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Calculation of Stable Controller Values for Single Area Isolated Power System using Boundary Locus Method

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Abstract:- The power system's operating point fluctuates constantly due to its extremely nonlinear nature. As a result, both actual and reactive power are impacted by the extremely low system performance. Real power shifts mostly impact the Changes in voltage magnitude are the primary determinant of changes in reactive power and system frequency. Reactive and real capabilities can therefore be managed independently. The Automatic Voltage Regulator (AVR) regulates the voltage magnitude and, therefore, the reactive power, whereas the Load Frequency Control (LFC) controls the actual power. The regulating of generator power output is known as load frequency control, or LFC, in an interconnected system. Generally speaking, fixed gain controllers are made for nominal operating settings and don't offer the optimal control performance under a variety of operating circumstances. Therefore, it is preferable to monitor operating circumstances and compute the control using updated parameters in order to maintain system performance close to optimal. Using the "Boundary Locus Method," a novel approach to identifying stabilising PID controllers for the LFC control system loop has been put forth in this study.

I. INTRODUCTION

Unusual circumstances like generating failures and load variations lead to the system frequency degrading from the intended level. With an appropriate LFC design, the generator loads must be controlled based on the ideal frequency value in order to guarantee the power supply's quality. Several strategies have been used in the past to account for parametric uncertainty and nonlinear limitations while maintaining system performance close to its ideal operating state [1].

A controller is a device that has the ability to rectify deviations by comparing regulated values with intended values. Achieving system stability is the primary goal of every controller. By reducing steady state errors, controllers increase steady state accuracy. Stability increases together with the precision of the steady state. Additionally, they aid in lowering the offsets generated inside the system. With these controllers, the system's maximum overrun may be managed. Additionally, they aid in lowering the system's noise signals. With these controls, the over-damped system's slow reaction may be accelerated. This study uses a novel approach to calculate all stabilising PI controllers [2]. and [3] is provided. Plotting the stability boundary locus in the (kp; ki) plane and then determining the stabilising values of a PI controller's parameters form the basis of the suggested approach. By solving a series of inequalities without the use of linear programming, the method does not need sweeping over the parameters or the Pade approximation. As a result, it provides a number of significant benefits above the current findings in this area. In addition to stabilisation, stabilising PI controllers that meet predetermined gain and phase margins are calculated using this technique. PID controllers for control systems with and without time delay are also designed using the suggested methodology. The (kp; ki), (kp; kd), and (ki; kd) planes yield the limiting values of a PID controller that stabilise a particular system with time delay.

II. BOUNDARY LOCUS METHOD

A. Design of Pi Controller

Examine Figure 1's single-input single-output (SISO) control system.

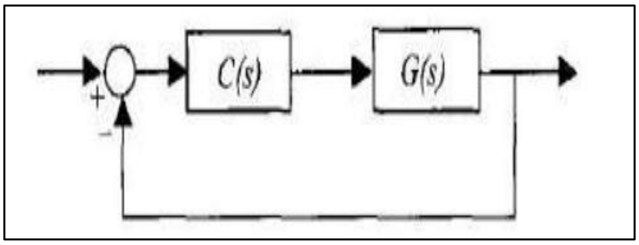

Fig 1: A SISO Control System

Where $G(S)\frac{N(S)}{D(S)}$ (1)

Is the plant that has to be managed, and C(s) is the form's PI controller.

$$G(S) = K_p + \frac{K_i}{S} = \frac{(K_pS+K_i)}{S} \quad (2)$$

The challenge is to calculate the PI controller's settings using Eq. (2), which stabilises the system in Fig. 1. Substituting s = jω after breaking down the numerator and denominator polynomials of Eq. (3) into their even and odd components yields

$$G(j\omega) = \frac{Ne\,(-\omega^2)+j\omega No(-\omega^2)}{De\,(-\omega^2)+j\omega Do(-\omega^2)} \quad (3)$$

The system's characteristic polynomial Δ(s) is shown in Fig.

Hurwitz stability is 1. The characteristic equation from Fig. 1 may be expressed as Δ(s)=1+G(s).C(s) The system's closed loop characteristic polynomial may be expressed as

$$\Delta(S) = [KiNe(-\omega 2) - Kp\omega 2N0(-\omega 2) - \omega 2D0(-\omega 2)] + j[Kp\omega Ne(-\omega 2) + Ki\omega N0(-\omega 2) + \omega D0(-\omega 2)] = 0 \quad (4)$$

The real and imaginary components of Δ(s) are thus equal to zero, yielding

$$[Kp\omega Ne(-\omega 2) + Ki\omega N0(-\omega 2) + \omega D0(-\omega 2)] = 0 \quad (5)$$

And

$$Kp\omega Ne(-\omega 2) + Ki\omega N0(-\omega 2) = -\omega D0(-\omega 2) \quad (6)$$

