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Optimal tuning of tilted integral derivative (TID) controller parameters for multi-area power system and frequency regulation using pelican optimization algorithm (POA)

Abstract: - Power generation plays a vital role in any electrical system, and load frequency control maintains its stability. Modern systems use effective load frequency controllers that maintain the frequency of the system. In this work, a fractional order tilted integral derivative (TID) controller is optimized by using the Pelican optimization algorithm for load frequency control in modern integrated power systems. The performance of the controller based on the pelican optimization algorithm is computed with the help of a multi-area interconnected system containing a hydro plant, a gas plant, and a thermal power plant. In this work, ITAE (integral time absolute error) and ISE (integral square error) are considered objective functions. With the tuning of the TID controller by the Pelican optimization algorithm, the results were tested by the already proposed methods as the Particle swarm optimization technique and Archimedes optimization algorithm (AOA). In this work, a step disturbance was given to area 1, and the response of the controller was observed. While evaluating the controller parameters, the system nonlinearity is also taken into consideration, such as generation rate constant (GRC), communication delays, etc. It was seen from the results that the enhanced performance of the system was obtained, which improves the power system stability and management for interconnected systems.

Keywords: TID (tilted integral derivative), ITAE (Integral Time Absolute error); ISE (Integral Square Error); PID (Proportional Integral Derivative), LFC (Load Frequency Control), POA (Pelican optimization algorithm); AOA (Archimedes optimization algorithm).

I. Introduction

Modern power system is the integration of various generating units, which can be renewable energy resources as well as some other generating units. Due to the integration of various units in the power system, the difficulty of the system increases, therefore, the control unit also needs to update according to the system [1]. To overcome these problems, various control strategies based on conventional controllers as well as some modern control strategies based on optimization techniques have been implemented in various research studies that have been published. The issue of mismatching arises in the integration of various renewable energy sources [2]. Due to these challenges, the grid problem can occur quite frequently, due to which grid failure can occur. Thus, load frequency control (LFC) is one of the most important aspects that is considered in a contemporary electrical grid [3]. The main purpose of load frequency control is to maintain the frequency of a system during normal as well as abnormal conditions in a system. LFC is the main solution to sustain the grid frequency and the power (tie line) between different areas [4]. The frequency deviation issue has been addressed by various researchers for different power systems with the help of various control techniques such as direct synthesis method, Fuzzy logic, model predictive control, and various artificial intelligence control techniques, and many more. Also, another control technique is the PID controller, which is the easiest and cheapest form of control that can be provided to the system. Based on the system, various control techniques with modifications in the PID controller to get the optimum performance of the system are being implemented in the system. Nowadays, various fractional order controllers are also being used to control the frequency deviation, which provides better control and optimum control over the conventional PID controller. Some of the fractional order controllers are as- FOPID, TID, etc. These controllers have gained immense attention due to their advantages over conventional controllers, as they are flexible according to the design specifications, and they can control a wide dynamic range. Also, the degree of freedom is two or more, therefore, it is less sensitive to the disturbance in the system, and therefore, better robustness can be provided with the help of fractional order controllers. In the modern structure, power system stability has been the major issue due to the interconnection of various system structures, which include single area power system as well as multi area power system. With the stability issues, various control strategies and controllers are based on load frequency control. One of a power network operator's top priorities is to guarantee frequency stability in a power system. AGC is used to maintain a balance between power generation and load demand by controlling the generator's output power and

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bringing the system back to its steady state. This aids in tie-line power and frequency stabilization. LFC is the process of responding to variations in load demand by keeping the frequency within predetermined bounds. The LFC is essential to preserving the stability of the power grid. Through the use of external controllers, frequency underestimates, overestimates, and settling time can be reduced, improving power system reliability. If the power generation is greater than the power demand, the frequency rises above its designated value; if the demand power is greater than the generated power, the frequency falls. To effectively stabilize multi-area power systems, researchers have invested a great deal of time and effort into enhancing the controller architecture and applying contemporary optimization techniques. There are numerous methods for controlling LFC in integrated power networks. Various authors have proposed a variety of PID controllers designed, Fractional order and fuzzy logic

