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Artificial Intelligence-Based Optimization of PID Controllers for Two-Area AGC Systems Using Particle Swarm Optimization

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ABSTRACT: Automatic Generation Control (AGC) is vital for maintaining constant and reliable power in interconnected systems, and AGC is also responsible for distributing loads between generators optimally as well as maintaining frequency stability, and controlling exchanges over tie lines. This study proposes the use of an AI-based optimisation approach to enhance the performance of AGC in a two-area power system. More specifically, the tuning settings of the Proportional-Integral-Derivative (PID) controller are optimised by employing the AI algorithm called Particle Swarm Optimisation (PSO), which is motivated by the social behaviour of swarms occurring naturally. Two scenarios are evaluated: AGC without PID control in the two areas, and AGC with PSO-optimised PID controllers in both areas. The simulation results obtained from this study demonstrate that the PSO-optimised PID controllers result in a significant reduction in frequency deviations, improve the integral of time-weighted absolute error, and provide better dynamic performance of the system. The study results also identified that AI-based optimisation methods incorporated in AGC design achieve better stability, frequency regulation, and tie-line power control with rapid response, thus preparing an intelligent and resilient operation of the power system.

Key Words: Automatic Generation Control (AGC), PID (Proportional Integral Derivative) controller, PSO (Particle Swarm Optimization).

Contents

1. Introduction

The regulation of frequency and management of tie-line load flow define the main prerequisites for the running of linked power systems [1]. AGC helps facilitate this process. The purpose of the proposed controller is that, if the load demand changes or variables are changed, the error should be brought back to its nominal value in the shortest possible time [2] [3]. This paper describes the AGC of a two-area system used with particle swarm optimization approaches. Conventional controllers and the particle swarm optimization approach are applied in the AGC for the two-area system. The overall error of the system is analysed through MATLAB SIMULINK® version R2023a. The control of frequency and power fluctuations guarantees the provision of an undisturbed power supply to consumers [4], and AGC is capable of managing the tie-line and constant frequency [5]. AGC in a two-area system helps distribute load across generators in both areas by adjusting generators' output to maintain system tie line power flow and frequency [6] [7].

Over the years, AGC's control techniques have been thoroughly investigated. Conventional linear control theory shows less accuracy under particular operating settings because of nonlinear charges and variations in function. In multi-area power systems, the PID controller stands for a very efficient control

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device that may greatly enhance AGC performance [8] [9]. Its simplicity of execution, strength, and efficiency help to explain this. PID controllers' unsuitable parameter settings might cause AGC to operate less than ideally [10]. In the context of AGC systems, PSO is promising for optimal PID controller parameter tuning. By formulating the tuning task as an optimisation problem—typically reducing a function, like the Integral Time Absolute Error (ITAE)—PSO can automatically identify the most effective set of PID gains that deliver superior system performance [11]. This improves the system's capacity to react quickly and reliably to load disturbances and does away with the necessity for manual tuning. The motivation behind this work lies in enhancing the operational efficiency and stability of linked power systems in a time when energy consumption is rising, integration of renewable sources, and increasing system uncertainties. By leveraging the capabilities of AI-based optimization methods like PSO, power utilities can improve AGC performance and move towards more autonomous, intelligent control frameworks.

2. Methodology

2.1. Automatic generation control

Automatic generation control is a process that changes the power output of power generators automatically in order to maintain the balance between power generation and load, and also to ensure a stable system frequency and power interchange [1] [12]. It does this by tracking frequency and tie-line power flow of the system and then sending signals to generators to change their output level [13] [14]. Fluctuations in load and variable resources cause AGC to be employed to keep appropriate frequencies during normal operation and as an initial reaction to system eventualities of an unplanned loss of a transmission line [15] [16]. And also, the frequency response reserves are supplied by AGC devices [17].

AGC is a method of adjusting the power output of multiple generators across several power sources in response to load variations [18]. Frequent changes to the output of generators are required as a power system calls for the load and generators to closely balance bit by bit [19]. Generators are required to have their output altered often in order for a power system to maintain a load and generators' track that is very closely balanced bit by bit. The balance can be seen by checking the system frequency, if the frequency is increasing, it means that there is more power being generated than consumed, this will cause the devices of the system to run at a higher speed while if the frequency of the system is decreasing, it will signify that the system has a demand that is greater than the supply from the generation hence every generators will work at a lower speed.

