Fuzzy Logic Control Based Load Frequency Control of Multi area Interconnected Power Systems

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Abstract- This work presents decentralized control scheme for Load Frequency Control in a multi-area Power System by appreciating the performance of the methods in a single area power system. A number of modern control techniques are adopted to implement a reliable stabilizing controller. A serious attempt has been undertaken aiming at investigating the load frequency control problem in a power system consisting of two power generation unit and multiple variable load units. The main focus of this work is on the controller to obtain good output frequency responses. The robustness and reliability of the various control schemes is examined through simulations.

Keywords — Fuzzy Logic , Load Frequency control ,Power System Control, tie line, Conventional Control

I. INTRODUCTION

In an electrical power system, LFC is a system to maintain reasonably uniform frequency, to divide the load between the generators, and to control the tie line inter change schedules, and decreasing overshoot of the disturbance so that the system is not too far from the stability[1]. The change in frequency is sensed when the rotor angle delta is changed. The error signals are transformed into real power command signal, which is sent to prime mover to call for an increment in the torque. The prime mover then brings change in the generator output by an amount which will change the values within the specified tolerance.

For large scale power systems which consists of inter-connected control areas load frequency control [2] then it is important to keep the frequency and inter area tie power near to the scheduled values. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle[3]. A well designed power system should be able to provide the acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits. Changes in the power system load affects mainly the system frequency, while the reactive power is less sensitive to changes in frequency and is mainly dependent on fluctuations of voltage magnitude [4]. So the control of the real and reactive power in the power system is divided separately.

II. CONTROLLER STRATEGY

A. P Controller

P controller is mostly used in first order processes with single energy storage to stabilize the unstable process. The main usage of the P controller is to decrease the steady state error of the system. As the proportional gain factor K increases, the steady state error of the system decreases. However, despite the reduction, P control can never manage to eliminate the steady state error of the system. As we increase the proportional gain, it provides smaller amplitude and phase margin, faster dynamics satisfying wider frequency band and larger sensitivity to the noise. We can use this controller only when our system is tolerable to a constant steady state error[5]. In addition, it can be easily concluded that applying P controller decreases the rise time and after a certain value of reduction on the steady state error, increasing K only leads to overshoot of the system response. P control also causes oscillation if sufficiently aggressive in the presence of lags and/or dead time. The more lags (higher order), the more problem it leads. Plus, it directly amplifies process noise.

B. PI Controller

P-I controller is mainly used to eliminate the steady state error resulting from P controller. However, in terms of the speed of the response and overall stability of the system, it has a negative impact. This controller is mostly used in areas where speed of the system is not an issue[6]. Since P-I controller has no ability to predict the future errors of the system it cannot decrease the rise time and eliminate the oscillations. If applied, any amount of I guarantees set point overshoot

C. PID Controller

They play a major role in industrial process control because more than 90 percent of processes in different electrical industries are controlled by PID controllers these days. A proportional integral derivative controller is a control loop feedback mechanism widely used in industrial control systems and a variety of other applications requiring continuously modulated control [7.]A PID controller continuously calculates an error value **e(t)** as a difference between the desired set point and a measured process variable and applies a correction based on proportional, integral and derivative terms. It is also used for minimizing the frequency deviations in the multi area power systems.

