Load Frequency Control by Quadratic Regulator Approach with Compensating Pole using SIMULINK

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Abstract— **in this research**, f**or the load frequency control (LFC) challenge, we provide a few possible approaches to building an optimum PID controller. This scheme employs the Quadratic Regulator Approach with Compensating Pole (QRAWCP) approach. In both multi-area and single-area power systems, this control law is used to solve load frequency concerns. And the other scenario that is considerable, the controller's robustness is evaluated on the same systems in terms of non-linearities, external disturbances, and parametric uncertainty such as the Governor Dead Band (GDB) as well as the Generation Rate Constraint (GRC). We demonstrated that, even when external interruptions and variable fluctuations are taken into account, the suggested control method still provides greater results for the LFC challenge. The performance of the control method is evaluated using Simulink simulations.**

Keywords— LFC, PID, QRAWCP, Two area network, Simulink.

I. INTRODUCTION

Due to the industrial revolution, technical advancements, and other factors, every country's electricity demand is steadily rising. Yet, distribution of electricity, the considerable challenge is to give client with a fluctuation in distribution despite any variables or constants values toggle from actual values or outside interruptions [1]. In Load Frequency Control we have mainly two terms are considerable one is regulated frequencies and the other one term is output reference tracking. These two terms are showing the stability of system and proper reference tracking. We want that over system approach over requirement and don't exceed allowable limitations. To address the problem of frequency control, [2] demonstrated that output power fluctuates with the constantly evolving power system. If the source and drain stability of wattage is not established, the frequency varies. As a result, frequency balance is necessary, which is accomplished via a rate regulator method. The technique is used as a first objective of maintaining control over the performance and capacity. From figure 1, the universal scheme of power generation section is label below where *f* is the invariant frequency *and* V_d is the demanded voltage, if the output wattage is increased the tool which has duty to control the speed of generator has reduces [3].

When it comes to power distribution and generation the LFC is the essential portion of AGC stands for Automatic Generation Control in whole plant. AGC is a technique for varying the electricity production from many generators across different power facilities that respond to variations in

How to cite: Rehman, A.U., Saeed, Z., Taseen, R., Shah, M.S., Ali, M.Z.H., Shaikh, I.U.H., Haseeb, A. (2023). Load Frequency Control by Quadratic Regulator Approach with Compensating Pole using SIMULINK. *JAREE (Journal on Advanced Research in Electrical Engineering), 7(2).*

the load [4] [5]. When a load varies, the plant's frequency deviates from its set point. Numerous control strategies are employed to the LFC complication in the control literature. Investigation on the LFC was already carried out every generation. However, due to rapid population growth, modernization, and urbanism, among other factors, energy consumption has risen dramatically in the last two decades. As a result of the frequency imbalances, power distribution failures have been reported.

We demonstrated that, even when external interruptions and variable fluctuations are taken into account, the suggested control method still provides greater results for the LFC challenge. Many scientists have previously suggested techniques to ensure a continuous flow of power [6]; an Internal Model Control (IMC) strategy for unclear models using part count lowering [7]. An integrated adjustments of proportional-integral-derivative (PID) control, while the transient response identification and immediate formulation to develop PID [8]. Controller parameters for the unsettling number of co systems based on Kharitonov's theorem [9], and an adaptable strategy used by LFC [10].

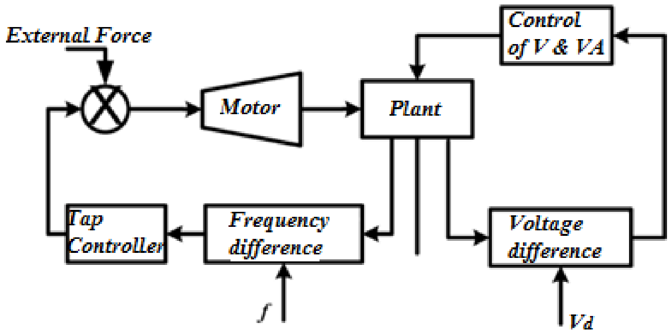

Figure 1: Basic Mechanism of Generating Plant

There are indeed a group of nonexistent approaches that have been published the prevent the spread that can exceed linear controllers; however, the majority of these would be analytically complex and challenging to implement for practical system. In contrast, since the PID controller is among the most basic linear controllers available, it is often employed in conjunction with optimum control.