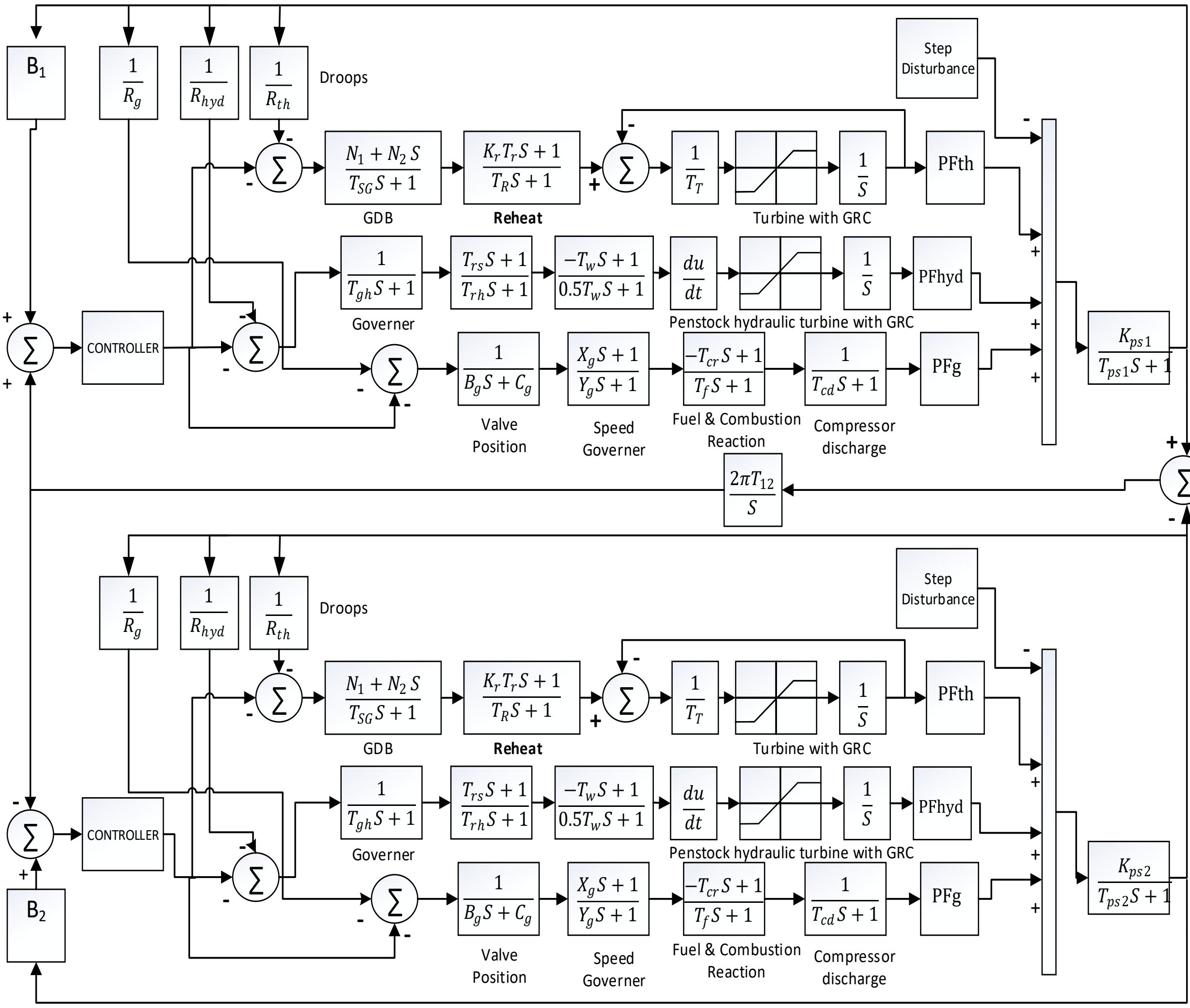

Figure 1: Dynamic representation of a multi-area power network [2]