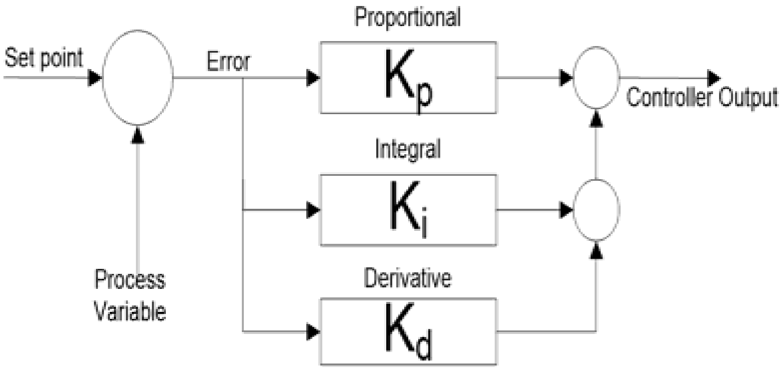


Fig 1: Block diagram of PID controller

D. Fuzzy Logic Controller

The use of fuzzy sets provides a basis for a systematic way for the application of uncertain and indefinite models. Fuzzy set is based on a logical system called fuzzy logic controller. Nowadays, fuzzy logic is used in almost all sectors of industry and science. One of them is the LFC problem [8]. Because of the complexity and multivariable conditions of the power system, conventional control methods may not give satisfactory solutions. On the other hand, robustness and reliability make the fuzzy logic controller useful in solving a wide range of control problems [9].

The FLPI controller to solve the problem consists of a fuzzy logic controller and a conventional PI controller, connecting in series. The fuzzy logic controller has two input signals namely, ACE and ACE* , and then the output signal (y) of the fuzzy logic controller is the input signal of the conventional PI controller. Finally, the output signal from the conventional PI controller called the control signal (u) is used for controlling the LFC in the interconnected power system.

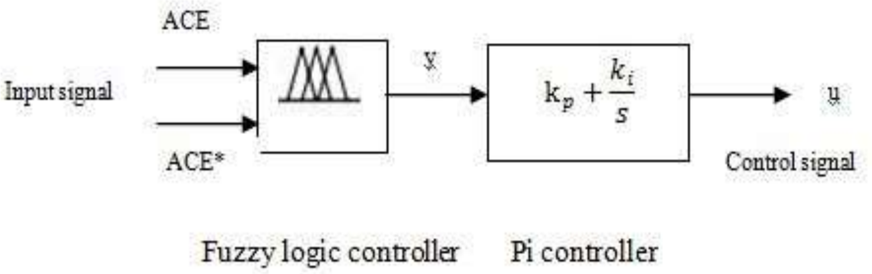


Fig 2: Structure of Fuzzy logic base proportional integral controller.

The fuzzy logic controller is comprised of four main components: the fuzzifier, the inference engine, the rule base, and the defuzzifier, as shown in Fig. 4. The fuzzifier transforms the numeric into fuzzy sets, so that, this operation is called fuzzification. The main purpose of the fuzzy logic controller is the inference engine, which performs all logic manipulations in a fuzzy logic controller. The rule base consists of membership functions and control rules. Last, the results of the inference process is an output represented by a fuzzy set, however, the output of the fuzzy logic controller should be a numeric value. Therefore, fuzzy set is transformed into a numeric value by using the defuzzifier, so that, this operation is called defuzzification.

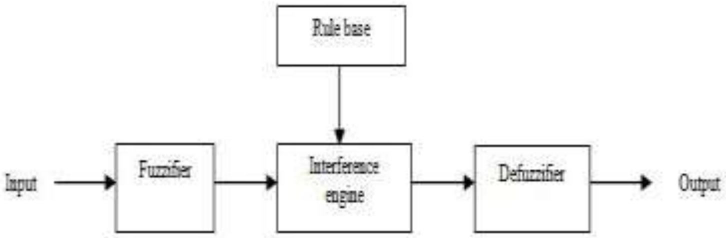
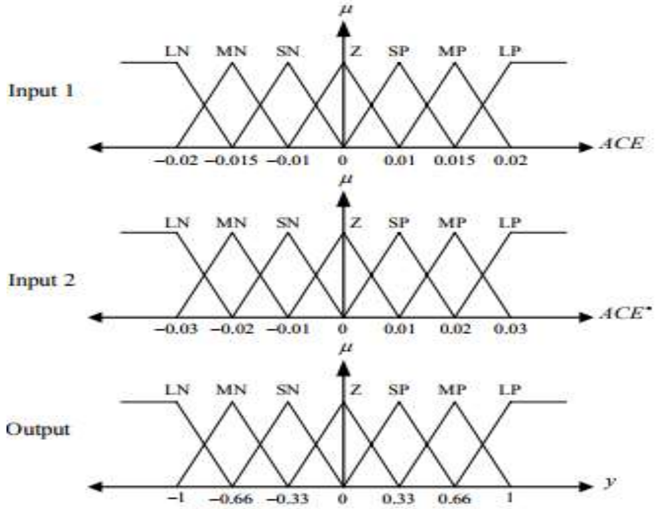


