

**GA-OPTIMIZED PID CONTROL STRATEGY FOR AUTOMATIC GENERATION CONTROL IN TWO-AREA INTERCONNECTED POWER SYSTEMS**

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**Abstract**

This paper compares the load frequency control of a two-area linked power system using genetic algorithm-optimized PID (GA-PID) controllers and conventional proportional-integral-derivative (PID) controllers. Three scenarios—without any controller, with a conventional PID controller, and with an optimized GA-PID system—are simulated for frequency deviation reactions under load perturbations. The two-area system's complete dynamic model is developed. The efficacy of each control approach is evaluated using key metrics such as steady-state frequency deviation, overshoot, and settling time. Simulation findings show that, in comparison to the uncontrolled system and the typical PID controller, the GA-PID controller significantly reduces frequency deviations and increases system stability. The new controller dampens oscillations faster and is more resilient to load perturbations. These findings imply that evolutionary optimization techniques, such as genetic algorithms, can effectively improve controller performance in complex power system applications.

**Keywords:** Two-Area Power System (TAPS), Load Frequency Control (LFC), frequency deviation ( $\Delta f$ ), PID controller, Genetic Algorithm GA.

**Introduction**

Power systems are complex networks that require effective control systems to maintain dependability, stability, and efficiency. In large, linked power systems, controlling generators at different sites is crucial for preserving supply and demand balance, regulating frequency, and minimizing voltage swings. Proportional-integral-derivative (PID) controllers are widely used in power systems for automatic control due to their simplicity of use and effectiveness in regulating generator output. Using optimization techniques like genetic approaches (GA), the optimal PID controller parameters for power system control can be automatically generated in this scenario. By mimicking the natural selection process and iteratively looking for the best solution within a specific



problem space, genetic algorithms can be used to optimize complex and nonlinear systems, such as power systems [1]. The automatic creation of PID control for a two-area power system using a Genetic Algorithm (GA) is a significant advancement in power system control and optimization. This approach combines the robustness and adaptability of evolutionary algorithms with the ease of use and effectiveness of PID controllers to provide optimal control performance in dynamic and complex power systems [2]. In the two-region power system, a simplified but realistic model of connected power grids, the control of generator outputs in each area has an impact on power flow distribution, frequency regulation, and system stability. PID controller design for these kinds of systems frequently involves human tweaking based on simulation research and engineering expertise. Nevertheless, manual tuning can be time-consuming and may not always yield the optimal results, particularly in large-scale and dynamic systems [3]. A Single Input Fuzzy Logic Gain Scheduling PID Controller (SIFL-PID) is developed in [4] as an extra loop for AGC of two area interconnected power systems in order to accelerate processing. In [5], a Hybrid Genetic Algorithm (HGA) is proposed to improve the dynamic performance of the power system using wind power and reduce frequency deviations. This new optimization technique, which is based on the minimization of the Integral of Squared Errors (ISE), finds the optimal configurations for the proportional-integral-derivative (PID) controller gains. [6] explain how the interconnected two-area power system is controlled by the Electrical Vehicle (EV) loading and the appropriate tuning of the fractional order PID (FPID) controller. The control performance and dynamic frequency response analysis of multi-unit two area interconnected systems are simulated and comprehensively examined using the Matlab/Simulink environment. [7] looks into the overall performance by looking at the settling times in areas one and two as well as the tie line power deviation. The system error is successfully decreased by optimizing GA with the Integral Time Absolute Error (ITAE) objective function. The objective of this study is to develop an improved control strategy for Automatic Generation Control (AGC) in a multi-area power system, Automatic Generation PID Control of Two Area Power System Using GA Algorithm. Optimizing PID Controller Parameters, in particular, uses Genetic Algorithms (GA) to automatically modify the parameters of PID controllers distributed across the power system. The goal is to maximize the PID controller gains (proportional, integral, and derivative terms) in order to improve the AGC system's overall performance. Next, more stable systems and better frequency control To increase frequency regulation and power system stability, especially in the face of varying load conditions and disturbances, use GA-tuned PID controllers to control generator output in each region and maintain system frequency within permissible bounds. Last but not least, minimize frequency deviations and control mistakes by optimizing the PID controller parameters using GA. The goal of the Two-Area Power Systems design, as shown in Fig. (1) below [8] [9], is to reduce steady-state error, overshoot, and settling time in frequency control such that the system operates within predetermined performance bounds.

