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ORIGINAL RESEARCH ARTICLE

LOAD FREQUENCY CONTROL USING CLASSICAL CONTROLLERS

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ABSTRACT

This paper presents a solution to the problem of load frequency control of a two area power system using PI and PID controllers. In electric power systems, the load demand varies at different times of the day and these load variations lead to changes in frequency of the power system. In an interconnected power system, the tie-line power also varies in addition to the frequency variations. These changes in frequency and tie-line power causes instability in the power system network and make it unreliable. Load frequency control therefore ensures that these changes in the tie-line power and frequency of the control areas are minimized with acceptable level of overshoot and settling time. The method used involves the modeling of the two area interconnected power system using Matlab/Simulink software, the PI and PID controllers were then tuned using the Ziegler-Nichols tuning rule and used to simulate the two area power system when a load change of 0.2pu occurred in control area one. The simulation results showed that both the PI and PID controllers were able to restore the changes in tie line power and frequency of the control areas caused by the change in load to their steady state values of zero but the PID controller has better dynamic performances of overshoot, rise time and settling time than the PI controller.

1.0 Introduction

Automatic Generation Control (AGC) or Load Frequency Control is a very important issue in power system operation and control for supplying sufficient and reliable electric power with good quality (Prakash and Sinha, 2011). This is because most electric power systems nowadays are made up of different generating stations connected to each other through the tie-line conductors to form an interconnected power system which is centrally controlled at the control centres or stations. Each generating station is referred to as a control area. The Successful operation of an interconnected power system requires the matching of total generation with total demand and associated system losses (Arivoli *et al.*, 2011). Thus whenever there is a load change in one control area, the different control areas interconnected with the affected area will share in the load change through the action of the tie-line and controllers. This change in load will lead to changes in the tie-line power and frequency of the control areas. These changes are undesired and should be restored back to their steady state values as soon as possible. Also, if any of the generating stations is out of service due to fault or maintenance, its own area would still be supplied with electricity till the generating station is brought back to service. Thus, interconnected power system ensures continuity, reliability and stability of the power system.

The random changes in load demand in electric power systems affects the active and reactive power balance of the electric power system. Both the active power balance and reactive power balance must be maintained between the different areas and the loads. Active and reactive powers have a combined effect on the frequency and voltage of the power system. Frequency depends on active power while voltage depends on reactive power, thus. the control problem of voltage and frequency can be separated into two. These are: Reactive power and voltage control and Active power and frequency control (Ganesh *et al.*, 2012). Therefore, voltage and frequency controllers are required to maintain the generated power quality in order to supply constant voltage and frequency to the utility grid (Kumar *et al.*, 2015). Load frequency control is thus the regulation of the power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading or a relation of these to each other so as to maintain the schedules system frequency and/or the established interchange with other areas within predetermined limits. (Surya and Sinha, 2010). It is very important for the right operation of the interconnected power system and requires the maintenance of a balance between the active power produced and that consumed. Also generator turbines are designed to operate at very precise speed and micro controllers are dependent on frequency for their timely operation (Kumar and Naidu, 2014). As the load demand keeps on increasing and decreasing during the steady state operation of the power system, the tie-line power flow should be maintained at a specified value irrespective of these load changes. This requires the manipulation of the operation of the valves of the governor with suitable control strategy so that constant speed can be maintained and the real power output of the generators controlled (Kansal and Singh, 2012). Thus, the objectives of LFC is to provide zero steady state errors of frequency and tie line power exchange variations, high damping of frequency oscillations and decreasing overshoots of disturbance (Atul and Anant, 2014).

According to the Transmission company of Nigeria, the interconnected power system in Nigeria is made up of 66 buses with 23 grid connected generating stations, transmission lines spanning over 20,000 Km and centrally controlled at the National Control Centre (NCC) Osogbo in Osun state with a transmission voltage of 330KV transmission voltage is 330kV.

In the Nigeria national grid, the changes in frequency are monitored in the control room at the NCC and when there are small changes in load, the frequency is controlled automatically by the action of the speed governors and spinning reserves of the generators.