Fig 3: Components of fuzzy logic controller

In designing the FLPI controller, important procedures are how to obtain the PI gains, membership functions and control rules. The PI gains have been determined easily, but the membership functions and the control rules are difficult. The membership functions of the fuzzy logic controller presented in Fig. 5 consist of three memberships functions (two-inputs and one-output). Each membership function has seven memberships, comprising two trapezoidal and five triangular memberships. All memberships are selected to describe all linguistic variables.



LN: large negative; MN: Medium negative; SN: Small negative; Z: Zero; SP: Small Positive; MP: Medium positive; LP: Large positive

Fig 4: Membership function for non optimal FLPI controller

For the determination of the control rules, it can be more complicated than membership functions, which depend on the designer experiences and actual physical system [10]. For the case of two-input and one output, the control rules can be shown graphically in a table when every cell shows the output membership functions of a control rule with the relationship between input 1 and 2. The control rules build from the if-then statement (if input 1 and input 2 then output 1). Table 1 indicates the appropriate rule bases in this study. Let us consider the third row and fourth column in Table 1, that means, if ACE is SN and • ACE is Z then y is SP

ACE/ ACE^*	LN	MN	SN	Z	SP	MP	LP
LN	LP	LP	LP	MP	MP	SP	Z
MN	LP	MP	MP	MP	SP	Z	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

Table1:Rules for non optimal FLPI controller

III. MATHMATICAL EQUATIONS

Swing Equation

A synchronous generator is driven by a prime mover. The equation governing the rotor motion is given by

$$J\frac{d^2\theta_m}{dt^2} = T_a = T_m - T_e \qquad \textbf{N}\text{-m} \qquad (1)$$

J is the total moment of inertia of the rotor mass in **kg-m²**

θ_m is the angular position of the rotor with respect to a stationary axis in **rad**

t is time in seconds **s**

T_m is the mechanical torque supplied by the prime mover in **N-m**

T_e is the electrical torque output of the alternator in **N-m**

T_a is the net accelerating torque, in **N-m**

Generator Modeling

In power system mathematical model of alternator can be developed using swing equation given by

$$\frac{2GH}{\omega_s}\frac{d^2\Delta\delta}{dt^2} = \Delta P_M - \Delta P_E \qquad (2)$$

Where '*H*' is the inertia constant in MJ/MVA, '*G*' is the rating of the machine in MVA ω_s is the synchronous angular speed in rad/sec, $\Delta\delta$ is change in the rotor angle in rad, ΔP_M and ΔP_E are the change in mechanical input power and electrical output power in MW respectively

$$\Delta w(s) = \frac{1}{2Hs}[\Delta Pm(s) - \Delta Pe(s)] \qquad (3)$$

Load Modeling

Electrical load in power system are generally of two types i.e. load which is independent of frequency known as frequency independent load & load which depends on frequency known as frequency sensitive load. Heating and lighting loads (resistive loads) are generally frequency independent. Whereas motor loads are treated as frequency sensitive loads. Therefore, the total electrical load can be expressed in Laplace transform as:

$$\Delta P_e(s) = \Delta P_L(s) + D\Delta\omega(s) \qquad (4)$$

Where ΔP_L is the non-frequency- sensitive load change,
$D\Delta\omega$ is the frequency sensitive load change.
D is expressed as percent change in load by percent change in frequency measured in Watt/(rad/sec).

