Automatic Generation Control–An Enhanced Review

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Abstract— *In this paper explanation about automatic generation control and its equivalent model with the help of MATLAB/Simulink. Power system operation active and reactive power demands are never steady and they continually vary with day to day. Generation must, therefore, be continuously changed with the active power demand. Reduce the machine speed will change consequently change in frequency. Power system frequency regulation entitled load frequency control (LFC), as a serious operate of automatic generation control (AGC), one of the necessary control issues in electric power system control and operation. The conventional frequency deviation on the far side bound limits will directly impact on grid operation and system dependability. A frequency deviation will injury equipment's, degrade load performance as a result of the transmission lines to be overload and may interfere with system protection schemes associate degree ultimately result in an unstable condition for the power system. Maintaining frequency and power interchanges with neighbour area is primary objectives of an LFC. The main objectives are to control error signal and it is known as area control error (ACE), that represents the important power imbalance between generation and load, and could be a linear combination of power interchange and frequency deviations.*

Keywords— *Proportional Integral (PI), Area Control Error (ACE), Automatic Generation Control (AGC), Speed Governing System.*

I. INTRODUCTION

ACE is employed to perform associate degree input control signal for a typically proportional integral (PI) controller. Looking on the control characteristics, the ensuing output control signal is conditioned by limiters, delays and gain constants. This control signal is then distributed among the LFC participant generator units in accordance with their participation factors to produce applicable control commands for set points of such that plants. The errors in frequency and net power interchange to be corrected by calibration the integral controller settings. Calibration of the dynamic controller is a vital issue to get optimum LFC performance. Correct calibration of parameters is required to get smart control action. [2]

The frequency control is changing into additional vital these days thanks to the increasing size, the ever-changing structure of complicated interconnected power systems. The controllers are set for a particular operating condition and they are responsible for small changes in the system without change in frequency and voltage exceeding the set limit.[6] Therefore, in the modern interconnected grid, LFC plays a basic role, as associate degree adjunct service, in supporting power exchanges and providing higher conditions for the electricity commerce.[

II. MODEL OF SINGLE AREA SYSTEM

To know the load frequency control drawback, we have a tendency to think about one thermal system activity an isolated load.

For LFC scheme of single generating unit has basically three parts:

A. Turbine speed governing system
B. Turbine
C. Generator and load.[3]

A. Model Speed Governing System

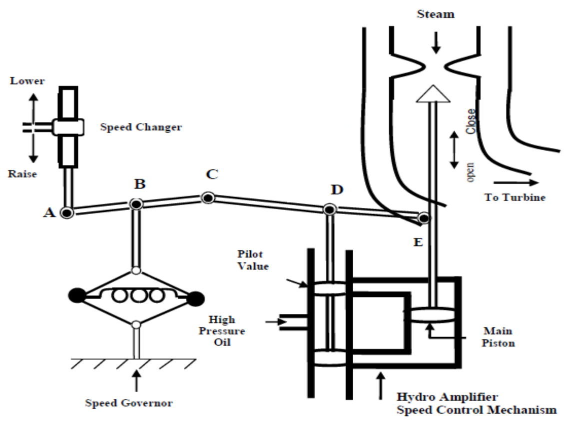


Fig. 1 represents schematically the speed governing system of a steam turbine.

The speed governing system consists of the following parts:

1) Speed Governor: this can be a fly-ball kind of speed governor and constitutes the guts of the system because it senses the modification in speed or frequency. With the rise in speed, the fly-ball moves outward and therefore the purpose B on linkage mechanism moves downwardly and the other way around.

2) Linkage Mechanism: ABC and CDE are the rigid links pivoted at B and D respectively. The mechanism provides a movement to the control valve within the proportion to the modification in speed. Link 4 provides a feedback from the steam valve movement.

3) Hydraulic Amplifier: This consists of the piston and pilot valve. Low power level pilot valve movement that is regenerate into high power level piston valve movement is critical to open or shut the steam valve against air mass steam.

4) Speed Changer: With the help of speed changer it maintains steady state power output setting for the turbine. Its downward movement opens the upper pilot valve so that more steam is admitted to the turbine under steady conditions. The reverse happens for upward movement of speed changer.

5) Model of Speed Governing System: Assume that the system is initially operating under steady conditions, the linkage mechanism is stationary and pilot valve is closed, steam valve opened by a definite magnitude, turbine running at constant speed with turbine power output balancing the generator load.

Let the operating conditions be characterized by

f^0 = System frequency (speed)

P_G^0 = Generator Output = turbine output (neglecting generator loss)

y_G^0 = Steam Valve Setting.