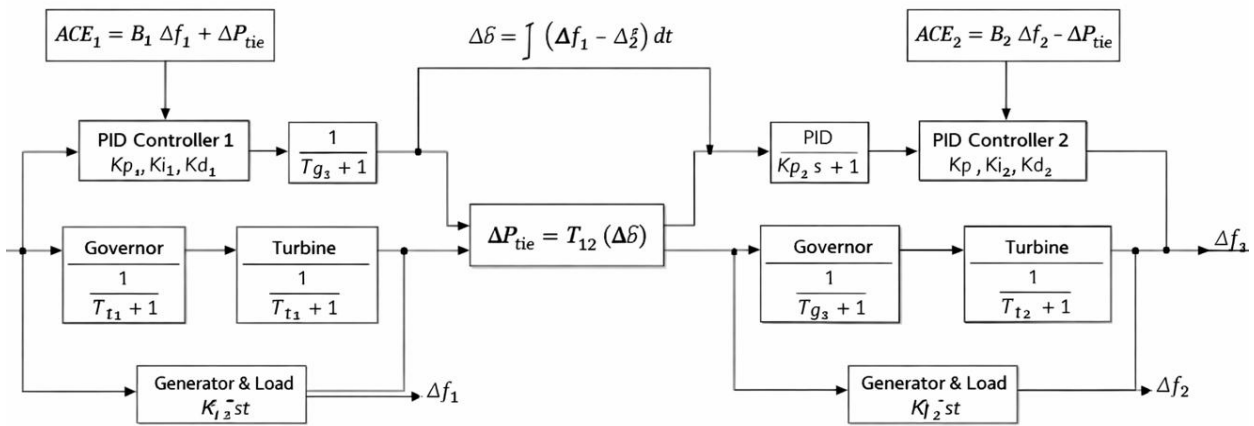


Fig. 1 block diagram of two area power system.

### A. Power System stability Classification

Power system stability can be divided into a number of categories, each of which focuses on a distinct facet of the system's behavior under a range of operating circumstances and disruptions. Fig. (2) illustrates the primary forms of power system stability [10][11]:

#### 1. Steady-State Stability:

The ability of the power system to maintain equilibrium under steady-state operating conditions is known as steady-state stability, sometimes called static stability. It ensures the balance of active and reactive power generation, transmission, and consumption within the system. Steady-state stability is essential to prevent voltage collapse or instability and to maintain voltage values within acceptable boundaries.

#### 2. Transient Stability:

It is, also known as dynamic stability, is the power system's capacity to recover and resume stable operation following an interruption. It involves monitoring how the system responds to sudden changes, such as failures or switching events, and ensuring that oscillations in the system eventually subside and return to a stable operating condition. Transient stability is crucial to maintaining system reliability and preventing cascading failures or blackouts.

#### 3. Voltage Stability:

It is the ability of the power system to maintain acceptable voltage levels at each node in the face of varying operating conditions and disturbances. It involves evaluating how the system responds to changes in load demand, generator output, or network configuration and ensuring that voltage levels remain within permitted bounds in order to prevent voltage collapse or instability. Voltage stability is essential to maintaining system dependability and ensuring the quality of the electrical supply to clients.

#### 4. Frequency Stability:

It is the power system's capacity to maintain constant frequency levels in the face of changing operating conditions and disturbances. It involves determining how the system responds to changes in generation, load demand, or network architecture and ensuring that frequency deviations remain

within permissible limits. Frequency stability is crucial for minimizing frequency collapse or instability, preserving system integrity, and maintaining generator synchronization.

### 5. Small-Signal Stability:

Small-signal stability refers to the power system's ability to maintain stability in the face of slight disturbances or perturbations. It involves monitoring how the system responds to small changes in operational variables, such as variations in load demand or network parameters, and ensuring that oscillatory modes remain damped over time. Small-signal stability analysis helps identify potential stability issues and develop appropriate control solutions to enhance system performance and stability.

### 6. Rotor Angle Stability:

The ability of synchronous generators to maintain constant rotor angles and phase relationships across dynamic events is known as rotor angle stability, commonly called angle stability or angular stability. It assesses the system's ability to prevent large changes in generator rotor angles, which can lead to loss of synchronism and cascading failures. Each type of power system stability addresses specific aspects of the system's behavior and requires different analysis techniques, modeling approaches, and control tactics to ensure dependable and secure operation. By understanding and resolving the many types of power system stability, operators can enhance the robustness and resilience of the electric power infrastructure, hence advancing sustainability and economic development goals [12][13].

