Computation of Stabilizing PID Controller for Single Area Load Frequency Control

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Abstract: As power system is highly nonlinear in nature, its operating point changes continuously. So, the system performance is very poor, which affect the real and reactive power. Changes in real power mainly affect the system frequency and changes in reactive power mainly depend on changes in voltage magnitude. Thus, real and reactive powers can be controlled separately. The Load Frequency Control (LFC) controls the real power and the Automatic Voltage Regulator (AVR) regulates the voltage magnitude and hence the reactive power. Load Frequency Control (LFC) of interconnected system is defined as the regulation of power output of generators. In general the fixed gain controllers are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions. So, to keep system performance near its optimum, it is desirable to track the operating conditions and use updated parameters to compute the control. In this project work a new method of finding stabilizing PID controllers has been proposed for LFC control system loop that is determined using "Boundary Locus Method"

Keywords: Boundary Locus Method, Load Frequency Control, PID Controller, Relative Stabilization

I. INTRODUCTION

Load fluctuations and abnormal conditions such as the generation outages, cause the system frequency to decay from the desired value. To ensure the quality of the power supply, it is necessary to regulate the generator loads depending on the optimal frequency value with a proper LFC design. In order to take the parametric uncertainty and the nonlinear constraints into account, and to keep the system performance near its optimal operating condition, different approaches have been applied in the past [1].

A controller is one which compares controlled values with the desired values and has a function to correct the deviation produced. The main objective of any controller is to attain the stability of a system.

- Controllers improve steady state accuracy by decreasing the steady state errors.
- As the steady state accuracy improves, the stability also improves.
- They also help in reducing the offsets produced in the system.
- Maximum overshoot of the system can be controlled using these controllers.
- They also help in reducing the noise signals produced in the system.
- Slow response of the over damped system can be made faster with the help of these controllers.

In this project, a new method for the computation of all stabilizing PI controllers [2] and [3] is given. The proposed method is based on plotting the stability boundary locus in the (kp; k_i) plane and then computing the stabilizing values of the parameters of a PI controller. The technique presented does not need to use Pade approximation and does not require sweeping over the parameters and also does not use linear programming to solve a set of inequalities. Thus it offers several important advantages over existing results obtained in this direction. Beyond stabilization, this method is used to compute stabilizing PI controllers which achieve specified gain and phase margins. The proposed method is also used to design PID controllers for control systems with and without time delay. The limiting values of a PID controller which stabilize a given system with time delay are obtained in the (kp; ki) plane, (kp; kd) plane, and (ki ; kd) plane.

II. BOUNDARY LOCUS METHOD

II.I DESIGN OF PI CONTROLLER:

Consider the single-input single-output (SISO) control system of Figure 2.1

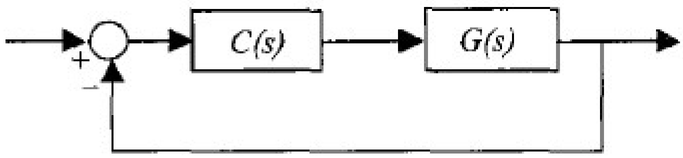

Fig.2.1 A SISO control system

Where $G(S) = \frac{N(S)}{D(S)}$ 2.1

is the plant to be controlled and C(s) is a PI controller of the from

$$G(S) = Kp + \frac{Ki}{S} = \frac{KpS+Ki}{S} \quad 2.2$$

the problem is to compute the parameters of the PI controller of Eq. (3.2) which stabilize the system of Fig 2.1

Decomposing the numerator and the denominator polynomials of Eq. (3.1) into their even and odd parts, and substituting s = jω , gives $G(j\omega) = \frac{Ne(-\omega^2)+j\omega No(-\omega^2)}{De(-\omega^2)+j\omega Do(-\omega^2)}$ 2.3

Characteristic polynomial Δ(s) of the system in Fig. 2.1 is Hurwitz stable.

