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Department of Electrical Engineering

Automatic generation control of two area power system using optimization technique

A graduation project submitted to the **Department of Electrical Engineering**, in partial fulfillment for the requirements for the award of the degree of Bachelor of **Electrical Engineering**

By

Abbas Khaled Anseel

Mohmmed Hassan Khalaf

Mustafa Karim Khalaf

Ali Mustafa Abdel Karim

SUPERVISED BY

Asst. Prof. Dr. Mohmmed Khalaf

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بسم الله الرحمن الرحيم

((وَلَقَدْ آتَيْنَا دَاوُودَ وَسُلَيْمَانَ عِلْمًا ۖ وَقَالَا الْحَمْدُ لِلَّهِ الَّذِي فَضَّلَنَا عَلَىٰ كَثِيرٍ مِّنْ عِبَادِهِ الْمُؤْمِنِينَ))

النمل اية (١٥)

صدق الله العلي العظيم

SUPERVISOR CERTIFICATION

I certify that the preparation of this project entitled:

Automatic generation control of two area power system using optimization technique

prepared by:

Abbas Khaled Anseel
Mohmmed Hassan Khalaf
Mustafa Karim Khalaf
Ali Mustafa Abdel Karim

was under my supervision at General Electrical Engineering Branch, Electrical Engineering Department, University of Misan in partial fulfilment of the requirements for the degree of Bachelor of Science in Electrical Engineering.

Signature:
Supervisor Name:
Scientific Degree:
Date:

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*Praise be to **ALLAH** who enabled us to complete this work under his benediction.*

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ABSTRACT

يركز هذا المشروع على التحكم التلقائي في التوليد (AGC) في نظام طاقة ذي منطقتين، بهدف تحسين أداء النظام باستخدام تقنيات تحسين الذكاء الاصطناعي.
طُوّر نموذج ديناميكي لتمثيل تبادل الطاقة وتغيرات الأحمال بين المنطقتين، مع التركيز بشكل خاص على استقرار التردد وتقليل الانحراف.

طُبّقت خوارزميتان ذكيتان للتحسين: تحسين سرب الجسيمات (PSO) ومستعمرة النحل الاصطناعي (ABC)، لضبط معلمات وحدة التحكم على النحو الأمثل وتحقيق أفضل استجابة ديناميكية.

أظهرت نتائج المحاكاة أن استخدام هذه التقنيات قد حسّن أداء النظام بشكل ملحوظ مقارنةً بأساليب التحكم التقليدية، لا سيما في تقليل التذبذبات وزمن الاستقرار.

يُسلّط هذا المشروع الضوء على أهمية دمج أساليب التحسين الحديثة في نظام التحكم في الطاقة لضمان تشغيل فعال ومستقر في ظل ظروف أحمال متفاوتة.

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Chapter One

1.1 Introduction

In the 1960s and 1970s, AGC systems evolved with the introduction of digital computers and supervisory control and data acquisition (SCADA) systems, which improved the speed and accuracy of generation control. These advancements allowed utilities to monitor grid conditions in real-time and optimize power dispatch more effectively. During this period, power grids also became highly interconnected, making AGC even more essential for maintaining stability across multiple regions.

By the 1980s and 1990s, power system deregulation and the integration of independent power producers introduced new challenges for AGC. The restructuring of electricity markets required AGC to not only maintain frequency stability but also support economic dispatch and market-based generation scheduling. As renewable energy sources such as wind and solar became more prevalent in the 2000s and beyond, AGC systems were further enhanced to manage the variability and intermittency of these sources. Modern AGC now incorporates artificial intelligence, machine learning, and energy storage technologies to optimize power system operations.

Today, AGC remains a fundamental component of modern power systems, ensuring grid reliability, frequency stability, and efficient power distribution across interconnected networks. With ongoing advancements in smart grids, distributed generation, and digital control technologies, the future of AGC is expected to further improve the efficiency and resilience of power systems worldwide [1]

1.2 Power System

A power system is a complex network that generates, transmits, and distributes electrical energy to consumers while ensuring reliability, efficiency, and stability. It plays a crucial role in modern society by providing electricity for residential, commercial, and industrial applications. The power system consists of three main stages: generation, transmission, and distribution, each with distinct functions and components that contribute to the seamless delivery of electrical energy.

Once electricity is generated, it needs to be transmitted over long distances to reach distribution centers and consumers. The transmission system consists of high-voltage power lines, transformers, and substations that ensure efficient energy transfer with minimal losses. High-voltage transmission is essential because it reduces resistive losses in power lines, improving efficiency. Transmission networks are often interconnected to form regional or national grids, allowing power exchange between different areas and enhancing overall system stability. Grid interconnections enable the sharing of electricity across borders, preventing shortages and improving reliability.

After transmission, electricity reaches the distribution network, where it is stepped down to lower voltages suitable for residential, commercial, and industrial use. The distribution system includes transformers, circuit breakers, and distribution lines that deliver electricity safely to end-users. The evolution of power distribution has led to the development of smart grids, which integrate advanced monitoring, automation, and communication technologies to improve efficiency, detect faults, and optimize energy use. Smart grids also facilitate the integration of distributed energy resources, such as rooftop solar panels and battery storage systems, enhancing grid resilience and reliability [2]

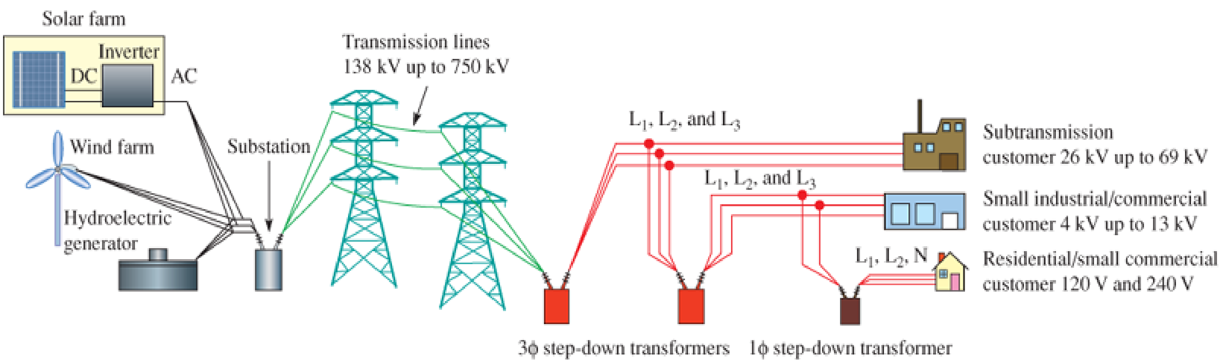

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Figure 1.1: Electrical Power System Components.

1.3 Load Frequency

Load Frequency Control (LFC) is a crucial aspect of power system operation, ensuring the stability and reliability of electrical networks by maintaining a consistent system frequency. The frequency of an electrical grid, typically 50 Hz or 60 Hz, is directly influenced by the balance between power generation and load demand. Any deviation from the nominal frequency can lead to instability, equipment malfunction, or even system-wide blackouts. LFC plays a fundamental role in regulating this balance by adjusting the output of power generators to match variations in demand.

The core concept of load frequency control lies in its ability to maintain system frequency within permissible limits. Power systems operate based on the principle that the total generation must equal the total load demand plus transmission losses. When there is an increase in load demand without a corresponding increase in generation, the rotational speed of generators decreases, causing a drop in frequency. Conversely, if the load demand decreases while generation remains unchanged, the frequency rises. These fluctuations can affect the efficiency and lifespan of electrical equipment, making precise frequency regulation essential.[3]

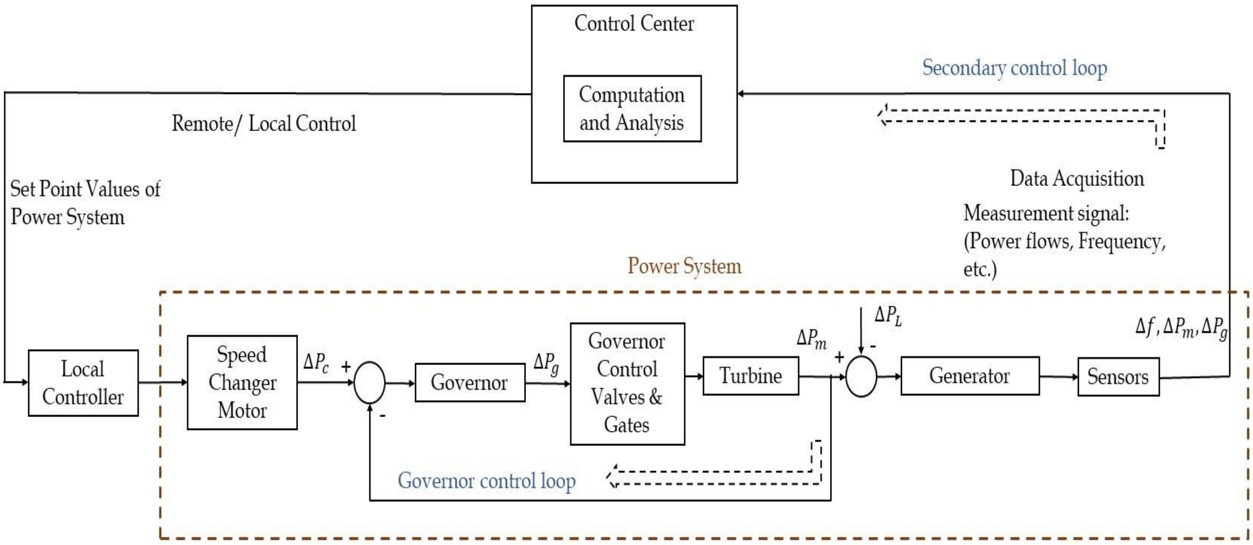

Figure 1.2: A typical load frequency control (LFC) loop

1.3.1 Control Mechanism LFC

1. Primary Control: also known as governor action, responds immediately to frequency deviations by adjusting the mechanical power input to the generator. This response is automatic and localized, meaning it occurs without centralized coordination. However, primary control alone cannot restore the frequency to its nominal value.