When the load change in the network is so large that the action of the speed governors and spinning reserves cannot stabilize the system frequency, an alarm will sound to alert the control room operators. The operators will then call the power generating stations to either increase or decrease their generations (depending on whether there was a decrease or increase in frequency). If the load change leads to a decrease in frequency and the generating stations cannot increase generation to stabilize the system frequency, then the control room operators will call the distribution companies to load shed so as to stabilize the system frequency. This control method is completely manual and may take a longer time before the system frequency is stabilized at the nominal value making the power supply system unstable and unreliable. This paper, therefore, aimed at controlling the frequency in an interconnected power system automatically using classical controllers. This is because classical controllers are used widely in industries with a reduced number of parameters to be tuned. Also with the Ziegler Nicols tuning rule for obtaining the parameters of the classical controllers, the plant model is not required but only the unit step response of the plant. The classical controllers that would be considered in this paper are the proportional plus integral (PI) and proportional plus integral plus derivative (PID) controllers. The most widely used classical controller for solving the LFC problem is the PI controller. The PI controller is simpler to implement but it settling time is more and it produces large frequency deviations (Chaturvedi and Dwivedi 2014). Thus the PID controller will be used to overcome the above drawbacks of the PI controller. This is because the PID controller has adequate system response considering the stability requirements and the performance of a system (Abdollah *et al.,* 2015).

2.0 Materials and methods

2.1 Materials

The materials used in this work are the speed governor of a generator, the turbine, the alternator and the tie-line conductor.

2.2 Method

The method involves modeling of the PI and PID controllers. This was followed by the modeling of an uncontrolled or isolated one area power system. The tie-line and the area control error were then modeled, followed by an uncontrolled two area power system. The controllers were then tuned and used for the simulation of the uncontrolled two area power system.

2.3 The Proportional Plus Integral Plus Derivative (PID) Controller

A PID controller is a control loop feedback mechanism commonly used in industrial control systems. It continuously computes an error signal which is a difference between a desired set point or reference signal and a measured process variable. The output of a PID controller is the control input to the plant. Its expression in the time domain according to Ogata (2011), is given in equation (1)

$$U(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt} \qquad (1)$$

Where K_p = Proportional gain, K_i = Integral gain, K_d = Derivative gain and t = time in seconds, e = error signal = reference signal – process output

The derivative and integral of this error signal is computed by the PID controller to produce the control signal. The control signal is sent to the plant and a new output is obtained. This new output is then fed back and compared to the reference to find the new error signal (e), the controller takes this new error signal and computes its derivative and its integral gain and the process continues. By taking the laplace transform of equation (1) we have,

$$U(s) = K_p E(s) + \frac{K_i E(s)}{s} + K_d s E(s) \qquad (2)$$

Thus with its three-term functionality covering treatment to both transient and steady-state responses, proportional integral-derivative (PID) control offers the simplest and yet most efficient solution to many real-world control problems (Ang *et al.,* 2005).

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The block diagram of a PID controller is as shown Figure 1.

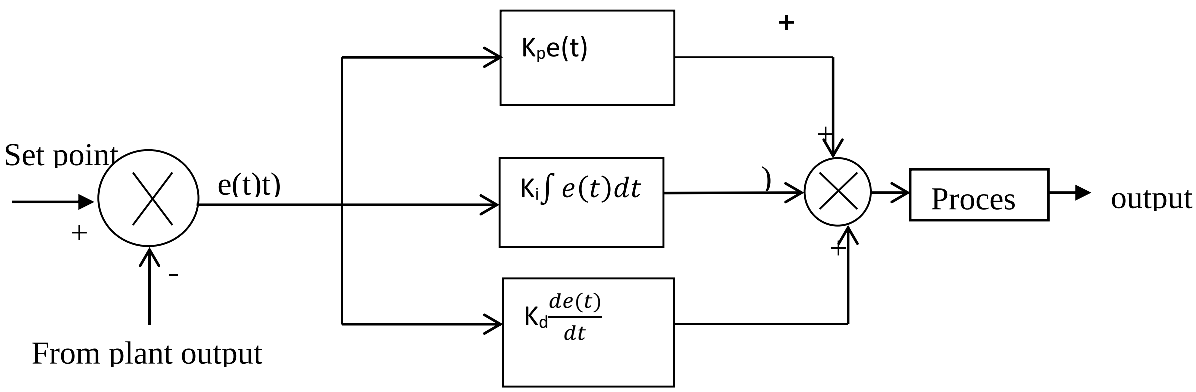

Figure 1: Block diagram of a PID controller (Atul and Anant, 2013)