From Fig. 2.1 characteristic equation can be written as Δ(s)=1+G(s).C(s)

The closed loop characteristic polynomial of the system can be written as

$\Delta(S) = [K_iN_e(-\omega^2) – K_p\omega^2N_0(-\omega^2) – \omega^2D_0(-\omega^2)] + j[K_p\omega N_e(-\omega^2) + K_i\omega N_0(-\omega^2) + \omega D_0(-\omega^2)] = 0$ 2.4

Then, equating the real and imaginary parts of Δ(s) to zero, one obtains

$$[K_p\omega N_e(-\omega^2) + K_i\omega N_0(-\omega^2) + \omega D_0(-\omega^2)] = 0 \quad 2.5$$

And $K_p\omega N_e(-\omega^2) + K_i\omega N_0(-\omega^2) = - \omega D_0(-\omega^2)$ 2.6

Let

$$Q(\omega) = -\omega^2N_0(-\omega^2),\ R(\omega) = N_e(-\omega^2)$$
$$S(\omega) = \omega N_e(-\omega^2),\ U(\omega) = \omega N_0(-\omega^2)$$
$$X(\omega) = \omega D_0(-\omega^2),\ Y(\omega) = -\omega D_e(-\omega^2) \quad 2.7$$

Then, Eq. (2.5) and Eq. (2.6) can be written as

$$K_pQ(\omega) +K_iR(\omega) = X(\omega)$$
$$K_pS(\omega) + K_iU(\omega) = Y(\omega) \quad 2.8$$

From these equations $K_p = \frac{X(\omega)U(\omega)- Y(\omega)R(\omega)}{Q(\omega)U(\omega)- R(\omega)S(\omega)}$ 2.9

And $K_i = \frac{Y(\omega)Q(\omega)- K(\omega)S(\omega)}{Q(\omega)U(\omega)- R(\omega)S(\omega)}$ 2.10

Solving these two equations simultaneously, the stability boundary locus, l(kp,ki,w), in the (k,.ki)-plane can be obtained. The stability boundary locus divides the parameter plane ((kp, ki) -plane) into stable and unstable regions. Choosing a test point within each region, the stable region which contains the values of stabilizing kp and ki parameters can be determined.

DESIGN OF PID CONTROLLERS:

Consider that C(s) of Fig 2.1 is a PID Controller of form

$$C(s) = K_p + \frac{K_i}{s} + K_d S \qquad 2.11$$

Using the procedure given in Section 2.1, the stability boundary locus in the (Kp, Ki) plane can be obtained for a fixed value of Kd or it can be easily obtained in the (kp, kd)-plane for a fixed value of ki. However, it is not possible to obtain the stability boundary locus in the (ki, kd)-plane for a fixed value of kp, since $(Q(\omega)U(\omega) - R(\omega)S(\omega))$ will be equal to zero for this case. Although the stability region in the (ki,kd) plane for a fixed value of Kp is a convex polygon, the stability region in the (kp, li)-plane for a fixed value of kd or in the (kp, kd)-plane for a fixed value of ki is not a convex polygon and it may not be even a convex set. However it is possible to obtain the stability region in the (ki, kd)-plane for a fixed value of kp using the stability region obtained in the (kp, ki) plane and (kp, kd)-plane as follows.

$$K_p = \frac{\omega^3 N_0 D_0 + \omega N_e D_0}{-\omega^2 N_0^2 - N_e^2}$$

$$K_i = \frac{\omega^2 N_0 D_e - \omega^2 N_e D_0}{-\omega^2 N_0^2 - N_e^2}$$

Substituting Ki in terms of Kd

$$K_i = \frac{\omega^2 N_0 D_e - k_d \omega^4 N_o^2 - \omega^2 N_e D_0 - K_d \omega^2 N_e^2}{-\omega^2 N_0^2 - N_e^2}$$

$$K_i = \frac{(\omega^2 N_0 D_0 - \omega^2 N_e D_0) + K_d \omega^2 (-\omega^2 N_o^2 - N_e^2)}{-\omega^2 N_0^2 - N_e^2}$$

$$K_d = \frac{-(\omega^2 N_o D_e - \omega^2 N_e D_0) + K_i (-\omega^2 N_0^2 - N_e^2}{\omega^2 (-\omega^2 N_o^2 - N_e^2)}$$

Thu, using these equations the stability regions in the (kp, ki) plane and (kp, kd) plane can be obtained.