The PID controller appropriate items, versatility, a proven track record of success, and the most comprehensive approach used by real-time monitoring challenges and the process industry [11] [12]. The three aspects of the PID controller increase both the steady-state and transient specifications of the control system response [13] [14] [15]. The first optimization technique for PID controllers is presented by Zeiglor [16]. Since then, many studies on PID have been conducted, including Internal Model Control (IMC), Hrones, Chien, Reswich (C-H-R), and Cohen-Coon, optimal solution techniques such as Particle Swarm Optimization (PSO) that has been done through Gaing in 2004 [17], we also have Big-Bang Big-Crunch (BBBC) methods named as Iruthayarajan and Baskar in 2009 [18], LQR- PID Hote as well as Hanwate in 2017 [19]. These strategies, on the other hand, offer some advantages and disadvantages over prior methodologies of transient and steady-state responsiveness. LQG and LQR regulators were used in another paper [20], although they were only shown for a specific region and did not include non-linear conditions. In 2018 recently proposed a quadratic regulator based PID for disturbance rejection in a Sun tracker system, however they didn't apply their work to quasi in complex applications [21]. Therefore, inside this research, using a simple modelling approach, we built an optimum PID controller for load frequency management using a QRAWCP and analysis method. Then we analyzed the performance achieved for multi-area and single situations, on behalf of practical problems like quasi plus parameterized unknowns, with both the appropriate method PID controller and any relevant controls to show the suggested procedure's effectiveness. We concentrated primarily on stability, highlighting the system's quick settling and lack of significant overshoots. The simulation is built on MATLAB with the help of controllers on different parameters [22-25].

In this research paper we used the QRAWCP method and calculate the parameters' of PID controller by adding the compensating pole. And then compare the result of our work with the research papers which we consider in our work.

II. PID CONTROLLER DESIGN USING QRAWCP APPROACH FOR LFC

The concept of wattage frequency control utilizing monitoring to correct for the variation of f that uses the appropriate monitor signal u is shown in Fig. 2. Until now, Hote and Hanwate in 2018 [10] have just developed the QRAWCP for a sun tracker system, but they have not explored stability in the presence of quasi such as GRC and GDB. Developing an optimum PID controller for a multi-area reheated rotor and a single non-reheated (NR) rotor using the QRAWCP technique. The stages again for the single area model are outlined first, accompanied by an expansion for the multi promoter region.

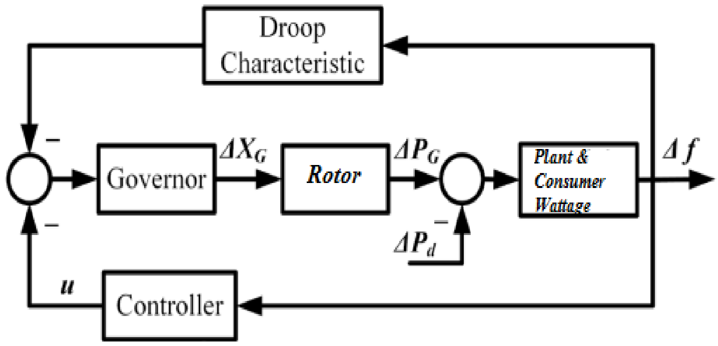

Figure 2: Representation for suggested control system

Table 1: The variables of the LFC system

Δf	Incremental frequency deviation (Hz)
ΔP_d	Load disturbance (p.u.MW)
f	Reference load frequency input
u	Control signal
K_E	Electric system gain
T_E	Electric system time constant (s)
K_C	Governor gain constant
T_C	Governor time constant (s)
K_R	Turbine Rotor gain constant
T_R	Turbine Rotor time constant (s)

S	Using governor action speed is limited (Hz/p.u.MW)
ΔP_G	Changes in power supply over time (p.u.MW)
ΔX_C	Governor valve position is gradually changed.