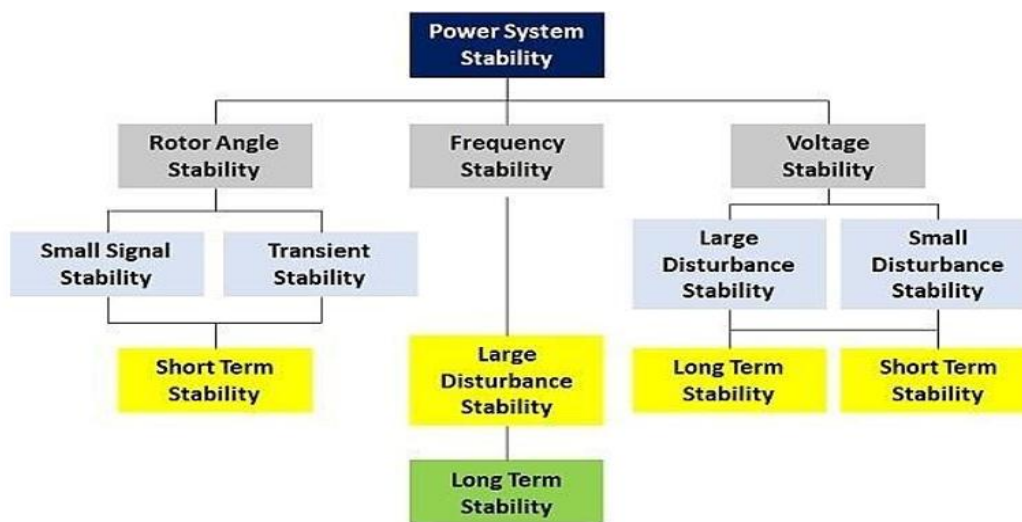


Fig. 2 Classification of Power System Stability.

## B. Factors Affecting Power System Stability

### 1. Generator Characteristics:

Power system stability is largely dependent on the dynamic response of generators, which includes governor action, damping, and inertia. Stronger damping properties and more inertia in generators help to improve system stability [11][12][13].

## **2. Transmission System:**

The system's capacity to tolerate disruptions and preserve stability is influenced by the impedance and reactance of transmission lines, transformers, and other network components. Voltage collapse and instability can result from long transmission lines and poor connections.

## **3. Characteristics of Load:**

The stability of the power system may be impacted by unbalanced loads or sudden changes in load demand. Examples of non-linear and time-varying loads that make maintaining system stability more challenging are induction motors and power electronics.

## **4. Control Systems:**

The effectiveness of control systems, such as voltage regulation, reactive power compensation, and automatic generation control (AGC), is essential to maintaining power system stability. Control techniques must respond swiftly to disturbances in order to prevent system instability and restore equilibrium.

## **5. Faults and Disturbances:**

Faults that generate disturbances that could make the electrical system unstable include short circuits and line outages. It is necessary to analyze how the system reacts to faults and implement fault detection algorithms and protective relay schemes in order to maintain dynamic stability [8][9][13].

## **C. Methods for Enhancing Power System Stability**

### **1. Dynamic Modeling and Simulation:**

Develop thorough dynamic models of the components that make up the power system and conduct simulation experiments to investigate system stability under various operating conditions and disturbances.

### **2. Control and Protection Systems:**

To increase system stability and resilience, make use of advanced control and protection systems and wide-area monitoring, control, and protection (WAMPAC) technologies.

### **3. Flexible AC Transmission Systems (FACTS):**

By using FACTS devices like SVCs (Static Var Compensators) and STATCOMs (Static Synchronous Compensators), you may increase overall system performance, reduce line losses, and improve voltage stability.

### **4. Energy Storage Systems (ESS):**

Include energy storage devices, such as batteries and supercapacitors, to provide rapid support for voltage regulation, frequency control, and grid stabilization during transient events.

### **5. Renewable Energy Integration:**

Make strategies to integrate reliable renewable energy sources, such wind and solar, into the power

grid. Utilize advanced control algorithms and grid-friendly renewable energy technology to lessen the intermittency and variability of renewable generation.

#### 6. Grid Planning and Operation:

Conduct comprehensive grid planning and operation studies to identify system vulnerabilities, optimize system configuration, and boost system resilience to disruptions and crises [11][12][14]. In general, power system stability is essential for sustaining a safe and reliable supply of electricity, fostering economic growth, and facilitating the transition to a sustainable energy future. By addressing the factors that affect stability and implementing appropriate mitigation measures, power system operators can increase the robustness and resilience of the electric power infrastructure.

## II. GENERAL CONTROL THEORY

### A. Proportional-Integral-Derivative controller (PID)

A popular control method in engineering and automation systems, such as power systems, industrial processes, robots, and more, is PID (Proportional-Integral-Derivative) control. Based on the discrepancy between the measured process variable and the intended setpoint, it seeks to control a system's output. An outline of a PID controller's three parts is provided here [15][16][17]:

#### 1. Proportional (P) Term:

An output proportionate to the current error is generated by the proportional term. By implementing a control action that is exactly proportionate to the error, it directs the system toward the setpoint. The proportional action's strength is established by the proportional gain ( $K_p$ ). A stronger reaction to changes in the error is produced by a higher proportionate gain.

