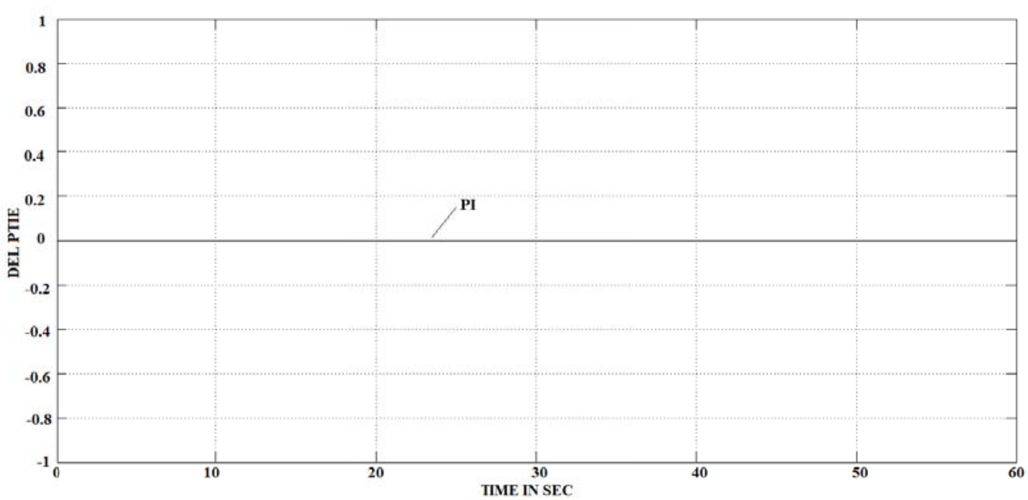


Fig. 10: Power deviation in tie line using PI.

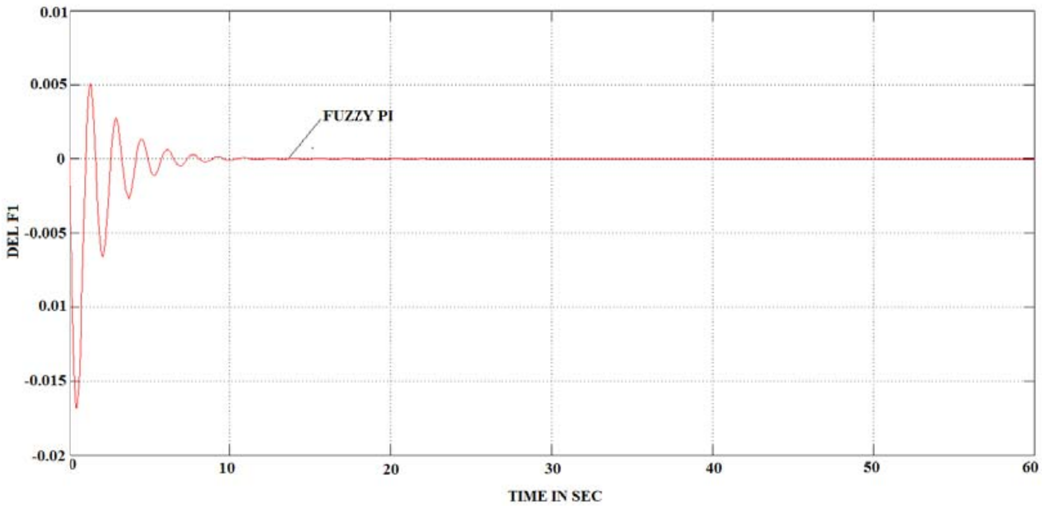


Fig. 11: Frequency deviation in system 1 using Fuzzy Gain Scheduling controller.