controllers are using different control techniques. In 2015 a new type of PID controller was designed based on the DS (Direct Synthesis) approach. Various optimization techniques were also used in the designing and tuning of various load frequency controllers. In 2018 a load frequency controller using the PSO-DV algorithm as a model approximation method for a hydropower dynamic system was developed [6]. In this document, by putting out an ideal model approximation technique, this work simplifies the design of frequency control for the load for a hydropower system model. By reducing the Integral Square Error, the model approximation is carried out. For load frequency control, a two-staged (PDF+1PI) controller [7] design was completed in 2020. This method involves calibrating the derivative filter's derivative gains and proportional with a derivative controller using the moth flame optimization (MFO) algorithm, cascade with the 1-Proportional Integral (PDF+1PI). In uses an altered version of the Jaya optimization technique to do online area controller tuning. The goal of the Balloon Effect (BE) adjustment is to make the Jaya algorithm more sensitive to changes in parameters as well as disturbances in system load. In 2020, an altered TID controller was proposed in 2022 to regulate the load frequency of a diverse-unit power system that was interconnected and comprised of two areas. To address the load frequency management problem in a multi-area interconnected multisource power system, a modified tilted integral derivative (TID) controller is designed in this study [7]. The suggested ID-T controller parameters are adjusted via the application of a novel optimization technique called the Archimedes optimization algorithm (AOA). Some of the proposed work is only compared with the classical PID methods, further, they can be checked and compared with some recent literature. In this research, a TID controller which is from a Fractional order controller family is used to solve load frequency control problems because it has superior disturbance rejection properties, it can change the values of a closed loop system, and also better optimization techniques. In the paper, a fractional order TID controller is used in a multi-area system, which consists of a thermal generation unit, a hydro generation unit, and a gas generation algorithm. The controller parameters are investigated in terms of ISE, ITAE, and IAE [10]. The studied model is a multi-area system, a hybrid interconnected power system that has a thermal unit. The TID controller is being used whose parameters are tuned based on different optimization power plant, a hydropower plant, and a gas unit in each area as shown in Figure 1. Each region has a 2000 MW rated power.

II. TID (TILTED INTEGRAL DERIVATIVE) CONTROLLER

Using various optimization techniques, the TID controller, a form of improved PID controller, is utilized in this research to examine a two-area interconnected power system and the system's transient and steady-state responses to a unit step disturbance in area 1. In the disturbance unit, the step signal is considered by using the unit step signal; both transient and steady state responses can be studied, whereas if we use a ramp or any other signal as a disturbance, then only transient state study can be obtained. Similar to a PID controller, a tilting component is used in place of the proportional component in a TID controller, as seen in Figure 2. Both areas have TID controllers installed. TID supervision provides more robustness than a PID controller, easier tuning, and a good disturbance rejection ratio. This is a real number n that is not zero. For the sake of this study, n is assumed to be 3. The control structure of the TID controller is shown in Figure 2, which shows the difference between the proportional and tilted schemes that are used in the PID and TID controllers, respectively.

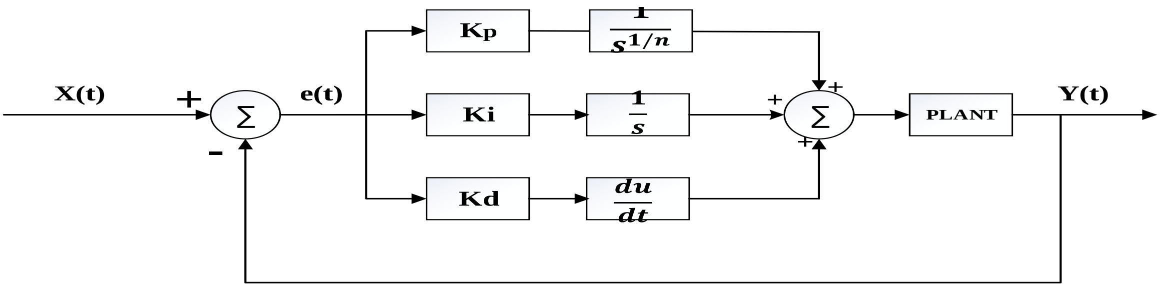

Figure 2: TID (Tilted Integral Derivative) control scheme

The transfer function of GDB obtained from the Fourier series is given by

$$\text{GDB}=\frac{N_1+N_2\,S}{T_{SG}S+1}\text{..................} \quad (1)$$

The transfer functions of PID and TID controllers are as [1]:

$$PID = K_P + \frac{K_I}{S} + K_d S \text{ ... ... } (2)$$

$$TID = \frac{K_t}{S^{1/n}} + \frac{K_I}{S} + K_d \quad \text{... ... . } (3)$$

III. FORMATION OF OBJECTIVE FUNCTION

The pelican optimization technique is used in this paper to optimize the TID controller. The tuning of the parameters of the TID controller can be done on various parameters of the system parameters such as ISE, ITAE, IAE, ITSE, etc. [15]. In this paper, the objective function is considered as ITAE and ISE. These performance indices should be considered according to the problem type [10]. Applications that call for quick response times and settling times can use this criterion. The squaring of error numbers causes the Integral Square Error (ISE) to favour minimizing large errors over minor errors. The system may have to work harder to maintain control and respond more quickly if this requirement is met. Higher errors during the very first transient reaction are penalized by ITSE, which integrates elements of both ISE and ITAE [6].