#### 2. Integral (I) Term:

Over time, the cumulative inaccuracy is explained by the integral term. In order to remove steady-state errors or biases, it executes a remedial step after integrating the error signal across time. The pace at which accumulated error is corrected depends on the integral gain ( $K_i$ ). It aids in removing any residual error that might remain as a result of system errors or disturbances.

#### 3. Derivative (D) Term:

The derivative term uses the error's rate of change to forecast its future trend. It applies a damping effect to offset abrupt changes in the error and predicts the system's future behavior. The damping action's strength is determined by the derivative gain ( $K_d$ ). It lessens oscillations and overshoot while enhancing system stability. Figure 3 below illustrates how a PID controller's output is determined by adding the proportional, integral, and derivative actions shown in equation (1):

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{de(t)}{dt}. \quad (1)$$

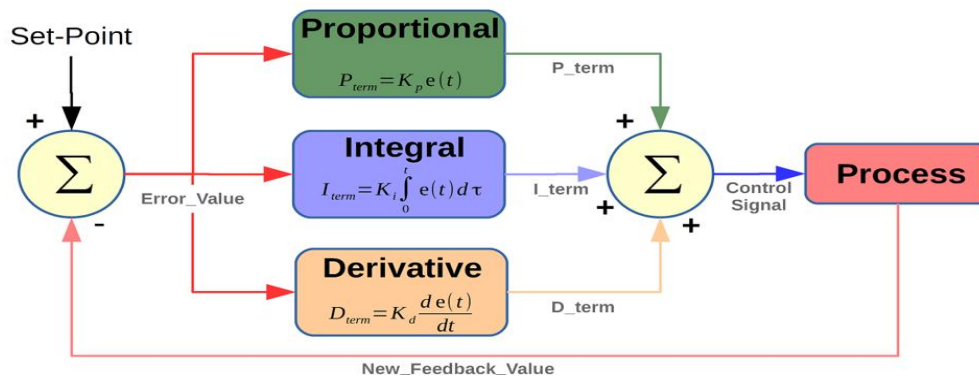


Fig. 3 Control System with (PID) Controller.

### B. Integrating Genetic Algorithms (GA)

provides a potent optimization method to adjust controller settings and enhance system performance with control systems, such as PID controllers. Natural selection and genetics serve as the inspiration for genetic algorithms, a subset of evolutionary algorithms. Fig. (4) below illustrates how GA can be used into control systems [15][16]:

#### 1. Parameter Optimization:

Based on predetermined performance criteria, GA can be used to optimize the parameters of control algorithms, such as PID controller gains. To determine the ideal parameter set, a population of possible solutions (individuals) is evolved over several generations using the parameters, which are encoded as genes in a chromosome.

#### 2. Population Evolution:

The initial population of candidate solutions (individuals), each of whom represents a set of controller parameters, is where the GA begins. The population changes throughout generations as a result of selection, crossover, and mutation. Fitter individuals—those who perform better—have a greater chance of procreating and passing on their qualities to the following generation.

#### 3. Fitness Evaluation:

Each member of the population's fitness is assessed according to how well they accomplish the control goals. For instance, measurements like rise time, settling time, overshoot, or integral absolute error (IAE) could be the basis for the fitness function in PID tuning. Better performers are more likely to be chosen for reproduction and obtain a higher fitness score [17][18].

#### 4. Selection:

Using methods like roulette wheel selection, tournament selection, or rank-based selection, individuals are chosen from the present population according to their fitness scores. While less suited individuals may be replaced by progeny produced by crossover and mutation, fitter individuals have a greater chance of being chosen.

#### 5. Crossover and Mutation:

In order to produce offspring with a blend of characteristics from both parents, pairs of chosen individuals exchange genetic information (controller parameter values) during crossover. New areas

of the solution space can be explored because mutation introduces random alterations to the offspring's genes. By preventing early convergence to less-than-ideal solutions, these actions aid in preserving population variety.

#### 6. Termination Criteria:

Until a termination requirement is satisfied, such as reaching a maximum number of generations, obtaining a good solution, or stagnating in improvement, the GA iterates over several generations. The optimal controller parameters are represented by the best-performing individual (solution) in the final population.

#### 7. Implementation and Validation:

Implemented in the control system, the optimized controller parameters derived from GA are verified by simulation or experimental testing. To determine how well the optimization procedure has improved system performance, performance measurements are compared to those of the original controller.