III. BASIC GENERATION CONTROL LOOPS

In an interconnected power system, LFC and AVR control loops are designed for each generator. The schematic diagram of the voltage and frequency control loop is represented in Fig.3.1. The controllers are set for a particular operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits. Small changes in real power are mainly dependent on changes in rotor angle δ and, thus, the frequency f. The reactive power is mainly dependent on the voltage magnitude (i.e. on the generator excitation) [4]. Change in angle is caused by momentary change in generator speed. Therefore, load frequency and excitation voltage controls are non-interactive for small changes and can be modelled and analyzed independently. Furthermore, excitation control is fast acting while the power frequency control is slow acting since, the major time constant contributed by the turbine and generator moment of inertia-time constant is much larger than that of the generator field. Thus, the cross coupling between the LFC loop and the AVR is negligible, and the load frequency and excitation voltage control are analyzed independently. In power system, both active and reactive power demands are never steady they continuously change with the rising or falling trend. The changes in real power affect the system frequency, while reactive power is less sensitive to changes in frequency and is mainly dependent on Changes in voltage magnitude. The main purpose of system generation control is to balance the system generation against the load and losses so that the desired frequency and power interchanges between neighboring systems are maintained. The two main control loops of a generation are Load Frequency Controller (LFC) and Automatic Voltage Regulator (AVR).

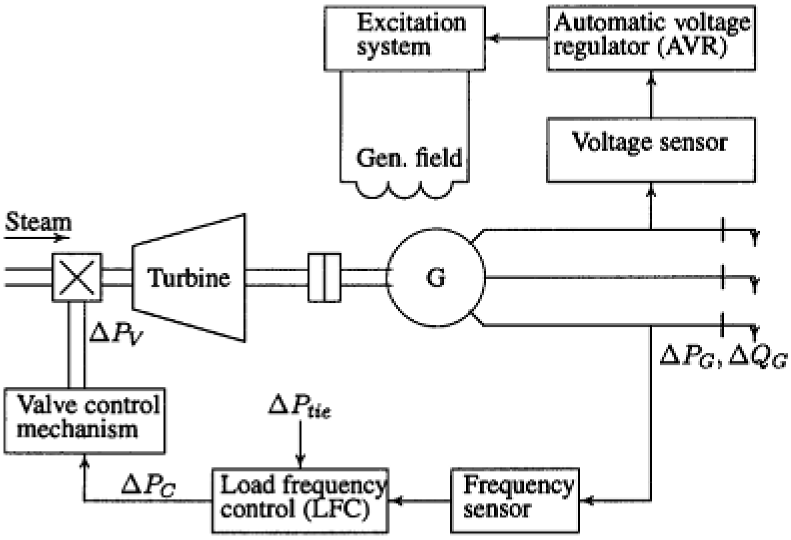

Fig 3.1: Schematic Diagram of LFC and AVR of a Synchronous Generator

IV. Load Frequency Control

Load frequency control is important in electrical power system design and operation. Moreover, to ensure the quality of the power supply, it is necessary to design a LFC system, which deals with the control of loading of generator depending on the frequency. Conventional controllers are quite often impractical for the implementation due to following reasons. The optimal control is a function of all the states of the system. In practice all the states may not be available. The inaccessible states or missing states are required to be estimated. It may not be economical to transfer all the information over long distances. The control, which is a function of the states in turn, is dependent on the load demand. Accurate prediction of load demand may be essential for realizing optimal controller.

The aim of LFC is to maintain real power balance in the system through control of system frequency. Whenever the real power demand changes, a frequency change occurs. This frequency error is amplified, mixed and changed to a command signal which is sent to turbine governor. The governor operates to restore the balance between the input and output by changing the turbine out-put. This method is also referred as Megawatt frequency or Power-frequency (P-f) control.

For the analysis purpose consider the following LFC Loop Parameters:

S.No	Block	Gain	Time Constant
1	Governor	K_g=1	T_g=0.2 Sec
2	Turbine	K_t=1	T_t=0.5 Sec
3	Generator Inertia Constant	H=5 Sec	
4	Governor Speed Regulation	R=0.05 Per Unit	
5	The load varies by 0.8 percent for a 1 percent change in frequency, i.e D=0.8		

Table 4.1: LFC Loop Parameters

A. DESIGN OF PI CONTROLLER:

The equivalent transfer function of Single Area Load Frequency Control is given by

$$G(S) = -\frac{\Delta\Omega(s)}{\Delta P_L(S)} = \frac{(1+T_g s)(1+T_t s)}{(2Hs+D)(1+T_g s)(1+T_t s)+\frac{1}{R}}$$

Now substituting the parameter values listed in Table, 4.1

$$G(S) = \frac{(1+0.2s)(1+0.5s)}{(2*5s+0.8)(1+0.2s)(1+0.5s)+\frac{1}{0.05}}$$

$$G(S) = \frac{0.1s^2+0.7s+1}{s^3+7.08s^2+10.56s+20.8}$$

Substituting $s = j\omega$;

$$G(S) = \frac{(-0.1\omega^2+1)+j\omega(0.7)}{(-7.08\omega^2+20.8)+j\omega(-\omega^2+10.56)}$$