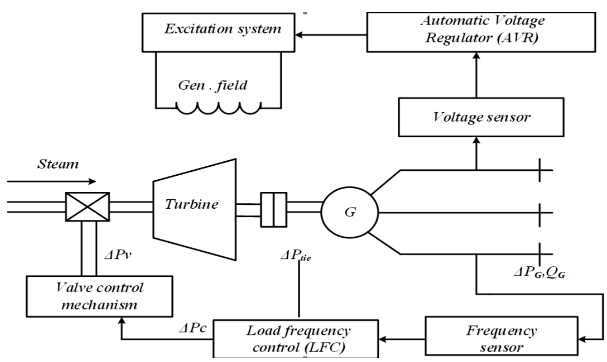

Figure 1: Schematic diagram of ALFC or AGC.

The control signals ΔPc and ΔPtie are modified, merged, and thereby transformed into a power signal that is employed for the regulation of the governor's position. To keep the real power balance, the turbine changes its output power following the governor's position. The automatic control system consists of two main parts: primary and secondary control. The frequency control methods are the generator governor response (which is the primary frequency control method) and load frequency control. LFC restores the frequency to its predefined value and reduces unscheduled tie-line power flows between control areas [20] [21]. The primary controller is definitely not going to use the normal speed as the set point, so there will be an offset. Integrating an integrator can bring the speed or frequency back to the correct level, though. The integral part is concerned with the average error during a given time and thus neutralizes the offset. This scheme is illustrated in Figure 1, where the ALFC or AGC is used to do it manually.

In case the load of the system increases, the turbine speed drops until the governor alters the steam input flow to match the new load. The error signal is reduced as the change in the speed value becomes smaller. The integrator is added to facilitate the frequency or speed return to the nominal value. The integral part will compensate for the deviation by keeping track of the average error over time. Integral action is the ability of a system to bring itself back to its target position, such as the rest action. The generator can restore the frequency to the nominal value automatically when the system demand changes. The function of AGC in an interconnected system is to distribute loads across systems, stations, and generators to achieve maximum efficiency while maintaining a stable frequency and controlling the planned interchanges of tie-line power [22] [23].

ACE is the signal that reflects the combination of the changes in the system frequency and the deviation in the flow of power through the tie-lines from the scheduled ones [24]. The ACE for each area is calculated as the weighted sum of frequency deviation and tie-line power deviation. The primary equation that is used in AGC is the Area ACE equation. It describes the energy flow that is not balanced in a system of interconnected power flows, along with the frequency deviations. [25]. The ACE equation is as follows:

$$ACE = \Delta P_{\text{tie}} + B\Delta f \tag{2.1}$$

Where ACE is the area control error (a measure of the Imbalance in a control area), ΔPtie is the change in tie line power flow from the scheduled value, B is the frequency bias factor (a constant that reflects the responsiveness of the area's generation to frequency changes) and Δf is the change in system frequency from the scheduled frequency (usually 60 Hz or 50 Hz).

2.2. Proportional integral derivative

The Proportional-Integral-Derivative (PID) controller is among the most well-known means of regulating systems in engineering, particularly in the case of electrical power systems. The device is chosen mainly due to its simplicity and reliability [26]. They have a lighter structural design and perform well in various scenarios. The PID control system has three major parameters: proportional (k), integral (i), and derivative (d). The PID controller's algorithm enables it to cater to the specific requirements of the process via the adjustment of the three parameters. The PID controller can be considered inefficient because this approach is non-linear; however, it is still able to control the process in a suitable manner