Now, a linear incremental model around these operating conditions is obtained.

Let the purpose A on the linkage mechanism be affected downward by a little quantity Δy_A. It's a command that causes the turbine power output to alter and might thus, be written as

$$\Delta y_A = K_C \,\Delta P_C \qquad (1)$$

Where- ΔP_C is the commanded increase in power.

The command signal ΔP_C sets into motion a sequence of events. The pilot valve moves upwards, high pressure oil flows on to the top of the main piston moving it downwards; the steam valve opening consequently increases, the turbine generator speed increases, i.e., the frequency goes up. Let us model these events mathematically

Two factors contribute to the movement of C:

(a) Δy_A Contributes $\left(\frac{l_2}{l_1}\right)\Delta y_A$ *or* $-K_1\,\Delta y_A$ (i.e. upwards) of $-K_1\,K_C\,\Delta P_C$ where K_1, K_c are constants.

(b) Increased frequency Δf causes the fly balls to move outwards so that B moves downwards by a proportional amount $K_2^{/}\,\Delta f$. The consequent movement of C with A remaining fixed at Δy_A is $\left(\frac{l_1 + l_2}{l_1}\right) K_2'\Delta f = K_2 \Delta f$.

The net movement of C is therefore,

$$\Delta\, y_C = -K_1\,K_C\;\Delta P_C + K_2\Delta f \qquad (2)$$

where K_2 is a constant.

The movement of D, Δy_D is the amount by which the pilot valve opens. It is contributed by Δy_C and Δy_E can be written as

$$\Delta\, y_D = K_3\,\Delta\, y_C + K_4 \Delta\, y_E \qquad (3)$$

Where K_3 and K_4 are constants.

Δy_E is the movement of point E.

The movement Δy_D depending upon its sign opens one of the parts of the pilot valve admitted high pressure oil into the cylinder thereby moving the main piston and opening the steam valve by Δy_E.

Certain Assumptions created are: -

i) Inertial reaction forces of main piston and steam valve area unit negligible compared to the forces exerted on the piston by high pressure oil.
ii) Due to (i) higher than, the speed of oil admitted to the cylinder is proportional to part opening Δy_D .

The volume of oil admitted to the cylinder is so proportional to the time integral of Δy_D

The movement Δy_E is obtained by dividing the oil volume by the realm of the cross-sectional of the piston. Thus,

$$\Delta\, y_E = K_5 \int_o^t (-\Delta\, y_D)dt \qquad (4)$$

It can be verified from the schematic diagram that a positive movement Δy_D causes negative movement Δy_E accounting for the negative sign used in (3).

Taking the Laplace transform of equations, we get

$$\Delta y_C(s) = -K_1 K_C\, \Delta P_C(s) + K_2 \Delta F(s) \quad (5)$$

$$\Delta y_D(s) = K_3 \Delta y_C(s) + K_4 \Delta y_E(s) \quad (6)$$

$$\Delta y_E(s) = \frac{K_5(-\Delta y_D(s))}{s} \quad (7)$$

Eliminating $\Delta y_D(s)$ from (7), we get

$$\Delta y_E(s) = \frac{K_5}{s}\left[-K_3\ \Delta y_C(s) - K_4\ \Delta y_E(s)\right] (8)$$

Also eliminating $\Delta y_C(s)$ from (8), we get

$$\Delta y_E(s) = \frac{K_5}{s}\left[-K_3\left(-K_1 K_C\, \Delta P_C(s) + K_2\, \Delta F(s)\right) - K_4\, \Delta y_E(s)\right]$$

(9)

$$\Delta y_E(s)\left[1 + \frac{K_5 K_4}{s}\right] = \frac{K_3 K_1 K_C K_5\, \Delta P_C(s)}{s}\ \frac{-K_3 K_2 K_5\, \Delta F(s)}{s}$$

(10)

or

$$\Delta y_E(s) = \frac{K_3 K_5\left[K_1 K_C\, \Delta P_C(s) - K_2\, \Delta F(s)\right]}{K_5 K_4 + s}$$

(11)

or

$$\Delta y_E(s) = \frac{K_3 K_5 K_1 K_C \left[\Delta P_C(s) - \dfrac{K_2}{K_1 K_C}\Delta F(s)\right]}{K_5 K_4 + s}$$

(12)

or
$$\Delta y_E(s) = \frac{\Delta P_C(s) - \dfrac{1}{R}\Delta F(s)}{\left[\dfrac{K_5 K_4}{K_3 K_5 K_1 K_C}\ \dfrac{s}{K_3 K_5 K_1 K_C}\right]}$$