The transfer function of a PID controller is given by equation (3)

$$G_c(s) = \frac{U_{(s)}}{E_{(s)}} = K_p(1 + \frac{1}{T_i s} + T_d s) \tag{3}$$

Where K_p is the proportional gain, T_i the integral time in seconds and T_d the derivative time in seconds.

2.4 The Proportional plus Integral (PI) Controller

The PI controller is obtained setting by the derivative time (T_d) of a PID controller equal to zero. Its control action according to (Ogata, 2011) is as given in equation 4

$$U(t) = K_p e(t) + K_i \int e(t)dt \tag{4}$$

Where K_p = Proportional gain and K_i = Integral gain
By taking the laplace transform of equation (4) we have equation (5).

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

The transfer function of a PI controller is given by

$$G_c(s) = \frac{U_{(s)}}{E_{(s)}} = K_p(1 + \frac{1}{T_i s}) \tag{6}$$

2.5 One Area Power System

Figure 2 shows the block diagram of an uncontrolled one area power system represented by a single generating unit asall generators in each of the control areas operate with the same frequency. That is, all the generators of the system swing in unison (Arivoli *et al.*, 2011). It is made up of the speed governor, the turbine and a rotating mass or the alternator. R is called the speed regulation of the governor and defined as the ratio of the per unit change in frequency to per unit change in power of the generator.

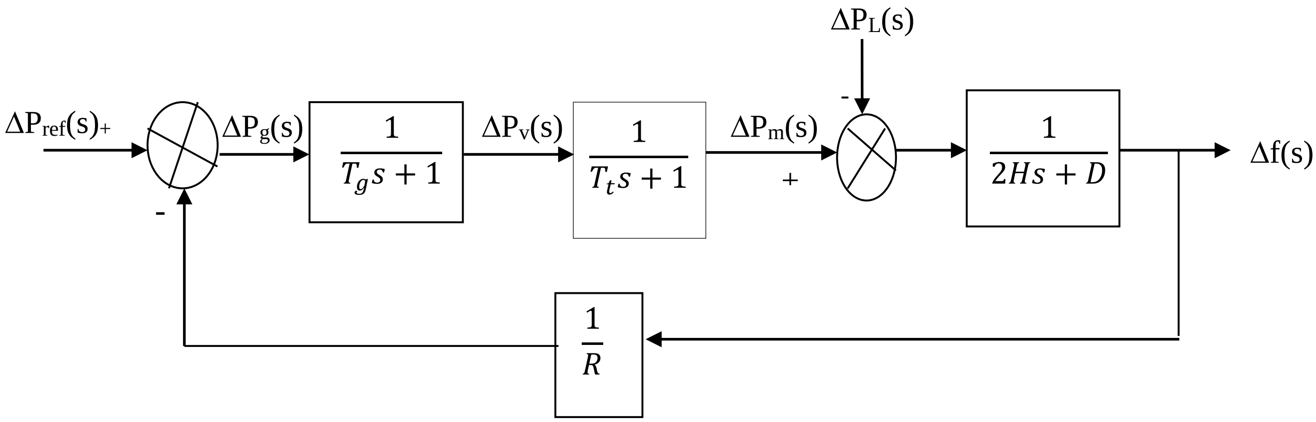

Figure 2: Block diagram of an uncontrolled one area power system (Sateesh *et al.,* 2014)

2.6 Two Area Power System

A control area is characterized by the same frequency throughout. Figure 3 shows the schematic diagram of a two area interconnected power system. The two areas are connected via a tie-line. Tie-lines are useful for exchange of power from one area to the other according to the contract made among them and also provide support during fault condition and thus helps in clearing of the fault (Tandel and Patel, 2017).