All things considered, the integration of GA with control systems offers a methodical and effective approach to parameter optimization, enabling the automatic tuning of controller parameters to accomplish specified control objectives and improve system performance [16][17][19].

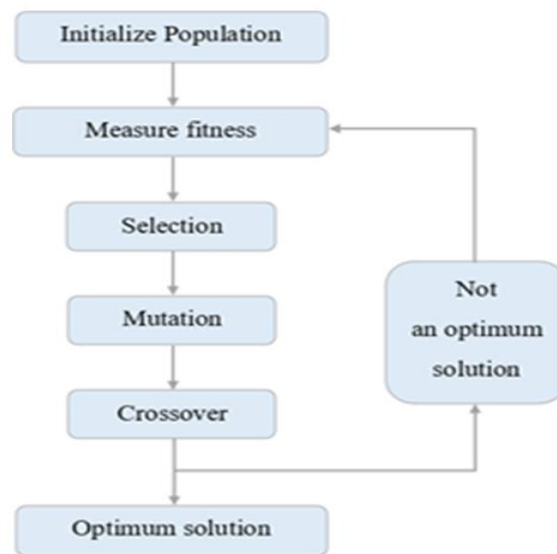


Fig. 4 Flow chart of Genetic Algorithm.

#### C. Optimizing the parameters PID controller by GA approach:

There are various benefits to using GA to automatically generate PID controller parameters [20][21][22][23]:

##### 1. Efficient Optimization:

In order to determine the ideal PID controller parameters that minimize a predetermined objective function, such as system deviation, settling time, or overshoot, GA iteratively searches the solution space. This method drastically cuts down on the time and effort needed to design controllers.

## 2. Robustness and Adaptability:

Finding resilient PID controller parameters that function effectively under a range of operating conditions and system disruptions is made possible via GA-based optimization. The controllers can react to changes in load circumstances or system dynamics thanks to GA's flexibility.

## 3. Exploration of Solution Space:

GA avoids local optima and encourages exploration of the whole solution space by using crossover, mutation, and selection processes to investigate a wide variety of potential solutions. Finding globally optimal controller parameters is more likely as a result.

## 4. Objective-Driven Optimization:

Among other control goals and constraints, the optimization approach can be tailored to minimize control effort, maximize system stability, or comply with regulatory requirements. GA can be used to integrate several constraints and objectives into the optimization framework.

## 5. Integration with Simulation and Testing:

The GA-generated PID controller parameters can be tested and verified using two-area power system simulation models. Before implementing the controllers in real systems, it is simpler to evaluate their performance and make necessary adjustments thanks to this link. All things considered, the efficacy, stability, and dependability of power system operation may be enhanced by using the GA algorithm to automatically create PID control for a two-area power system. By leveraging the potential of evolutionary optimization, this approach opens the door to intelligent and adaptive control schemes that can adapt to the shifting dynamics of modern power grids [22][23].

## II. TWO - AREA POWER SYSTEMS INTERCONNECTION MATHEMATICAL MODEL

Linearized transfer function models are used to depict the dynamic behavior of the two-area interconnected power system. Each control area is connected by a tie-line and includes a speed governor, turbine, and generator-load model. Under load disturbances, the system as a whole is intended to control frequency deviation ( $\Delta f$ ) and tie-line power/angle deviation ( $\Delta P$ ). Creating a mathematical description of the two-area power system, including generators, loads, transmission lines, and connections between areas, is part of the research's system modeling phase. As seen in Fig. (6) [24][25][26], the model provides a foundation for controller design and optimization by capturing the dynamic behavior and interactions of system components.

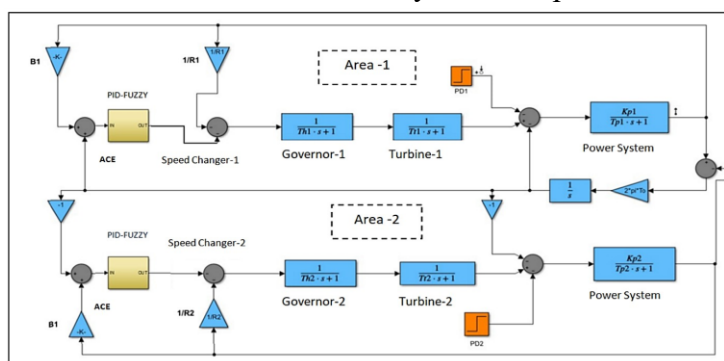


Fig. 6 Optimal Design of Automatic Generation Control.