2. Secondary Control: also called Automatic Generation Control (AGC), comes into play. AGC adjusts the power output of multiple generating units in a coordinated manner, ensuring the system frequency is restored to its normal operating range while also managing power exchange between interconnected grids.

1.3.2 Load frequency control problems

Despite its importance, load frequency control faces several challenges. One major issue is the increasing penetration of renewable energy sources, such as wind and solar power, which introduce variability and intermittency into the system. Unlike conventional power plants, renewable sources are highly dependent on weather conditions, making it difficult to maintain a stable frequency. The unpredictable nature of renewable energy generation requires advanced control strategies, energy storage solutions, and grid modernization efforts to ensure effective frequency regulation.

Another challenge in LFC is the time delay in control response. Although primary control reacts quickly to frequency deviations, secondary control takes a longer time to restore the system to its nominal frequency. This delay can lead to short-term instability, requiring more advanced control algorithms and real-time monitoring to improve response times. Additionally, interconnected power systems face the issue of frequency fluctuations propagating across different regions. A frequency disturbance in one area can affect neighboring grids, making coordinated control between regions essential to prevent widespread instability.[4]

1.3.3 Objectives of Load Frequency Control (LFC)

- **Maintaining System Frequency Stability**

• One of the fundamental goals of LFC is to regulate the system frequency within permissible limits (typically 50 Hz or 60 Hz). Frequency deviations occur due to imbalances between power generation and load demand, and LFC helps restore balance to prevent instability.

❖ **Balancing Power Generation and Load Demand**

• LFC continuously monitors power demand and adjusts generation accordingly to ensure that supply matches demand in real-time. This balance is essential to avoid overloading generators or causing frequency drops that could lead to system failures.

❖ **Ensuring Tie-Line Power Exchange Regulation**

• In interconnected power systems, LFC helps regulate the power exchange between different control areas. This ensures that each region maintains its scheduled power interchange, preventing unintended power flows that may disrupt system operation.

❖ **Enhancing System Reliability and Stability**

• By stabilizing frequency deviations, LFC improves the overall reliability of the power system, reducing the risk of blackouts and protecting sensitive electrical equipment from damage caused by frequency fluctuations.

❖ **Reducing Governor Hunting and Oscillations**

• LFC minimizes unnecessary fluctuations in generator output by optimizing governor control mechanisms. This helps prevent excessive oscillations that could lead to mechanical stress and wear on power system components.

1.4 Automatic Generation Control

AGC is a generator control system that adjusts the real power output of generators in response to control signals from the system operator's energy management system (EMS) within a time frame that is typically two to five seconds. The EMS monitors system frequency and sends signals to generators to adjust supply as needed to maintain the system frequency (50 or 60 Hz depending on the region). Control signals are transmitted via telemetry to remote terminal units (RTU) at the generator. The RTUs convert the raise/lower megawatts (MW) into instructions to the generator governor, which results in a change in the generator output power. AGC is used to maintain acceptable frequencies during normal operation due to fluctuations in load and variable resources, and as an early response to system contingencies such as the unexpected loss of a generator or a transmission line. AGC units are used to provide frequency response reserves[5].

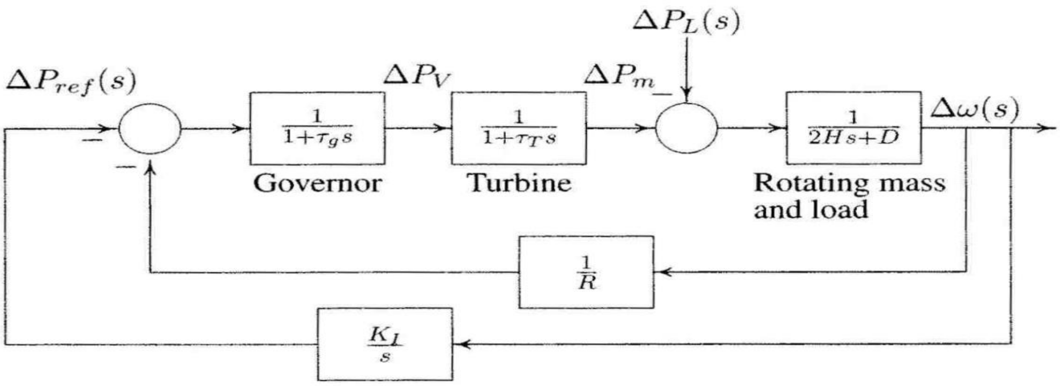

Figure 1.3 AGC for an isolated power system.

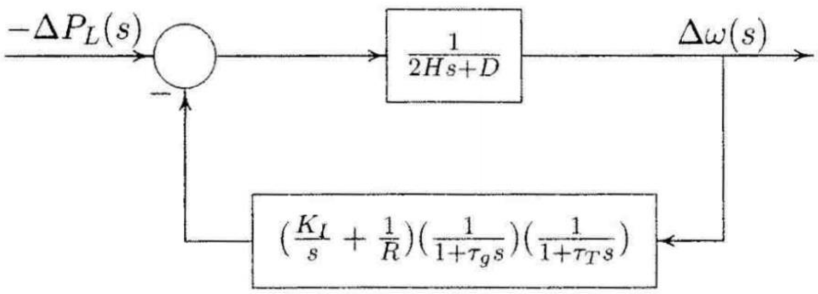

Figure 1.4 The equivalent block diagram of AGC for an isolated power system.

1.4.1 AGC Challenges

Automatic Generation Control (AGC) is essential for maintaining the balance between electricity supply and demand, ensuring stable system frequency and scheduled power exchanges in interconnected power systems. However, AGC faces several challenges:

- **Adaptability to Nonlinearities:** Traditional AGC systems often struggle to adapt to the inherent nonlinear characteristics of modern power systems, leading to suboptimal performance.
- **Slow Response Times:** Conventional AGC mechanisms may not react swiftly enough to rapid changes in load or generation, especially with the integration of renewable energy sources that are variable and less predictable.
- **Integration of Renewable Energy Sources:** The increasing penetration of renewable energy introduces variability and uncertainty, challenging AGC systems to maintain frequency stability and manage power fluctuations effectively.
- **Susceptibility to Uncertainties and Disturbances:** AGC systems are vulnerable to various uncertainties, including sudden load changes, generator outages, and unforeseen disturbances, which can compromise system stability.
- **Cybersecurity Threats:** As AGC systems become more digitized and interconnected, they are increasingly exposed to cyber threats, necessitating robust cybersecurity measures to protect against potential attacks.

1.5 Problem Statement

The load has two components: a scheduled load with a 24-hour periodic behaviour, and stochastic deviation. The load deviation is the difference between the actual load and the scheduled load. The deviation in load affects the power production demand and cause a frequency deviation. The frequency deviation affects the power system stability. The frequency deviation on the system has to be eliminated as soon as possible, because it will jeopardize the safety of all devices in the system.

Figure 1.5 shows a model of how the load deviation (ΔPL) affects the frequency (Δω).

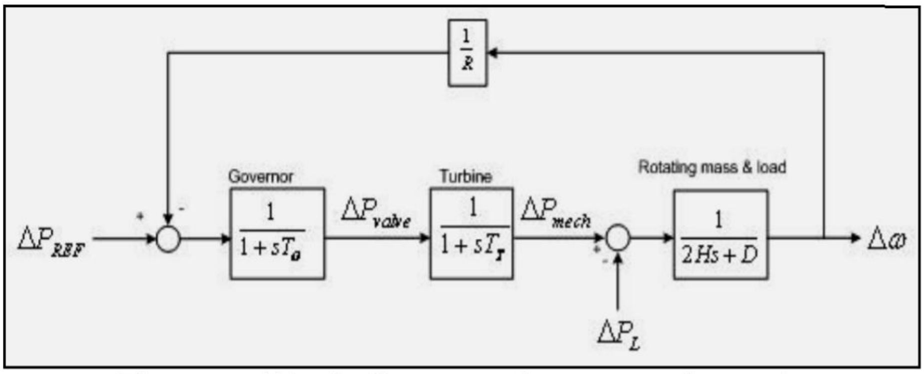

Figure 1.5: Block diagram of a generating unit

In figure 1.5:

- **TG** is time constant of governor.
- **TT** is time constant of turbine.
- **H** is constant value of inertia, which is the change of kinetic energy over the machine rating.
- **D** is expressed as percent change in load divided by percent change in frequency.

- **R** is constant of speed regulation.
- **ΔPREF** is a reference input to the system. It purposes is to control the governor. However, in this system, the ΔPREF is being neglected temporary, until the system with integral control is determined.

For example, the generator in unit 1 has an incremental change in load input that creates frequency deviation as shown on figure 2.3.