Although more oscillatory behaviour may arise from this criterion, it balances response speed and control effort. All errors, regardless of size, are given equal weight by the Integral Absolute Error (IAE) system. When compared to other criteria, this one produces a faster response and requires less control effort, but it may also cause a slower reaction. Comparing the ITSE to an integral of squared error (ISE) index, which has a time factor of t, penalizes the potential of oscillation in later phases of the time domain dynamic responses. Thus, settling time can be effectively decreased by employing the ITSE index. Comparable to an integral of time multiplied by absolute error (ITAE) index, the ITES index's larger power of the error term generates a heavier penalty for higher error values to lessen the likelihood of a massive peak error [10].

$$ITAE = \int_0^\infty t|e^2(t)|dt \dots\dots\dots\dots\dots \quad (4)$$

$$ISE = \int_0^\infty e^2(t)dt \dots\dots\dots\dots\dots\dots \quad (5)$$

$$IAE = \int_0^\infty |e(t)|dt \dots\dots\dots\dots\dots\dots \quad (6)$$

$$ITSE = \int_0^\infty te^2(t)dt \dots\dots\dots\dots\dots\dots \quad (7)$$

IV. PELICAN OPTIMIZATION TECHNIQUE (POA)

This technique was proposed by Dervis Karaboga in the year 2020 [14]. Pelican optimization is a newer metaheuristic optimization algorithm. It is based on the natural behaviour of pelicans in the wild. Pelicans are well known for cooperative hunting and efficient foraging strategies. Due to these properties, it serves as inspiration for the optimization algorithm. The flowchart of the POA algorithm is shown in Figure 3.

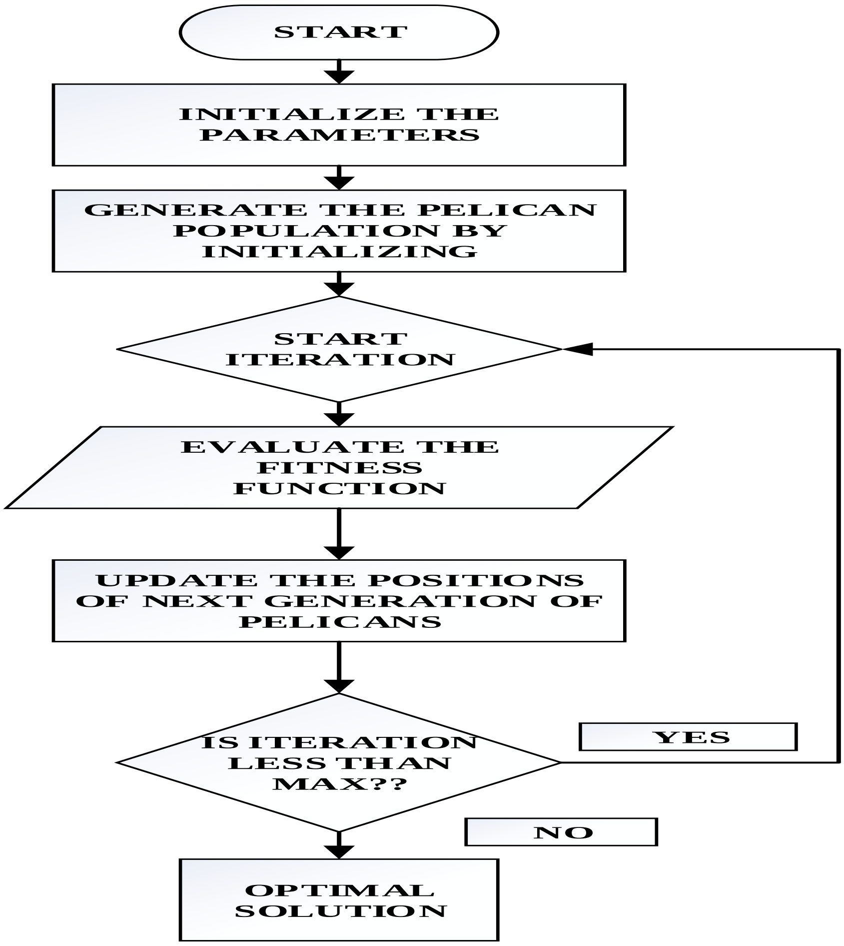

Figure 3: Pelican Optimization Algorithm (POA)