### 1. Governor Model

The main control component that adjusts the mechanical input to the turbine in response to variations in frequency is the speed governor. Based on the control signal obtained from the Area Control Error (ACE), it modifies the steam valve position. A first-order transfer function is frequently used to model the governor [27][28]:

$$G_g(s) = \frac{1}{T_g s + 1} \quad (2)$$

where the governor time constant is denoted by  $T_g$ . The steady-state relationship between frequency deviation and power output is also defined by the governor's droop characteristic:

$$\Delta P_g = \frac{1}{R} \Delta f \quad (3)$$

where the speed regulation parameter (droop coefficient) is denoted by  $R$ . Appropriate load sharing between generating units is guaranteed by this feature.

### 2. Turbine Model

Steam's mechanical energy is transformed into rotational energy by the turbine, which powers the generator. A first-order model is usually used to depict its dynamics, which are comparatively slower than those of the governor:

$$G_t(s) = \frac{1}{T_t s + 1} \quad (4)$$

where the turbine time constant is denoted by  $T_t$ .

The governor output directly affects the turbine output power fluctuation, which in turn affects the generator input.

### Generator-Load Model

The coupled dynamics of the generator rotor and the load demand are represented by the generator-load model. It explains how power imbalance and frequency variation are related. The expression for this model is:

$$G_p(s) = \frac{K_p}{T_p s + 1} \quad (5)$$

$$K_p = \frac{1}{D}, \quad T_p = \frac{2H}{D}$$

where  $T_p$  is the power system time constant and  $K_p$  is the system gain. The power system's damping and inertia properties are captured by this block. The control system corrects frequency variation caused by any mismatch between generation and load.

### 3. Tie-Line Model

The tie-line facilitates power transfer between the two control locations. The difference in rotor angles between the two regions determines how much power flows through the tie-line. The following yields the incremental tie-line power deviation:

$$\Delta P_{tie} = T_{12}(\Delta \delta_1 - \Delta \delta_2) \quad (6)$$

where the synchronization coefficient is denoted by  $T_{12}$ .

The tie-line power can also be written as follows in terms of frequency deviation:

$$\Delta P_{tie}(s) = \frac{2\pi T_{12}}{s} (\Delta f_1(s) - \Delta f_2(s)). \quad (7)$$

The dynamic interplay between the two domains is captured by this model, which is crucial to AGC performance.

#### 4. Area Control Error (ACE)

The Area Control Error (ACE) is the main control signal used in AGC. It displays the combined effect of frequency deviation and tie-line power deviation.

For **Area 1**:

$$ACE_1 = \Delta P_{tie} + B_1 \Delta f_1. \quad (8)$$

For **Area 2**:

$$ACE_2 = -\Delta P_{tie} + B_2 \Delta f_2. \quad (9)$$

The frequency bias factor is denoted by  $B$ . The controller (PID or GA-PID), which modifies the governor input to restore system balance, receives the ACE signal as input [29][30].

### III. SYSTEM SIMULATION AND RESULTS ENVIRONMENT

Numerical experiments are performed to evaluate the performance of the optimized controllers under different operating conditions, disturbances, and control objectives in order to simulate and evaluate the automatic generation PID control of a two-area power system using a Genetic Algorithm (GA). MATLAB/Simulink is used to model and simulate the two-area linked power system in order to assess the Automatic Generation Control (AGC) performance under various control strategies (Fig. 6) and parameters (Table 1 below). Three different scenarios are examined for the system: one with no controller, one with a traditional PID controller, and one with a PID controller optimized by the Genetic Algorithm (GA).

Table 1 System Parameters of Two-Area Power System

Parameter	Area 1	Area 2
Governor Time Constant (T <sub>g</sub> )	0.2 s	0.2 s
Turbine Time Constant (T <sub>t</sub> )	0.5 s	0.5 s
Power System Time Constant (T <sub>p</sub> )	20 s	20 s
System Gain (K <sub>p</sub> )	120	120
Frequency Bias (B)	0.425	0.425
Tie-Line Coefficient (T <sub>12</sub> )	0.545	—

Equations (2), (4), and (5) are the transfer function blocks used to simulate each control area. The Area Control Error (ACE) is calculated using frequency deviation and tie-line power deviation as the functions derived in equations (6 to 9). The two areas are connected by a tie-line model. In the first scenario, there is no additional control mechanism (i.e  $\Delta P_c = 0$ ) and the system is simulated.

Thus, frequency deviation is governed only by disturbance:

$$\Delta f(s) = \frac{G_p(s)}{1+G_p(s)G_t(s)G_d(s)} \Delta P_L(s). \quad (10)$$

The system responds to load perturbations with notable frequency fluctuations, and the governor only uses its intrinsic droop feature. The following characteristics define the variances in both Area 1 and Area 2 show Figs. (7 and 8) and Table 4:

- Excessive peak overshoot.
- A slow damping pattern.
- A longer time to settle.
- A steady-state mistake could occur.