Let
Q(ω) = -ω 2N0(-ω 2), R(ω) = Ne(-ω 2)
S(ω) = ωNe(-ω 2), U(ω) = ωN0(-ω 2)
X(ω) = ωD0(-ω 2), Y(ω) = -ωDe(-ω 2) (7)

Equations (5) and (6) may therefore be expressed as

$$K_pQ(\omega) + K_iR(\omega) = X(\omega)$$

$$K_pS(\omega) + K_iU(\omega) = Y(\omega) \quad (8)$$

From these equations

$$K_p = \frac{X(\omega)U(\omega) - Y(\omega)R(\omega)}{Q(\omega)U(\omega) - R(\omega)S(\omega)} \quad (9)$$

And

$$K_i = \frac{Y(\omega)Q(\omega) - K(\omega)S(\omega)}{Q(\omega)U(\omega) - R(\omega)S(\omega)} \quad (10)$$

The stability boundary locus, l(kp,ki,w), in the (k,.ki)-plane may be found by concurrently solving these two equations. The parameter plane ((kp,ki)-plane) is separated into stable and unstable areas by the stability boundary locus.

The stable zone containing the stabilising kp and ki parameter values may be identified by selecting a test point within each region.

B. *Design of Pid Controllers:*

Assume that Fig. 1's C(s) is a PID controller of type

$$C(S) = K_p \frac{K_i}{S} K_d S \quad (11)$$

The stability boundary locus in the (Kp, Ki) plane can be found by following the steps in Section 1. be readily produced in the (kp, kd)-plane for a fixed value of ki, or it can be acquired for a fixed value of Kd. For a given value of kp, however, the stability boundary locus in the (ki, kd)-plane cannot be obtained because will, in this instance, equal zero. While the stability area in the (ki,kd) plane for a fixed value of Kp is a convex polygon, it is not a convex polygon and might not even be a convex set in the (kp, li)-plane for a fixed value of kd or in the (kp,kd)-plane for a fixed value of ki. However, by employing the stability region found in the (kp, ki) plane and (kp, kd)-plane as follows, the stability region in the (ki, kd)-plane may be determined for a fixed value of kp.

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

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

Substituting Ki in terms of Kd

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

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

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

Thus, the stability areas in the (kp, ki) and (kp, kd) planes may be found using these equations.

III. BASIC GENERATION CONTROL LOOPS

Each generator in an integrated power system has its own LFC and AVR control loop. Fig. 2 shows the schematic representation of the voltage and frequency control loop. The frequency and voltage magnitude are kept within the designated bounds by the controllers, which are configured for a certain operating state and handle slight variations in load demand. Variations in the rotor angle δ and, consequently, the frequency f, are the primary determinants of slight variations in actual power. The magnitude of the voltage, or the generator excitation, is the primary determinant of reactive power [4]. A brief variation in generator speed results in a change in angle ⊞. For minor variations, load frequency and excitation voltage controls are therefore non-interactive and amenable to separate modelling and analysis. Additionally, because the generating field's time constant is significantly less than the turbine's and generator's moment of inertia-time constant, the power frequency control is slow acting and the excitation control is rapid acting. As a result, the load frequency and excitation voltage control are examined separately, and there is very little cross coupling between the LFC loop and the AVR. Active and reactive power demands in a power system are never constant; they fluctuate constantly in response to growing or dropping trends.

While reactive power is primarily dependent on changes in voltage magnitude and less sensitive to frequency variations, changes in actual power have an impact on the system frequency. System generation control's primary goal is to maintain the intended frequency and power exchanges across adjacent systems by balancing system generation against load and losses. The Automatic Voltage Regulator (AVR) and the Load Frequency Controller (LFC) are a generation's two primary control loops.