(13)

or

$$\Delta y_E(s) = \frac{\Delta P_C(s) - \dfrac{1}{R}\Delta F(s)}{\left(1 + \dfrac{s}{K_4 K_5}\right)}\ \frac{K_3 K_1 K_C}{K_4}$$

(14) or

$$\Delta y_E(s) = \left[\Delta P_C(s) - \frac{1}{R}\Delta F(s)\right] \times \left(\frac{K_g}{1 + T_g s}\right)$$

(15)

Where

$$R = \frac{K_1 K_C}{K_2} = \text{speed regulation of governor}$$

$$K_g = \frac{K_1 K_3 K_C}{K_4} = \text{gain of speed governor}$$

$$T_g = \frac{1}{K_4 K_5} = \text{time constant of speed governor}$$

Equation (15) can be represented in the form of block diagram as follows:

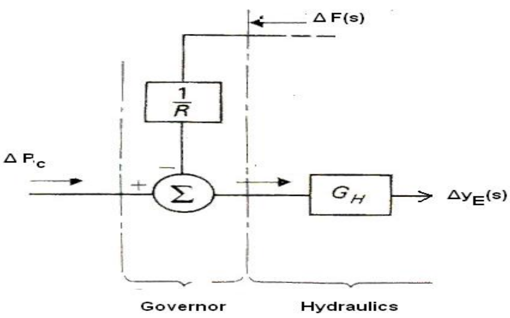


Figure 2 Block Diagram of Governor Model

B. *Turbine model*

The model requires a relation between changes in power output of the steam turbine to changes in its steam value opening Δy_E (s).The response of a non-reheat turbine can be approximated by a single time constant T_t and is given by

$$\Delta P_m(s) = \frac{1}{1 + T_t s}\Delta y_E(s) \qquad (16)$$

Where $\Delta y_E(s)$ = steam valve opening

$\Delta P_m(s)$ = Laplace transform of Δy_m, the change in power developed by the turbine.

T_t = time constant of turbine (generally 0.25 sec or so).

C. *Model of Generator*

Assuming generator to be loss free, the mechanical power input to the generator is equal to the electrical power output.

$$\Delta P_T(s) = \Delta P_G(s)$$

D. Model of Generator with load

The increment is power input to the generator – load system is $\Delta P_G - \Delta P_D$ where $\Delta P_G = \Delta P_T$.

This increment in power input to the system is accounted for in two ways:-

(i) Rate of increase of stored kinetic energy in the generator rotor. At scheduled frequency (f^o), the stored energy is

$$W_{ke}^{\ o} = H \times P_r \ \ kw{-}\sec \ (KJ) \qquad (17)$$

Where P_r is the KW rating of the turbo – generator and H is defined as its inertia constant.

The kinetic energy being proportional to square of speed, the kinetic energy at a frequency $f^0+\Delta f$ is given by:

$$W_{Ke} = W_{ke}^{\ o}\left(\frac{f^o + \Delta f}{f^o}\right)^2$$

$$= H\,P_r\left(1 + \frac{2\Delta f}{f^o}\right)$$

Rate of change of kinetic energy is therefore

$$\frac{d}{dt}(W_{Ke}) = \frac{2HP_r}{f^o}\frac{d}{dt}(\Delta f) \qquad (18)$$

(ii) As the frequency changes, the motor load changes being sensitive to speed, the rate of change of load with respect to frequency i.e. $\partial P_D / \partial f$ can be regarded as nearly, constant for small changes in frequency Δf and can be expressed as

$$\left(\frac{\partial P_D}{\partial f}\right) sf = B\Delta f \qquad (19)$$

Where the constant B can be determined empirically, B is positive for a predominantly motor load. Writing the power balance equation, we have

$$\Delta P_G - \Delta P_D = \frac{2HP_r}{f^o}\frac{d}{dt}(\Delta f) + B\Delta f \qquad (20)$$

Dividing throughout by P_T and rearranging we get

$$\Delta P_G(pu) - \Delta P_D(pu) = \frac{2H}{f^o}\frac{d}{dt}(\Delta f) + B(pu)\Delta f \qquad (21)$$

Taking the Laplace transform, we can write $\Delta F(s)$ as

$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{B + \frac{2H}{f^o}s}$$

Or

$$\Delta F(s) = [\Delta P_G(s) - \Delta P_D(s)] \times \left(\frac{K_p}{1 + s\,T_p}\right) \qquad (22)$$