These features show weak system stability and poor dynamic performance since the system does not take enough corrective action to compensate for variations in load. As seen in Figs. (7 and 8), below, the frequency oscillations last longer, which is indicative of poor inter-area coordination and insufficient system damping.

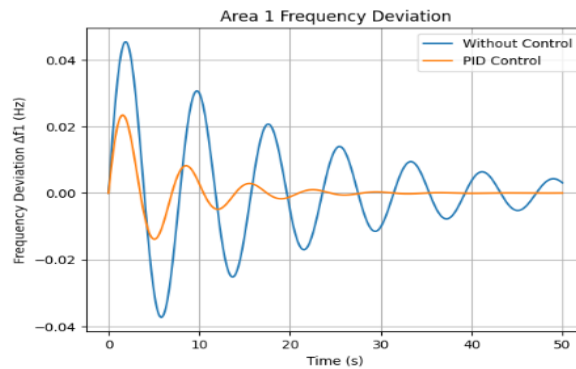


Fig. 7 Frequency Deviation for Area 1 without – PID controller.

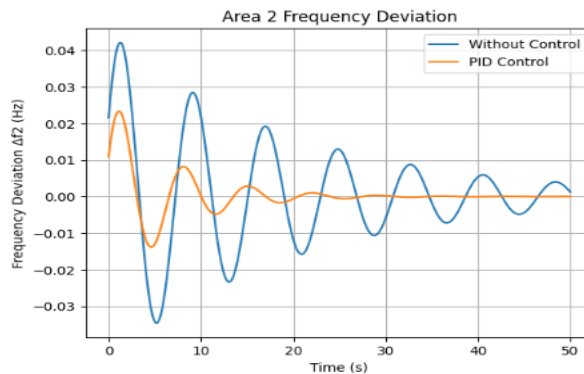


Fig. 8 Frequency Deviation for Area 2 without – PID controller

In the second scenario, each control region is equipped with a traditional PID controller ( $G_c(s)$ ), input control signal ( $\Delta P_c$ ) and the Closed-loop transfer function ( $\Delta f(s)$ ) for each area respectively are represented by:

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s. \quad (11)$$

$$\Delta P_c(s) = -G_c(s) \cdot ACE(s). \quad (12)$$

$$\Delta f(s) = \frac{G_p G_c G_g}{1 + G_p G_c G_g G_c} \cdot \Delta P_L(s). \quad (13)$$

In order to improve the Automatic Generation Control (AGC) system's dynamic performance, a traditional proportional-integral-derivative (PID) controller is integrated into each control region as shown in Table 2 below.

Table (2) Conventional PID Parameters

Area	(K <sub>p</sub> )	(K <sub>i</sub> )	(K <sub>d</sub> )
Area 1	0.8	0.5	0.1
Area 2	0.75	0.45	0.1

The Area Control Error (ACE), which represents the combined impact of tie-line power deviation and frequency deviation, is used by the controller. The PID controller uses the (ACE) signal, which is continuously monitored. In order to regulate the mechanical input to the turbine, the controller produces a corrective control signal that modifies the governor setpoint. Equation (1), where  $e(t) = \text{ACE}(t)$ , provides the control law. The system response is considerably altered with the addition of the PID controller as shown in Figs. (7 and 8) and Table 4:

- Decrease in oscillations by providing damping, the derivative action lessens oscillatory activity in the frequency response.
- Better Settling Time: Compared to the uncontrolled situation, the system reaches steady-state more quickly.
- Steady-State Error Elimination: Following a disturbance, the integral term guarantees that the frequency deviation returns to zero.
- Increased Stability: Constant corrective action makes the closed-loop system more stable.

In the third scenario, a Genetic Algorithm (GA) is used to optimize the Proportional–Integral–Derivative (PID) controller parameters (K<sub>p</sub>, K<sub>i</sub>, and K<sub>d</sub>) in order to improve the Automatic Generation Control (AGC) system's dynamic performance. The GA offers a methodical, global optimization methodology to find the ideal set of controller gains, in contrast to traditional tuning techniques as shown in Table 3 below.

Table 3 GA-Optimized PID Parameters

Area	(K <sub>p</sub> )	(K <sub>i</sub> )	(K <sub>d</sub> )
Area 1	1.25	0.85	0.25
Area 2	1.20	0.80	0.22

Every control area uses the GA-optimized PID controller, with the Area Control Error (ACE) serving as the controller's input. In order to modify the turbine output and stabilize the system frequency, the optimal controller produces a control signal that modifies the governor input. Using a performance index like the Integral of Squared Error (ISE), as shown in Equation (14), the GA seeks to reduce the overall system error:

$$J = \int_0^T (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie}^2) dt. \quad (14)$$

This guarantees the simultaneous minimization of tie-line oscillations and frequency variations. On the other hand, the dynamic response of the system with the GA-PID controller is significantly better.