Prime Mover Modeling

The source of power generation is commonly known as the prime mover. It may be hydraulic turbines at waterfalls, steam turbines whose energy comes from burning of the coal, gas and other fuels. The model for the turbine relates the changes in mechanical power output ΔPm to the changes in the steam valve position ΔP_V.

$$G_T = \frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1+\tau_T s} \qquad (5)$$

Where τ_T, the turbine constant is, in the range of 0.2 to 2.0 Seconds.

Governor Modeling

In modern power plant there is always a mismatch between generated power and load demand. When the electrical load on a generator suddenly changes with same mechanical input power, the turbine speed changes as a result the frequency of generation also changes. Governor employed in generating system senses this change in speed and accordingly the valve position is changed to adjust the steam in case of thermal power plant and water input in case of hydro power plant to the turbine so as to maintain rated frequency

$$\Delta P_v(s) = \left(\frac{1}{1+sT_g}\right) * \left(\Delta P_{ref}(s) - \frac{1}{R}\Delta w(s)\right) \qquad (6)$$

Where,

$\Delta P_v(s) = \frac{1}{K_g}\Delta Y_E(s)$,$\Delta P_{ref}(s) = \Delta P_C(s)$ and $R = R_1 * 2\pi$ is the speed regulation of the governor.

By observing all the above equations we get individual transfer functions by combining all together we get the following.

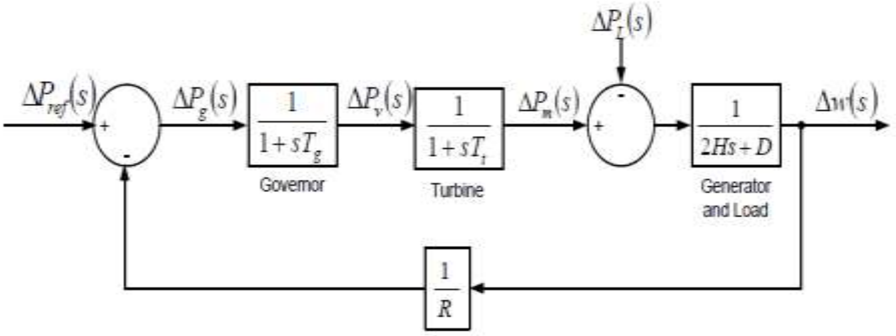


Fig 5: Transfer function model of LFC of an isolated thermal power system

IV MODEL OF TWO AREA POWER SYSTEM

Each area is assumed to have only one equivalent generator and is equipped with governor turbine system. They are the control signals from the controllers we choose.