Where

$$T_p = \frac{2H}{B f^o} = \text{power system time constant}$$

$$K_p = \frac{1}{B} = \text{power system gain}$$

Equation (22) can be represented in block diagram form as shown in figure below

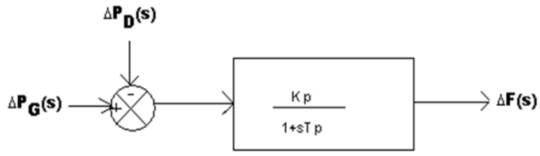


Fig. 3 Block diagram representation of generator load model

E. Complete Modelling of AGC in single area system

In this section, the analysis of load frequency control of one space grid is conferred. the entire system to be thought of for the look of controller is shown in Figure four. The system response has been obtained for uncontrolled and controlled system.

1) **Steady state response**

In uncontrolled case, speed changer has fixed settings, i.e. $\Delta P_{ref} = 0$

For step load change $=\Delta P_D$

Laplace transform of it is $\Delta P_{ref} = 0$

Now from block diagram shown in Figure 3, system equation can be written as

$$\left[\left\{\Delta P_{ref} - \tfrac{1}{R}\Delta f\right\} * K_G.K_T - \Delta P_D\right] = \Delta f \qquad (23)$$

Laplace transform

$$\Delta f(s) = \frac{K_P}{\left(1+\frac{1}{R}K_P.K_G.K_T\right)}\Delta P_D(S) \qquad (24)$$

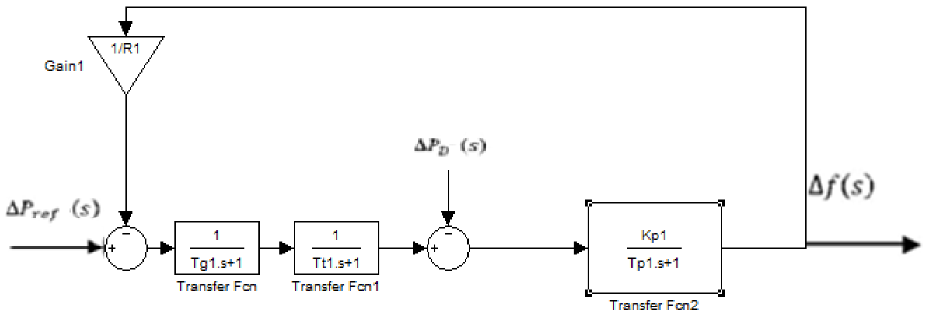


Figure 4 Complete block diagram of single area Thermal system

Using the final value theorem

$$\Delta f_{ss} = \lim_{s\to 0}[s\Delta f(s)] = \frac{s.K_P}{\left(1+\frac{1}{R}K_P.K_G.K_T\right)}\frac{\Delta P_D}{s} \quad (25)$$

$$= \frac{K_P \Delta P_D}{1+\frac{K_P}{R}} \qquad = -\frac{\Delta P_D}{1+\frac{1}{R}} \qquad (26)$$

If β = [1 + 1/R] p.u. MWHz

Then

$$\Delta f_{ss} = -\left(\frac{\Delta P_D}{\beta}\right) \qquad (27)$$

Where β is called area frequency response characteristic (AFRC). Thus, in uncontrolled case the steady state response has constant error.

2) **Dynamic response**

The dynamic response of a single area thermal system for a step load is calculated in this section. By taking inverse Laplace transform of equation (23), the frequency can be calculated in time domain Δf (t). However, as K_G, K_T, K_p contain at least one time constant each, the denominator will be of third order, resulting in unwieldy algebra.

($T_g << T_t << T_p$) where T_p is generally 20 s. $T_g \approx T_t \le 1$ s, thus assume $T_g = T_t = 0$ and the dynamic frequency response can be calculated as

$$\Delta f(s) = \frac{\frac{K_P}{1+sT_P}}{1+\frac{1}{R}\frac{C}{(1+sT_P)}} * \frac{\Delta P_D}{s} \qquad (28)$$

Above equation can also be written as

$$\Delta f(S) = -\Delta P_D * \frac{R.K_P}{R+K_P}\left(\frac{1}{s} - \frac{1}{s+\frac{R+K_P}{R.T_P}}\right) \qquad (29)$$

Taking inverse Laplace transform of above equation

$$\Delta f(t) = -\Delta P_D * \frac{R.K_P}{R+K_P}\left[1 - e^{-t\left(\frac{R+K_P}{R.T_P}\right)}\right] \qquad (30)$$

Thus the error = $e^{-t\left(\frac{R+K_P}{R.T_P}\right)}$ this persists in uncontrolled case.