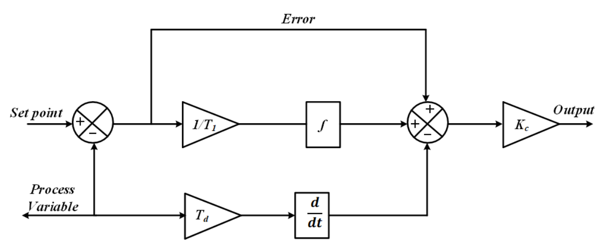

Figure 2: Schematic block diagram of a fundamental PID control system

A PID controller is a device that continuously calculates an error value, which is the difference between the desired set point and the measured variable. Then the controller, which is based upon the proportional, integral, and derivative parts of that error, carries out a correction[28]. Each of these three elements is focused on different aspects of the process of shaping the response of the control. The sum of these three acts makes the PID control law, whose aim is to provide a balanced and responsive control strategy. More precisely, in power systems like AGC (Automatic Generation Control), a PID controller is used to adjust the frequency and tie-line power changes by altering the load of the generators. It is absolutely necessary to tune the PID gains (proportional gain, integral gain, and derivative gain) correctly in order to achieve the best operation [29]. A properly tuned PID controller has the ability to provide an accelerated response, minimal overshoot, and fall time; thus, it becomes a very good device to represent the solution for dynamic systems such as AGC.

Nowadays, tuning PID controllers in practical applications is difficult due to the fact that real-world systems are complicated and nonlinear. However, it is good that intelligent optimization algorithms like PSO are extensively utilized for automatic search of the best PID parameters that fit a system, thus not only stabilizing but also enhancing the performance of the system.

2.3. Artificial Intelligence – Particle Swarm Optimization

Particle Swarm Optimisation is a type of artificial intelligence that is based on nature and is part of the larger field of swarm intelligence [29]. PSO is especially helpful in resolving intricate optimisation issues that are challenging to tackle with conventional analytical or mathematical techniques [30]. It is widely applied in fields such as control systems, power systems, robotics, image processing, and machine learning due to its simplicity, efficiency, and ability to locate nearly ideal answers in a high-dimensional search space [31].

Artificial Intelligence-based algorithm, PSO, was inspired by the group behaviour and movement dynamics of fish, birds, and insects [32]. The PSO performs with diversity and flexibility. Over the last several years, the idea of PSO has been shown to be beneficial when used on several issues, including neural networks and structural optimization. This optimization approach offers simple implementation and delivers quick convergence criteria in comparison to other techniques [33]. For efficiently handling near-global optimization tests, it has become one of the most promising optimization strategies. The communal and cooperative character shown by flying birds determines the mechanism's motivation.

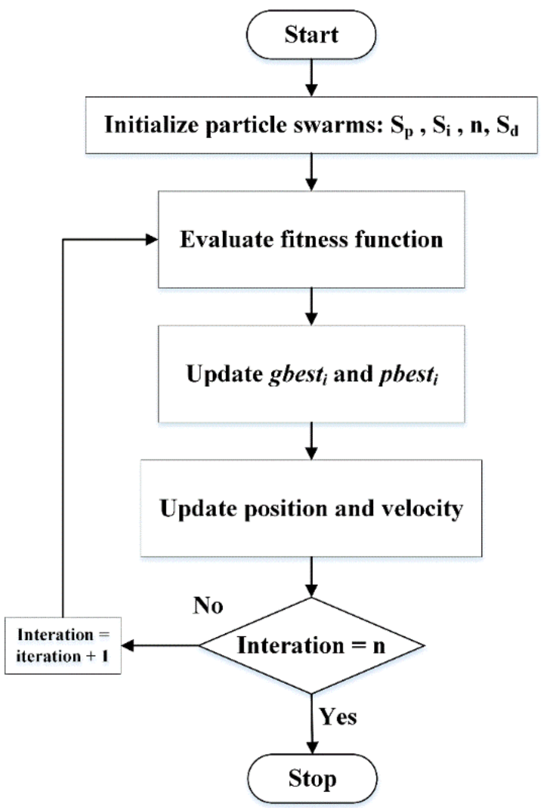

Figure 3: Flowchart of PSO.

Initially, particles that represent solutions to the problem, specifically the Proportional Integral Derivative controller parameters Sp, Si, and Sd, were randomly generated within the designated exploration areas. During every iteration, all the particles will adjust their position and velocity, utilizing their historical best location and the best location within their neighborhood to progress towards a location characterized by a lower fitness value [34] . The fitness value is determined by applying equation (2). The position and speed of each particle in every iteration are determined using

$$S_{id}(t+1) = S_{id}(t) + c_1 r_1 \left(Pbest_{id}(t) - X_{id}(t)\right) + c_2 r_2 \left(Gbest_{id}(t) - X_{id}(t)\right) \tag{2.2}$$

$$X_{id}(t+1) = X_{id}(t) + S_{id}(t+1) \tag{2.3}$$

In this context, c1 and c2 represent the cognitive and social acceleration coefficients, respectively, while r1 and r2 denote two uniform random values generated within a specified interval.