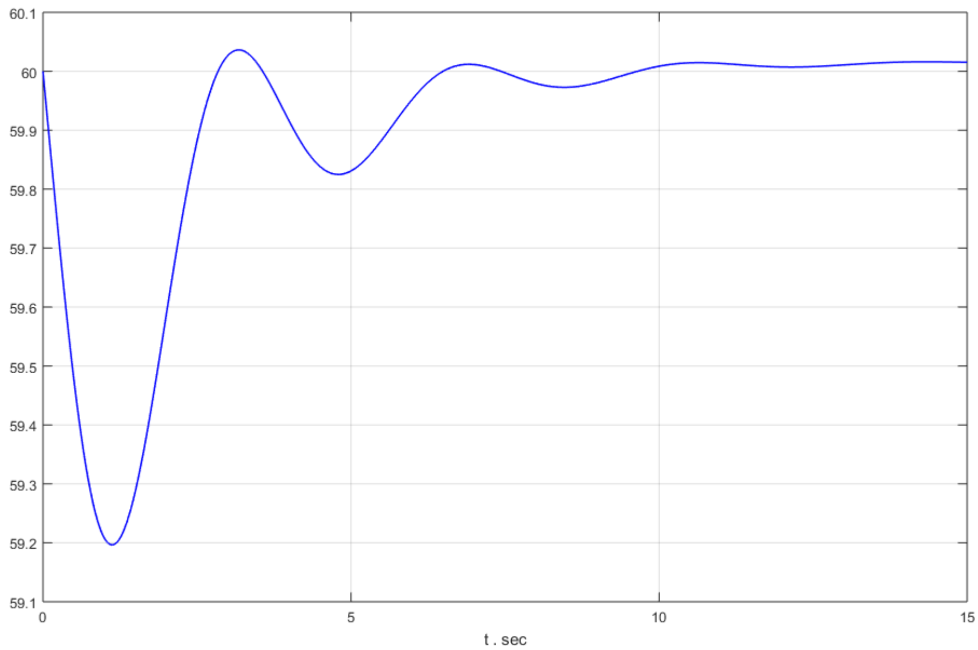

Figure1.6: Frequency deviation step response unit 1

When the load changes, the generation units need to be controlled regarding of cost efficiency. In other words, the function of the controller is to distribute the current load between the generators, in such a way that the cost of fuel is minimized. On high peak load, all the generating units have to be working regardless of their efficiency. However, on medium and low demands, the most efficient generating units must have higher priority to be activated [6].

1.6 Objectives of Automatic generation control (AGC)

Here are the main objectives of Automatic Generation Control (AGC):

- Maintain system frequency within acceptable limits by adjusting generation in response to load changes.
- Regulate tie-line power flows between interconnected control areas to scheduled values.
- Ensure optimal load sharing among multiple generating units or areas.
- Enhance system reliability and stability during normal and disturbed conditions.
- Support economic dispatch by controlling generation levels efficiently.

CHAPTER TWO

Chapter Two
Automatic Generation Control

2.1 Introduction

Power system operation has to be stable when supplying a varying load demand [7]. The power system has to be controlled to produce power efficiently. One method is known as Automatic Generation Control (AGC) [8]. The AGC method has been enhanced continuously to increase power system efficiency significantly. Figure 2.1 shows the diagram of a power system control. It shows that the power system has a load and a control block. Efficient communication between them is crucial to have a good control. The control block controls several generating units; furthermore, the generating units have to have unit commitment to each other. Thus, the power system production needs to be sufficient, but yet still efficient. In this paper, the number of generating units is set to 5. All of the generating units are thermal units and each of them has different characteristics.

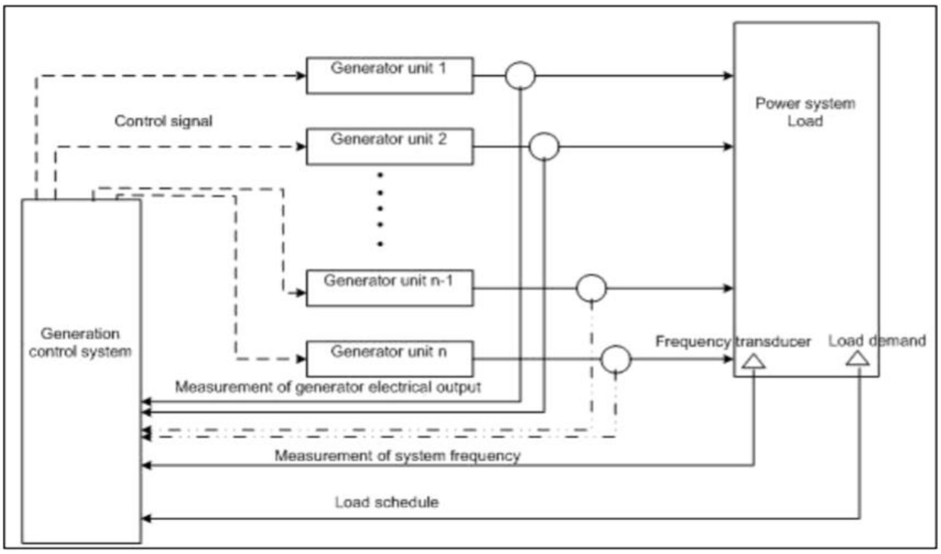

Figure2.1: Power system control diagram

2.2 PID Control

2.2.1 PID Controllers: Proportional-Integral-Derivative (PID) control is the most widely used control algorithm in industry due to its flexibility and effectiveness in regulating linear and simple dynamic systems. It corrects the error between the desired value (setpoint) and the actual value (process variable) through three components: proportional, integral, and derivative [9].

❖ **Definition of PID**: PID control is a control algorithm used to regulate dynamic systems through three core components [10]:

- **Proportional (P):** Reduces the current error between the desired setpoint and the measured value.
- **Integral (I):** Eliminates steady-state error by integrating past errors.
- **Derivative (D):** Improves system stability by predicting future errors.

- **History:**

  1922: Engineer Nicolas Minorsky introduced the concept of derivative control for warship steering.

  1942: Development of the Ziegler-Nichols method for tuning PID parameters**.**

  1960s: Widespread adoption of PID in chemical and thermal control industries.

2.2.2 PID Challenges and Modern Solutions:

- **Key Challenges:**
  - Tuning Difficulty: Manual determination of **(KP, KI, KD)** requires expertise**.**
  - Nonlinear Systems: PID performance degrades in complex dynamics (e.g., robotics).
  - Time Delay: Causes instability (oscillations).
  - Noise Sensitivity: The derivative term (KD) amplifies measurement noise.
- **Modern Solutions:**
  - **Fuzzy-PID Control:** Uses linguistic rules to auto-tune PID parameters.
  - **Machine Learning:** Neural networks to estimate optimal PID gains
  - **Adaptive PID:** Real-time parameter adjustment based on system changes.

2.2.3 Practical Applications

- **Chemical Industry:** Temperature and pressure regulation in reactors.

- **Electric Vehicles:** PID control in regenerative braking systems.
- **Renewable Energy**: Adjusting wind turbine blade angles to maximize power output [11].

2.3 Integral Control for Frequency Deviation

The frequency deviation is removed from the system using an integral control [12]. Integral control uses feedback of the frequency deviation and a load reference to adjust the governor. The block diagram of the integral control can be seen in figure2.2

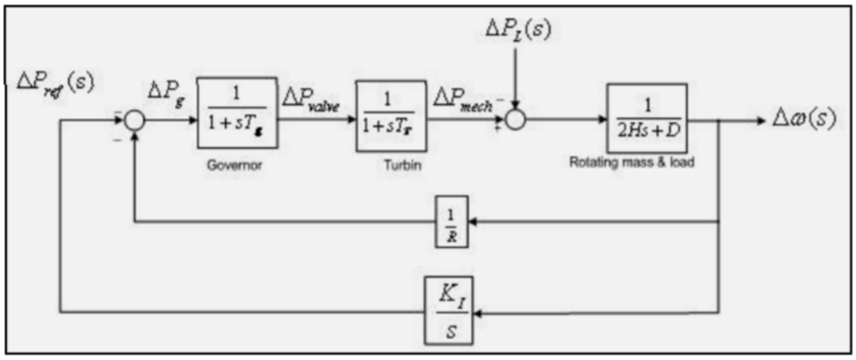

Figure 2.2: An integral control on a generating unit

2.4 AGC in a signal Area System

With the primary LFC loop, a change in the system load will result in a steady date frequency deviation, depending on the governor speed regulation. In order to reduce the frequency deviation to zero, we must provide a reset action. The rest action can be achieved by introducing an integral controller to act on the load Terence setting to change the speed set point. The integral controller increases the system type by 1 which forces the final frequency deviation to zero. The LFC system, with the addition of the secondary loop, is shown in Figure 2.3. The integral controller gain *Ki* must be adjusted for a satisfactory transient response. miming the parallel branches results in the equivalent block diagram shown in [13]

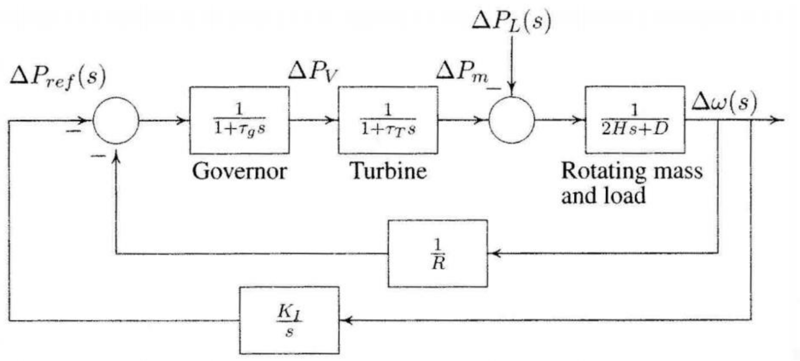

Figure 2.3: AGC for an isolated power system.