Model of uncontrolled single area is shown in Figure .5.

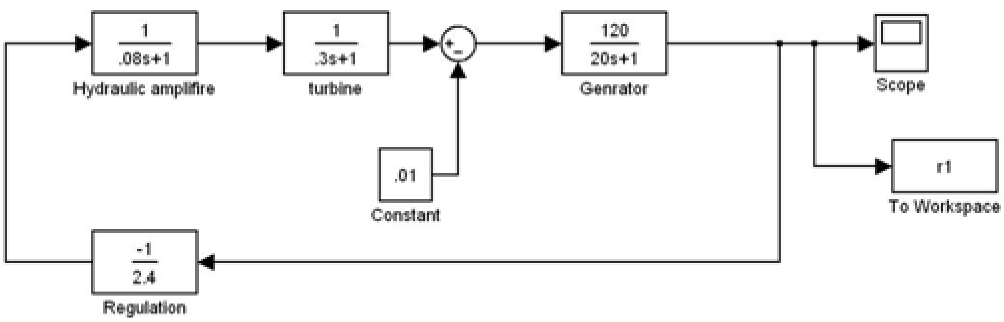


Fig. 5 Block diagram model of single area Thermal System

III. Modelling of Two Area System

A. Tie line model

The power flow over the line is

$$P_{12} = \frac{|V_1|\,|V_2|\sin(\delta_1 - \delta_2)}{X} \qquad (31)$$

P_{12} = Power transfer from system 1 to system 2

Where

$|V_1|$ & $|V_2|$ = voltage magnitudes at ends 1 and 2

δ_1 & δ_2 = phase angles of voltages V_1 and V_2.

X = reactance of tie line

For small deviations in angles δ_1 and δ_2, the change in power transfer ΔP_{12} is

$$\Delta P_{12} = \frac{|V_1|\,|V_2|}{X} \cos\,(\delta_1 - \delta_2)\,(\Delta\delta_1 - \Delta\delta_2) \quad (32)$$

The synchronizing coefficient T of tie line is defined as

$$T_{12} = \frac{|V_1||V_2|}{X}\cos(\Delta\delta_1 - \Delta\delta_2) \quad (33)$$

Then $\Delta P_{12} = T_{12}(\Delta\delta_1 - \Delta\delta_2)$ (34)

The frequency deviation Δf can be expressed in terms of reference angle $\Delta\delta$ by the equation.

$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}(\delta + \Delta\delta) = \frac{1}{2\pi}\frac{d}{dt}(\Delta\delta)$$

Or $\Delta\delta = 2\pi \int_o^t \Delta f \; dt$

(35)

Therefore equation 4 can be written as

$$\Delta P_{12} = 2\pi T\left[\int_o^t \Delta f_1\,dt - \int_o^t \Delta f_2\,dt\right] \quad (36)$$

Taking Laplace transform

$$\Delta P_{12} = \frac{2\pi T}{s}\left[\Delta f_1(s) - \Delta f_2(s)\right] \quad (37)$$

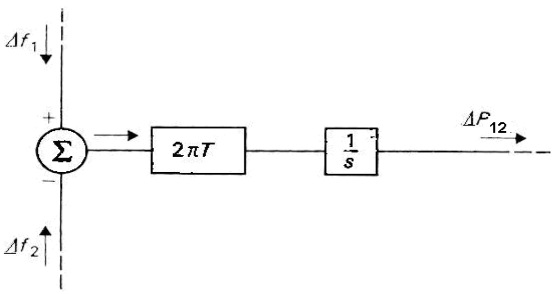


Figure 6 Linear representation of tie-line

B. Implementation of Area Control Error in Model

The control signals (for each area) are proportional to the change in frequency as well as change in tie line power. As in the case of single area systems, integral control is preferable because it gives zero steady state error [6]. The area control errors for a two area system are given by

$$ACE_1 = \Delta P_{12} + B_1\,\Delta f_1 \quad (38)$$

$$ACE_2 = \Delta P_{12} + B_2\,\Delta f_2 \quad (39)$$

where

ACE_1 = Area control error of system 1

ACE_2 = Area control error of system 2

ΔP_{12} = Change in power transferred from 1 to 2 (+ve or –ve)

$\Delta P_{12} = -\Delta P_{21}$

B_1 and B_2 is constants which specify the frequency bias and are determined from knowledge of the size of the system.