PSO is an extremely effective technique in control system optimization, such as tuning PID controllers in AGC systems. The conventional PID tuning techniques may not yield the minimum system performance if they rely on trial and error or fixed rules that are only suitable for simple and static systems. The PSO is able to perform the automatic search of the optimal set of PID gain parameters by reducing the performance index ITAE, which thus guarantees better transient and steady performance. Because PSO does not require gradient information or any system models, it is also very suitable for nonlinear, time-varying, or multi-objective optimization problems.

PSO's ability to strike a balance between exploitation (improving the best existing solutions) and exploration (exploring new regions of the solution space) is one of its advantages. This, however, means that it still needs appropriate parameter adjustment, just like other metaheuristic algorithms (for example, inertia weight, cognitive and social coefficients), if one wants to prevent the algorithm from premature convergence or getting stuck. On the other hand, due to its simple implementation, low computational needs, and flexibility, it remains a widely used AI instrument for solving optimization problems in various fields.

3. Simulation Results and Discussion

This paper presents a MATLAB/Simulink simulation of the automatic generation control (AGC) of a two-area interconnected power system, constructed on a 1000 MVA base with each area set up for a 50 Hz nominal frequency. A severe fault scenario that involved a sudden 187.5 MW load increase in Area 1 resulted in the system frequency falling to 49.75 Hz, thus indicating a 7.5 MW generation deficit as only 180 MW was supplied. In order to solve this problem, an AI-PSO (Artificial Intelligence-Particle Swarm Optimisation) based PID controller is put into practice with the assumption that it will not only successfully bring back the system frequency to 50 Hz but also be able to meet the power demand and realize the dynamic response and stability improvement of the power system.

Table 1: Parameters for Area 1 and Area 2

Area	1	2
Time Constant of Turbine	$T_{t1} = 0.5\,\text{sec}$	$T_{t2} = 0.6\,\text{sec}$
Time Constant of Governor	$T_{g1} = 0.2\,\text{sec}$	$T_{g2} = 0.3\,\text{sec}$
Speed Regulation	$S_1 = 0.05$	$S_2 = 0.0625$
Base power	1000 MVA	1000 MVA
Frequency sensitive load coefficient	$F_1 = 0.6$	$F_2 = 0.9$
Inertia constant	$I_1 = 5$	$I_2 = 4$

The load in area 1 has been altered to 187.5 MW. The frequency in the system has gone down to 49.75 Hz as a result of the sudden change in the load in area 1. However, it is still less than 50 Hz. Though the change in load was 187.5 MW, only 180 MW of the load was provided by both generators. 7.5 MW is still needed. Both generators will be able to provide the whole 187.5 MW when the frequency reaches 50 Hz again. Hence, we are going to apply AI-PSO based on PID controllers to bring the frequency back to the nominal value.