A two area model is adapted in the work is shown in figure 6

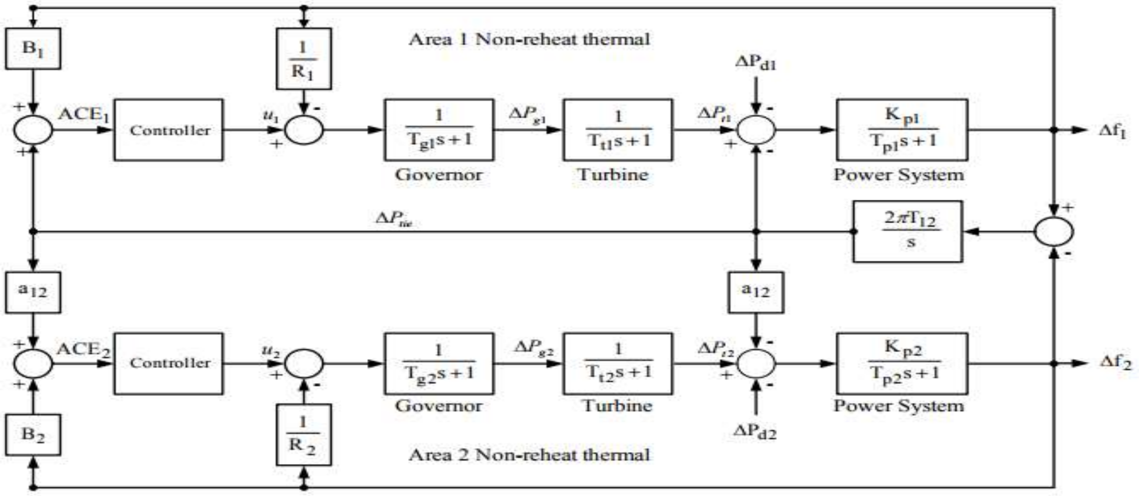


Fig 6: Two-area interconnected power system with controller

The terms showed in the figure 7 are termed given below:
Δf1&Δf2 : Frequency Deviations in Areas 1&2
ΔPtie(1,2):Tie Line Power Deviation in Two Areas Systems
R_1 & R_2 : Regulations of Governors in Areas 1, 2
u_1 & u_2 : Control Inputs in Areas 1& 2
ΔP_{g1} & ΔP_{g2} :Deviations in Governor Power Outputs in Thermal Areas 1 & 2
ΔP_{t1} & ΔP_{t2}: Deviations in Turbine Power Outputs in Thermal Areas 1 & 2
ΔP_{d1} &ΔP_{d2}: Load Disturbances in Areas 1& 2
K_{P1}&K_{P2}: Power System Constants in Areas 1&2
T_{P1}&T_{P2}: Power System Time Constants in Areas 1& 2
B_1 & B_2: Tie Line Frequency Bias in Areas 1&2
T_{12}: Synchronizing Coefficients for Tie Lines between Pair of Areas
For the Two-Area System
T_{g1} & T_{g2}: Governor Time Constants for Thermal Areas 1 & 2
T_{t1} & T_{t2}: Turbine Time Constants for Thermal Areas 1 & 2
a_{12} : Ratio of Rated Powers of a Pair of Areas in the Two Area System

V MATLAB SIMULINK MODEL RESULTS

5.1 Power system model using different controllers

In two area system, two single area systems are interconnected via tie-line. Interconnections established increases the overall system reliability. Even if some generating units in one area fail, the generating units in the other area can compensate to meet the load demand. The PID controller improves steady state error simultaneously allowing a transient response with little or no overshoot. As long as error remains, the integral output will increase causing the speed changer position, attains a constant value only when the frequency error has reduced to zero.

The gain value of different type of controllers using in two area power systems is given in table 2

	Kp		Ki		Kd		Settling time (sec.)
Controller	Area1	Area2	Area1	Area 2	Area 1	Area 2	
I	-	-	0.2742	0.4680	-	-	35
PI	0.1109	0.0121	0.2742	0.2019	-	-	25
PID	0.1109	0.0121	0.2742	0.2019	0.1110	0.003	10