2.5 AGC in the Multiarea System Two Area

In many cases, a group of generators are closely coupled internally and swing in unison. Furthermore, the generator turbines tend to have the same response characteristics. Such a group of generators are said be *coherent*. Then it is possible to let the LFC loop represent the whole system, which is referred to as a *control area*. The AGC of a multiarea system can be realized by studying first the AGC for a two-area system. Consider two areas represented by an equivalent generating unit interconnected by a lossless tie line with reactance *Xtie*- Each area is represented by a voltage source behind an equivalent reactance as shown in Figure 2.4[14]

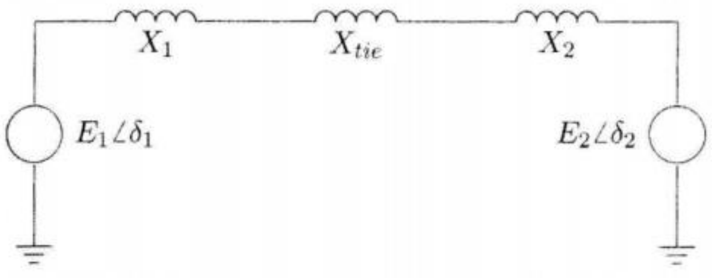

Figure 2.4: Equivalent network for a two-area power system.

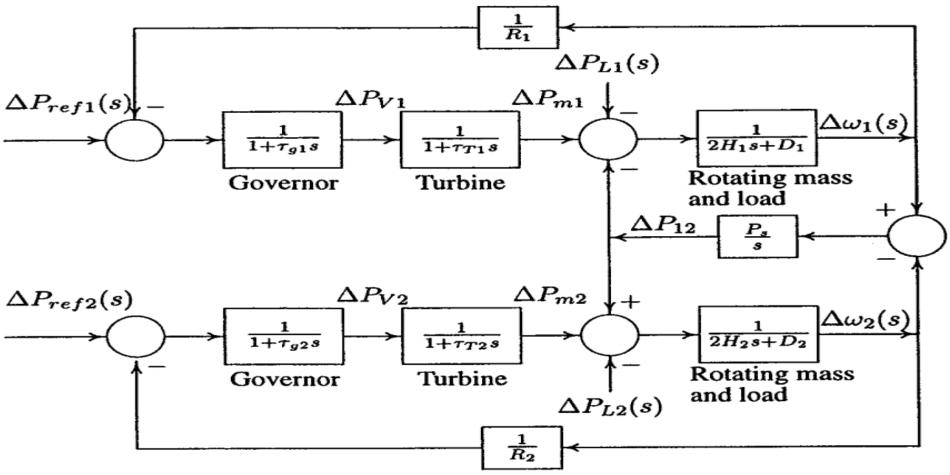

Figure 2.5: AGC a two-area system with only primary LFC loop

2.6 Modern Control Mechanisms in Automatic Control Adjustment

2.6.1 Optimal Control: Optimal control is a branch of control theory focused on designing control laws that optimize the performance of a dynamic system over time by minimizing (or maximizing) a specified cost (or utility) function, while adhering to system constraints (e.g., equations of motion, control limits, or terminal conditions) [15].

❖ **Key Elements :**

- State Variables **:** Describe the system dynamics (e.g., velocity, position).
- Cost Function: Represents the objective to be achieved.

❖ **Applications:**

- Rocket guidance
- fuel efficiency optimization

- robotics control
- financial portfolio management.

2.6.2 Data Analytics : Data analytics is the process of examining raw data, organizing it, and transforming it to discover useful patterns, trends, and insights using statistical techniques and advanced algorithms to support decision-making in fields such as business, science, and engineering.

❖ **Key Components:**

Types of Analysis:

- Descriptive: Summarizing historical data (e.g., sales rates).
- Diagnostic: Identifying causes of phenomena (e.g., productivity decline).
- Predictive: Forecasting future scenarios using machine learning models.
- Prescriptive: Proposing proactive solutions (e.g., optimizing supply chains).

❖ **Tools and Techniques :**

- Programming languages: Python (libraries like Pandas, NumPy), R, SQL .
- Data visualization platforms: Tableau, Power BI.
- AI algorithms: Classification, Clustering.

❖ **Practical Applications :**

- Enhancing customer experience through behavior analysis .
- Detecting financial fraud .
- Improving operational efficiency in industries.

2.7 AGC Components

The AGC consists of several components [16], The figure 2.8 shows the components:

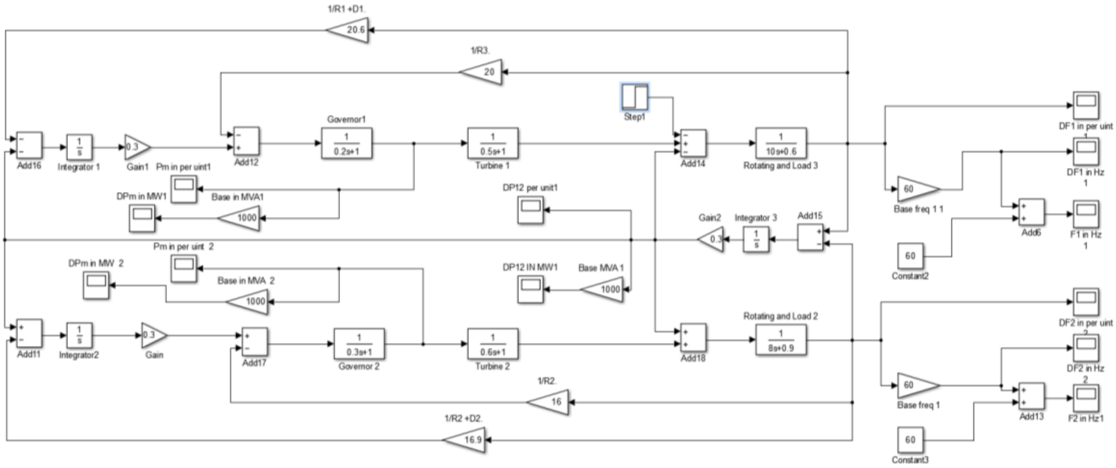

Figure 2.8: simulation block diagram AGC

CHAPTER THREE

3.1 Introduction

3.2 Description of the Two-Area Interconnected Power System

3.2.1 Overview

3.2.2 System Components

3.2.3 System Interconnection

3.3 Mathematical Modeling of the Two-Area AGC System

3.3.1 Linearized Transfer Functions

3.3.2 Tie-line Power Model

3.3.3 Area Control Error (ACE)

3.4 Optimization Techniques for Controller Tuning

3.4.1 Purpose of Optimization

3.3.4 Block Diagram in Simulink

3.4.3 Objective Function Design

3.4.4 Optimization Variables

Chapter Three
Methodology and Application of Optimization Techniques in Two-Area Automatic Generation Control

3.1 Introduction

This chapter describes in detail the methodology used for modeling, designing, and optimizing a two-area Automatic Generation Control (AGC) system. The AGC plays a vital role in maintaining the system frequency within acceptable limits and regulating the power flow across interconnected areas. In modern power systems, optimization techniques have become essential for fine-tuning controller parameters to enhance system performance. The methodology involves creating a mathematical model of the two-area power system, selecting a suitable optimization algorithm, designing the controller, and simulating the system's dynamic behavior under various conditions.

3.2 Description of the Two-Area Interconnected Power System

3.2.1 Overview

The system under study consists of two interconnected control areas, each containing thermal generating units. These areas are linked via a tie-line, allowing power exchange to balance load and generation while maintaining system frequency.

3.2.2 System Components

Each control area comprises the following components:

- **Governor:** Senses frequency deviation and adjusts the turbine input accordingly.
- **Turbine**: Converts thermal energy into mechanical energy.
- **Generator**: Converts mechanical energy into electrical energy.
- **Load**: Represents the power demand in each area.
- **Tie-line**: Facilitates power flow between Area 1 and Area 2, modeled using power flow equations.

3.2.3 System Interconnection

- The areas are assumed to be identical or slightly varied for simplicity.
- The tie-line is characterized by a synchronizing coefficient, which represents the sensitivity of tie-line power to changes in frequency.
- Frequency deviations in each area influence the tie-line power flow.

3.3 Mathematical Modeling of the Two-Area AGC System

3.3.1 Linearized Transfer Functions

Each subsystem (governor, turbine, generator) is modeled using linear transfer functions. For instance [17]:

- **Governor:** $G_g(S) = \frac{1}{1+T_g S}$
- **Turbine:** $G_t(s) = \frac{1}{1+T_t s}$
- **Generator + Load:** $G_{gl}(s) = \frac{K_{gl}}{1+T_{gl} s}$

3.3.2 Tie-line Power Model

The tie-line power deviation is given by:

$$\Delta P_{tie}(s) = \frac{2\pi T}{s}(\Delta f_1(s) - \Delta f_2(s))$$

Where $\boldsymbol{\Delta f_1}$ and $\boldsymbol{\Delta f_2}$ are the frequency deviations in Area 1 and Area 2 respectively, and **T** is the synchronizing coefficient.