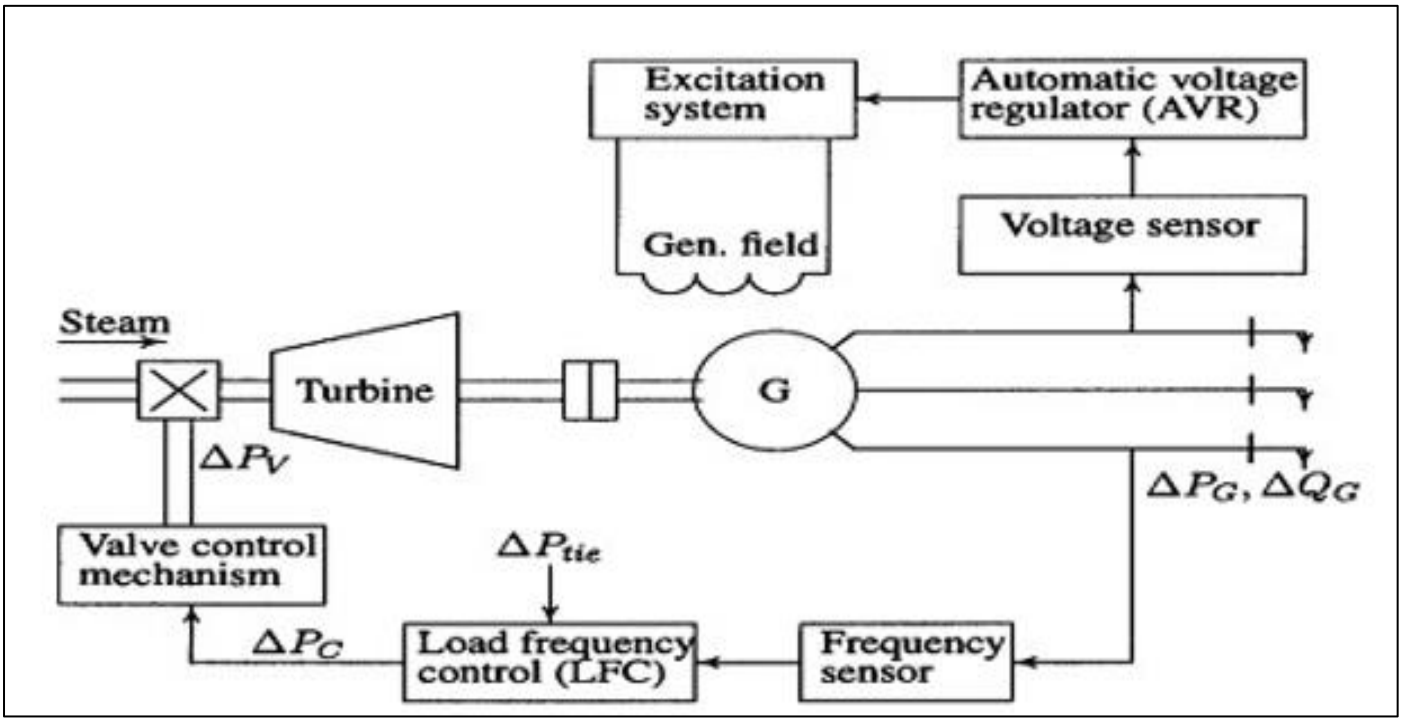

Fig 2: Schematic Diagram of LFC and AVR of a Synchronous Generator

IV. LOAD FREQUENCY CONTROL

In the design and operation of electrical power systems, load frequency management is crucial.

Furthermore, an LFC system that controls generator loading based on frequency must be designed in order to guarantee the quality of the power supply. For the following reasons, conventional controllers are frequently impractical for implementation. All of the system's states influence the ideal control. In reality, not every state could be accessible. It is necessary to assess the states that are unavailable or absent.

It could not be cost-effective to send all of the data over great distances. The control, which depends on load demand, is a function of the states. Realising the ideal controller may depend on an accurate load demand prediction.

By controlling the system frequency, LFC seeks to preserve the system's actual power balance. There is a frequency variation whenever the actual power demand varies. The turbine governor receives this frequency error after it has been amplified, combined, and converted into a command signal. By altering the turbine's output, the governor works to bring the input and output back into balance.

Megawatt frequency or power-frequency (P-f) control are other names for this technique. Take into account the following LFC Loop Parameters for the analysis:

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Table 1: LFC

S.No	Block	Gain	Time Constant
1	Governor	Kg=1	Tg=0.2 Sec
2	Turbine	Kt=1	Tt=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		

A. Design of Pi Controller

Single Area Load Frequency Control's analogous transfer function is provided by

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

Changing the parameter values shown in Table 1 now

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

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

Substituting S = j ω;

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

From above equation, we have

$$\mathrm{R}(\omega) = -0.1\omega^2+1, U(\omega) = 0.7\omega$$

$$\mathrm{Q}(\omega) = -0.7\omega^2, S(\omega) = -0.1\omega^3+\omega$$

$$\mathrm{Y}(\omega) = 7.08\omega^3-20.8\omega, X(\omega) = -\omega^4+10.56\omega^2$$

$$K_p = \frac{0.008\omega^5-1.768\omega^3+20.8\omega}{-0.01\omega^5-0.29\omega^3-\omega} \quad (12)$$

$$K_i = \frac{-0.1\omega^7-2.9\omega^5+4.396\omega^3}{-0.01\omega^5-0.29\omega^3-\omega_3} \quad (13)$$

Shifting all of the poles of a control system's characteristic equation to a desired area in the complex plane—for instance, to a shifted half plane that ensures a given response settling time—is crucial for control system analysis and design.

This section's goal is to identify all values of S=ρ, where (ρ= constant).