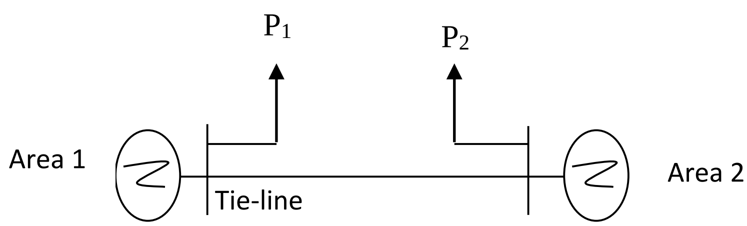

Figure 3: Schematic diagram of a two area power system **(**Gupta, 2011**)**

2.7 Tie-Line Modeling

The power flow over the tie- line in figure 3 from area one to area two in the s- domain according to (Prakash and Sinha, 2011) is as given in equation 7

$$\Delta P_{12}(s) = \frac{2\pi T}{s}[\Delta f_1(s) - \Delta f_2(s)] \tag{7}$$

where $\Delta P_{12}(s)$ = change in power flow from Area I to Area 2 in MW

T = Synchronizing power coefficient, $\Delta f_1(s)$ = Change in frequency of Area I in Hz and

$\Delta f_2(s)$ = Change in frequency of area 2 in Hz

Putting equation (6) in block diagram form gives Figure 4

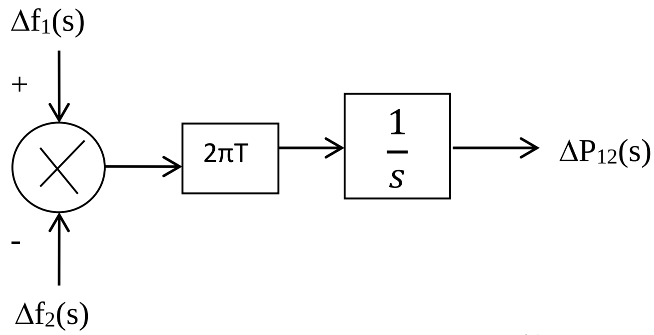

Figure 4: Tie-line model block diagram (Avdhesh *et al.*, 2017)

2.8 Area Control Error (ACE)

As stated in the introduction, the aim of LFC is not only to cancel the frequency error in each area but to also cancel the tie-line power exchange error. The ACE defined as the change in area frequency which when used in an integral loop forces the steady state frequency error to zero (Nilaykumar and Kotwal, 2012). It expression is as given (Sharma *et al.*, 2017) in equation 8

$$ACE_i = \sum P_{ij} + B_i \Delta f_i \tag{8}$$

Where i and j are the areas and B is called the frequency response characteristic of an area and is expressed as $B_i = D_i + \frac{1}{R_i}$
where D is the damping coefficient
For area 1, the ACE is expressed as

$$ACE_1 = \Delta P_{12} + B_1 \Delta f_1 \tag{9}$$

For area two it is expressed as

$$ACE_2 = \Delta P_{21} + B_2 \Delta f_2 \tag{10}$$

Where $B_1 = D_1 + \frac{1}{R_1}$ and $B_2 = D_2 + \frac{1}{R_2}$B
It can be seen that ACE_1= -ACE_2.
Combining the block diagram models of an uncontrolled one area power system, tie-line power and ACE gives the block diagram of the two area power system as shown in Figure 7 together with the controllers (PI and PID). The ACEs are the inputs to the controllers while the change in reference power settings (ΔP_{ref}) are their outputs.