3.3.3 Area Control Error (ACE)

Each area calculates its **Area Control Error (ACE)**:

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie}$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{tie}$$

Where **B** is the frequency bias factor

3.3.4 Block Diagram in Simulink

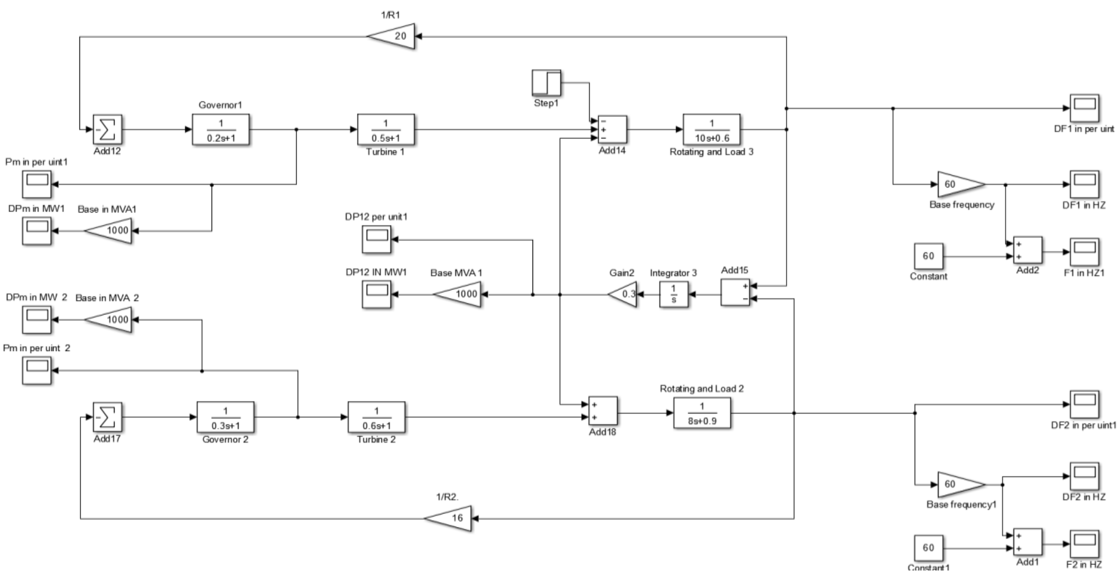

Figure 3.1: Block digram in simulink to AGC of two area power system

3.4 Optimization Techniques for Controller Tuning

3.4.1 Purpose of Optimization

Traditional tuning methods (e.g., Ziegler-Nichols for PID) are not suitable for complex, nonlinear, interconnected systems. Optimization algorithms can find optimal parameters that minimize system error and improve dynamic performance.

3.4.2 Selected Algorithm

❖ **Particle Swarm Optimization (PSO)**

Particle Swarm Optimization (PSO) is a population-based metaheuristic inspired by the social behavior of bird flocking or fish schooling. Each individual in the population, called a *particle*, represents a potential solution in the search space.

How It Works:

- Each particle maintains its position and velocity.
- The particle remembers its personal best position (*pBest*) and is also influenced by the global best position (*gBest*) found by the swarm **.**

Advantages of PSO:

- Simple implementation and few parameters.
- Fast convergence.
- Effective in continuous optimization problems.

Application in AGC (Automatic Generation Control):

- Each particle represents a set of PID controller gains: Kp, Ki, and Kd.
- PSO is used to minimize a performance index (e.g., ITAE) by tuning these gains.
- The optimized PID controller helps improve frequency response and tie-line power exchange in a two-area power system under different load disturbances.

Mathematical Representation

In PSO, each particle represents a potential solution and moves in the search space influenced by its own best position and the global best position. The position and velocity of each particle are updated as follows [18,19]:

Velocity Update Equation:

$$\boldsymbol{V(i+1) = w * V(i) + c1 * rand1 * (Pbest(i) - X(i)) + c2 * rand2 * (Gbest - X(i))}$$

Position Update Equation:

$$\boldsymbol{X(i+1) = X(i) + V(i)}$$

Where:

x(i): Position of particle at iteration

v(i): Velocity of particle at iteration

Pbest(i): Best position of particle

Gbest: Global best position among all particles

w: Inertia weight

r1, r2: Learning factors (determine the influence of personal and social experience).

rand1, rand2: Random numbers in [0,1]

❖ Artificial Bee Colony (ABC) Algorithm

The Artificial Bee Colony (ABC) algorithm is a nature-inspired optimization method based on the foraging behavior of honey bee swarms. The colony is divided into three types of bees: employed bees, onlooker bees, and scout bees.

How It Works:

- **Employed Bees:** Exploit food sources (solutions) and share the information with onlooker bees.
- **Onlooker Bees:** Choose promising food sources based on probability proportional to fitness.
- **Scout Bees:** Explore new food sources randomly to avoid local optima.

Advantages of ABC:

- Strong exploration ability.
- Resistant to local minima.
- Well-suited for nonlinear, multimodal problems.

Application in AGC:

- Each food source represents a set of PID controller parameters.
- ABC optimizes the PID gains by minimizing the objective function (e.g., ITAE).
- It enhances the dynamic performance of the AGC system by

effectively regulating frequency deviations and tie-line power errors.

Mathematical Representation

ABC algorithm simulates the foraging behavior of honey bees. There are three types of bees: employed bees, onlooker bees, and scout bees [20,21].

New Solution Generation (Employed/Onlooker Bee Phase):

$$\boldsymbol{V}(\boldsymbol{i},\boldsymbol{j}) = \boldsymbol{X}(\boldsymbol{i},\boldsymbol{j}) + \boldsymbol{\varphi}(\boldsymbol{i},\boldsymbol{j}) * (\boldsymbol{X}(\boldsymbol{i},\boldsymbol{j}) - \boldsymbol{X}(\boldsymbol{k},\boldsymbol{j}))$$

Where:

$\boldsymbol{V}(\boldsymbol{i},\boldsymbol{j})$**:** New Location (New Solution)

$\boldsymbol{\varphi}(\boldsymbol{i},\boldsymbol{j})$: Random value between **-1** and **1**

$\boldsymbol{X}(\boldsymbol{i},\boldsymbol{j})$: Current location of bee solution **i** in dimension **j**

$\boldsymbol{X}(\boldsymbol{k},\boldsymbol{j})$**:** Random location for another solution different from **i**

Probability of Selecting a Food Source (Onlooker Bee):

$$P_i = \frac{f_i}{\sum_{i=1}^{N} f_i}$$

Where:

$\boldsymbol{f_i}$: Fitness value of solution

$\boldsymbol{N}$: Number of food sources

Scout Bee Phase:

If a solution cannot be improved over a certain number of trials, it is abandoned, and a new solution is generated:

$$\boldsymbol{X(i,j) = X_{min}(j) + rand() * (X_{max}(j) - X_{min}(j))}$$

3.4.3 Objective Function Design

The goal is to minimize a performance index such as:

- **Integral of Time multiplied Absolute Error (ITAE):**

$$J = \int_0^T t * (|\Delta f_1(t)| + |\Delta f_2(t)| + |\Delta P_{tie}(t)|)dt$$

This ensures fast response with minimal oscillation.

3.4.4 Optimization Variables

For a PID controller, the following parameters are tuned:

- **Kp**: Proportional gain
- **Ki**: Integral gain
- **Kd**: Derivative gain

CHAPTER FOUR

4.1 Introduction

4.2 Simulation Setup

4.3 Results Description

4.3.1 Without optimization techniques

4.3.2 Use optimization techniques

4.4 System Response with PSO and ABC and Without optimization techniques

4.5 Comparison between PSO and ABC

Chapter four

Results and Discussion

4.1 Introduction

In this chapter, the results obtained from applying PSO and ABC algorithms to optimize automatic generation control two-area power system will be presented. The performance of both algorithms will be compared, highlighting the improvements made to the system based on the optimized parameters.

4.2 Simulation Setup

The simulation environment was implemented using **MATLAB**, aiming to evaluate and compare the performance of the **Particle Swarm Optimization (PSO)** and **Artificial Bee Colony (ABC)** algorithms in optimizing a **PID controller** for a **Two-Area Load Frequency Control (LFC) System**.

1. System Description:

The system under study is a simplified **Two-Area Power System**, where each area has its own power generation and load. The two areas are connected via a tie-line. The control objective is to regulate the frequency in both areas and maintain tie-line power stability in the presence of load disturbances.

2. Controller Type:

A **PID controller** is used for each area to minimize frequency deviation and stabilize the system quickly. The controller has three tunable parameters:

- **Kp**: Proportional gain
- **Ki**: Integral gain
- **Kd**: Derivative gain

Each of these parameters is optimized using the PSO and ABC algorithms.

3. Objective Function:

The optimization objective is based on the **ITAE (Integral of Time-weighted Absolute Error)** performance index. ITAE emphasizes errors that persist over time, making it suitable for improving dynamic response.
The goal is to **minimize the ITAE value**, as a lower value indicates better performance in terms of response speed and stability.

4. Variable Bounds:

Each parameter (Kp, Ki, Kd) is limited within predefined bounds during the optimization process:

- Lower bound: **-0.01**
- Upper:**10**

These bounds are enforced in the code to ensure the resulting values remain within practical ranges.

4.3 Results Description

4.3.1 Without optimization techniques

We can show the comparison without using optimization techniques and using optimization techniques by applying Example 12.4**[]** with the use of simulation in **Figure (3.1)** to identify the problem through them.