Using s+ρ instead of s in quation 1 & 2.

Next, determine the Kp and Ki planes' relative stabilisation and ρ =0.5. By repeating the previous step, we determine Kp and Ki.

$$K_p = \frac{0.058\omega^5-0.117\omega^3+38.465\omega}{-0.01\omega^5-0.365\omega^3-1.8906\omega} \quad (14)$$

$$K_i = \frac{-0.1\omega^7-3.65\omega^5+2.9\omega^3}{-0.01\omega^5-0.365\omega^3-1.8906\omega} \quad (15)$$

From the equations 12, 13, 14 and 15, the stability region is shown in Fig 3.

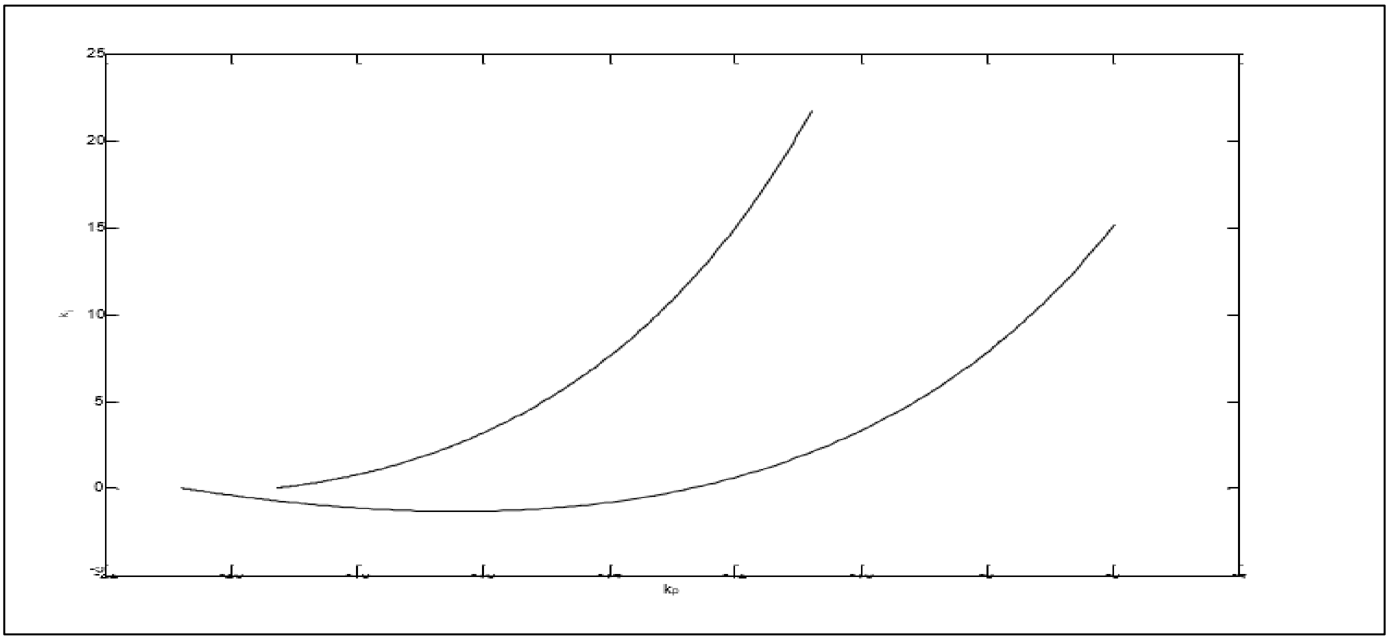

Fig 3: Stability Regions for ρ=0 and ρ=0.5

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 K_p *and* K_i

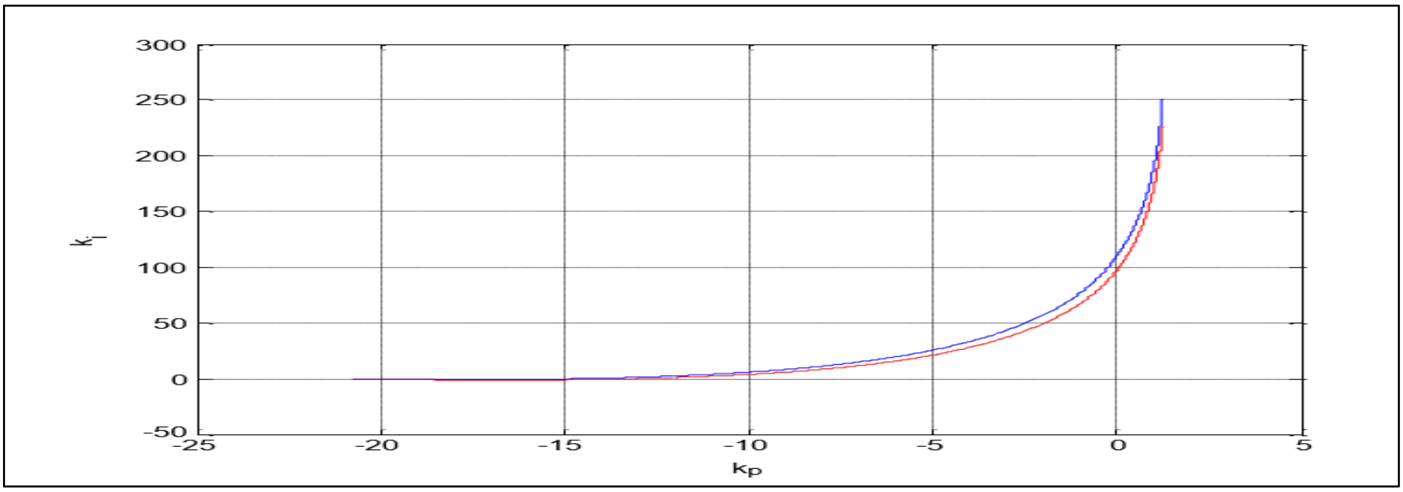

Fig 4: Stability Region in the (Kp, Ki) plane for Kd=0 and Kd=1

