## Scilab case study project on

# Simulation and Analysis of Two – Area Load Frequency Control System with Tie – Line Bias Control

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Power System Stability, Load Frequency Regulation and Tie – Line Bias Optimization.

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## 1. Abstract:

This project studies a Two-Area Load Frequency Control (LFC) System with Tie – Line Bias Control using Xcos to improve power system stability and reliability. LFC systems help control frequency changes caused by varying electricity use across connected power grids. Adding Tie – Line Bias Control helps manage power flow between areas, making the system more stable. This project uses Xcos, a tool for system modelling and simulation, to create detailed simulations. Research notes show that using Xcos allows for accurate modelling of complex systems. These simulations show how the system behaves under different conditions, measuring how well it controls frequency and handles sudden changes. The project looks at how better grid stability can benefit society by providing reliable electricity and reducing environmental impacts. Features of this project include studying transient and steady-state behaviour, evaluating performance metrics like frequency response, and assessing damping coefficients. The findings show that the proposed LFC strategy effectively improves grid performance and resilience. Research also indicates that such strategies can be cost-effective and easy to implement. This work can be used to make the grid more stable, integrate renewable energy like wind and solar, quickly restore power after problems, lower electricity costs, reduce pollution, improve smart grids, support small local power grids, and manage energy better overall. Additional benefits include helping with energy planning, supporting new energy policies, and making future power systems more flexible and efficient.

## 2. Introduction:

In the dynamic landscape of modern power systems, ensuring the stability and reliability of electrical grids is a multifaceted challenge. Load Frequency Control (LFC) systems play a pivotal role in maintaining the equilibrium between supply and demand, crucial for the smooth operation of interconnected power networks. These systems regulate the frequency of electrical power to prevent deviations caused by fluctuations in consumer demand and variable renewable energy sources. The concept of Tie – Line Bias Control further enhances the capabilities of LFC systems by optimizing the distribution of power between different geographical areas connected through transmission networks. By strategically adjusting the flow of electricity across tie-lines, this control mechanism not only improves frequency regulation but also enhances grid resilience against disturbances and operational uncertainties. This study focuses on simulating and analysing a Two – Area Load Frequency Control System with Tie-Line Bias Control using Xcos, an advanced simulation tool known for its versatility in modelling complex dynamic systems. Beyond technical intricacies, the project explores the broader implications of enhanced grid stability, including the socioeconomic benefits of reliable electricity supply and the environmental impacts of optimized energy management strategies. Through detailed simulations and analytical insights, this case study aims to contribute to the understanding of power system dynamics and management, offering valuable insights into the operational challenges and opportunities associated with modernizing energy infrastructures. By studying the interplay of technological advancements and regulatory frameworks, this study seeks to pave the way for sustainable and resilient energy solutions in a rapidly evolving global energy landscape.

## 3. Problem Statement:

Challenges in Frequency Management:

In the context of modern power systems, ensuring stable and reliable operation amidst dynamic changes in demand and generation is crucial. Load Frequency Control (LFC) systems are essential for regulating the frequency of electrical power to maintain grid stability. However, in interconnected power networks, effectively managing frequency deviations across multiple areas presents a complex challenge. Managing frequency deviations across interconnected power networks is complex, requiring optimized power exchange between regions to enhance grid stability. The integration of Tie-Line Bias Control aims to optimize power exchange between interconnected regions, enhancing frequency regulation and grid resilience. Despite its potential benefits, implementing and optimizing such a system requires thorough simulation and analysis to ensure effectiveness and reliability.

Innovative Control System Design:

The proposed solution addresses these challenges by developing a robust Two – Area Load Frequency Control System with Tie-Line Bias Control using Xcos. This system is designed to regulate frequency deviations within interconnected power grids, ensuring stable operation despite varying loads and generation inputs. The integration of Tie – Line Bias Control optimizes the distribution of electrical power between areas, thereby enhancing frequency response and minimizing the impact of disturbances on system stability. Developing a robust Two – Area Load Frequency Control System with Tie – Line Bias Control using Xcos aims to enhance grid stability.

Strategies for System Improvement:

To further improve the performance of the proposed system, several key enhancement strategies can be considered. Firstly, refining the parameters of the PID controller and adjusting droop control characteristics can optimize the system's response to frequency deviations. Secondly, enhancing the dynamics of governors and improving the accuracy of turbine-governor modelling can enhance the system's transient stability and response times. Thirdly, implementing advanced economic dispatch strategies can optimize the utilization of generation resources, thereby improving overall grid efficiency and reliability.

Simulation and Analysis Approach:

The methodology used to achieve the objectives of this project involves comprehensive simulation and analysis using Xcos. This advanced simulation tool enables the detailed modelling of complex dynamic systems, facilitating a thorough exploration of the Two – Area Load Frequency Control System with Tie – Line Bias Control. Through rigorous simulations conducted under various operational scenarios, this study aims to evaluate critical performance metrics such as frequency response, transient stability, and efficiency. By systematically analysing and optimizing the integrated control strategy, the project aims to validate its effectiveness and provide insights for enhancing power system resilience and reliability.

## 4. Basic Concepts Related to the Topic:

This study explores the simulation and analysis of a Two-Area Load Frequency Control (LFC) System with Tie-Line Bias Control using Xcos. LFC is crucial for maintaining grid stability by regulating frequency deviations. Tie-Line Bias Control optimizes power exchange between regions, enhancing system resilience and reliability.

Two – Area Load Frequency Control with Tie – Line Bias Control:

Two Area Load Frequency Control – An extended power system can be divided into a number of Two Area Load Frequency Control areas interconnected by means of tie lines. Without loss of generality, we shall consider a two-area case connected by a single tie line as illustrated in Fig. 8.13.

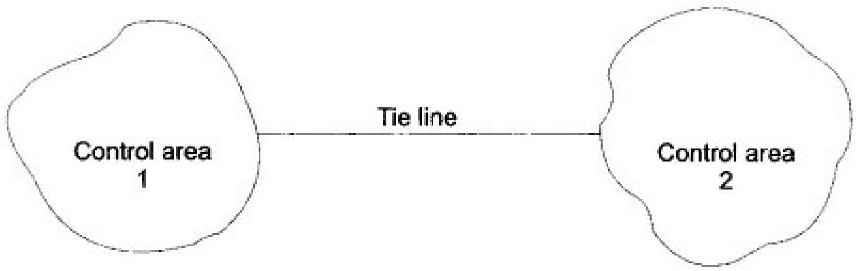



**Fig. 8.13** Two interconnected control areas (single tie line)

The control objective now is to regulate the frequency of each area and to simultaneously regulate the tie line power as per inter-area power contracts. As in the case of frequency, proportional plus integral controller will be installed so as to give zero steady state error in tie line power flow as compared to the contracted power.