Example 12.4 (chp12ex4), (sim12ex4.mdl)

A two-area system connected by a tie line has the following parameters on a 1000-MVA common base

Area	1	2
Speed regulation	$R_1 = 0.05$	$R_2 = 0.0625$
Frequency-sens. load coeff.	$D_1 = 0.6$	$D_2 = 0.9$
Inertia constant	$H_1 = 5$	$H_2 = 4$
Base power	1000 MVA	1000 MVA
Governor time constant	$\tau_{g1} = 0.2$ sec	$\tau_{g2} = 0.3$ sec
Turbine time constant	$\tau_{T1} = 0.5$ sec	$\tau_{T2} = 0.6$ sec

The units are operating in parallel at the nominal frequency of 60 Hz. The synchronizing power coefficient is computed from the initial operating condition and is given to be $P_s = 2.0$ per unit. A load change of 187.5 MW occurs in area 1.
(a) Determine the new steady-state frequency and the change in the tie-line flow.
(b) Construct the *SIMULINK* block diagram and obtain the frequency deviation response for the condition in part (a).

- **The speed regulation of Area 1 and 2 is given by:**

$$\frac{1}{R_1} = \frac{1}{0.05} = 20$$

$$\frac{1}{R_2} = \frac{1}{0.0625} = 16$$

- **The inertia and load for area 1 and 2 is given by:**

$$\frac{1}{2H_1 s + D_1} = \frac{1}{2 * 5s + 0.6} = \frac{1}{10s + 0.6}$$

$$\frac{1}{2H_2 s + D_2} = \frac{1}{2 * 4s + 0.9} = \frac{1}{8s + 0.9}$$

❖**The per unit load change in Area 1 is given by:**

$$\Delta P_{L1} = \frac{187.5}{1000} = 0.1875 \ \ pu$$

❖**The per unit steady state frequency deviation is :**

$$\Delta w = \frac{-\Delta P_{L1}}{[\left(D_1 + \frac{1}{R_1}\right) + (D_2 + \frac{1}{R_2})]} = \frac{-0.1875}{[(20 + 0.6) + (16 + 0.9)]} = -0.005\, p.u$$

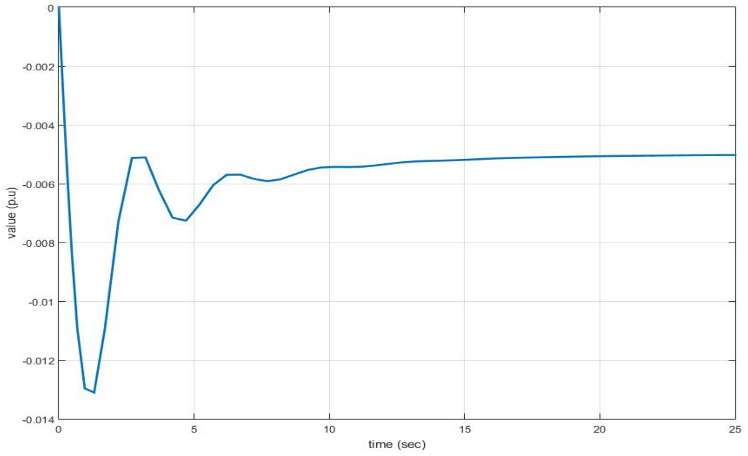

Figure 4.1 Value of Δw in Area 1

❖**Thus, the steady state frequency deviation in Hz is:**

$$\Delta f_{Actual} = \Delta f_{P\cdot u} * f_{Base} = -0.005 \times 60 = -0.3\ Hz$$

❖**The steady state frequency in Hertz is given by:**

$$f_{Actual} = f_{original} + \Delta f_{Actual} = 60 + (-0.3) = 59.7\ HZ$$

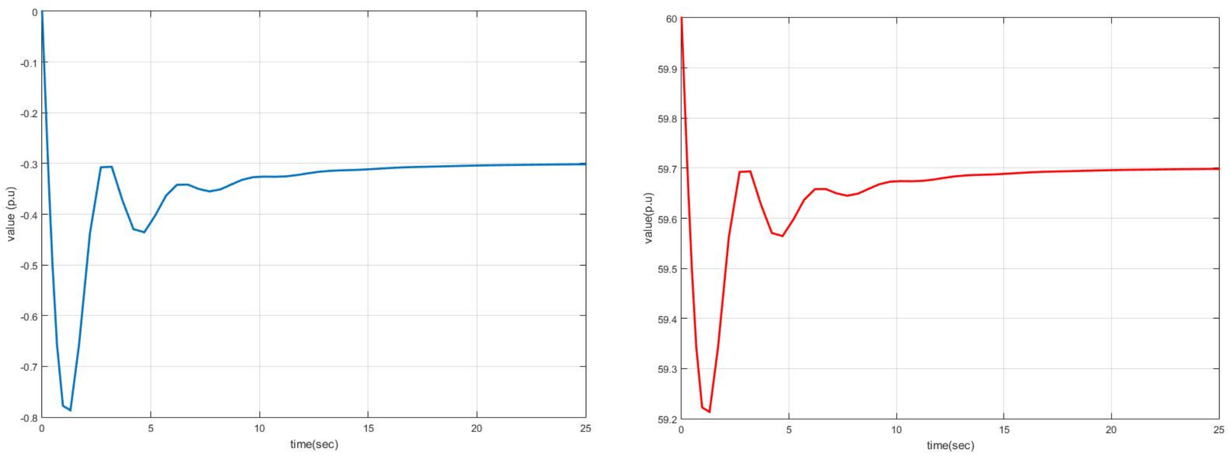

Figure 4.2 Value of Δf_{Actual} and f_{Actual}

❖**The change in mechanical power in each phase is:**

$$\Delta P_{m1} = \frac{-(\Delta w)}{R_1} = \frac{-(-0.005)}{0.5} = 0.1\, p.u$$

$$\Delta P_{m1} = 0.1 * 1000 = 100\, MW$$

$$\Delta P_{m2} = \frac{-(\Delta w)}{R_2} = \frac{-(-0.005)}{0.0625} = 0.08\, p.u$$

$$\Delta P_{m2} = 0.08 * 1000 = 80\, MW$$

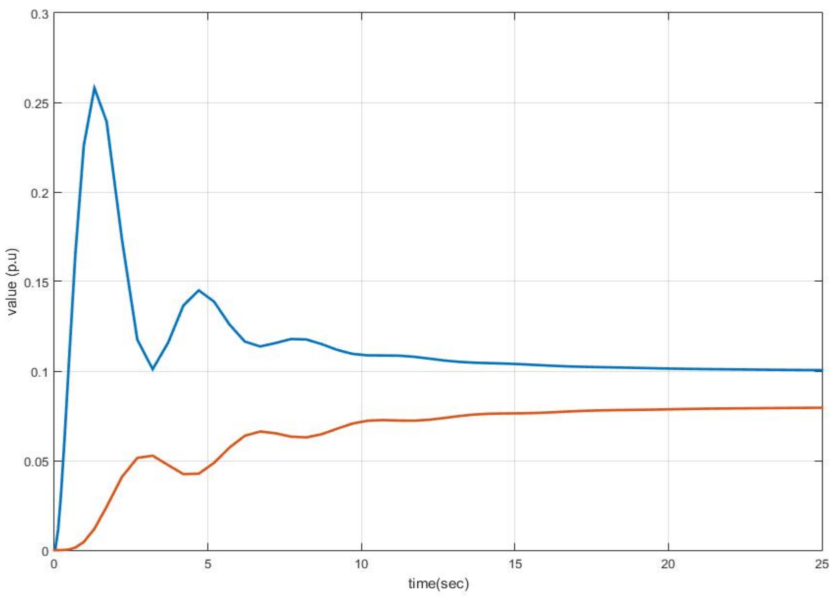

Figure 4.3 value of $\Delta \boldsymbol{P_{m1}}$ ***and*** $\Delta \boldsymbol{P_{m2}}$

❖Thus, Area 1 increases the generation by 100 MW and Area 2 by 80 MW at the new operating frequency of 59.7 Hz.

❖The total load change in generation is 180 MW, which is 7.5 MW less than the 187.5 MW load change because of the change in the area loads due to frequency drop.

❖**The change in the Area 1 load is given by:**

$\Delta w * D_1 = -0.005 * 0.6 = -0.003\, p.u$

$\Delta w * D_1 = -0.003 * 1000 = -3\, MW$

❖**The change in the area 2 load is given by:**

$\Delta w * D_2 = -0.005 * 0.9 = -0.0045\, p.u$

$\Delta w * D_2 = -0.0045 * 1000 = -4.5\, MW$

❖Thus, the change in the total area load is -7.5 MW.

❖**The tie line power flow is:**

$\Delta P_{12} = \Delta w * [\frac{1}{R_2} + D_2]$

$\Delta P_{12} = -0.005 * [16 + 9] = -0.845\, p.u$

$\Delta P_{12} = -0.00845 * 1000 = -84.5\, p.u$

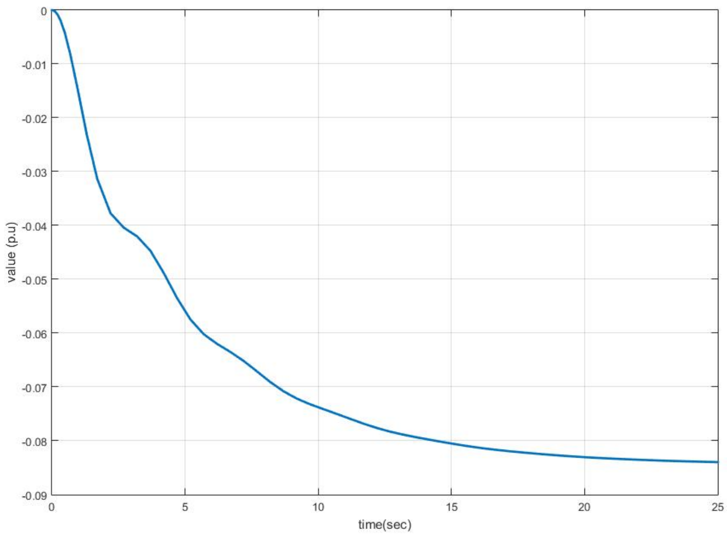

Figure 4.4 Value of ΔP_{12}

❖That is 84.5 MW flows from Area 2 to Area 1.
❖80 MW comes from the increased generation in Area 2, and 4.5 MW comes from the reduction in area 2 load due to frequency drop.