The commands to the speed changers are of the form

$$\Delta P_{ref\,1} = -K_1 \int (\Delta P_{12} + B_1\Delta f_1)dt \quad (40)$$

$$\Delta P_{ref\,2} = -K_2 \int (\Delta P_{21} + B_2\Delta f_2)dt \quad (41)$$

The constants K_1 and K_2 are integrator gains. The minus sign in the above equation is essential because the generation in each area must increase if either its frequency error or tie line power increment is negative.

Most of the time a control area is interconnected with many other areas through several tie lines. Let there be a total of m tie lines. Then for the ith control area, the net interchange is the sum of power transfer over all the m tie lines. The area control error ACE_i of the ith area should be proportional to total exchange of power and can be expressed as

$$ACE_i = \sum_{j=1}^{m} \Delta P_{ij} + B_i\,\Delta f_i \quad (42)$$

The tie line power data of all the lines are sampled continuously at sampling intervals of about 1 second or so. These data are added in an energy control centre and compared with desired interchange (decided earlier by mutual agreements). The total line power transfer error is added to frequency bias power transfer error is added to frequency bias error $B_i\;\Delta f_i$ to give the area control error. The ACE command is communicated to the speed changers of all the generators in the area.

The equipment consists of load frequency controller and tie line load recorder controller. The tie line instrument biases the frequency controller till a desired relationship between the tie line loading and frequency is obtained.

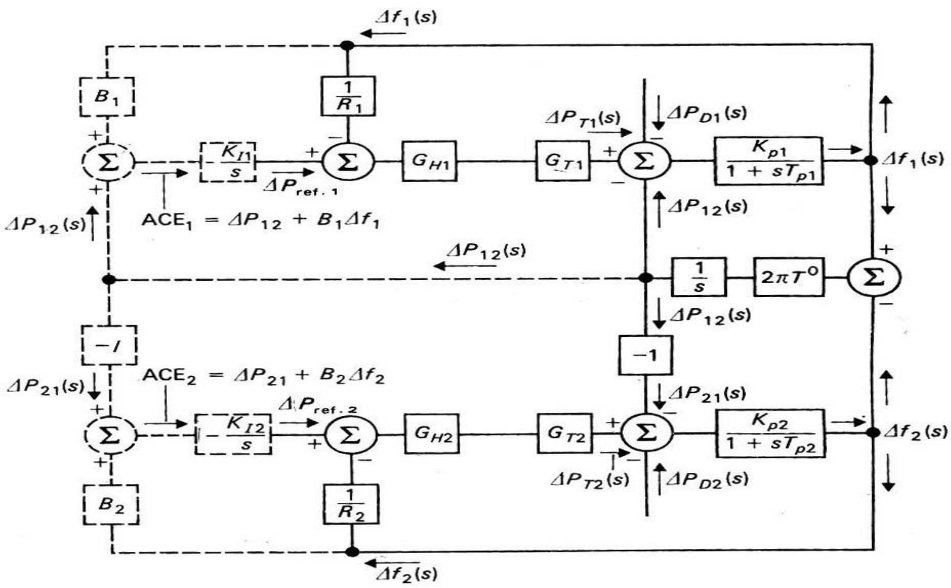


Figure 7 Linear Model of Two-Area System

IV. AGC SYSTEM WITH PI CONTROLLER

The complete block is diagram shown in figure 8 models the complete frequency controller system. However the above configuration does not result in steady-state nominal value of the frequency. There is always some steady state error in frequency present in the system. To minimize the steady-state deviation in frequency, therefore, the secondary controllers are used. The best controller suited for this purpose is integral controller [21].

The modified diagram of an isolated power system used with integral controller is shown below**:**

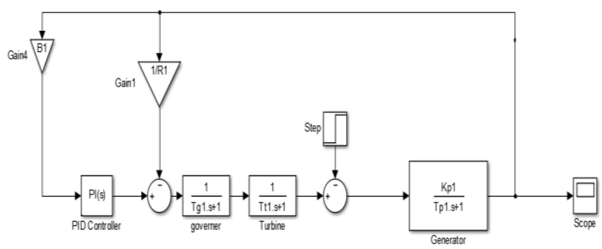
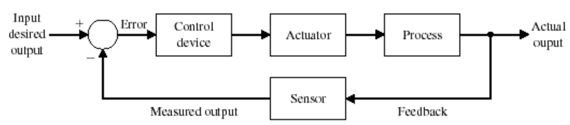


Figure 8 Implementation of Integral Controller in single area system

V. METHOD OF TUNNING PID CONTROLLER

From last six decades research has been carried out on tuning of P-I-D controllers. Several methods have also been implemented. Maximum model based, i.e. they design the mathematical model of the system which is available to the designer. In fact, if the mathematical model of the system is available, most of them perform better than conventional Ziegler-Nichols method. But the good thing in ZN method is that it does not need a mathematical model, but controller parameters can easily be chosen by experiment process. We would be discussing the three experimental techniques those come under the commonly known Ziegler-Nichols method.