Where$G_p = \frac{1}{2Hs+D}$ and $G_{HT} = \frac{1}{(T_g s+1)(1+T_t s)}$G

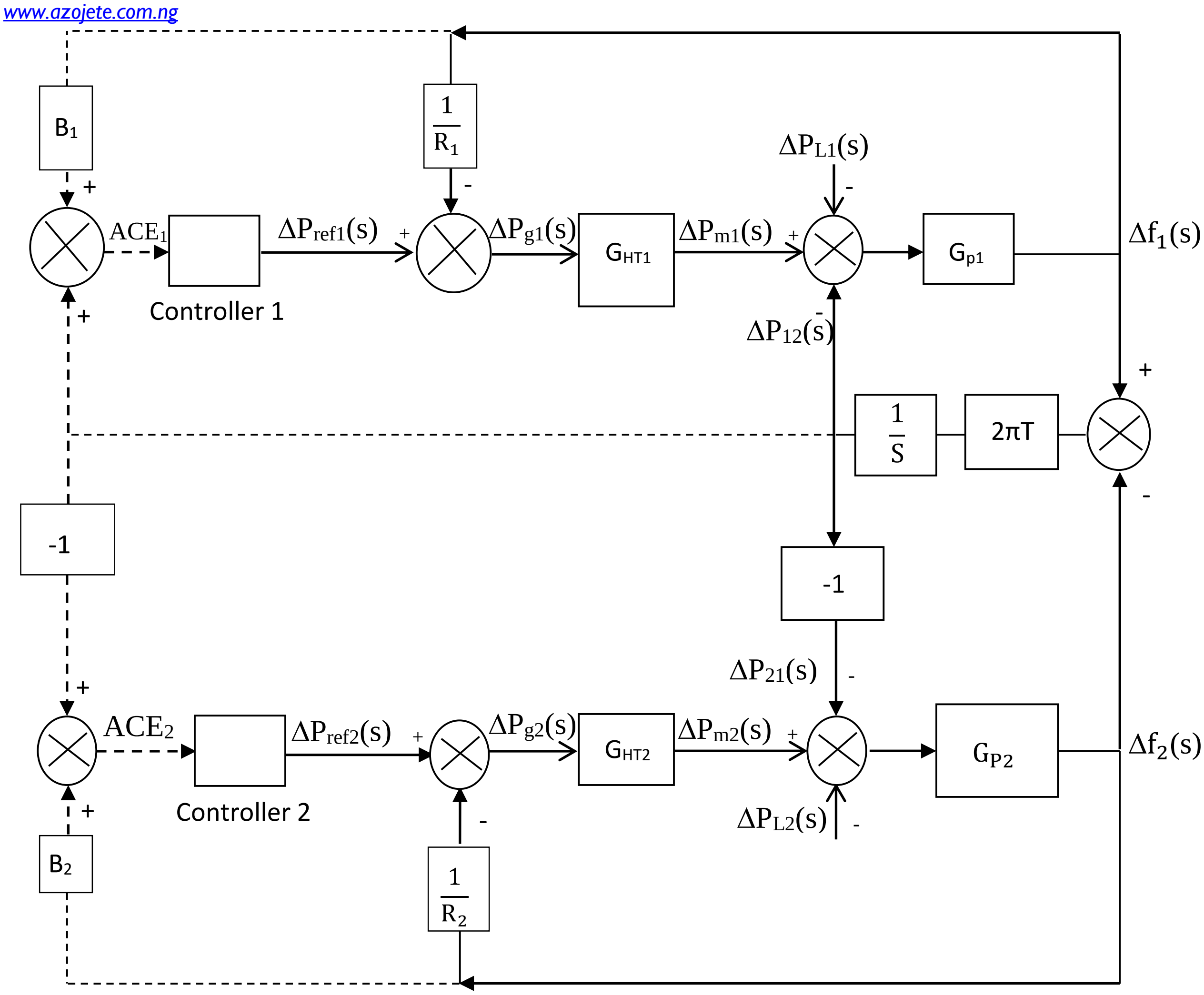

Figure 5: Block diagram of a two area power system with the ACE and controllers

Table 1 shows the control area/simulation parameters for areas one and two

Table 1: Control Area parameters for areas 1and 2

Parameter	Area 1	Area 2
R	0.05	0.0625
D	0.6	0.9
H	5	4
T_g (s)	0.2	0.3
T_t (s)	0.5	0.6

$2\pi T = 2$, Base MVA= 1000, $\Delta P_L = 0.2$pu (Saadat,1999)

2.9 Tuning of the Controllers

In tuning the controllers, that is obtaining the values of the proportional gain (K_p), integral gain (K_i) and derivative gain (K_d), Ziegler-Nichols tuning rule was used and the values of these constants for the control areas are as given in Table 2 for PI and PID controllers respectively.