From above equation, we have

$$R(\omega) = -0.1\omega^2+1, U(\omega) = 0.7\omega$$
$$Q(\omega) = -0.7\omega^2, S(\omega) = -0.1\omega^3+\omega$$
$$Y(\omega) = 7.08\omega^3-20.8\omega, X(\omega) = -\omega^4+10.56\omega^2$$

Substitute these in equations 3.9 & 3.10

$$K_p = \frac{0.008\omega^5-1.768\omega^3+20.8\omega}{-0.01\omega^5-0.29\omega^3-\omega} \quad 4.1$$

$$K_i = \frac{-0.1\omega^7-2.9\omega^5+4.396\omega^3}{-0.01\omega^5-0.29\omega^3-\omega} \quad 4.2$$

In the analysis and design of control systems, it is important to shift all poles of the characteristic equation of a control system to a desired region in the complex plane, for example, to a shifted half plane that guarantees a specified settling time of the response. The aim of this section is to find all values of $s = \rho$, where (ρ= constant). Using $s+\rho$ instead of s in equation 2.1 & 2.2.

Now calculate the relative stabilization of K_p and K_i plane and $\rho = 0.5$. Repeating the above procedure, we calculate K_p, K_i.

$$K_p = \frac{0.058\omega^5-0.117\omega^3+38.465\omega}{-0.01\omega^5-0.365\omega^3-1.8906\omega} \quad 4.3$$

$$K_i = \frac{-0.1\omega^7-3.65\omega^5+2.9\omega^3}{-0.01\omega^5-0.365\omega^3-1.8906\omega} \quad 4.4$$

From the equations 4.1, 4.2, 4.3 and 4.4, the stability region is shown in Fig 4.1

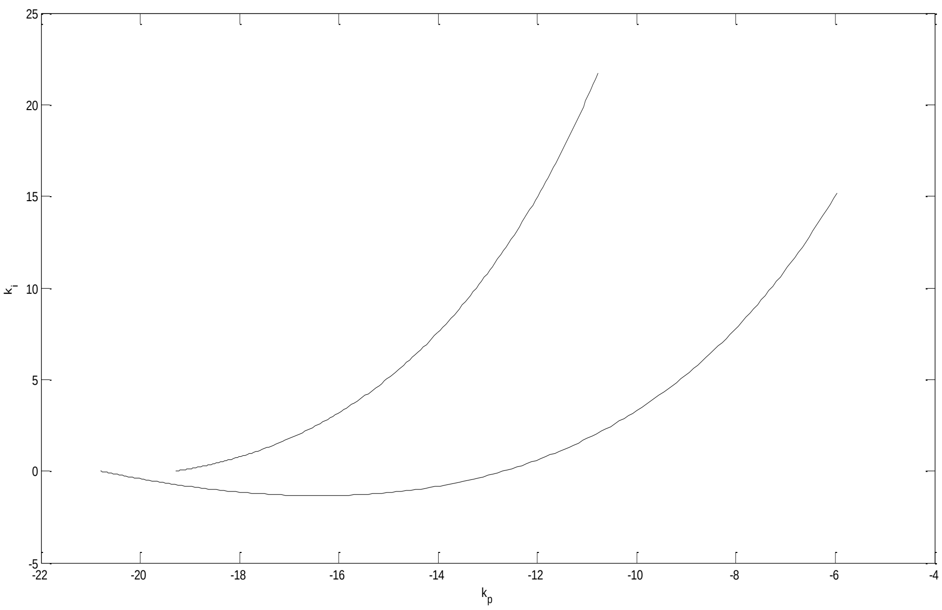

Fig 4.1: Stability Regions for $\rho = 0$ and $\rho = 0.5$

B. DESIGN OF PID CONTROLLER FOR LFC:

Now Consider Kd.