Table2: Different values of gain for different controllers

5.1 Results for integral,pi,pid controllers

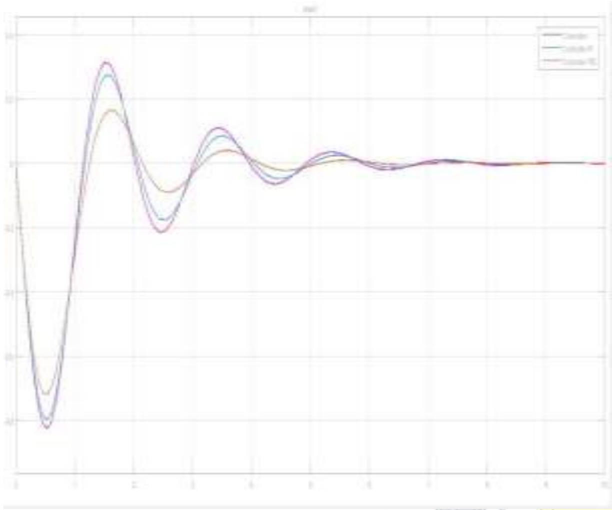


Fig 7:output response of Area1

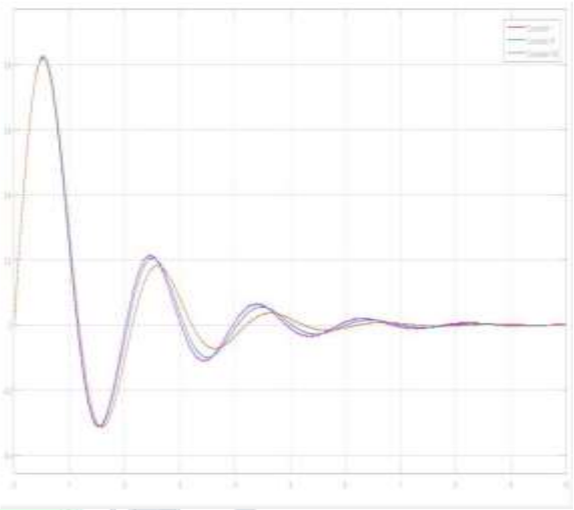


Fig 8 : Output response of Area2

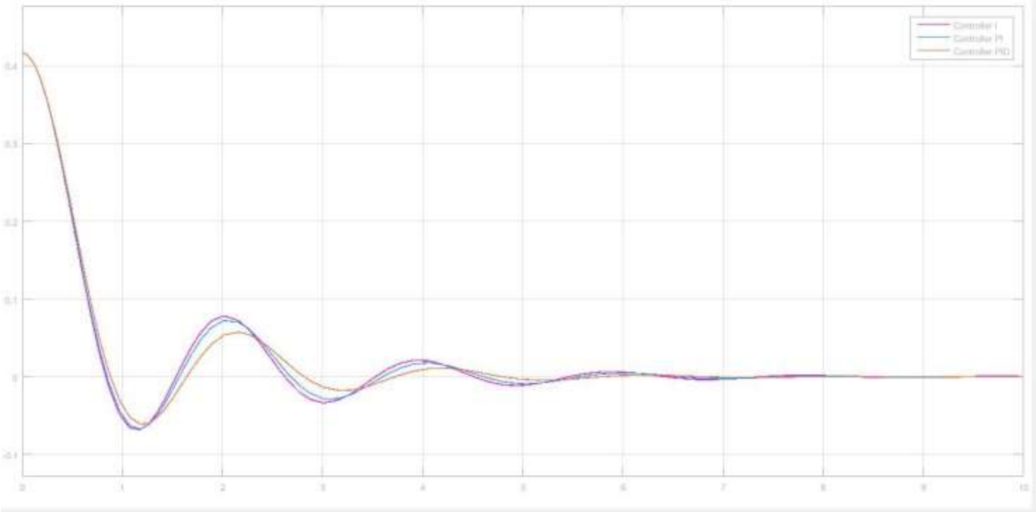


Fig 9:Output response of tie line power systems

5.2 Results for pid,fuzzy logic controller

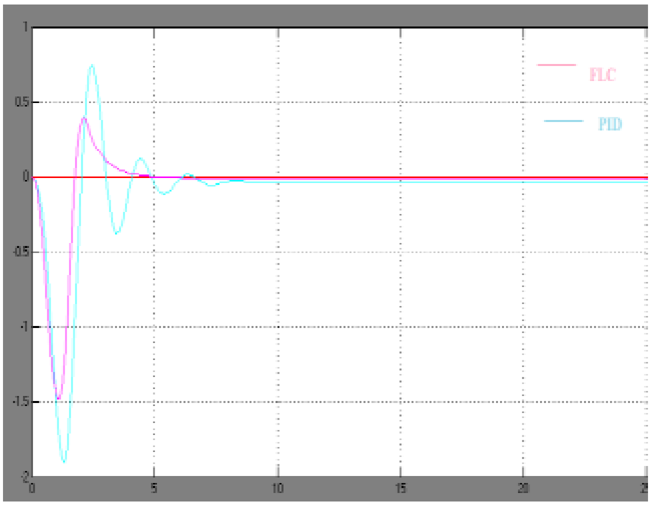


Fig 10: Output response of Area1