Pelican optimization is being applied to various engineering problems, in design and scheduling, etc., due to its ability to handle both discrete optimization techniques and continuous optimization problems. Once their prey is located, pelicans dive from 10 to 0 meters to capture it. At lower altitudes, certain creatures hunt. They subsequently extended their reach on the water to trick fish into shallower depths, making it easier for them to be caught and eaten. Pelicans have to tip their heads forward before eating because water gets into their beaks as they catch fish. Their shrewd hunting strategies and behaviours have allowed pelicans to develop into expert hunters. The planned POA's design was mostly inspired by the modelling of the previously discussed strategy. By achieving a proportionate balance between exploration and exploitation, POA outperforms other competing algorithms in offering optimal solutions for optimisation issues, according to the simulation results and their analysis. [14]

V. PERFORMANCE ANALYSIS OF POA

Utilizing the MATLAB software, the simulation results of the system under consideration are produced. Where the optimization process is carried out by integrating the POA's code, which is implemented in an M file, with the Simulink model of the power system under study. The simulation results are run on a laptop computer running a 64-bit Intel Core i5 CPU at 3.2 GHz. Additionally, the TID controller based on the POA performs better than the PSO and AOA-based controllers in the analysed two-area interconnected multi-source power system under various operating situations. Due to limitations in thermal and mechanical processes, large thermal power plants are unable to quickly modify their power output. Several restrictions, including boiler dynamics, the GRC, GDB, and Communication Time Delay (CTD), are frequently disregarded or studied separately. These factors must be taken into consideration while analysing the system. In this instance, the GRC and GDB nonlinearity effects are taken into consideration when the time domain simulations are carried out for a 0.01 P.U. step load perturbation (SLP) in area 1. To solve the optimization problem, the POA algorithm is repeatedly used. Several iterations resulted in several nearly ideal solutions for the nominal system parameters. As the controller's final optimized settings, the solution with the lowest value of the ISE and ITAE index is selected. Taking into account an appropriate objective function is crucial when determining the controller parameters to dampen the oscillations effectively. Integral time absolute error (ITAE) and integral square error (ISE) are chosen for this paper. Though other objective functions can also be considered. In the initial transient reaction, Integral Time Absolute Error (ITAE) emphasizes reducing error and penalizes larger errors for longer periods. Use of this criterion is possible for applications that require fast response and settling times. Because error values are squared, the Integral Square Error (ISE) gives preference to reducing large errors over tiny ones. Meeting this need could force the system to use greater effort to keep control and react faster. By combining aspects of both ISE and ITAE, Integral Time Square Error (ITSE) penalizes higher errors during the initial transient reaction. This criterion balances control effort with response speed, however, it may result in greater oscillatory behavior. In addition, the simulation is set up like this:

A. Evaluation of system parameters

In this, different load patterns are applied to the studied multi-area model shown in Figure 1. Consider the different optimization techniques when a step load disturbance is provided to the system area 1 only. With this, the effectiveness of the POA is verified through a comparison with the PSO and AOA methods. This study is further classified into two parts, in which the two different optimization function parameters are considered and the system is studied differently. Table 1 shows the parameters of the controller that are studies when the objective function is considered as ISE. Furthermore, Table 2 shows the studied parameters of the controllers when the objective function is considered as ITAE. From Figures 4-6 considering the objective function as ISE the convergence characteristics of TID with the POA algorithm are better than the other characteristics. Similarly, from Figures 7-9 considering the objective function as ISE the convergence characteristics of TID with the POA algorithm are better. Based on the convergence characteristics the various system parameters are obtained that are shown in Table 3 and 4 with the objective function as ISE and ITAE respectively. Also, it can be concluded that depending upon the required parameters, the optimal control scheme can be obtained whose optimal parameters can be obtained by optimization techniques.