Step 1: Let us consider Ki,

$$K_i = \frac{a_1\omega^7 + a_2\omega^5 + a_3\omega^3}{-0.01\omega^5 - 0.29\omega^3 - \omega}$$

Where $a_1 = -0.1 - 0.01K_d, a_2 = -2.9 - 0.29K_d, a_3 = 4 - K_d$

Stability region for $K_d = 0$

$$K_i = \frac{-0.1\omega^7 - 2.9\omega^5 + 4\omega^3}{-0.01\omega^5 - 0.29\omega^3 - \omega}$$

Stability region for $K_d = 1$

$$K_i = \frac{-0.11\omega^7 - 3.19\omega^5 + 4\omega^3}{-0.01\omega^5 - 0.29\omega^3 - \omega}$$

Now the plots are obtained for Kp and Ki:

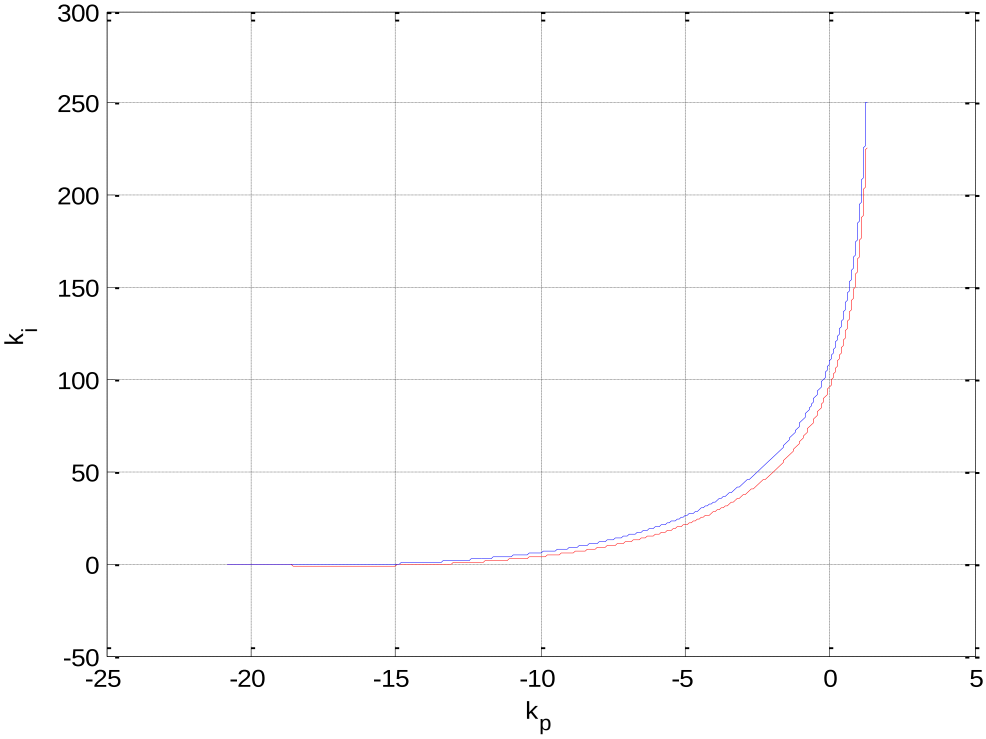

Fig 4.2: Stability region in the (Kp, Ki) plane for K_d=0 and K_d=1

Step 2:

Obtain equation K_d in terms of K_i

$$K_i = \frac{0.1\omega^7 + b_1\omega^5 + b_2\omega^3 + b_3\omega}{-0.01\omega^7 - 0.29\omega^5 - \omega^3}$$

$$Where\ b_1 = 2.9 - 0.01K_i, b_2 = -4 - 0.29K_i, b_3 = -K_i$$

Stability regions for $K_i = 0$

$$K_d = \frac{0.1\omega^7 + 2.9\omega^5 - 4\omega^3}{-0.01\omega^7 - 0.29\omega^5 - \omega^3}$$

Stability region for $K_i = 1$

$$K_d = \frac{0.1\omega^7 + 2.89\omega^5 - 4.29\omega^3 - \omega}{-0.01\omega^7 - 0.29\omega^5 - \omega^3}$$