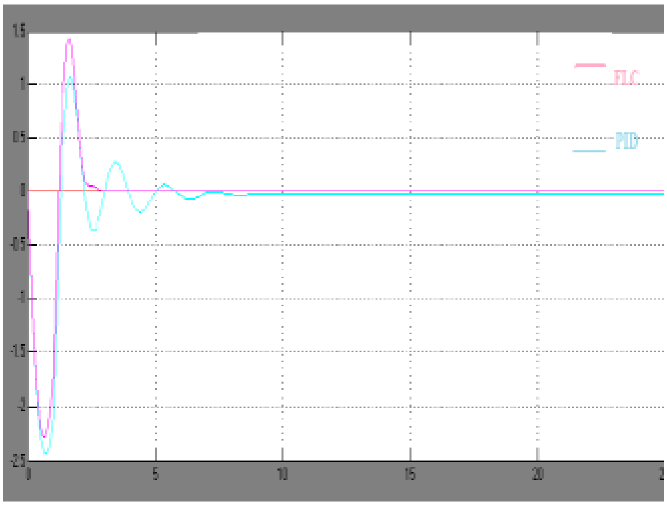


Fig 11 : Output response of Area 2

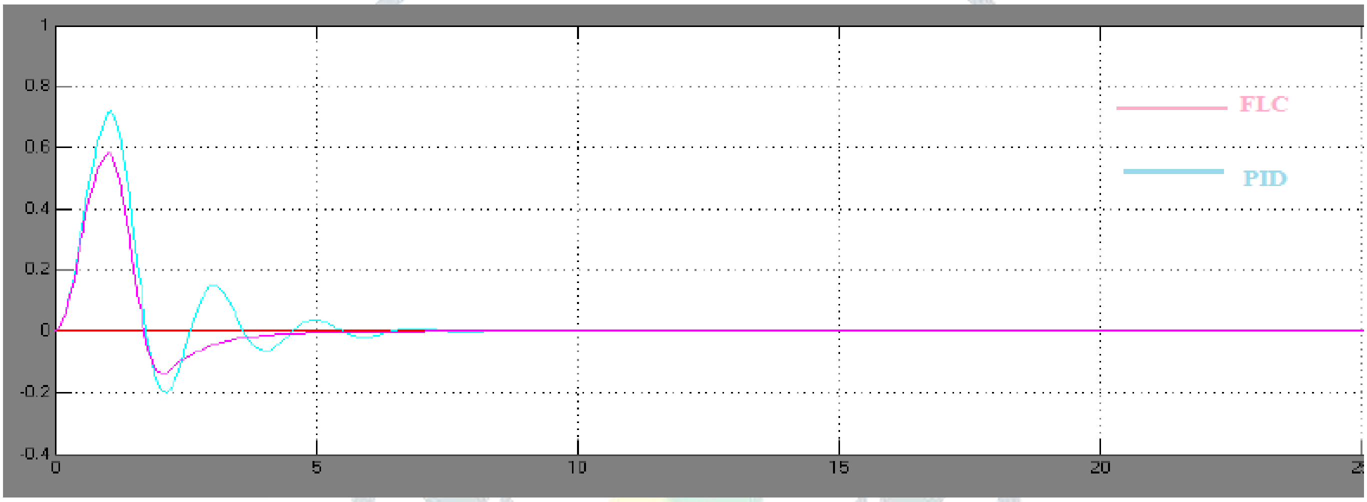


Fig 12 : Output response of tie line power system

APPENDIX

In the following, most of the parameters of the two-area interconnected power system in Fig. 1 are from Refs [12,13] and some parameters have been modified
R1 = R2 = 2.4 Hz/p.u. Tp1 = Tp2 = 20s, K p1 = K p2 =120 Hz/p.u., a12 = −1 , B1 = B2 = 0.425 , T12=0.086 , Tt1=Tt2=0.3s.

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