It is conveniently assumed that each control area can be represented by an equivalent turbine, generator and governor system. Symbols used with suffix 1 refer to area 1 and those with suffix 2 refer to area 2.

In an isolated control area, the incremental power ($\Delta P_G - \Delta P_D$) was accounted for by the rate of increase of stored kinetic energy and increase in area load caused by increase in frequency. Since a tie line transports power in or out of an area, this fact must be accounted for in the incremental power balance equation of each area.

Power transported out of area 1 is given by,

$$P_{\text{tie, 1}} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta_1^o - \delta_2^o) \qquad (8.26)$$

where,

$\delta^0{}_1, \delta^0{}_2$ = power angles of equivalent machines of the two areas.

For incremental changes in $\delta_1$ and $\delta_2$, the incremental tie line power can be expressed as,

$$\Delta P_{\text{tie, 1}}(\text{pu}) = T_{12}(\Delta\delta_1 - \Delta\delta_2) \qquad (8.27)$$

where,

$$T_{12} = \frac{|V_1||V_2|}{P_{r1}X_{12}}\cos(\delta_1^o - \delta_2^o) = \textit{synchronizing coefficient}$$

Since incremental power angles are integrals of incremental frequencies, we can write Eq. (8.27) as,

$$\Delta P_{\text{tie, 1}} = 2\pi T_{12}\left(\int \Delta f_1 \mathrm{d}t - \int \Delta f_1 \mathrm{d}t\right) \quad (8.28)$$

where Δf1 and Δf2 are incremental frequency changes of areas 1 and 2, respectively.

Similarly, the incremental tie line power out of area 2 is given by,

$$\Delta P_{\text{tie, 2}} = 2\pi T_{21}\left(\int \Delta f_2 \mathrm{d}t - \int \Delta f_1 \mathrm{d}t\right) \quad (8.29)$$

where,

$$T_{21} = \frac{|V_2||V_1|}{P_{r2}X_{21}}\cos(\delta_2^o - \delta_1^o) = \left(\frac{P_{r1}}{P_{r2}}\right)T_{12} = a_{12}T_{12} \quad (8.30)$$

With reference to earlier equation, the incremental power balance equation for area 1 can be written as,

$$\Delta P_{G1} - \Delta P_{D1} = \frac{2H_1}{f_1^o}\frac{\mathrm{d}}{\mathrm{d}t}(\Delta f_1) + B_1\Delta f_1 + \Delta P_{\text{tie},1} \quad (8.31)$$

It may be noted that all quantities other than frequency are in per unit in Eq. (8.31).

Taking the Laplace transform of Eq. (8.31) and reorganizing, we get,

$$\Delta F_1(s) = [\Delta P_{G1}(s) - \Delta P_{D1}(s) - \Delta P_{\text{tie, 1}}(s)] \times \frac{K_{ps1}}{1 + T_{ps1}s} \quad (8.32)$$

where as defined earlier,

$$K_{ps1} = 1/B_1$$
$$T_{ps1} = 2H_1/B_1 f^o \quad (8.33)$$

Compared to earlier equation of the isolated control area case, the only change is the appearance of the signal ΔPtie,1(s) as shown in Fig. 8.14.

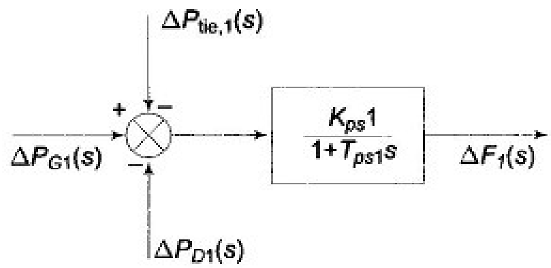



**Fig. 8.14**

Taking the Laplace transform of Eq. (8.28), the signal ΔPtie,1(s) is obtained as,

$$\Delta P_{\text{tie},\,1}(s) = \frac{2\,\pi T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] \tag{8.34}$$

The corresponding block diagram is shown in Fig. 8.15.

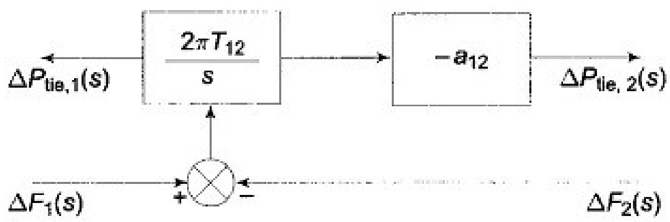



**Fig. 8.15**

For the control area 2, ΔPtie,2(s) is given by Eq. (8.29)

$$\Delta P_{\text{tie},\,2}(s) = \frac{-2\,\pi a_{12} T_{12}}{s}[\Delta F_1(s) - \Delta F_2(s)] \tag{8.35}$$

which is also indicated by the block diagram of Fig. 8.15.

Let us now turn our attention to ACE (Area Control Error) in the presence of a tie line. In the case of an isolated control area, ACE is the change in area frequency which when used in integral control loop forced the steady state frequency error to zero. In order that the steady state tie line power error in a two-area control be made zero another integral control loop (one for each area) must be introduced to integrate the incremental tie line power signal and feed it back to the speed changer. This is accomplished by a single integrating block by redefining ACE as a linear combination of incremental frequency and tie line power. Thus, for control area 1,

$$\text{ACE}_1 = \Delta P_{\text{tie},\,1} + b_1 \Delta f_1 \tag{8.36}$$

where the constant b1 is called area frequency bias.

Equation (8.36) can be expressed in the Laplace transform as,

$$\text{ACE}_1(s) = \Delta P_{\text{tie, 1}}(s) + b_1 \Delta F_1(s) \tag{8.37}$$

Similarly, for the control are a 2, ACE2 is expressed as,

$$\text{ACE}_2(s) = \Delta P_{\text{tie, 2}}(s) + b_2 \Delta F_2(s) \tag{8.38}$$

Combining the basic block diagrams of the two control areas, with ΔPC1(s) and ΔPC2(s) generated by integrals of respective ACEs (obtained through signals representing changes in tie line power and local frequency bias) and employing the block diagrams of Figs. 8.14 to 8.15, we easily obtain the composite block diagram of Fig. 8.16.