Now the plots are obtained for $K_p$and K_d

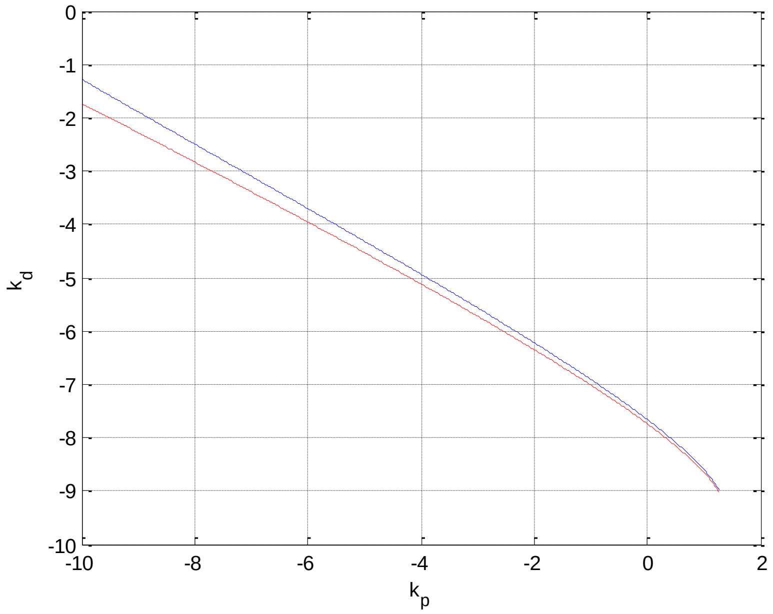

Fig 4.3: Stability region in the (Kp, Ki) plane for K_i=0 and K_i=1

From the above two graphs we obtain 8 points for K_p= 0 are (36.57, 0), (42.97, 1), (0, 0), (0, 1), (0, -5.71), (1, -5.55), (0, 0), (1, 0)