➤ *Step 2:*

Obtain equation K_d om 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=2.9-0.01 K_i,b_2= -4-0.29K_i,$b_3 = K_i$

Stability regions for $K_i = 0$

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

Stability region for $K_i = 1$

$$K_d = \frac{0.1\omega^7 + 2.89\omega^5 - 4.29\omega^3}{-0.1\omega^7 - 2.9\omega^5 - \omega^3}$$

Now the plots are obtained for $K_p and\ K_d$

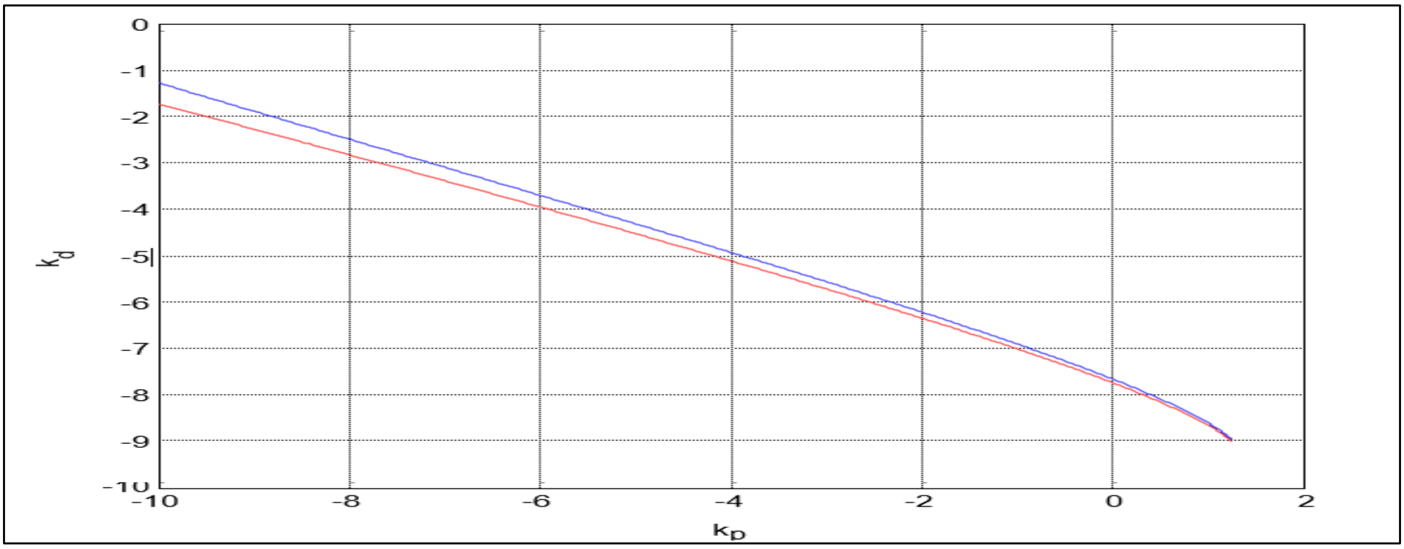

Fig 5: Stability Region in the (Kp, Ki) Plane for Ki=0 and Ki=1

From the above two graphs we obtain 8 points for Kp= 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 c -5.71, K_d =0

K_d = 0.016K_i c -5.71, K_d =0

Now, sketch these lines' patch shape. Plots for Kp, Ki, and Kd are now available.