Let the step changes in loads ΔPD1 and ΔPD2 be simultaneously applied in control areas 1 and 2, respectively. When steady conditions are reached, the output signals of all integrating blocks will become constant and in order for this to be so, their input signals must become zero. We have, therefore,

$$\Delta P_{\text{tie, 1}} + b_1 \Delta f_1 = 0 \left(\text{input of integrating block} - \frac{K_{i1}}{s}\right) \tag{8.39a}$$

$$\Delta P_{\text{tie, 2}} + b_2 \Delta f_2 = 0 \left(\text{input of integrating block} - \frac{K_{i2}}{s}\right) \tag{8.39b}$$

$$\Delta f_1 - \Delta f_2 = 0 \left(\text{input of integrating block} - \frac{2\pi T_{12}}{s}\right) \tag{8.40}$$

From Eqs. (8.28) and (8.29),

$$\frac{\Delta P_{\text{tie,1}}}{\Delta P_{\text{tie, 2}}} = -\frac{T_{12}}{T_{21}} = -\frac{1}{a_{12}} = \text{constant} \tag{8.41}$$

Hence Eqs. (8.39) — (8.41) are simultaneously satisfied only for

$$\Delta P_{\text{tie, 1}} = \Delta P_{\text{tie, 2}} = 0 \tag{8.42}$$

and,

$$\Delta f_1 = \Delta f_2 = 0$$

Thus, under steady condition change in the tie line power and frequency of each area is zero. This has been achieved by integration of ACEs in the feedback loops of each area.

Dynamic response is difficult to obtain by the transfer function approach (as used in the single area case) because of the complexity of blocks and multi-input ($\Delta P_{D1}$, $\Delta P_{D2}$) and multi-output ($\Delta P_{tie,1}$, $\Delta P_{tie,2}$, $\Delta f_1$, $\Delta f_2$) situation. A more organized and more conveniently carried out analysis is through the state space approach (a time domain approach). Formulation of the state space model for the two-area system.

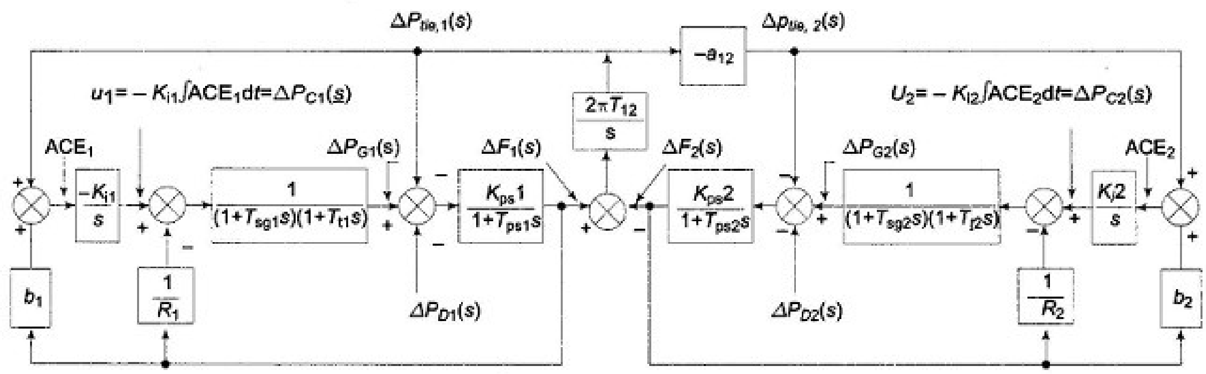



**Fig. 8.16** Composite block diagram of two-area load frequency control (feedback loops provided with integral of respective area control errors)