Step 1: G(s) is the LFC transfer function and shown in (1) for the single area network, and since $\Delta f(s) = G(s)U(s)$,
we have,

$$G(s) = \frac{K}{s^3 + c_2 s^2 + c_1 s + c_0}$$

Where:

$$K = \frac{K_E K_R K_C}{\sigma},$$

$c_o = 1 + \frac{K_E K_R K_C}{\sigma S}, c_1 = \frac{T_C + T_R + T_R}{\sigma}, c_2 = \frac{T_C T_T + T_C T_P + T_R T_P}{\sigma}$

And,

$$\sigma = T_C T_R T_P$$

Now we know that system model of each control area in a multi-area power system is $B_i G$. Further, the state space model becomes, $\dot{x}(t) = Ax(t) + Bu(t)$ and $y(t) = Cx(t)$ and given in (2). Where Table 1 shows *the LFC system variables*, considered from Saxena and Hote (2016).

$$\begin{bmatrix} \dot{x_1} \\ \dot{x_2} \\ \dot{x_3} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -c_0 & -c_1 & c_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ K \end{bmatrix} u$$
$$y = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

In (2), $A \in \mathbb{R}^{m\times m}, B \in \mathbb{R}^{m\times l}$, and $C \in \mathbb{R}^{1\times m}$. The PID controller's transfer function is given by $C(s) = (P_d s^2 + sP_p + P_i)/s$, where $P_p = proportional\ gain, P_i = integral\ gain\ and\ P_d = derivative\ gain.$

Step 2: The characteristic equation for a closed-loop system $C(s)$ as well as plant $G(s)$ is $\Delta(s) = 1 + G(s)C(s)$ and equating $\Delta(s)$ to zero, we get,

$$s^4 + c_2 s^3 + (c_1 + KP_d)s^2 + (c_0 + KP_p)s + KP_i = 0$$

Step 3: The LQR technique is used to find the control scheme. The QR technique is a closed-loop system that is optimized to reduce a quadratic cost function. The performance index is intended for uncontrolled linear time-invariant systems objectives with constraints such as u, y, and error (e).

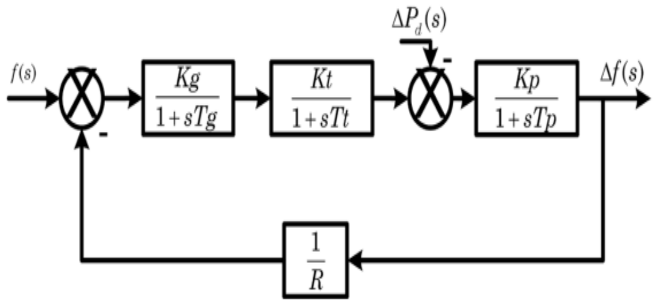

Figure 3: Single-area energy schematic model

From $u(t) = -\lambda x(t)$, u(t) is the appropriate control vector. As a result, unconstrained optimal action is explored in this case. As a result, the system's Performance Index (PI) is defined as follows:

$$J = \int_0^\infty (x^T Q x + u^T R u) dt$$

Where $Q \in \mathbb{R}^{m\times m}\ and\ R \in \mathbb{R}^{l\times l}$ is Positive semidefinite and symmetric positive definite, respectively For the LFC scenario, l = 1 and m = 3 are used. As a result, its LTI system model is,

$$\dot{x} = \tilde{A}x$$

We also know that $\tilde{A} = (A - B\lambda)$, so B and A are convenient, A˜ has eigenvalues that should also be on the top left of such s-plane. Then (4) could be rearranged as follows:

$$J = \int_0^\infty (x^T (Q + \lambda^T R \lambda) x)\, dt$$

Assuming,

$$\frac{d}{dt}(x^T P x) = -(x^T (Q + \lambda^T R \lambda) x)$$
$$(x^T (Q + \lambda^T R \lambda) x) = -x^T P \dot{x} - \dot{x^T} P x$$

Using (5) in (7) and then substituting in (6), we get,

$$J = -\int_0^\infty x^T \left[P\tilde{A} + \tilde{A}^T P\right] x\, dt$$

The fact that P must be a positive definite matrix is a requirement. When we evaluate (7) to (8), we obtain,

$$P\tilde{A} + \tilde{A}^T P = -(Q + \lambda^T R \lambda)$$

As $(A - B\lambda)$ is a constant, on the left side of the s-plane are its Eigen values. Thus, the cost function may be obtained by solving for a positive definite matrix P that can fulfil (9),

$$\psi = \int_0^\infty (x^T (Q + \lambda^T R \lambda) x)\, dt$$

From (7),

$$\psi = -x^T P x \int_0^\infty dt$$
$$\psi = -x^T(\infty) P x(\infty) + x^T(0) P x(0)$$

As (5) is nearly constant, where $x(\infty) \to 0$. As a result, $\psi = x^T(0) P x(0)$. This is determined by the starting circumstance.