Table 2: PI and PID constants for control areas one and two

Control area	PI Constants		PID Constants		
	K_p	K_i	K_p	K_i	K_d
one	0.2	0.6	-10	-13	-4
two	-0.1	0.2	-7	-4	-3

3. Results and Discussion

In order to determine the dynamic response of load frequency control of the two area interconnected power system, simulation of the two area power system was carried out using Matlab/Simulink software, first without any controller, then using PI and PID controllers when control area one was subjected to a load change of 0.2pu and the following results were obtained. Figures 6 and 7 show the changes in frequency and tie-line power response of the two control areas respectively without any controller

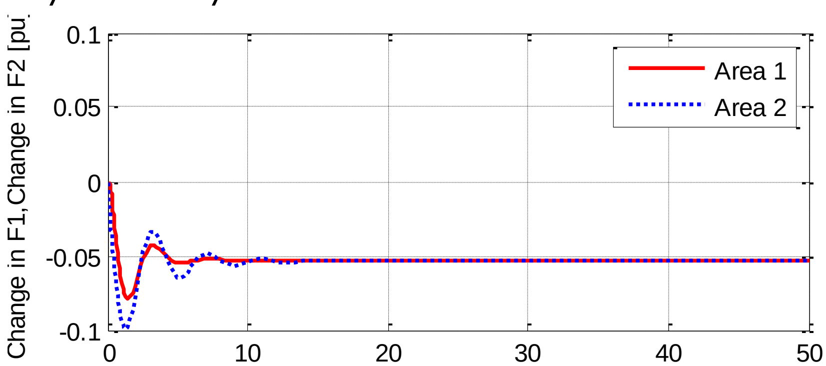

Figure 6: Frequency response of Areas 1 and 2 without any controller

At transient, it was observed that the change in frequency of area one dropped to -0.075pu while that of area two dropped to -0.1pu from their steady state values of zero and were never restored back to their steady state values again but settled on a new steady state value of -0.05pu. The settling time for area one was 4secs while that of area two was 7secs.

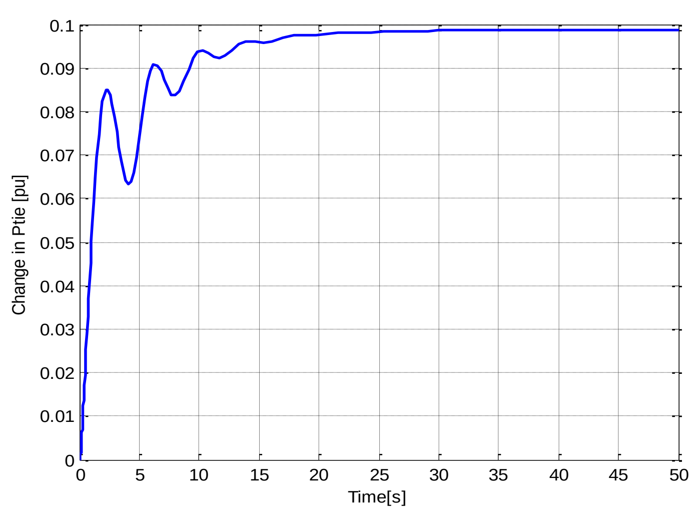

Figure 7: Tie-Line power response of the two area power system without any controller

The change in tie-line power increased from the steady state value of zero with transient oscillations, reached its peak value of 0.1pu at 30secs and never returned to the steady state value of zero but remained in its new steady state value of 0.1pu with a settling time of 15seconds.