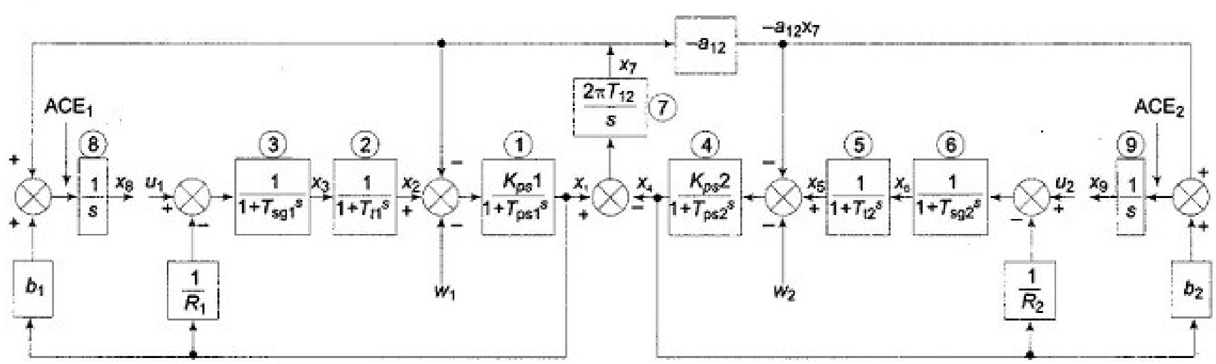



**Fig. 8.17** State space model of two-area system

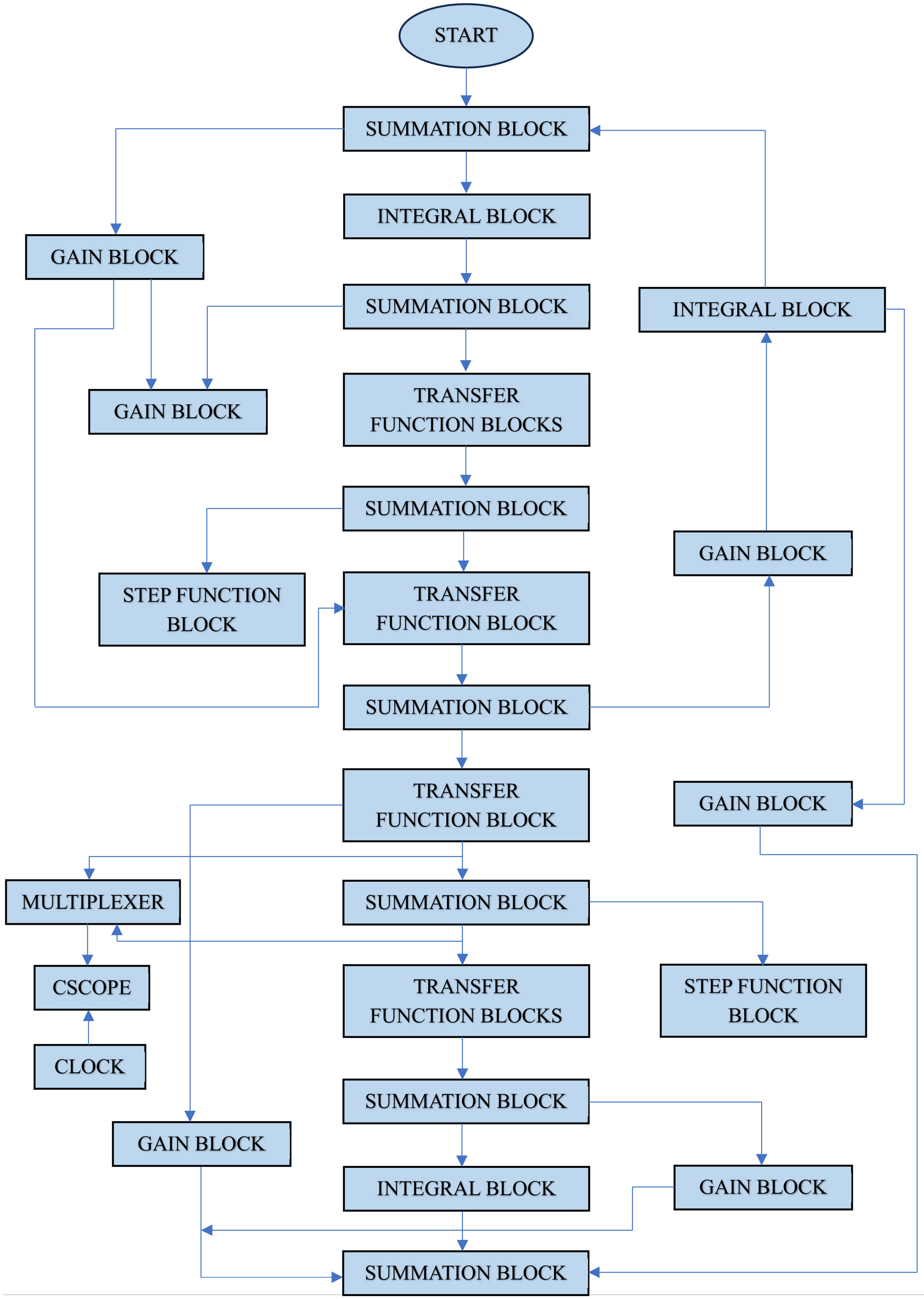
## 5. Software/Hardware Used:

a) Operating System: Windows 11 Pro.

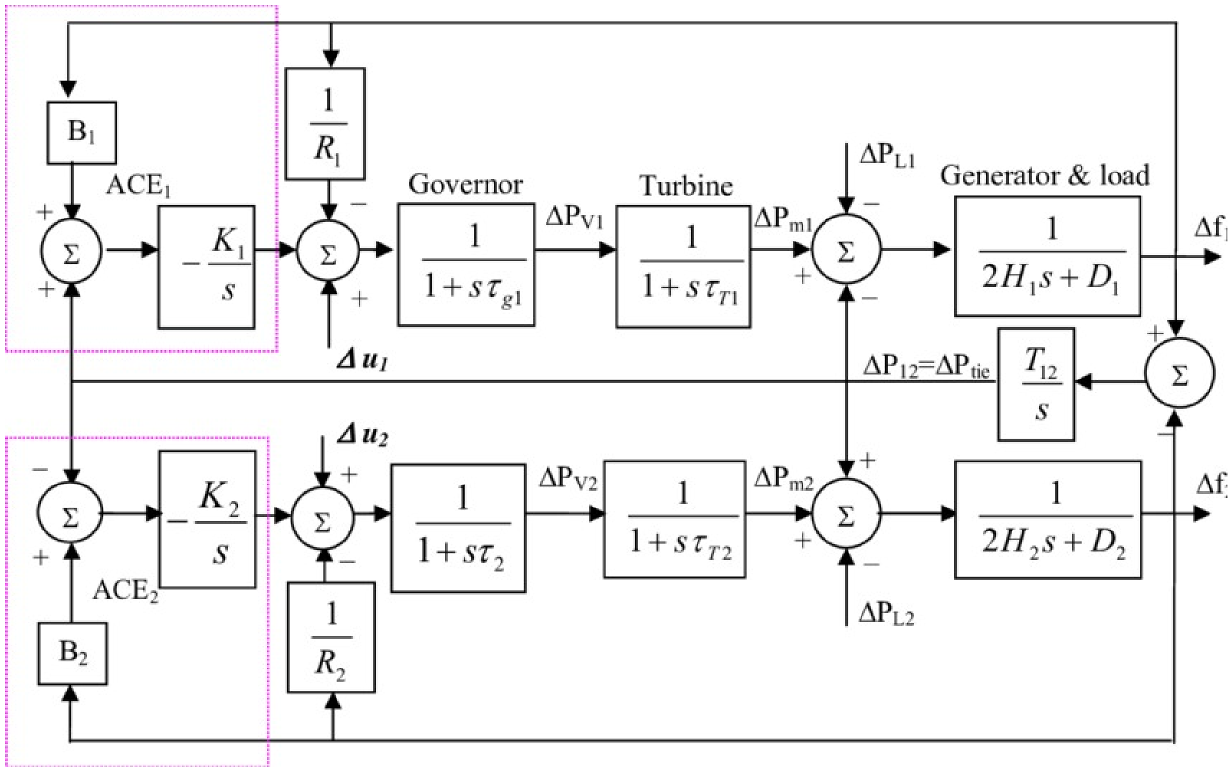
b) Scilab Version: Scilab 6.1.1. (2024.0.0)

c) Hardware: N/A (The case study doesn't involve specific hardware requirements.)

## 6. Flowchart:


START
SUMMATION BLOCK
INTEGRAL BLOCK
GAIN BLOCK
SUMMATION BLOCK
INTEGRAL BLOCK
GAIN BLOCK
TRANSFER FUNCTION BLOCKS
SUMMATION BLOCK
GAIN BLOCK
STEP FUNCTION BLOCK
TRANSFER FUNCTION BLOCK
SUMMATION BLOCK
TRANSFER FUNCTION BLOCK
GAIN BLOCK
MULTIPLEXER
SUMMATION BLOCK
CSCOPE
TRANSFER FUNCTION BLOCKS
STEP FUNCTION BLOCK
CLOCK
SUMMATION BLOCK
GAIN BLOCK
INTEGRAL BLOCK
GAIN BLOCK
SUMMATION BLOCK

## 7. Block Diagram for Load Frequency Control of Two – Area System:




## 8. Procedure of Execution:

STEP 01: Launch Scilab on your Computer.