The frequency deviation curves show in Figs. (9 and 10) and Table 4 below:

- A notable decrease in overshoot.
- Quicker oscillation damping.
- A shorter time to settle.
- The steady-state error is almost nil.

Optimizing PID settings using the Genetic Algorithm increases the controller's ability to search for globally optimal gains, improving both transient and steady-state performance. Because of the coordinated control action in both domains, frequency fluctuations are quickly suppressed and the system recovers to nominal frequency more successfully. The GA-PID controller also makes the system more resilient to interruptions, ensuring consistent performance in both domains even when load demand varies. When comparing three cases in two areas, Fig. (11) shows how the connectivity between the two areas is better managed, lowering oscillatory interactions and improving overall system stability characteristics, as shown in Table 4 below.

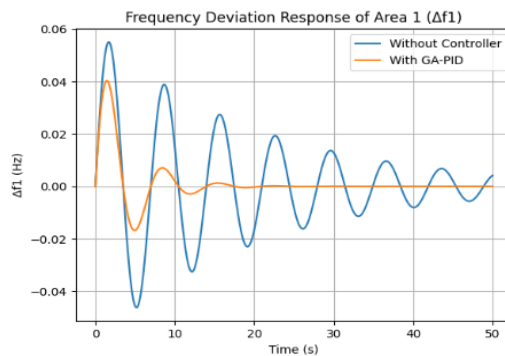


Fig. 9 Area 1's frequency deviation without a GA-PID controller.

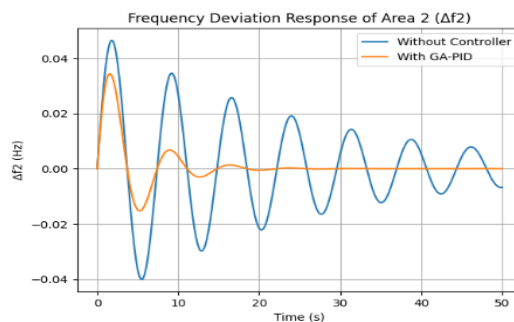


Fig. 10 Area 2's frequency deviation without a GA-PID controller.

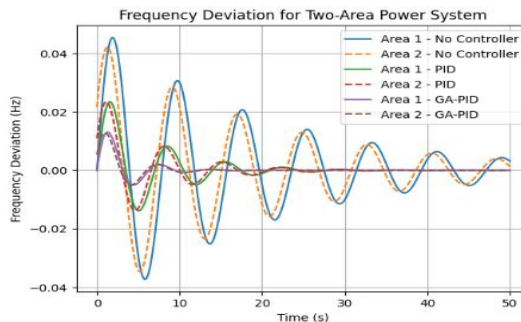


Fig. 11 Three scenarios of frequency deviation in a Two-Area power system.



Table 4 Stability Parameters Performance Comparison.

Case	Area	Settling Time (s)	Max Overshoot (Hz)	Steady-State Error	Damping	Oscillations
Without Control	Area 1	45–50	0.0453	High	Very Low	Severe
	Area 2	45–50	0.0421	High	Very Low	Severe
Conventional PID	Area 1	20–25	0.0221	Small	Moderate	Reduced
	Area 2	20–25	0.0201	Small	Moderate	Reduced
GA-PID Controller	Area 1	8–12	0.0121	0	High	Very Small
	Area 2	8–12	0.0101	0	High	Very Small

#### IV. CONCLUSION

This study demonstrates that the use of a Genetic Algorithm-based PID controller significantly improves the performance of a two-area load frequency management system as compared to the uncontrolled scenario. The results validate that:

- In both regions, the frequency variations ( $\Delta f$ ) are greatly reduced using the GA-PID controller.
- The transient response is increased with less overrun and faster damping.
- Reducing steady-state error guarantees accurate frequency regulation.
- The significantly shorter settling time indicates that the system recovers from interruptions more quickly.

The Genetic Algorithm for PID parameter tuning ensures optimal controller performance by effectively handling the power system's complex and nonlinear features. More dynamic stability and improved inter-area frequency synchronization are thus provided by the GA-PID controller. In conclusion, the proposed GA-PID approach is a very effective and reliable method for load frequency control in multi-area power systems, making it a strong candidate for modern smart grid applications and complex power system management strategies.

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