From these we obtain 4 straight lines

$$K_d = 0.015K_i - 5.71, K_d = 0$$
$$K_d = 0.16K_i - 5.71, K_d = 0$$

Now draw the patch form for these lines

Now the plots are obtained for K_p and K_i and K_d

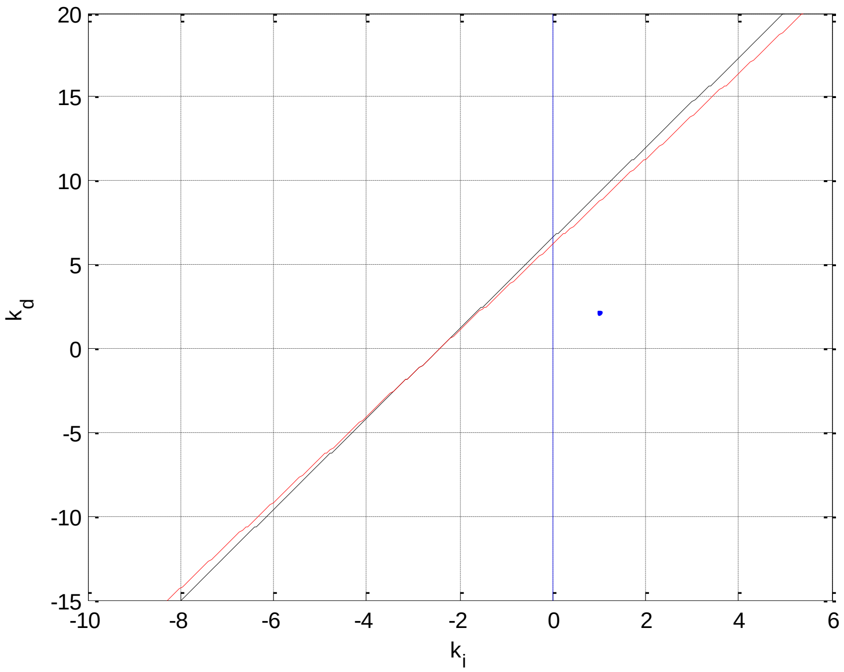

Fig 4.4(a) Stabilizing Kp, Ki, and Kd Region

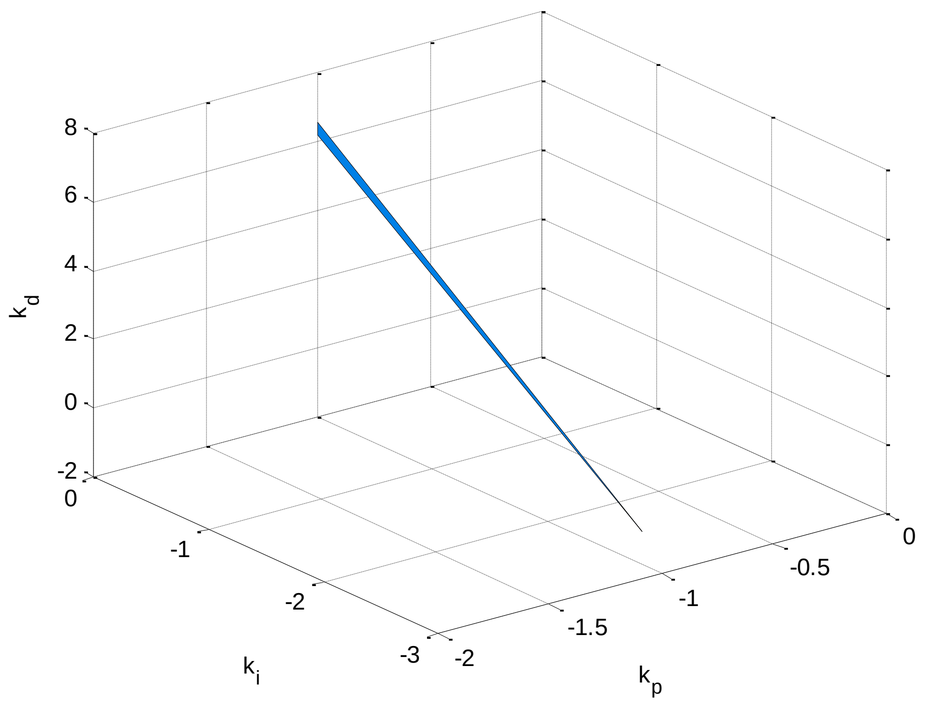

Fig 4.4(b) Stabilizing Kp, Ki, and Kd Region

V. Simulation Results

The constructed Simulink block is shown in Fig 5.1

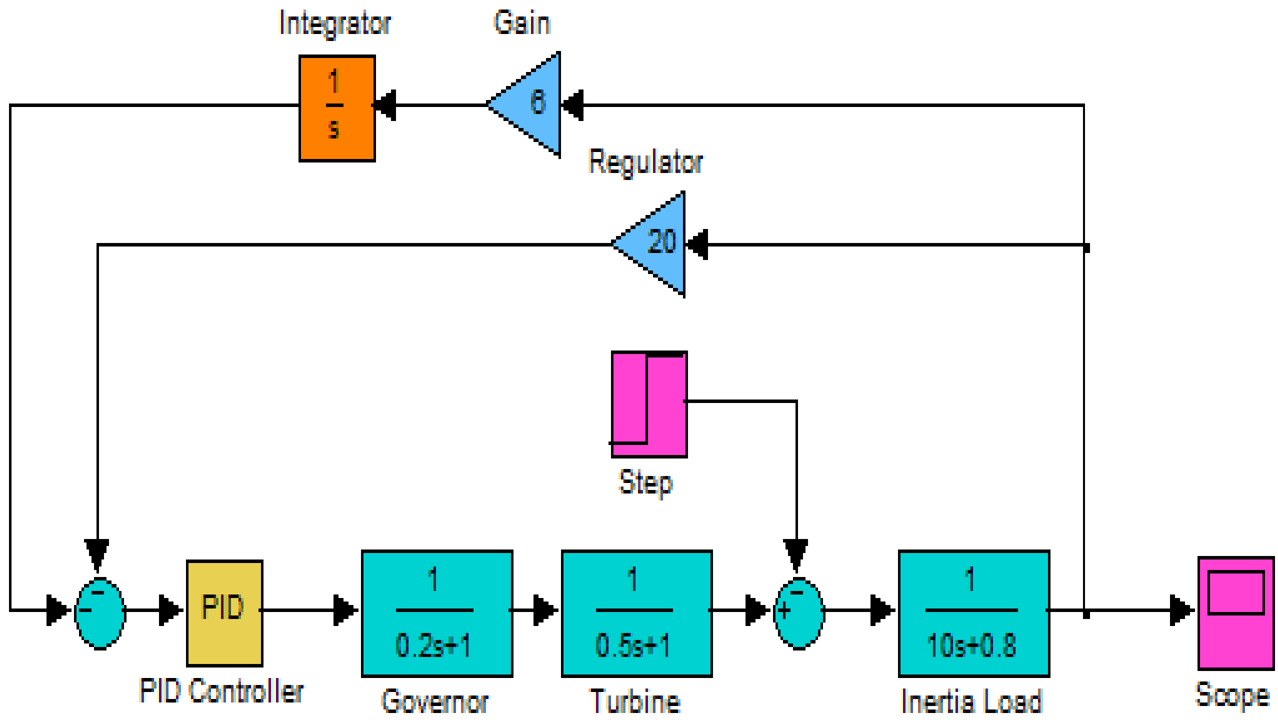

Fig 5.1: Simulink LFC Block

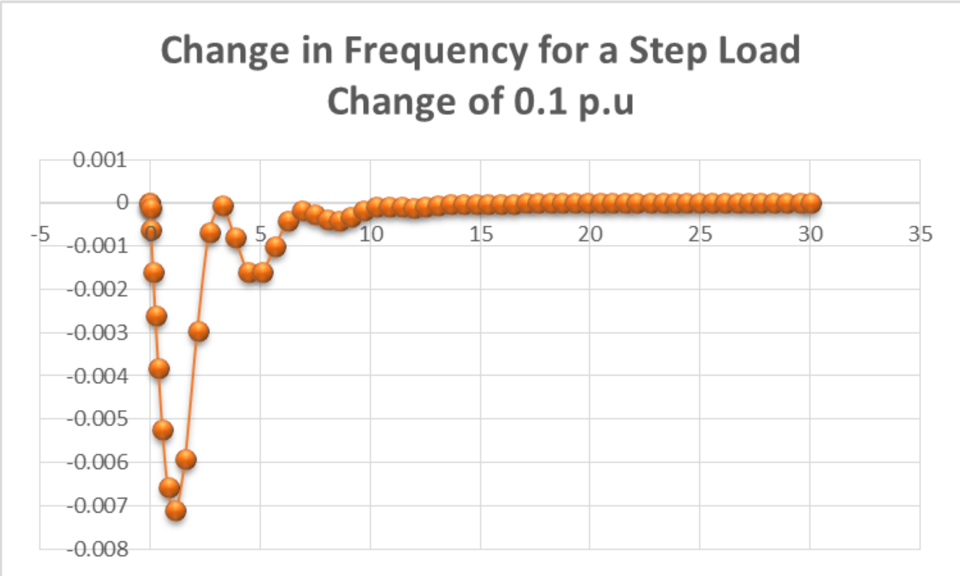

Fig 5.2: Plot for change in frequency for a step load change of 0.1 p.u

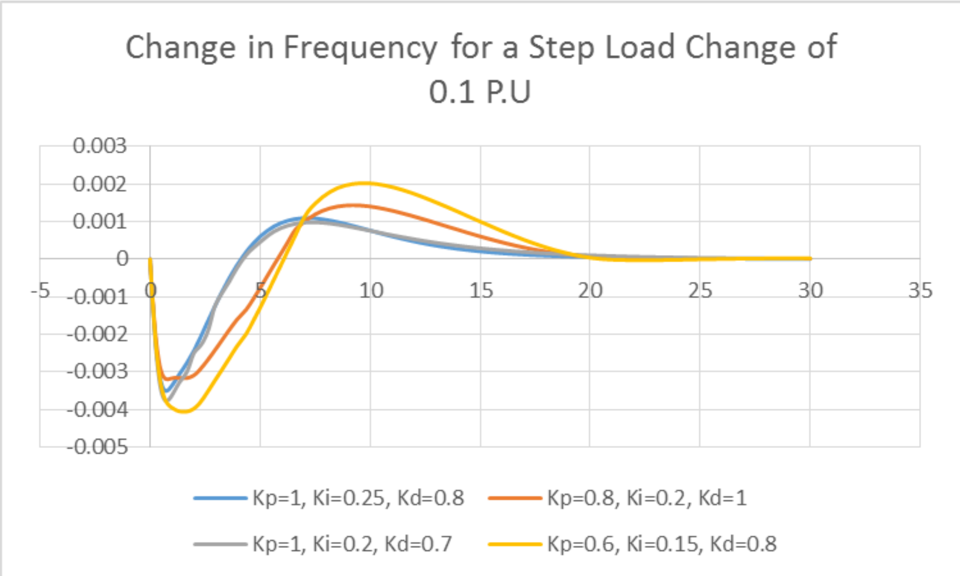

Fig 5.2: Plot for Change in frequency for a step load change of 0.1 p.u

VI. CONCLUSION

The quality of the power supply is determined by the constancy of frequency and voltage. The stabilizing PID control parameters of LFC control system for controlling the real power and frequency are obtained using "Stability boundary locus method". The simulation results revealed that the proposed PID Controller using "Boundary Locus Methods" can obtain the optimal parameters of LFC quickly and efficiently. It can be concluded that, the PID controllers provide a satisfactory stability between frequency overshoot and transient oscillations with zero steady state error. The simulation results demonstrate the effectiveness response.

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