STEP 02: Right - Click on the Xcos Icon from the Ribbon menu and open it using Xcos.

STEP 03: Save your Schematic Representation with a desired name in .xcos extension.

STEP 04: Execute the whole Schema by right clicking on the execute menu in the ribbon bar.

STEP 05: Run your schematic diagram and switch to the Frequency Response Tab.

STEP 06: Observe the Frequency Response and record the readings from the output.

STEP 07: Enter different values for $T_{g1}$, $T_{t1}$, $T_{ps1}$, $T_{g2}$, $T_{t2}$, $T_{ps2}$, $T_{12}$, $R_1$, $R_2$ and other gain inputs.

STEP 08: Execute the whole Schema by right clicking on the execute menu in the ribbon bar.

STEP 09: Run your schematic diagram and switch to the Frequency Response Tab.

STEP 10: Observe the Frequency Response and record the readings from the output.

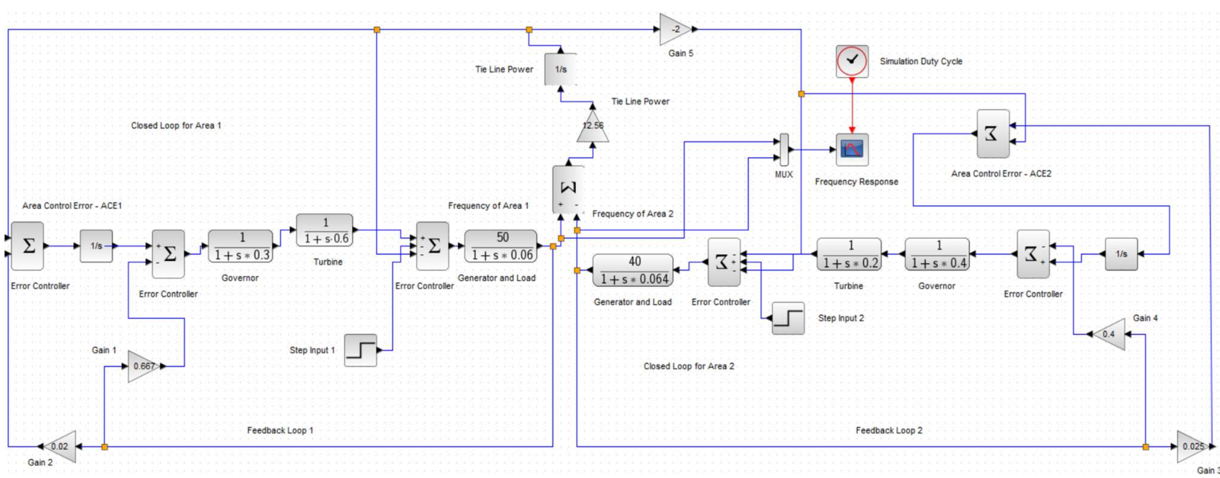
STEP 11: End the Execution.

## 9. Simulation Results:

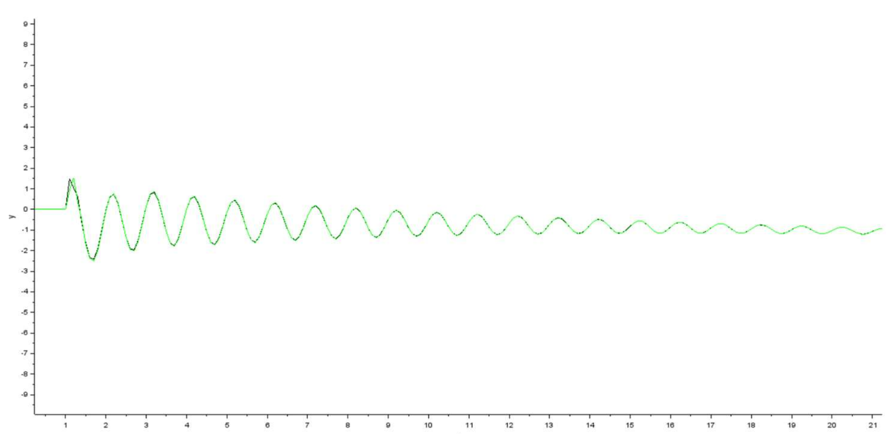
### A) When $\tau_g = 0.3$, $\tau_t = 0.6$, $\tau_{ps} = 0.06$ for the Closed Loop Area 1 and $\tau_g = 0.4$, $\tau_t = 0.2$, $\tau_{ps} = 0.064$ for the Closed Loop Area 2:

The simulation of the Xcos model for the Two – Area Load Frequency Control System with Tie – Line Bias Control has been successfully executed. The output indicates that the system effectively regulates frequency deviations and optimizes power exchange between the two interconnected areas. The frequency response curves initially showed oscillations, which gradually stabilized to the nominal frequency, demonstrating the system's capability to maintain grid stability. These results validate the proposed control strategy's efficacy in enhancing the overall reliability and performance of the power system. The detailed analysis of the simulation outputs provides valuable insights into the dynamic behaviour and operational efficiency of the implemented control mechanisms.