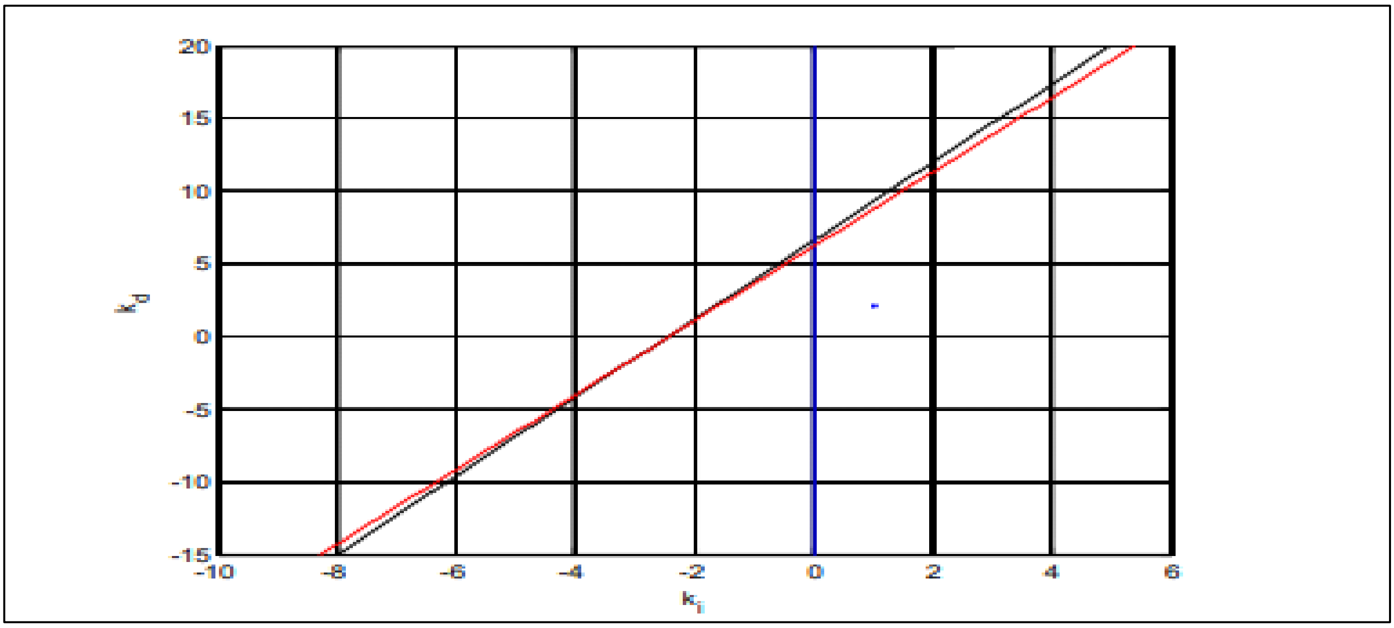

Fig 6(a): Stabilizing Kp, Ki, and Kd Region

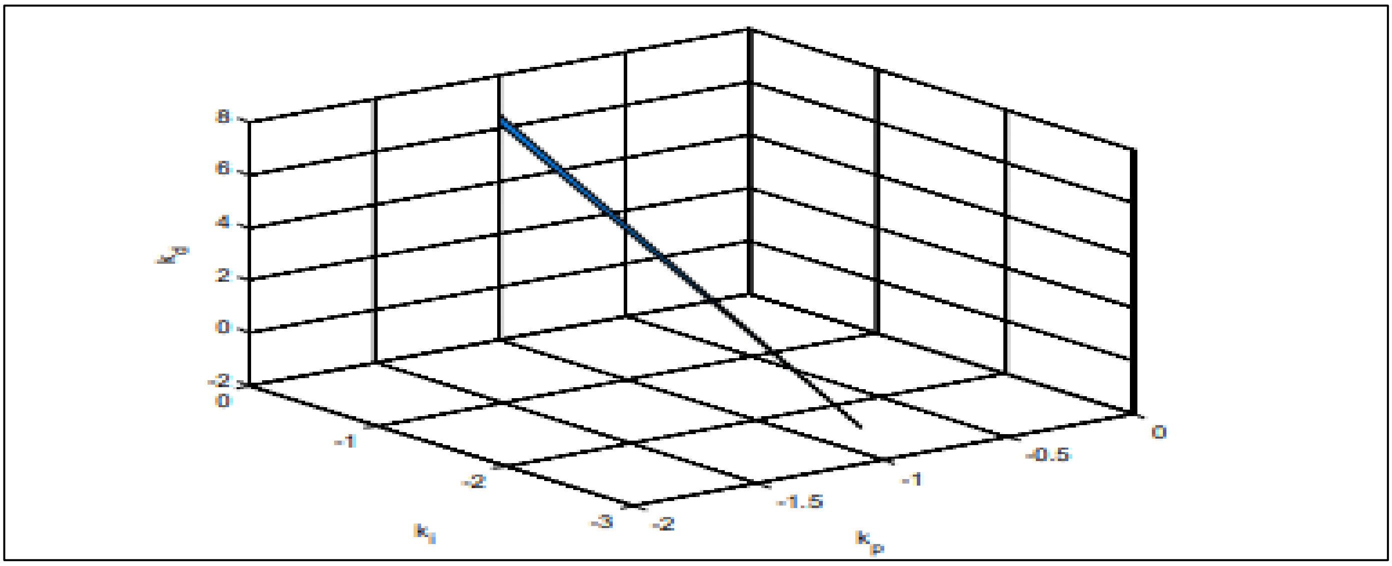

Fig 6(b): Stabilizing Kp, Ki, and Kd Region

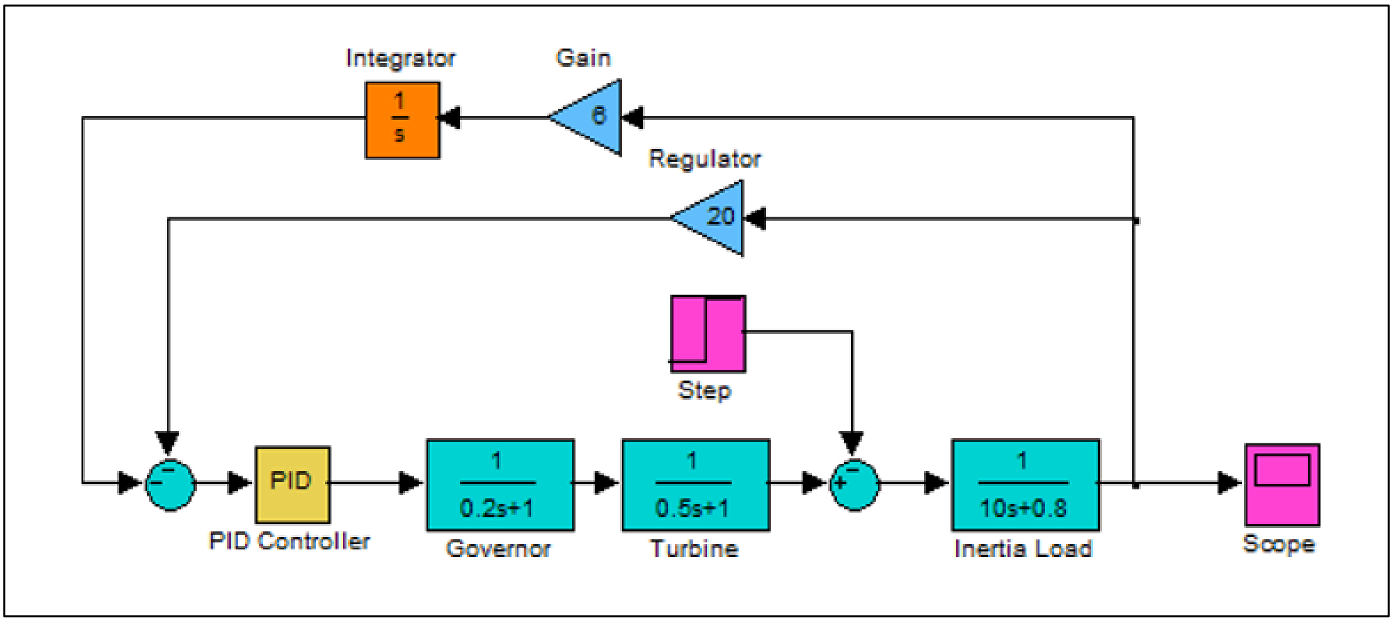

Fig 7: Simulink LFC Block

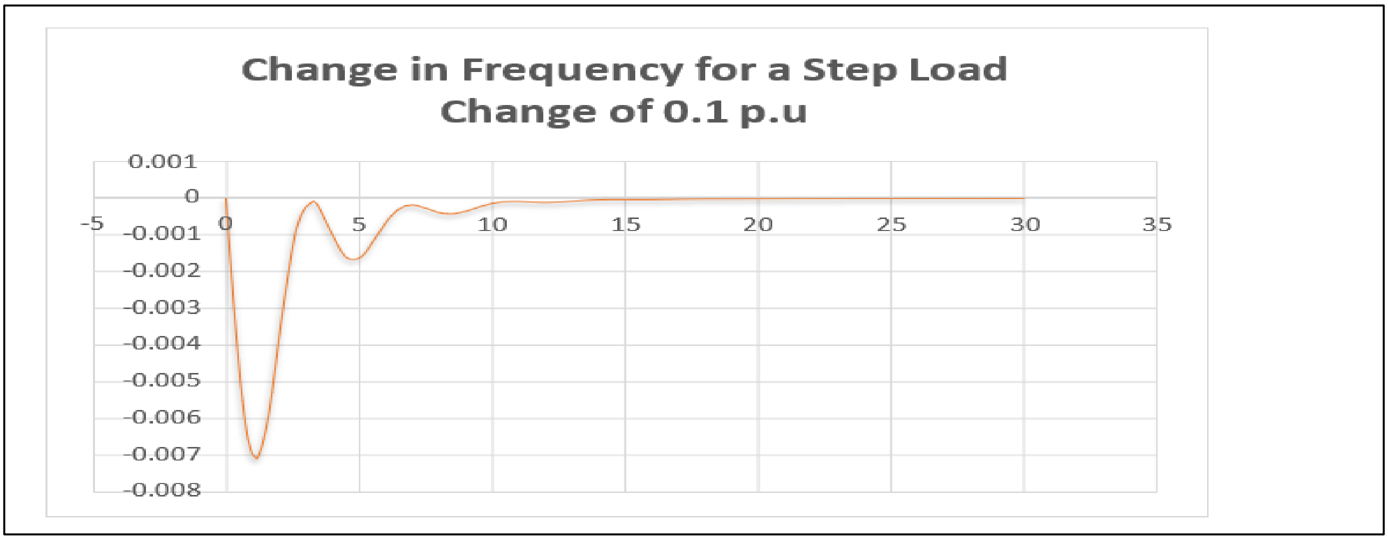

Fig 8: Plot for Change in Frequency for a Step Load Change of 0.1 p.u

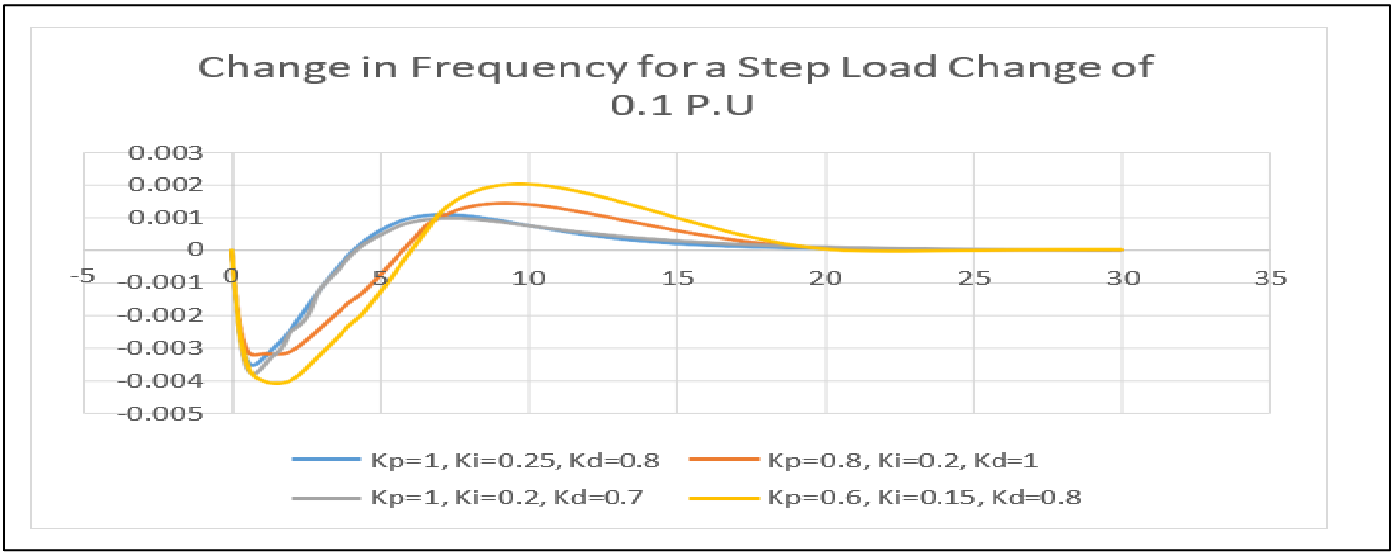

Fig 9: Plot for Change in Frequency for a Step Load Change of 0.1 p.u

V. CONCLUSION

The quality of the power supply is defined by the stability of its frequency and voltage. In this context, the stabilizing PID control parameters for the Load Frequency Control (LFC) system, which manages real power and frequency, are determined using the "Stability Boundary Locus Method." Simulation results indicate that the proposed PID controller, based on this method, efficiently and rapidly achieves optimal LFC parameters. The results further show that the PID controllers offer satisfactory stability by balancing frequency overshoot and transient oscillations, while maintaining zero steady-state error. Overall, the simulations demonstrate the effectiveness of the control response.

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