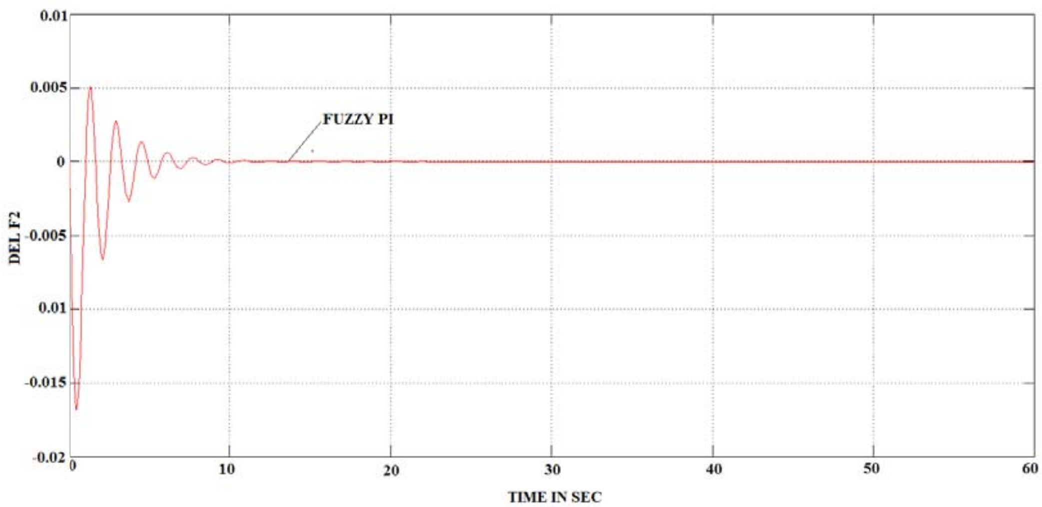


Fig. 12: Frequency deviation in system 2 using Fuzzy Gain Scheduling controller.

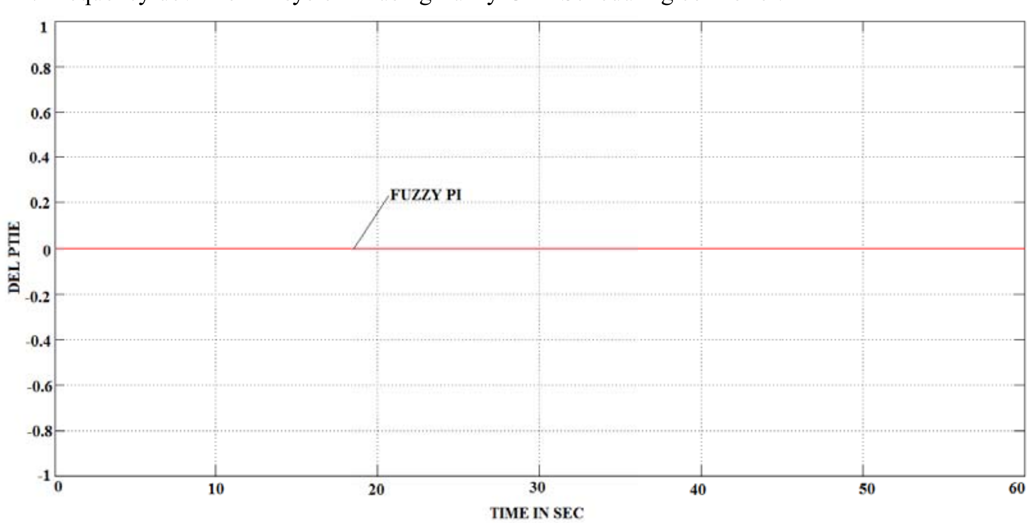


Fig. 13: Power deviation in tie line using Fuzzy Gain Scheduling controller.

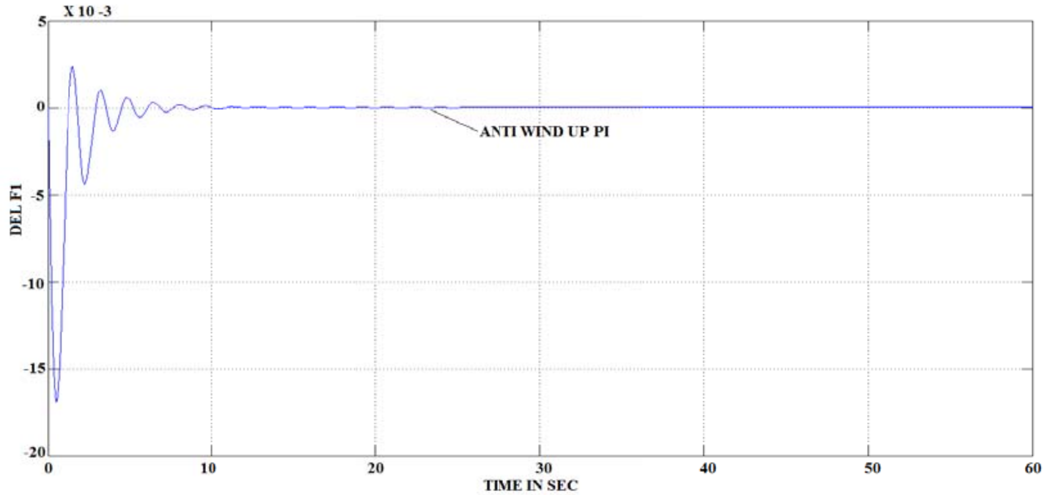


Fig. 14: Frequency deviation in system1 using AWPI.