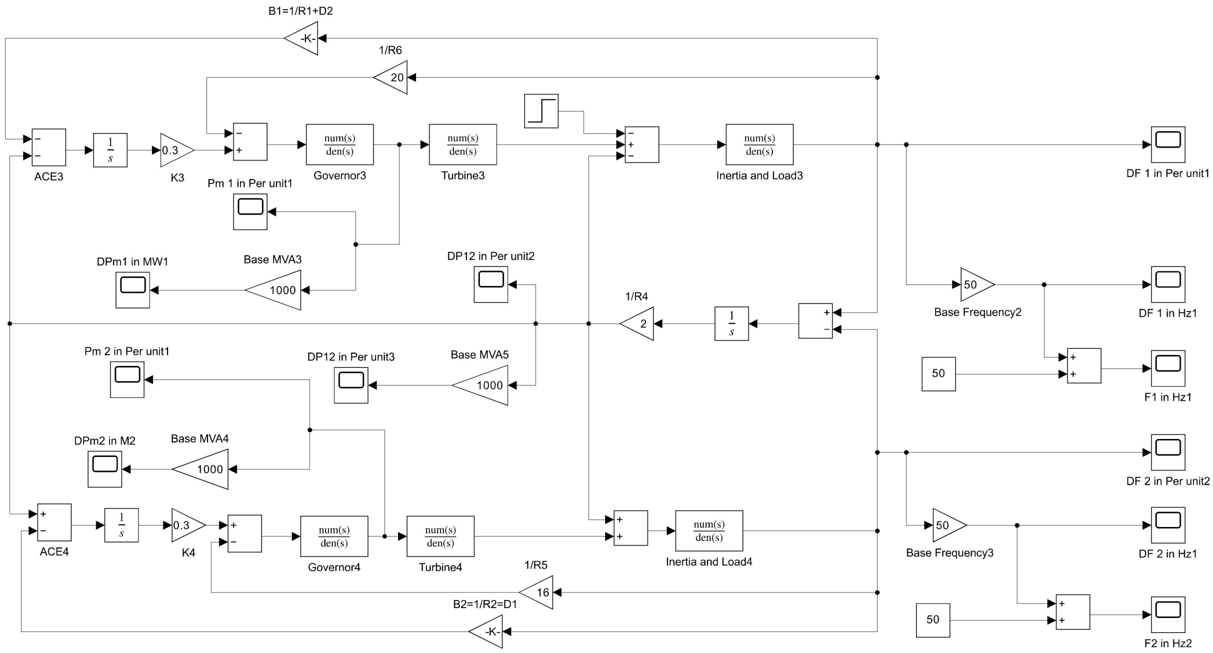

Figure 4: Two area power system with only Automatic generation control.

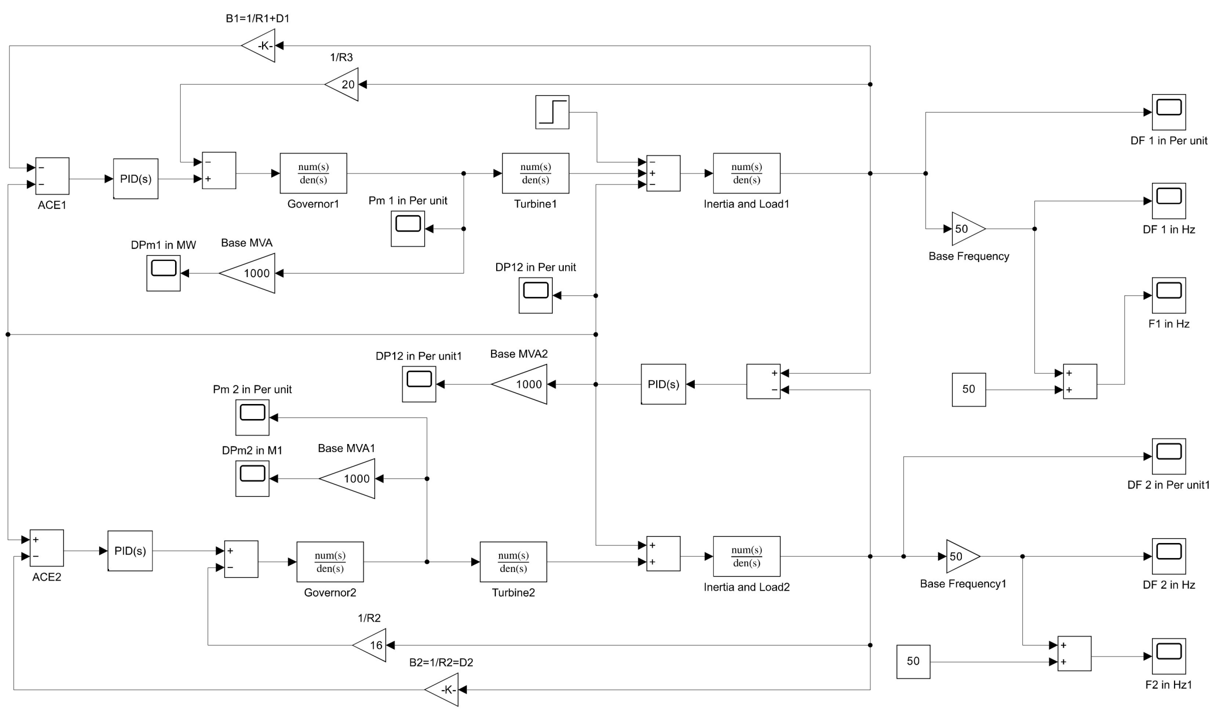

Figure 5: Two-area system with Automatic generation control using a PID controller based on PSO.