While considering the ITAE as the objective function, the POA algorithm provides the optimal values concerning area 1. It provides less overshoot than PSO in area 1, whereas in area 2, it provides a significantly less overshoot as compared with the PSO, and similarly, for the tie line power, POA is found to be better. In case of undershoot, the POA shows slightly similar values as obtained from the PSO. The settling time obtained in POA is found to be less as compared with PSO algorithm. Similar results are obtained when the objective function is considered as ISE. From the conclusion it can be seen that the proposed work shows the improvement in the system parameters of the multi-area interconnected power system when a disturbance occurs in the system. To compare the statistical performance of the three algorithms (PSO, AOA, and POA), the average control performance values, the average computational time attained by 30 separate runs, and the values of maximum ITAE and ISE are computed. The suggested approach outperforms the others, as demonstrated by statistical results.

Table 1
Summary of data obtained from the three optimization algorithms when the objective function is ISE.

Algorithm	Area 1	Area 2	*ISE*
PSO	K_t=1	K_t=3.97	
	K_i=2.38	K_i=1.87	0.0051
	K_d=2.10	K_d=2.50	
AOA	K_t=1.02	K_t=1.44	
	K_i=1.68	K_i=1.73	0.0066
	K_d=1.34	K_d=1.98	
POA	K_t=1.68	K_t=2.68	
	K_i=1.30	K_i=1.18	0.0030
	K_d=2.20	K_d=2.01	

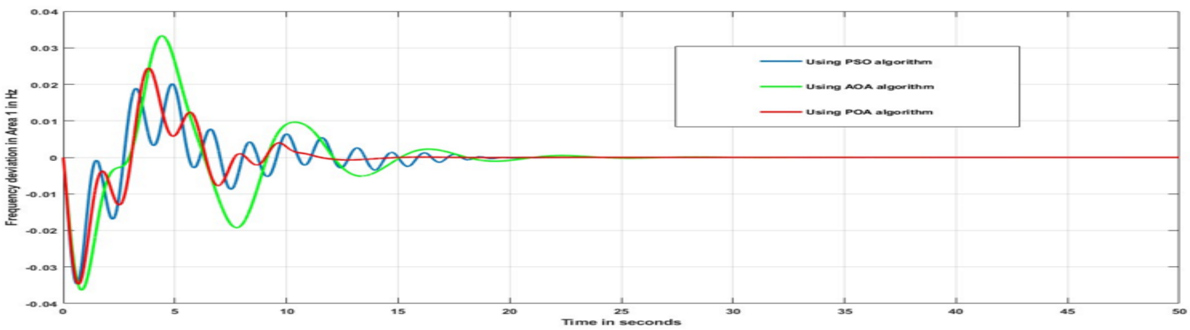

Figure 4: Variation in Area’s 1 frequency expressed in Hz (ISE)

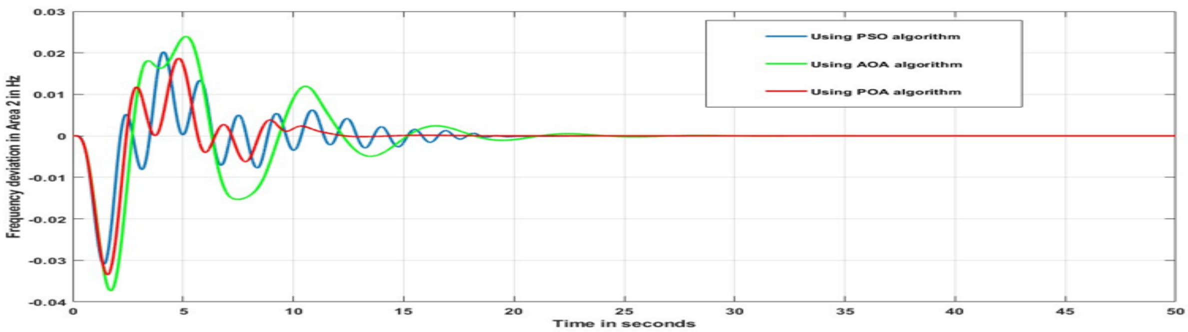

Figure 5: Variation in Area’s 2 frequency expressed in Hz (ISE)