The error signal e (t) is fed to the controller and also the controller generates output u (t). Since the capability of the controller to deliver output power is restricted, associate mechanism is required in between the controller and also the method, which is able to actuate the control signal. It should be a valve actuator to open or shut a valve; or a damper actuator to regulate the air flow through a damper. The controller thought of here could be a P-I-D controller whose input and output relationship is given by the equation:

$$u(t) = k_p \left[k(t)\tau_d \frac{de(t)}{dt} + \frac{1}{\tau_i}\int_0^t e(\tau)d\tau \right]$$

Our objective is to find out the optimum settings of the P,I,D parameters, namely k_p, $d\tau$ and τ_i through experimentation, which will provide satisfactory closed loop performance, of the particular process in terms of say, stability, overshoot, setting time etc. Three methods of tuning are elaborated by various methods.

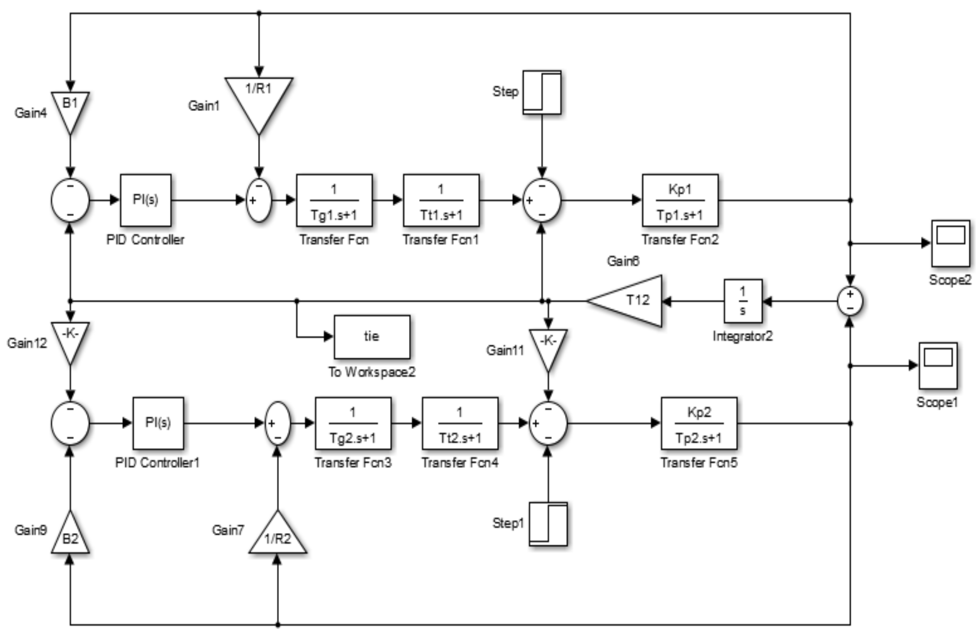


Figure 9 Simulink Model of Two Area Thermal System with PI Controller

- Reaction Curve Technique
- Closed Loop Technique (Continuous Cycling method)
- Closed Loop Technique (Damped oscillation method)

VI. SIMULATION RESULT

The system which is investigated comprises a single area thermal system. The nominal system parameters of the system investigated are given in appendix.

The response for the frequency deviation of the single area system without controller is given in figure 10, and with conventional PI controller is given in figure 11. [15]