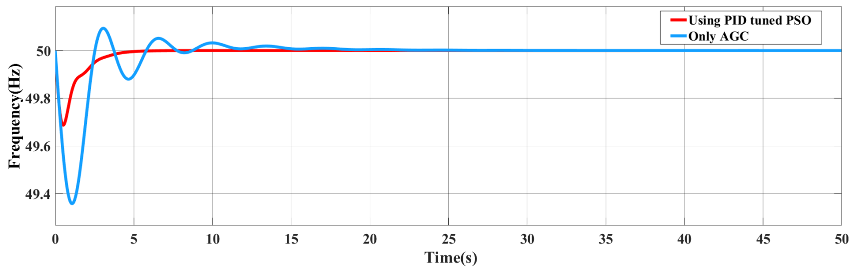

Figure 6: Combine response of frequency variation for Area 1.

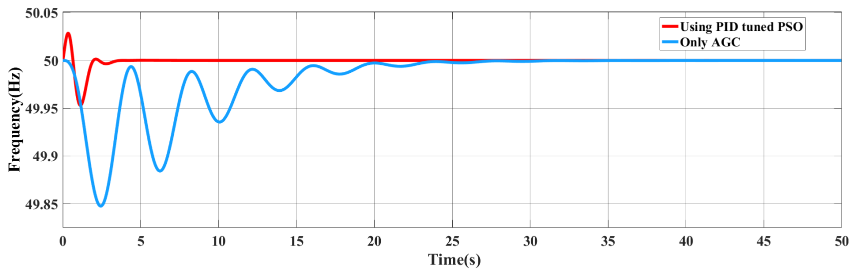

Figure 7: Combine response of frequency variation for Area 2.

Figures 6 and 7 show for the AGC system, the frequency variation impulse response for Area 1 and Area 2, designated as area 1 frequency and area 2 frequency by a PID controller implemented in Area 1 and Area 2 as obtained by PSO, the feedback is provided for scenarios without a PSO tuned PID controller and with a PSO tuned PID in both areas. After a few seconds, the case studies and analysis of the Figures. 4 and 5 show the variation of frequency for area 1 and area 2 as they approach a steady-state value. Their response properties—more especially, those related to fall time, rising time, settling time, undershoot, and overshoot—define their differences. Based on the results obtained, the PSO-tuned PID controller is more stable and robust because it prevents overshooting.

Table 2: Frequency variation impulse response of Automatic Generation Control for each area

Area	**Parameter**	**Without a PSO-tuned PID Controller**	**With PSO-tuned PID Controller**
1	Sp_1	-	1
	Si_1	-	1
	Sd_1	-	1
	Rise time (s)	0.957886	2.684
	Fall time (s)	0.683208	0.285385
	Overshoot	14.368%	0.505%
	Undershoot	18.868%	1.888%
	Settling time (s)	12.403	3.160
2	Sp_2	-	0.8893
	Si_2	-	0.6432
	Sd_2	-	1
	Rise time (s)	1.236	0.476187
	Fall time (s)	1.266	0.228271
	Overshoot	1.586%	2.198%
	Undershoot	4.134%	12.521%
	Settling time (s)	19.481	1.876
	ITAE	-	0.02234

Table 2 presents the response Characteristics related to the variation of frequency for Area 1 and Area 2. Using a PSO-tuned Proportional Integral Derivation controller shows better performance in the variation of frequency impulse response of Area 1 frequency and Area 2 frequency in contrast to the situations without its use. Using a PID controller with PSO in both areas produces an Integral Time Absolute Error value. It shows that AGC with a PSO-tuned PID controller is more stable and robust and has lower frequency deviation compared to using only AGC.

4. Conclusion

The work demonstrated the effectiveness of using Particle Swarm Optimization to enhance Automatic Generation Control performance inside area 1 and area 2 power systems. The result shows that the stabilization of frequency using PID and PSO together is faster than using AGC only in both areas. And also it shows that by lowering frequency deviations, shortening fall time, settling time, and so lowering the Integral of Time-weighted (ITAE), the application of a PID controller in both domains, optimized through PSO, resulted in a notable increase in system stability. When compared to circumstances without a PID controller, the optimal dual-PID solution proved better in load frequency management and tie-line power regulation. This approach highlights how well PSO-based optimization strategies preserve dependable and stable operation of power systems.

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