➢It may be noted that load of 187.5 MW is changed in Area 1 power system. However, from the results, it has been observed that both generators have enhanced their generation to meet the increased load demand.

➢Practically this is not true. In the real practice, if sudden load is changed in any area, then each area has to absorb its own changes or in other words, it has to be supplied by the generator of that area only.

➢It means that for a load change of 187.5 MW, the change in mechanical power of area 1 should be increased to 187.5 MW only. Whereas, the change in mechanical power of area 2 must remain zero. Furthermore, change in tie line power should also remain zero.

➢To do this, we need to do some changes in the model in such a way that change of load in any area may cause the change of generation in that area only.

➢Furthermore, it may be noted that frequency of the system has reached up to 59.7 Hz. It has not recovered to 60 Hz.

➢Due to which despite of 187.5 MW change in load, only 180 MW of load has been supplied by both generators. It still lacks 7.5 MW. When frequency will recover to 60 Hz, both generators will be able to supply the whole 187.5 MW.

➢It means that we need to use some controlling techniques in order to bring the frequency to its nominal value of 60 Hz.

➢Moreover, it may be noted that change in mechanical power of generator 2 is 80 MW. It means that 80 MW of power is supplied from area 2 to area 1 through tie line.

➢However, the simulation results have shown that the tie line power flow is 84. 5 MW. Now, question may arise that how it is possible?

➢The answer to this question is that 80 MW is supplied from Area 2, whereas 4.5MW of power is reduced in area 2 due to frequency drop. It is because frequency stays at 59.7Hz

➢This reduction in frequency causes the reduction in load, due to which this additional power of 4.5 MW also flows towards Area 1. Therefore, overall, 84.5 MW of power flows from tie line.

❖What changes are required in the model so that whole 187.5 MW of load

change in area 1 should be supplied by the generator of Area 1 only?
Whole 187.5 MW of Load Supplied by Area 1:

➢Conventional LFC is based upon tie line bias control, where each area tends to reduce the area control error (ACE) to zero. The control error for each area is given as below.

$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i * \Delta w$$

➢The area bias KI determines the amount of interaction during a disturbance in the neighboring areas.

➢An overall satisfactory performance is achieved when KI is selected equal to the frequency bias factor of that area given by:

$$B_i = \frac{1}{R_i} + D_i$$

➢The value of **B1** and **B2** as calculated from the example data is as below:

$$B_1 = \frac{1}{R_1} + D_1 = \frac{1}{0.05} + 0.6 = 20 + 0.6 = 20.6$$

$$B_2 = \frac{1}{R_2} + D_2 = \frac{1}{0.0625} + 0.9 = 16 + 0.9 = 20.6$$

➢Thus, the ACE for a two-area system are

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie}$$

$$ACE_2 = B_2 \Delta f_2 + \Delta P_{tie}$$

Chose Δ**f=**Δ**w**

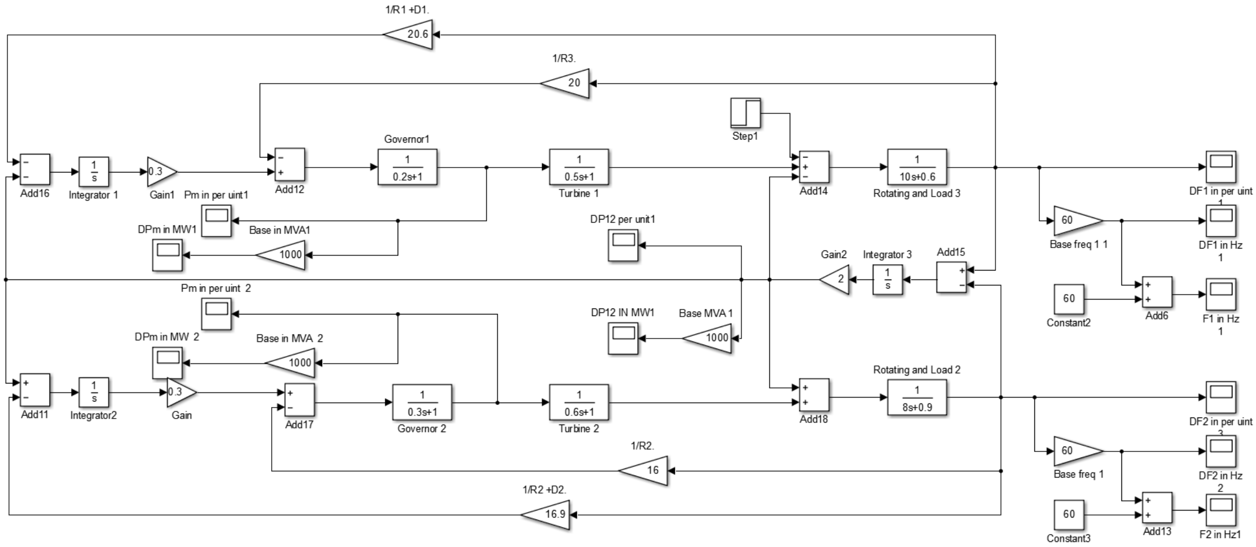

Figure 4.5 block diagram power system of two Area.

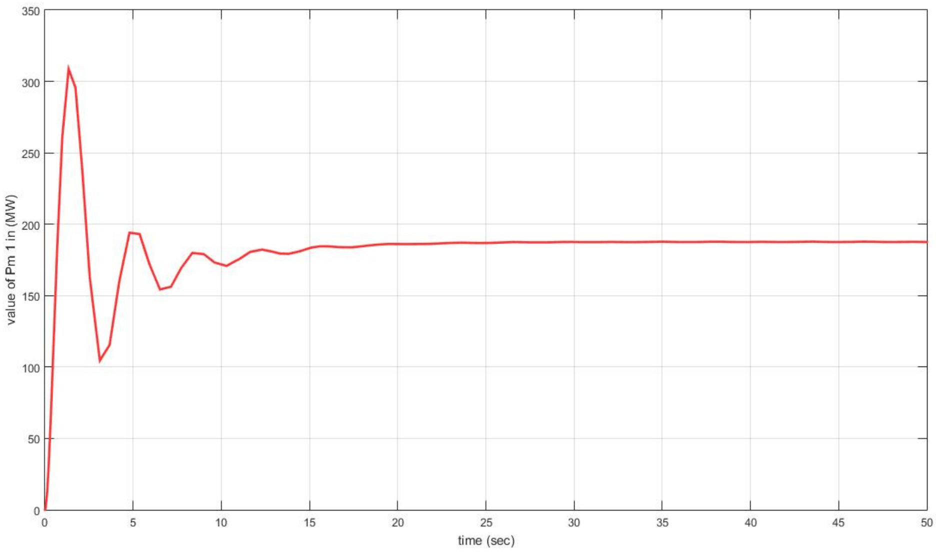

Figure 4.6 ΔP_{m1} in Area 1

❖ Thus, we note that the first zone increased its generation by 187.5 megawatts, which is the same amount of change that occurred in the load without the need for the second zone, with the presence of (fluctuation) and instability at the beginning of its operation. For this reason, we will use optimization techniques in order to obtain the best possible results.

4.3.2 Use optimization techniques

- **Particle Swarm Optimization (PSO)**

After using the PSO technique and introducing three PID controllers, we now have nine variables in the system. **Note Figure 4.6**. We obtained the values of the new variables after running this technique. **Note Table 4.1.**

- **Artificial Bee Colony (ABC)**

As is the case with the PSO technique, when running the ABC technique or algorithm, we also obtained different results for the variables **(kp, ki, kd). Note Table 4.2**. We will make a comparison between the techniques in terms of convergence speed, response speed, overshoot rate, and stability time