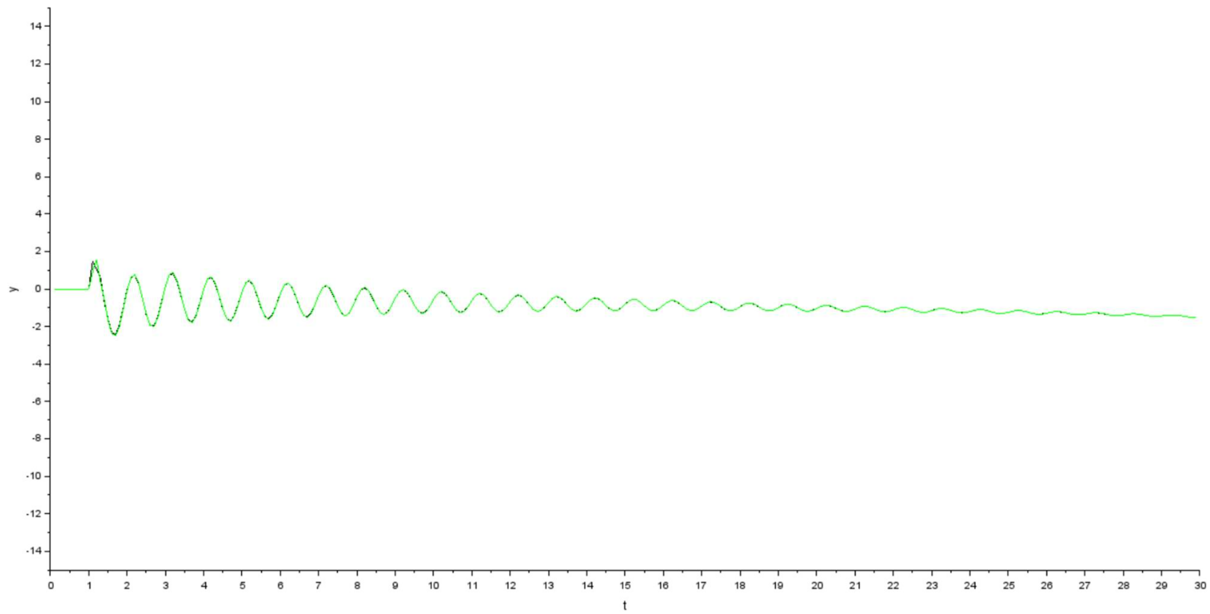
**Xcos Schematic Representation:**




**Frequency Response:**



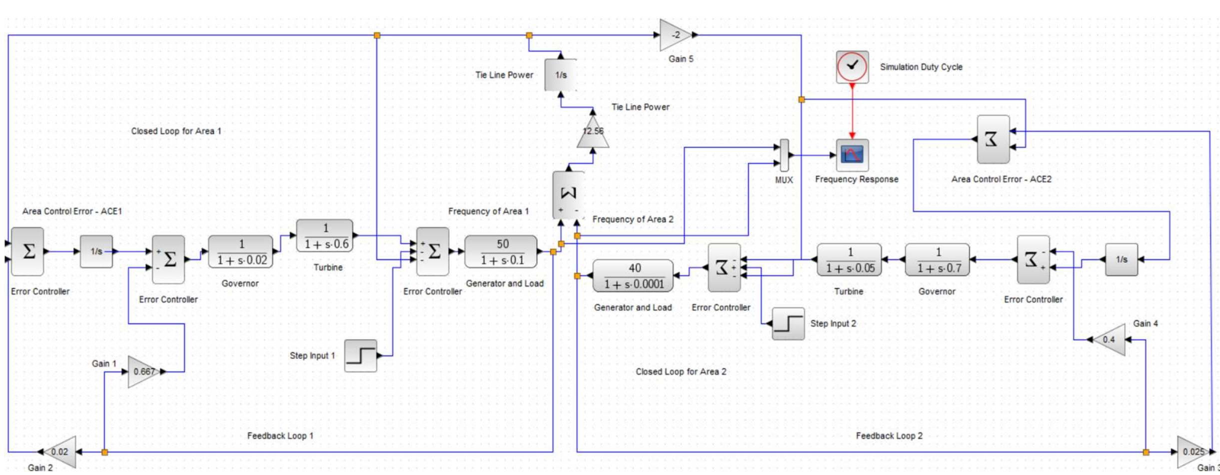
**Final Frequency Response:**




**B) When $\tau_g$ = 0.02, $\tau_t$ = 0.6, $\tau_{ps}$ = 0.1 for the Closed Loop Area 1 and $\tau_g$ = 0.7, $\tau_t$ = 0.05, $\tau_{ps}$ = 0.0001 for the Closed Loop Area 2:**

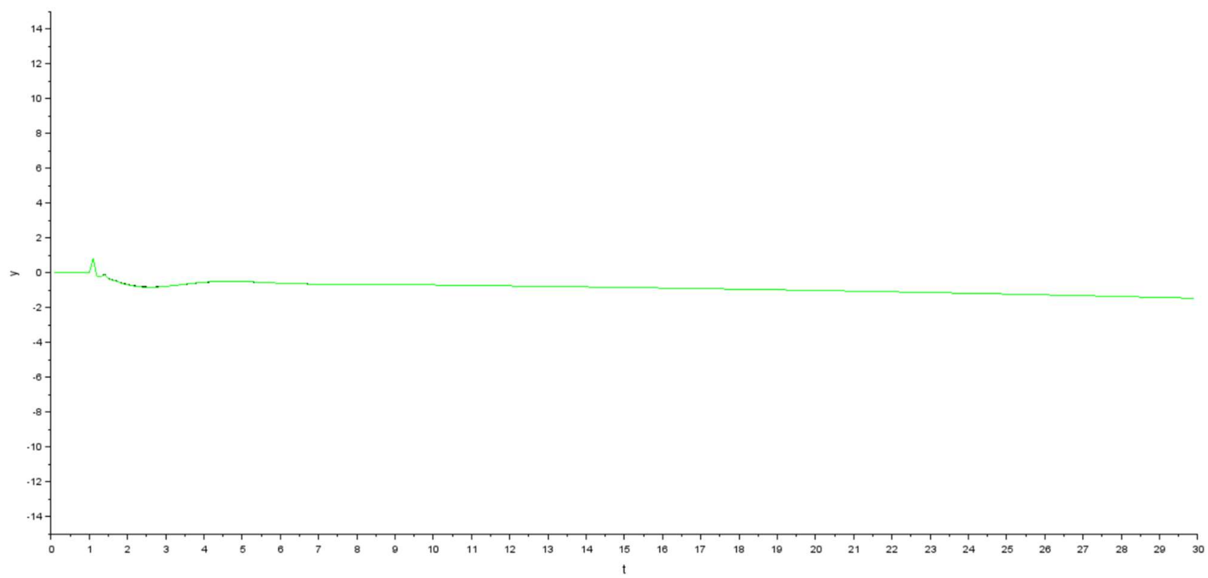
After adjusting the parameters of the Two-Area Load Frequency Control (LFC) System with Tie-Line Bias Control, the frequency response improved significantly. It showed minimal harmonic oscillations, signifying a well-damped response. The oscillations quickly decayed, and the system reached a steady state swiftly. These changes highlight the enhanced stability and damping capabilities of the system under new parameter settings. This rapid stabilization underscores the effectiveness of the chosen control strategy and parameter values in maintaining grid stability.