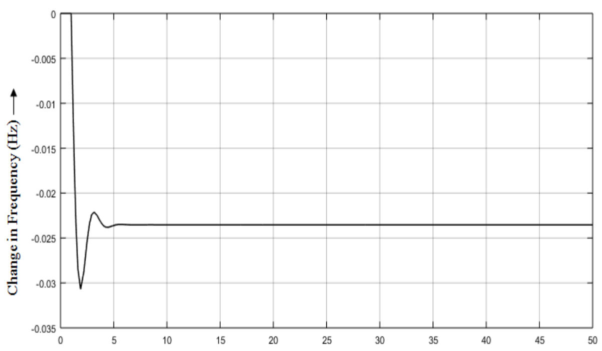


Figure 10 Simulated result of single area Thermal System without controller

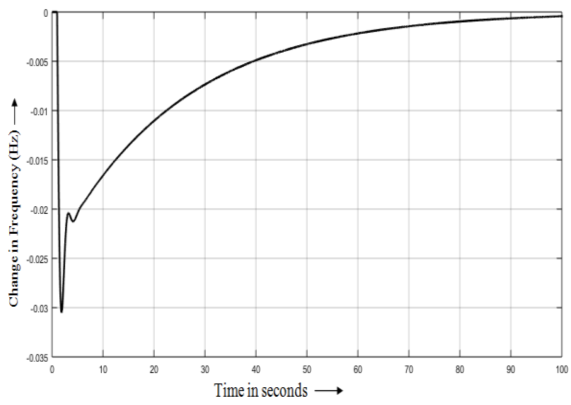


Figure 11 Simulated result of single area System with PI controller

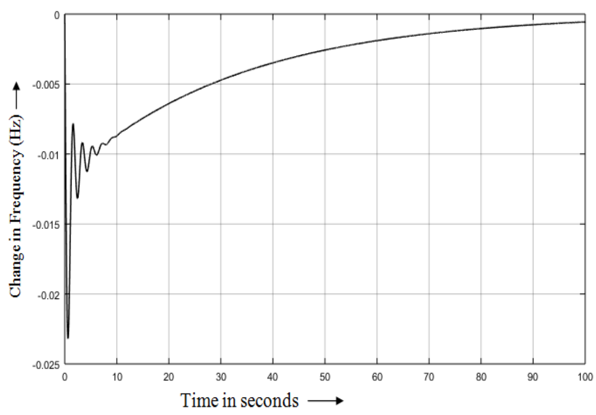


Figure 12 Simulated results of two areas Thermal System with PI controller for area1

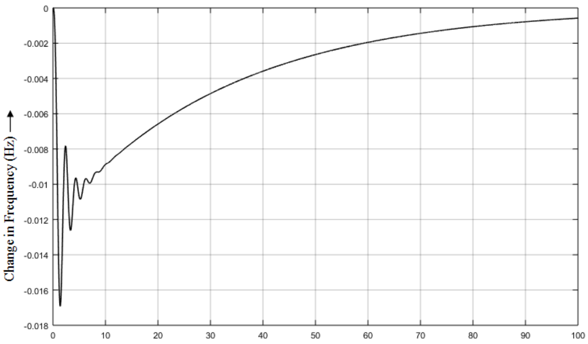


Figure 13 Simulation result of two area Thermal System with PI controller for area2

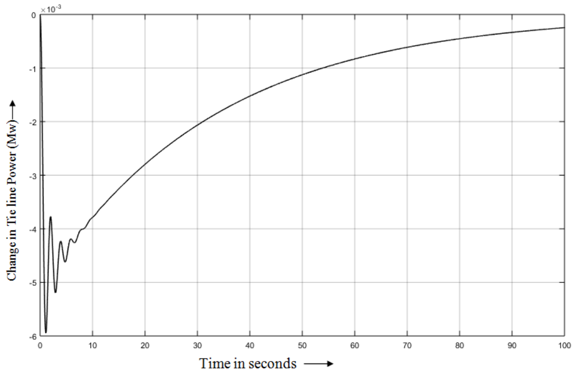


Figure 14 Simulation result of tie line power for two area Thermal System with PI controller

Table 1 Time analysis parameters of simulations of single area Thermal system when 1% disturbance in this area

Parameters	System Without Controller	System With PI controller
Undershoot(Hz)	0.031	0.031
Settling time(sec)	Not settle	90

Table 2 Time analysis parameters of simulations of area 1 for Thermal-Thermal system when 1% disturbance in area1

Parameters	System Without Controller	System With PI controller
Undershoot(Hz)	0.023	0.023
Settling time(sec)	Not settle	100

Table 3 Time analysis parameters of simulations of area2 for Thermal-Thermal system when 1% disturbance in area1

Parameters	System Without Controller	System With PI controller
Undershoot(Hz)	0.017	0.017
Settling time(sec)	Not settle	110

Table 4 Time analysis parameters of simulations of tie line for Thermal-Thermal system when 1% disturbance in area1

Parameters	System Without Controller	System With PI controller
Undershoot(Mw)	0.006	0.0059
Settling time(sec)	Not settle	120

VII. CONCLUSION

In this Paper we studied the modelling of AGC in single area and two area of thermal power system. As steady state frequency deviation is not zero so PI controller is used to make it zero in this work. PI controller not gives fast steady state response also high amplitude oscillation present in output response. Tuning of PI controller is so complicated task so we need to design more controllers which will give fast response as well as less oscillation. So advance controller like Fuzzy logic controller approach can be applied for control the deviation in frequency.

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