Figures 8 and 9 show the change in frequency response of control areas 1 and 2 respectively with the PI and PID controllers.

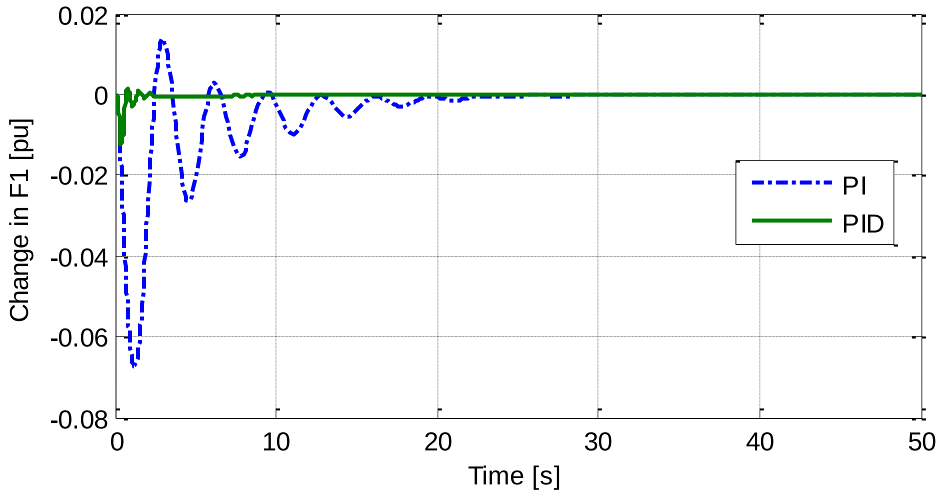

Figure 8: Frequency response of area one using PI and PID controllers

With the PI and PID controllers, it is observed that the change in frequency of control area 1 was restored back to the steady state value of zero unlike in the uncontrolled case. Also the PID controller showed a negligible overshoot while the PI controller had a peak overshoot of 0.012pu. The PID controller had a settling time of 1sec and the PI controller had a settling time of 22seconds. The PID controller had a rise time of 1second while the PI controller had a rise time of 2.5 seconds.

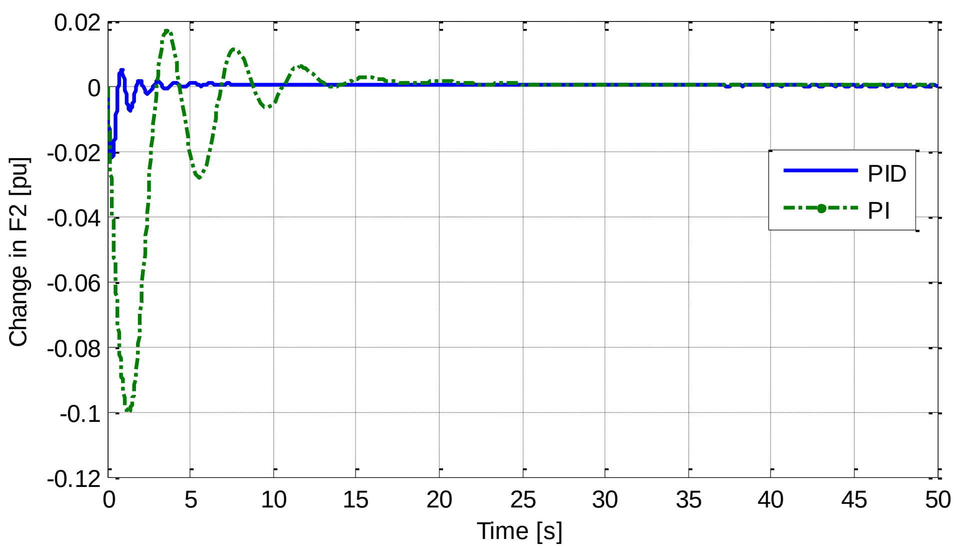

Figure 9: Frequency response of area two using PI and PID controllers

Similarly, in control area two, the changes in frequency were also restored back to their steady state values of zero with the PI and PID controllers as compared to the uncontrolled case. The

PID controller had a peak overshoot of 0.005pu while the PI controller had a peak overshoot of 0.018pu. Also the PID controller had a settling time of 2 seconds while the PI controller had a settling time of 13 seconds. The rise time of the PID controller was 1 second and that of the PI controller was 3 seconds.