**Xcos Schematic Representation:**



**Frequency Response:**

After changing the values, the frequency response showed minimal, incomplete oscillations and quickly reached a steady state, indicating improved system stability and rapid damping. The system's swift stabilization highlights the effectiveness of the updated control parameters in managing frequency deviations efficiently. Additionally, this quick response minimizes the risk of prolonged frequency instability in the grid.

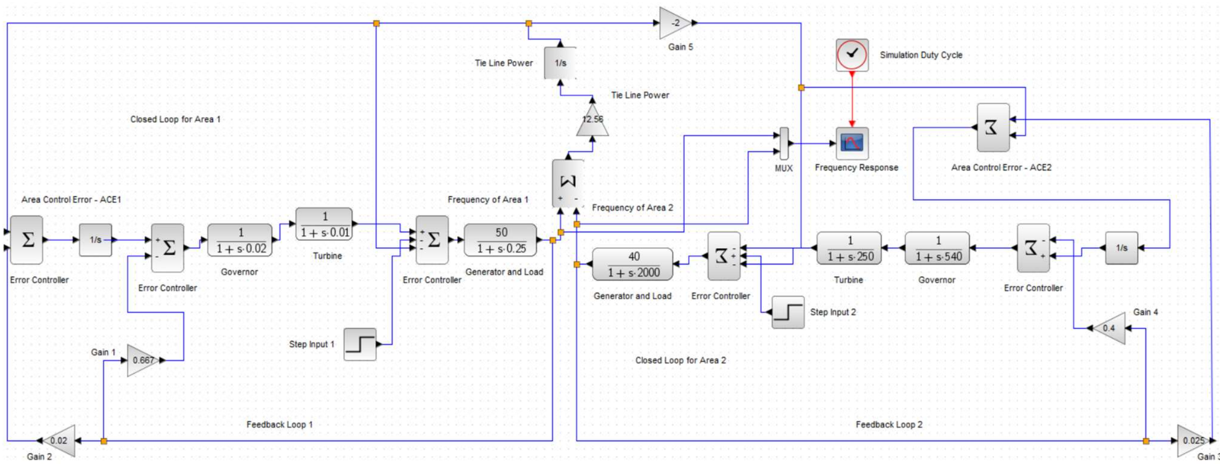



## C) Effect of Extreme Time Constant Variations on System Response:

Differences in time constants across system areas can profoundly affect stability and response dynamics, influencing how effectively the system manages oscillations and maintains operational stability.

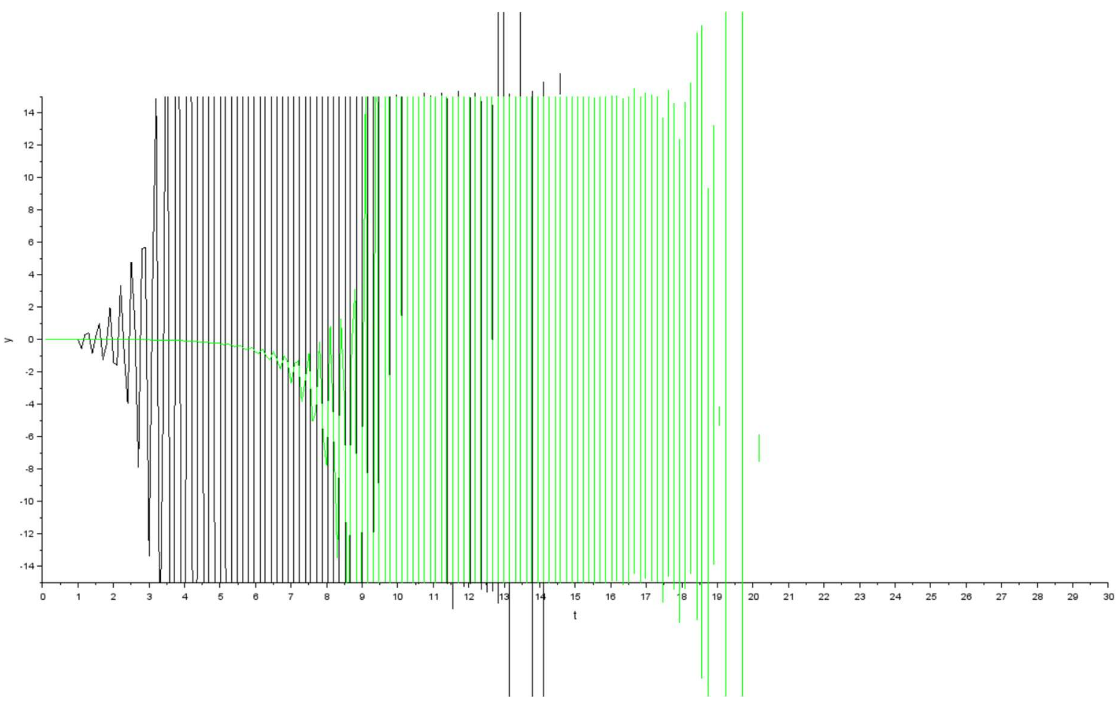
- **Harmonic Oscillations:** Setting very low time constants in one area and very high time constants in another can lead to numerous closely spaced harmonic oscillations.
- **Frequency Distortion:** The extreme variation in time constants can cause significant distortion in the frequency response of the system.
- **Instability Issues:** Such disparities may induce instability, making it challenging for the system to achieve and maintain a stable operating point.
- **Control Complexity:** Managing control actions becomes complex, as the system may oscillate erratically due to the mismatch in response times between different areas.

## Xcos Schematic Representation:




## Frequency Response:

When time constants vary widely across different areas of a system, the frequency response can become highly erratic. Areas with very low time constants respond rapidly to changes in load or generation, often causing frequent and intense oscillations. Conversely, areas with very high time constants exhibit delayed responses, which can exacerbate oscillations and compromise overall system stability. This disparity in response times between system areas challenges effective frequency regulation and can lead to inefficient control actions, highlighting the critical need for balanced time constant settings to ensure stable and reliable operation of power systems.



## Theoretical Graphical Result (For Normal Systems):

The theoretical graphical results of the Two-Area Load Frequency Control System with Tie – Line Bias Control are depicted through the frequency response curves obtained from the Xcos simulation. Initially, the system exhibits oscillatory behaviour due to sudden load changes or disturbances. These oscillations are represented by harmonic sinusoidal waves in the frequency response graph. Over time, the control system adjusts the power output, and the oscillations dampen, leading to a steady-state frequency close to the nominal value.