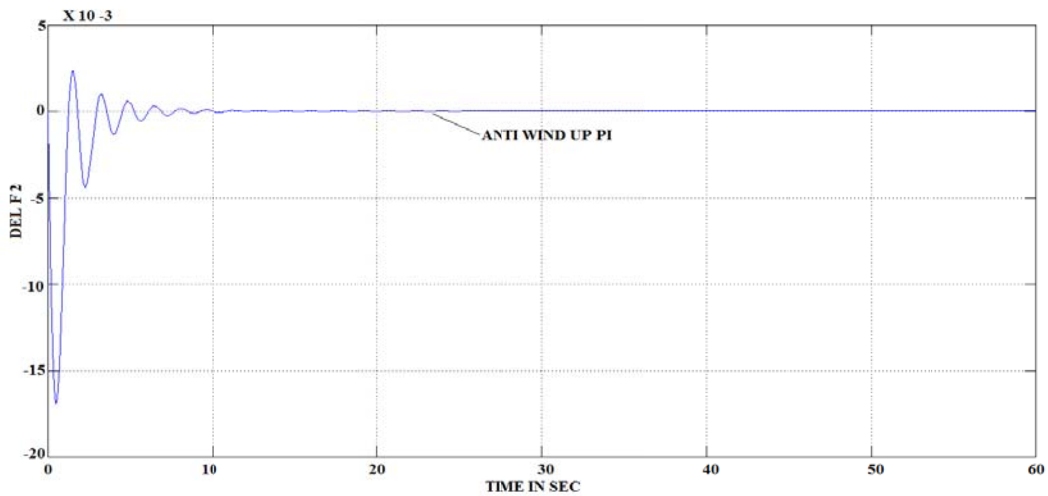


Fig. 15: Frequency deviation in system 2 using AWPI.

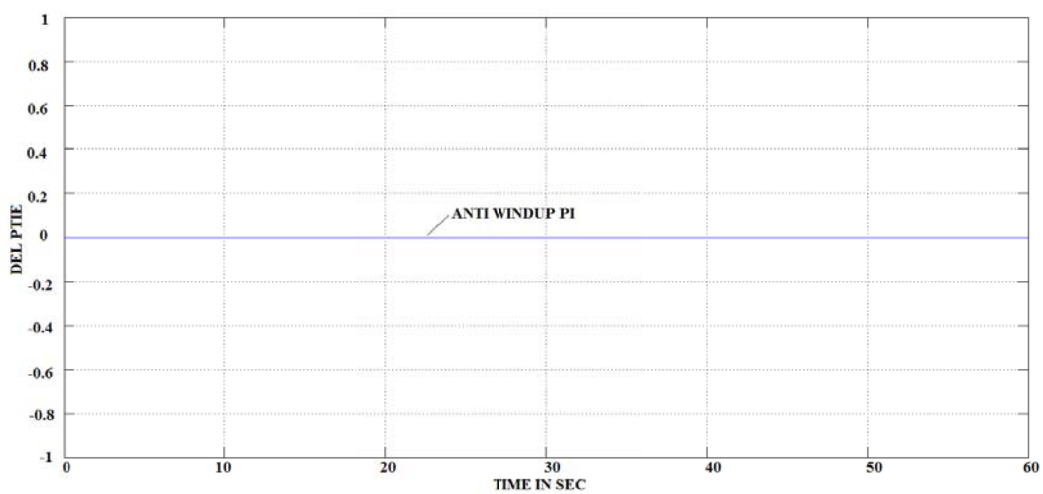


Fig. 16: Power deviation in tie line using AWPI.