Step 4: In (4), the state feedback control law $u = -\lambda x$ is obtained by minimizing of ψ using Pontryagin's minimal principle. The feedback gain λ is calculated as follows:

$$\lambda = R^{-1}B^T P$$

We develop Algebraic Riccati Equation (ARE) by further simplifying (5) with this control.

$$A^T P + PA - PBR^{-1}B^T P + Q = 0$$

In (13), R and Q are chosen as that $diag(q11, q22, q33)$ is $q11 > q22 > q33 > 0$ and $R = V^T V > 0$, where $V \in \mathbb{R}^m > 0$.

Step 6: The closed-loop mathematical expression $(sI - \tilde{A})$ is expressed as follows:

$$s^3 + (c_2 + p_{33}K^2)s^2 + (c_1 + p_{23}K^2)s + (c_1 + p_{13}K^2) = 0$$

Step 7: The closed-loop approach (3) has a fourth order, while (15) has a third-order order. As a result, to evaluate the two equations, we should insert one pole. According to the QRAWCP approach, we achieve it by strengthening one pole.

$$s^4 + (\alpha_4 + (c_2 + p_{33}K^2))s^3 + \begin{pmatrix} (c_1 + p_{23}K^2) \\ +(c_2 + p_{33}K^2)\alpha_4 \end{pmatrix} s^2 + ((c_1 + p_{13}K^2) + (c_1 + p_{23}K^2)\alpha_4)s + (c_1 + p_{13}K^2) = 0$$

Now α_4 may be obtained by relating (16) to each independent variable of (3),

$$\alpha_4 = -p_{33}K^2$$

For the statistical comparison, the above (16) may be expressed in a simpler version as,

$$s^4 + p_1 s^3 + p_2 s^2 + p_3 s + p_4 = 0$$

Where:

$$p_1 = p_{33}K^2 + c_2 + p_{33}K^2$$
$$p_2 = (c_1 + p_{23}K^2) + (c_2 + p_{33}K^2)p_{33}K^2$$
$$p_3 = (c_1 + p_{13}K^2) + (c_1 + p_{23}K^2)p_{33}K^2$$
$$p_4 = c_1 + p_{13}K^2$$

Step 8: By correlating (3) and (18), we may obtain the following C(s) variables,

$$P_p = \frac{1}{K}(c_1 + p_{13}K^2 + (c_1 + p_{23}K^2)p_{33}K^2 - c_0)$$
$$P_i = \frac{1}{K}(c_1 + p_{13}K^2)$$
$$P_d = \frac{1}{K}(p_{23}K^2 + (c_2 + p_{33}K^2)p_{33}K^2)$$

III. RESULTS AND DISCUSSION

Now looked at three possible scenarios in this part. Situations 2 and 1 deal for single-area scenarios via parameter uncertainties as well as technology non-linearity variables, correspondingly, whilst example (3) deals with a two-area scenario. We acquired PID parameters from QRAWCP:$P_p = 4.2401, P_i = 6.21$ and $P_d = 1.13$.

A. Case 1: Single area Network

We used the parameters for single area plant is: $K_E = 120$, $T_E = 20$, $K_R = 1$, $T_R = 0.3$, $K_C = 1$, $T_C = 0.08$, $S = 2.4$. The simulation result of over system is attached in following figure with and without controllers.