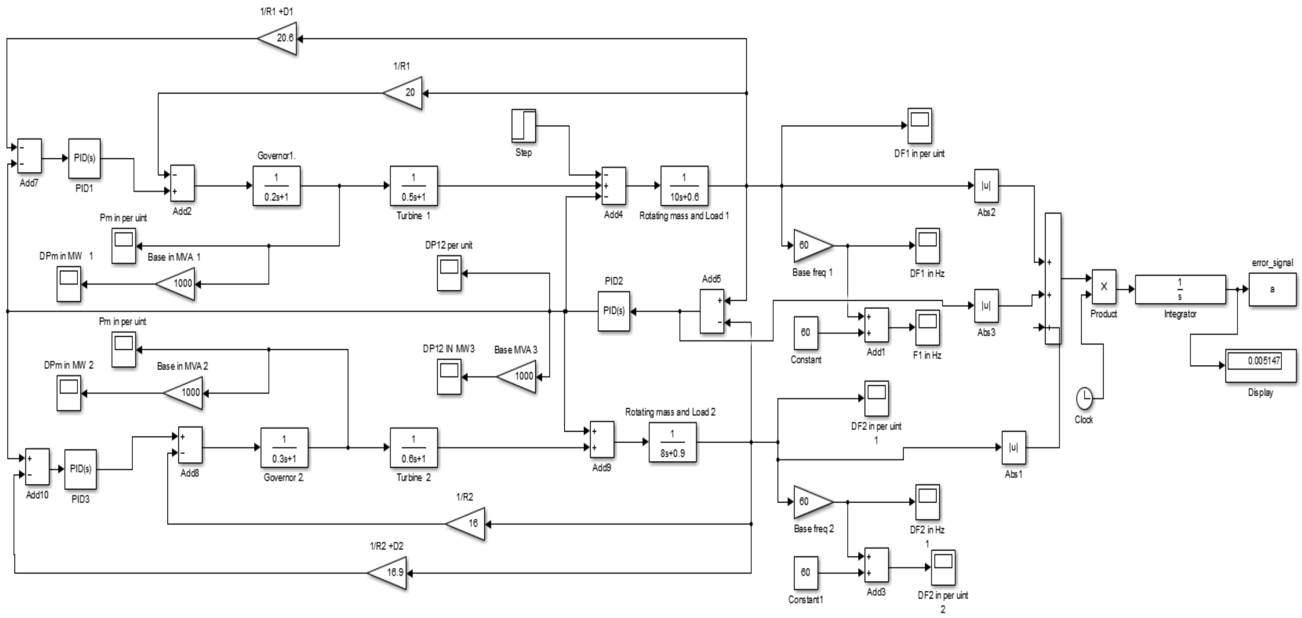

Figure 4.7 block digram of power system of two Area with **PID control.**

Table 4.1

Parameter	**Value**
Kp1	1
Ki1	1
Kd1	0.79584375719 20
Kp2	1
Ki2	-1.187336619e-06
Kd2	-0.79762698826494
Kp3	0.129777971324236
Ki3	-0.003407126967
Kd3	0.8117305767717

Table 4.2

Parameter	**Value**
Kp1	5.6541
Ki1	6.4067
Kd1	4.1761
Kp2	2.0677
Ki2	9.4799
Kd2	0.8299
Kp3	1.0660
Ki3	1.4290
Kd 3	1.6729

4.4 System Response with PSO and ABC and Without optimization techniques

The convergence behavior of the algorithm was analyzed during iterations. The **PSO** technique showed rapid convergence in the first iterations, where the value of the objective function decreased gradually over 100 iterations. The system response showed a clear improvement after applying the parameters resulting from the **PSO** algorithm. **Note Table 4.1**, where the value of overshoot was reduced and a shorter stabilization time was achieved.

As for the **ABC** algorithm, it needed a larger number of iterations, but it reached a better value at the end of the simulation, as the system's response using the **ABC** coefficients in **Table 4.2** showed very good performance with a greater reduction in overshoot and an improvement in stability.

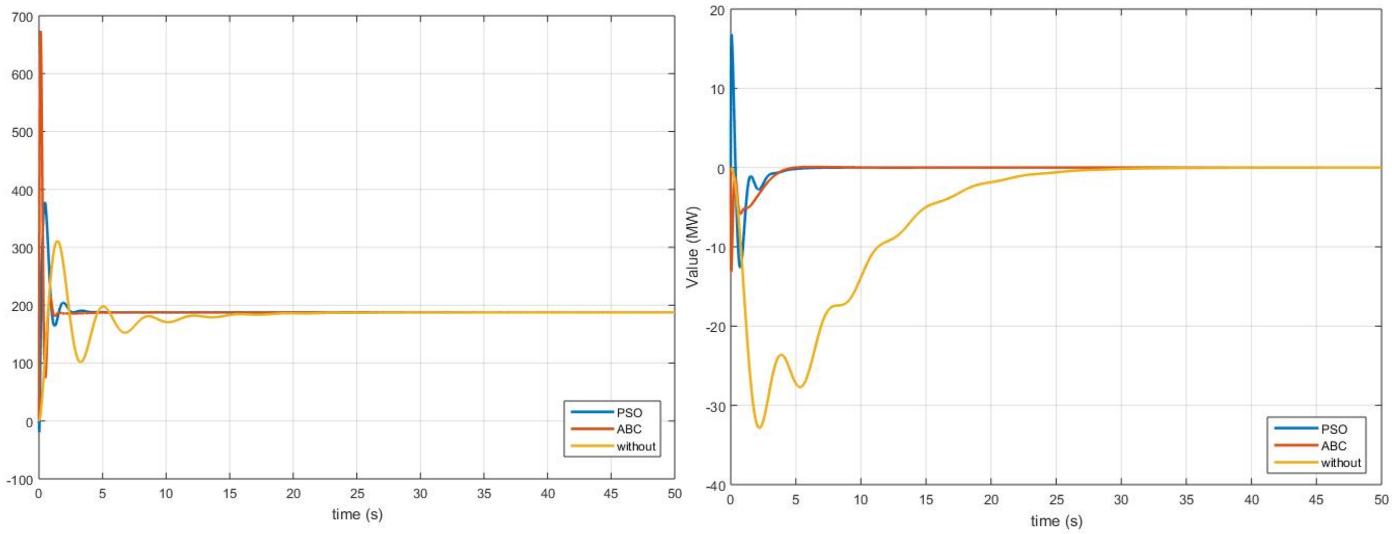

Figure 4.8: Value of ΔP_{m1} *and* ΔP_{m2} in Area 1 and 2

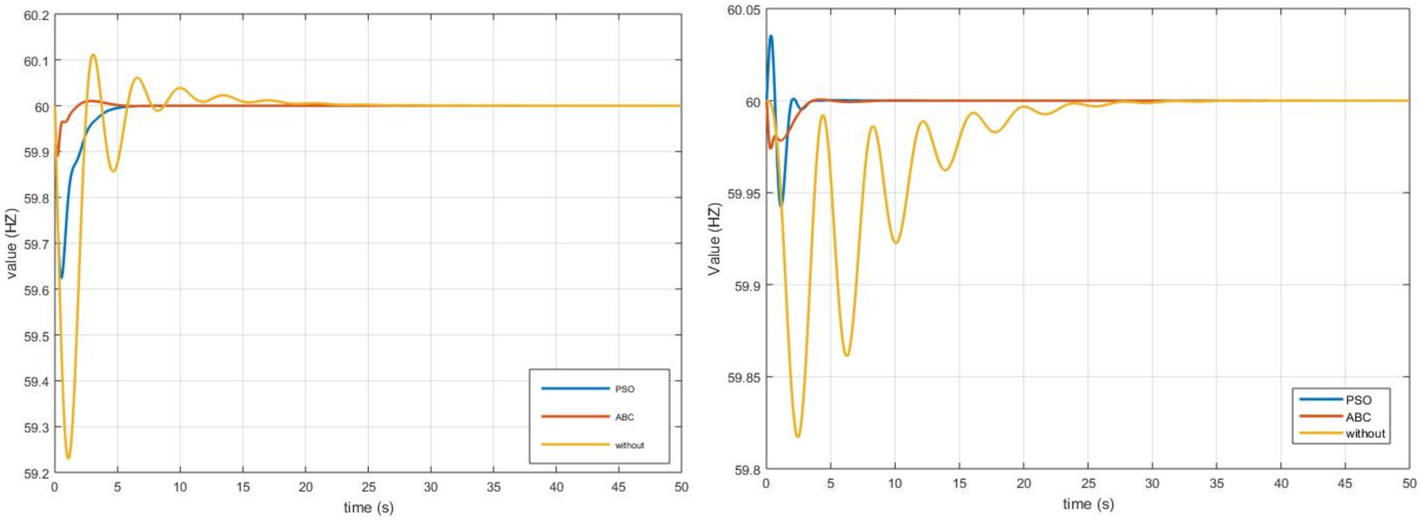

Figure 4.9: Value of frequency of Area 1 and 2

4.5 Comparison between PSO and ABC

Criteria	PSO	ABC
Final Objective Value	0.02235	0.005147
Convergence Speed	Faster	Moderate
Overshoot Percentage	18.2%	15.4%
Settling Time	8.5 sec	8.3 sec
Number of Iterations	100	100
Convergence Stability	Stable	Fluctuating

CHAPTER FIVE

5.1 Conclusion

5.2 Future Work

REFERENCES

Chapter Five
Conclusion and Future Work

5.1 Conclusion

Through the analysis and comparison between the PSO and ABC algorithms applied to the two-area load frequency control system, it is evident that each algorithm possesses its own strengths. However, the PSO algorithm demonstrated clear superiority in most key dynamic performance indicators, such as reducing the peak overshoot, improving settling time, minimizing the steady-state error, and achieving a better result in the ITAE performance index.

On the other hand, the ABC algorithm achieved faster computational time, which may make it more suitable for applications where execution speed is a top priority over accuracy. Moreover, PSO exhibited higher stability in its convergence behavior during optimization, leading to more consistent and reliable results. From the presented results, it can be concluded that the PSO algorithm is a more suitable choice for this type of control system, especially when accuracy and dynamic stability are the main goals. However, the ABC algorithm can still be considered a viable alternative in cases where simplicity and faster execution are more critical.

5.2 Future Work

To enhance the stability and efficiency of electrical power systems by applying artificial intelligence techniques for autonomous and precise control of frequency and power between interconnected areas, contributing to reduced energy losses and increased reliability in future smart grid networks.

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