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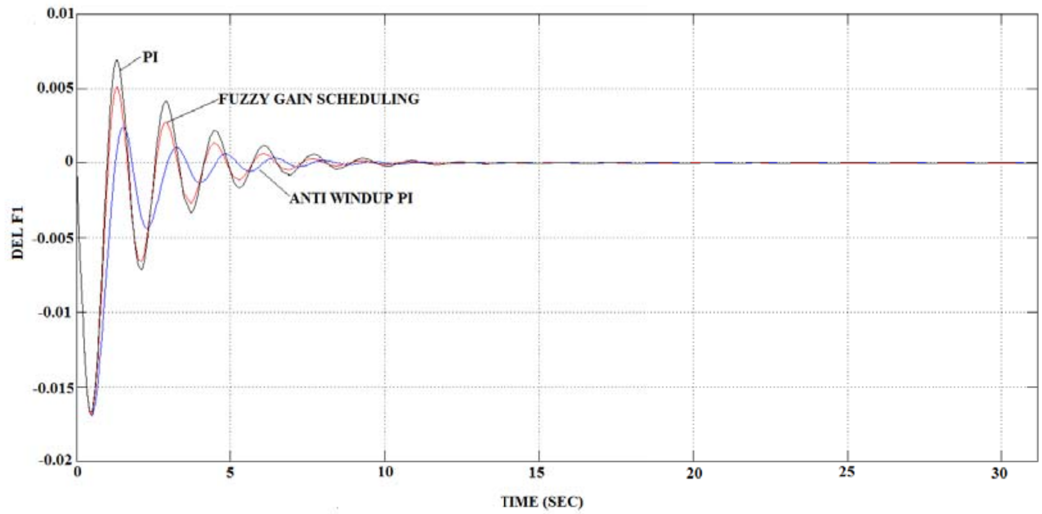

Fig. 17: Comparison of frequency deviation in system 1 using PI, Fuzzy Gain Scheduling &AWPI controller.

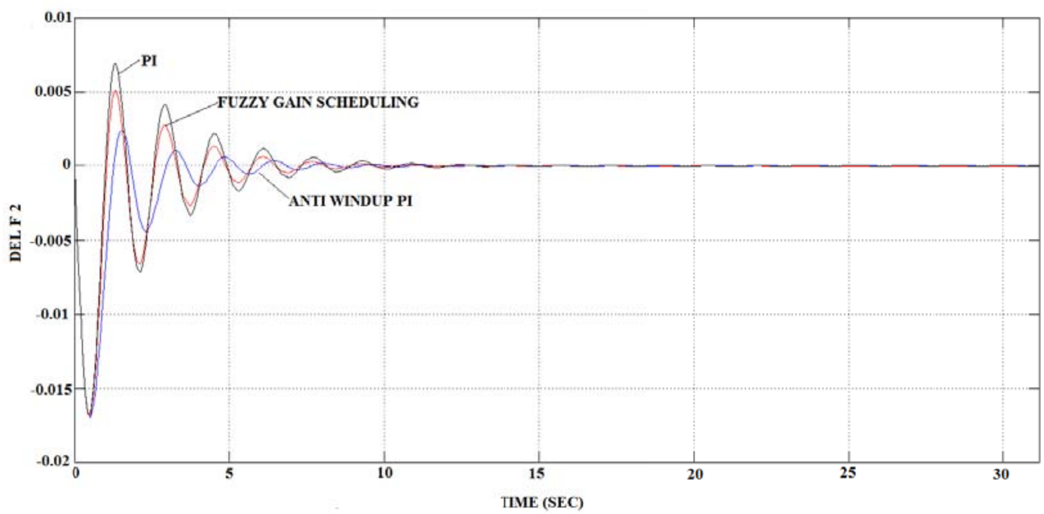

Fig. 18: Comparison of frequency deviation in system 2 using PI PI, Fuzzy Gain Scheduling &AWPI controller.

Comparison of frequency deviation of three controllers in system 1 and system 2 are shown in Figure 17 & Figure 18 respectively. Table II shows performance comparisons of various controllers.

Table II: Comparison of controller performance.

Controller	Overshoot Δf in Hz	Settling Time in Sec
PI	0.0068	25
Fuzzy Gain Scheduling controller	0.005	30
AWPI	0.0024	20

7. Conclusions:

In this study load frequency control on two area thermal- thermal interconnected system is analyzed. Initially the system is analyzed using a PI controller designed using Zeigler Nicholas' method. By observing these results PI controller reduces steady state error. But it has over shoot and long settling time. Then the Fuzzy Gain Scheduling controller is implied to improve performance of the system. It is an online tuning of controller gains and delivers reduces overshoot and increased settling time. To enhance the performance of system Anti windup PI controller is applied to the system. It is an integral windup method of control and it produces very less overshoot and settling time. All controllers are analyzed with the same load disturbance. From all above results it is obvious that Anti windup PI controller has better performance than other two controllers in frequency deviations and tie line power deviations.

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