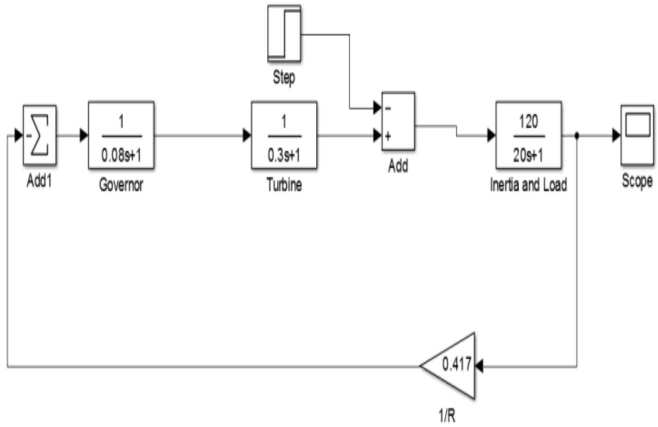

Figure 4: Schematic Diagram of Single Area without Controller

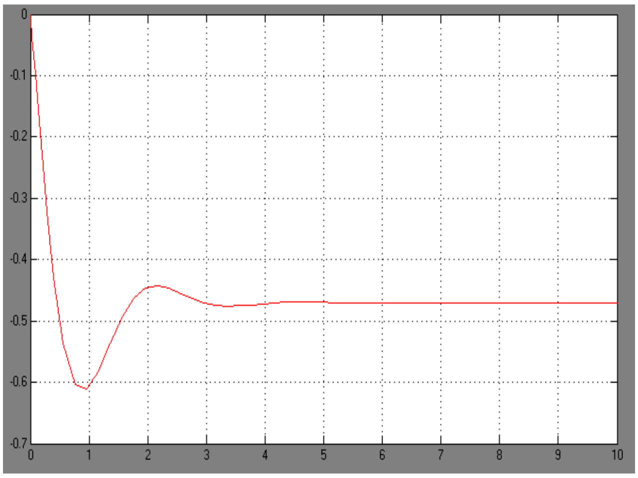

Figure 5: Output Waveform of Uncontrolled Plant

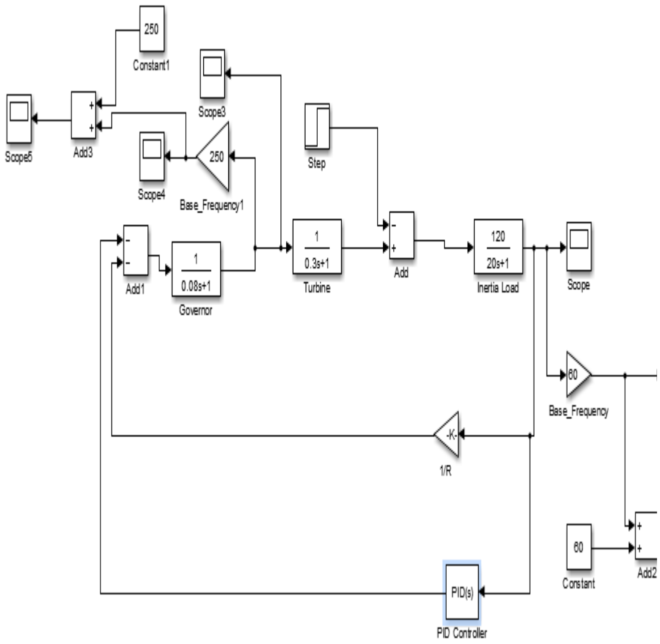

Figure 6: Single Area Network with PID controller

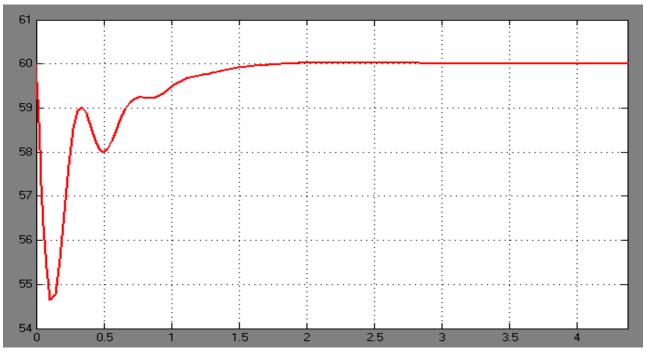

Figure 7: Output Waveform with Controlled Parameters

In these simulations we conclude that in single area network when the load is changes it means that the disturbance is added, and the system fluctuate and couldn't reach to its average frequency that is demand of 60 Hz. After applied the controller and set the controller parameters we conclude that the system has somehow delay but approaches to its reference point or frequency. By comparing it with the previous research we say that we somehow better than earlier research. The following parameters shows the rise time, peak time and settling time.

Table 2: Parametric Values

Performance and Robustness	**Uncontrolled Plant**	**Controlled Plant**
Rise Time	0	0.0793
Settling Time	0	1.23
Peak	0	1.43
Overshoot (%)	Infinity	32.5%
Closed Loop Stability	Stable	Stable

B. Case 2: LFC for two area control

In this example, the methodology is being generalized to a two-area power system model. For this reason, a model with two reheating generators, one for each area, is considered. Fig. 10 illustrates an example of the specific regions and their relationships, which has been adapted from Rehman and Majhi papers [22] [8]. The parameters that are used in two-area which seems to be as similar as in the single-area network where the connection relates to the T_1 and T_2 and frequency bias is B_1 is 20.6 and B_2 is 16.9. The schematic diagram and simulation result are shown in the following figures.