Key observations from the theoretical graphical result include:

1. **Initial Oscillations:** The frequency response graph shows pronounced oscillations immediately following a disturbance, indicating the system's initial reaction to changes in load or generation.
2. **Damping Effect:** As the Tie-Line Bias Control and LFC mechanisms work together, the oscillations gradually reduce in amplitude, showcasing the system's ability to dampen frequency deviations effectively.
3. **Steady-State Achievement:** Eventually, the frequency stabilizes at the nominal value, demonstrating the control system's effectiveness in maintaining grid stability over time.
4. **Inter – Area Power Flow:** The power exchange between the two areas, depicted by the tie – line power flow graph, shows how the Tie-Line Bias Control optimizes the distribution of power, contributing to frequency regulation.

These graphical results underscore the system's robustness in handling disturbances and maintaining frequency stability, thereby validating the theoretical foundations and control strategies implemented in the Xcos model.

## Frequency Response:

In the theoretical analysis of the system, the frequency response initially shows harmonic oscillations followed by a transition to steady state. This behavior reflects the system's natural response to load changes, where initial fluctuations settle over time to achieve a stable operating frequency. This theoretical framework helps predict how the system would behave under ideal conditions without considering specific simulation inputs or external disturbances, providing insights into its inherent stability and response characteristics.

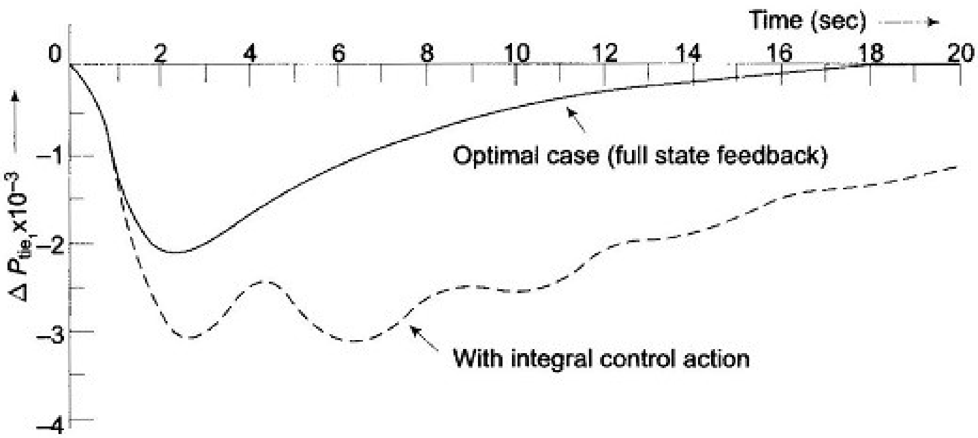



**Fig. 8.18** Change in tie line power due to step load (0.01 pu) change in area 1

**Final Frequency Response:**

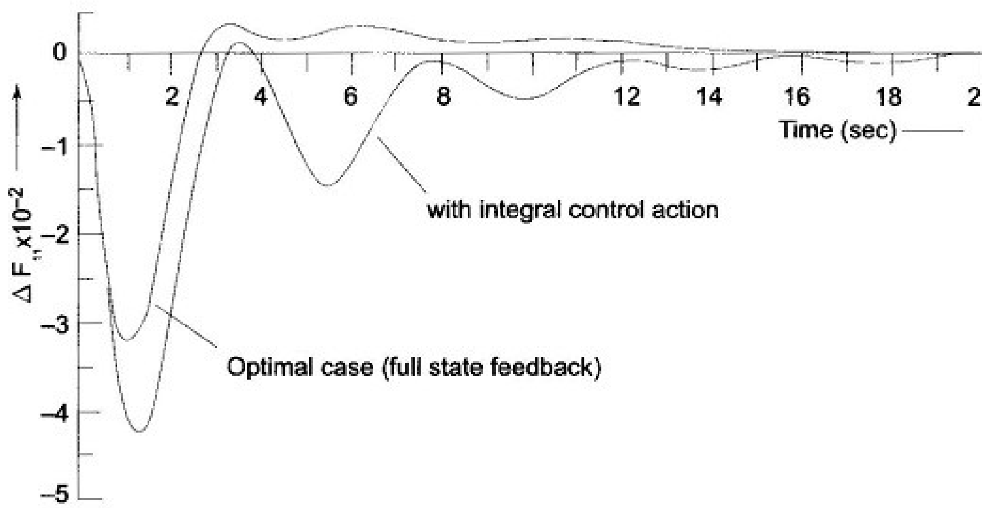



**Fig. 8.19** Change in frequency of area 1 due to step load (0.01 pu) change in area 1

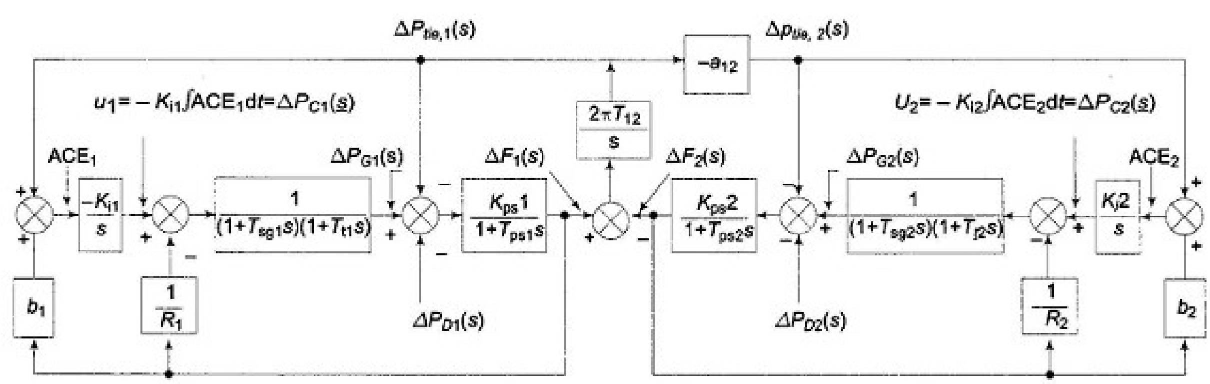



**Fig. 8.16** Composite block diagram of two-area load frequency control (feedback loops provided with integral of respective area control errors)

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