Figure 10 shows the change in tie-line power response of the two control areas with the PI and PID controllers.

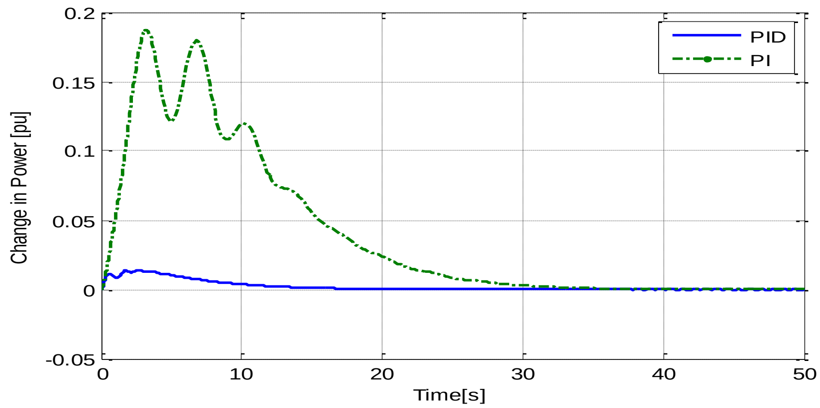

Figure 10: Tie-line power response of the two areas using PI and PID controllers.

The change in tie-line power was restored back to the steady state value of zero with the PI and PID controllers as compared to the case without the controllers. With the PID controller, the peak overshoot was 0.015pu while with the PI controller it was 0.185pu. PID controller had a settling time of 10 seconds and the PI controller had a settling time of 30 seconds.
In Figure 10, the change in tie-line power was restored back to the steady state value of zero with the PI and PID controllers.

Table 3: Summary of the performance of the two controllers in areas 1 and 2

Control area	parameter	PI controller	PID controller
	Peak overshoot(pu)	0.012	negligible
One	Settling time(s)	22	1
	Rise time(s)	2.5	1
	Peak overshoot(pu)	0.018	0.005
Two	Settling time(s)	13	2
	Rise time(s)	3	1

The simulation results obtained show that when a load change of 0.2pu occurred in area one, without any controller, there were deviations in both the change in frequency of areas one and two and the change in tie-line power from their steady state values of zero which were never restored back but instead, new steady state values were obtained for both the change in frequency and change in tie-line power. But with the PI and PID controllers, both the change in frequency of areas one and two and the change in tie-line power were restored back to their steady state values of zero. It was also observed that the PID controller has better dynamic properties of peak overshoots, rise time and settling time than the PI controller. Also the PI controller had more number of oscillations in all the cases at transient than the PID controller.

The simulation results obtained show that when a load change of 0.2pu occurred in area one, the frequency and tie-line power changes caused by the load change never returned to their steady state values of zero in the uncontrolled case but with the PI and PID controllers, these changes in frequency and tie-line power were restored to their steady state values of zero. A comparison of the performance of the two controllers also shows that the PID controller has better dynamic properties of peak overshoots, rise time and settling time than the PI controller. Also the PI controller had more number of oscillations at transient than the PID controller.

4.0 Conclusion

In this paper, a two area interconnected power system was modeled using Matlab/Simulink software package, PI and PID controllers were then tuned and used to simulate the two area power system. From the simulation results, it was observed that when a load change of 0.2pu occurred in control area one, without the controllers, the changes in tie-line power and frequencies of control areas one and two were deviated from their steady state values of zero. But with the PI and PID controllers in the control areas, the changes in the tie-line power and frequencies of the control areas were restored back to their steady state values of zero. A comparison of the performance of the controllers shows that the PID controller has better dynamic properties of overshoot, rise time and settling time than the PI controller.

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