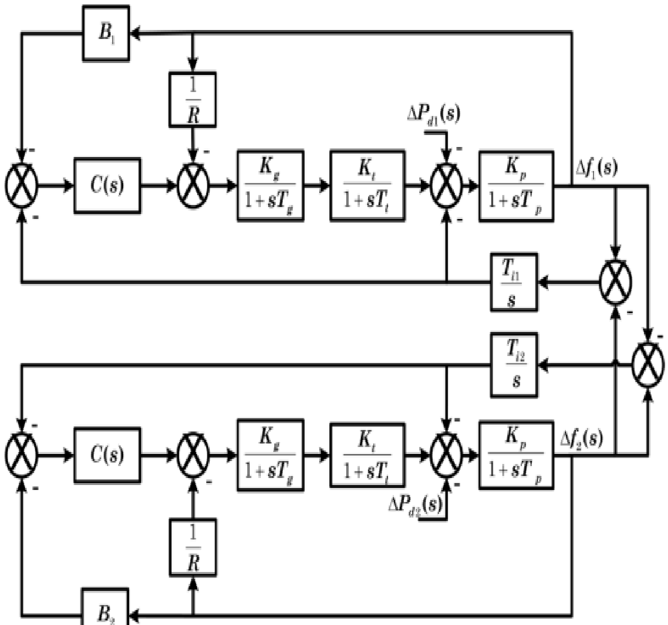

Figure 8: General Block diagram of multi two area power systems

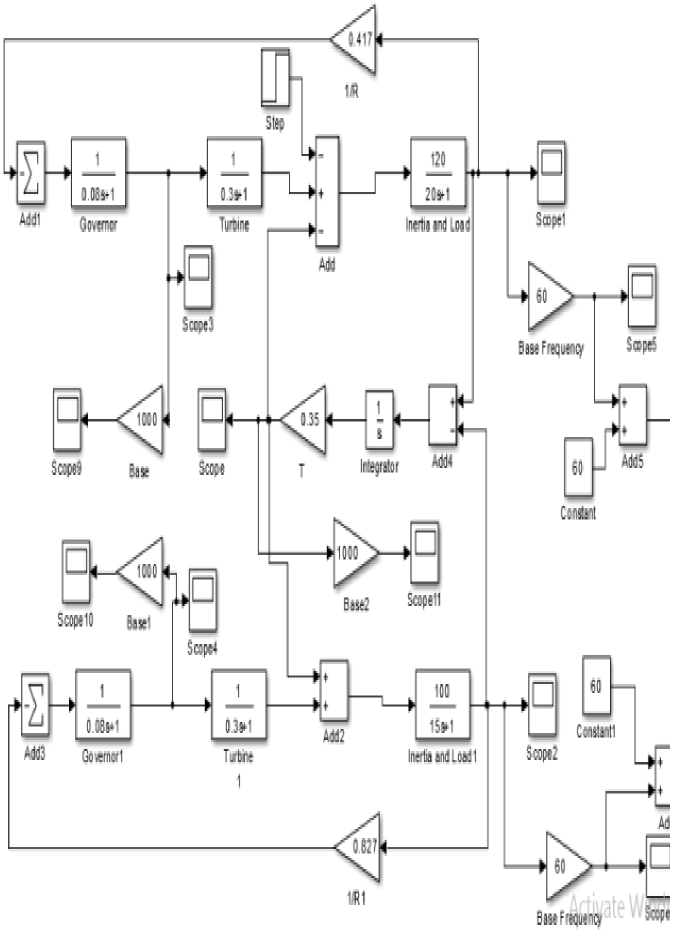

Figure 9: Without PID Controller Two-area Network

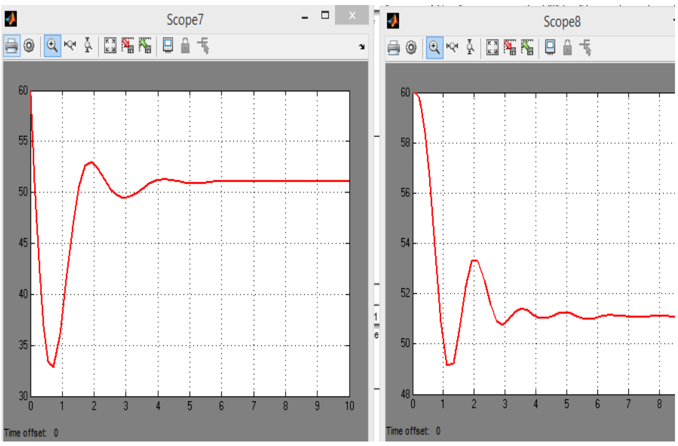

Figure 10: Simulation without PID Controller

Which shows the system is not reached to its average value i.e., 60Hz. So, in the following simulation we change the parametric values and by the placement of PID controller we achieved over result and the frequency approaches to 60Hz after taking its settling time.

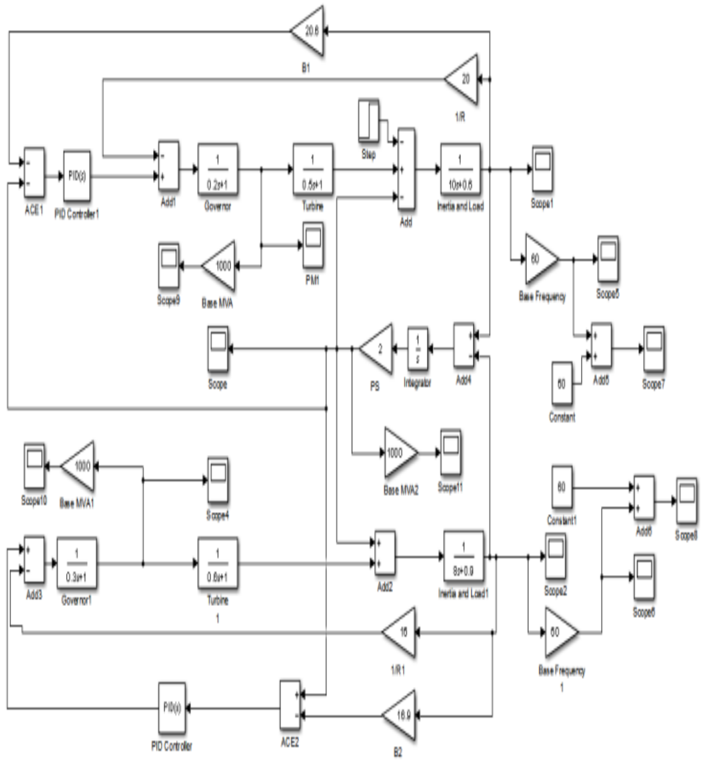

Figure 11: Two-area Network with PID controller

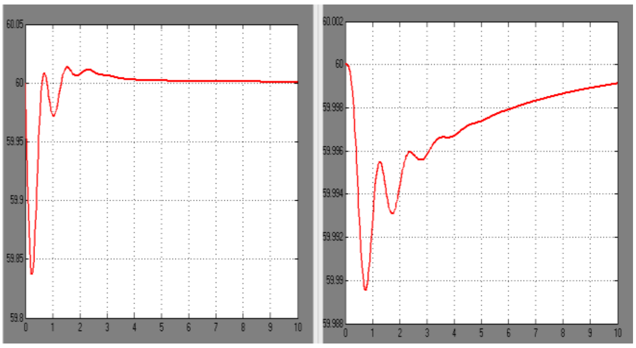

Figure 12: Simulation Result with PID Controller

Table 3: Two Area Network Parametric Values

1st Area Network Parameters		
Performance and Robustness	**Uncontrolled Plant**	**Controlled Plant**
Rise Time	0	0.16 s
Settling Time	0	1.89 s
Peak	0	1.45
Overshoot (%)	Infinity	17.2%
Closed Loop Stability	Stable	Stable
2nd Area Network Parameters		
Performance and Robustness	**Uncontrolled Plant**	**Controlled Plant**
Rise Time	0	0.196 s
Settling Time	0	3.4 s
Peak	0	1.57
Overshoot (%)	Infinity	24.5%
Closed Loop Stability	Stable	Stable

IV. CONCLUSION

To address the LFC problem, a unique framework PID controller approach that is based on the LQR technique with an additional offsetting pole is presented. In two separate scenarios, it is used and analyzed to current innovations for the same challenge. The methodology, QRAWCP-PID, as well as newer ones, is used to manage load frequency in all of these scenarios. The results of these analyses show that the suggested control system achieves higher ones in terms of the LFC challenge, even when external interruptions and variable fluctuations are considered. Considering and analyzing the integral performance characteristics for each strategy adds to the knowledge of the suggested control logic's supremacy.

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