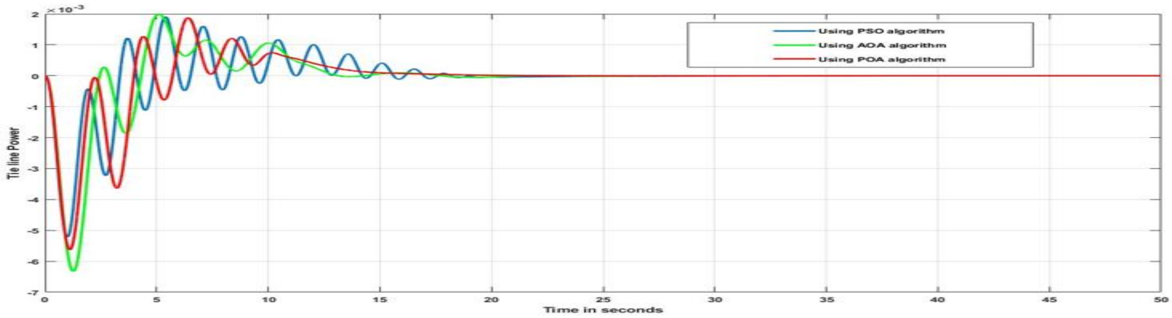

Figure 6: Variation in Tie line power per unit (ISE)

Table 2
Summary of data obtained from the three optimization algorithms when the objective function is ITAE.

Algorithm	Area 1	Area 2	*ITAE*
PSO	K_t=1.81	K_t=1.86	
	K_i=3.35	K_i=1.02	0.8863
	K_d=2.31	K_d=3.33	
AOA	K_t=1.47	K_t=1.35	
	K_i=1.09	K_i=1.40	1.117
	K_d=1.40	K_d=2	
POA	K_t=2.01	K_t=3.44	
	K_i=2.09	K_i=1.58	0.7534
	K_d=3.28	K_d=1.42	

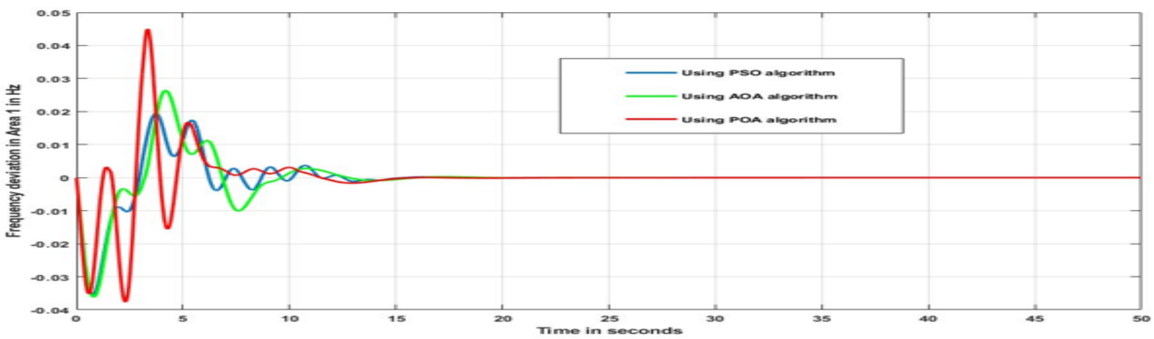

Figure 7: Variation in Area's 1 frequency expressed in Hz (ITAE)

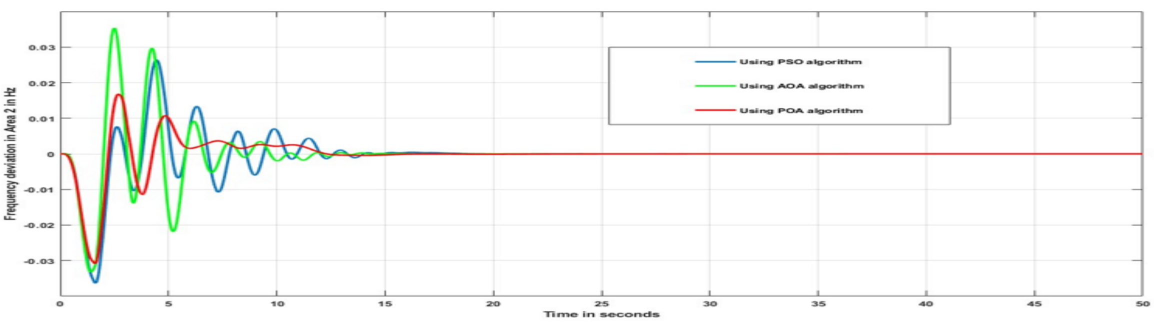

Figure 8: Variation in Area's 2 frequency expressed in Hz (ITAE)

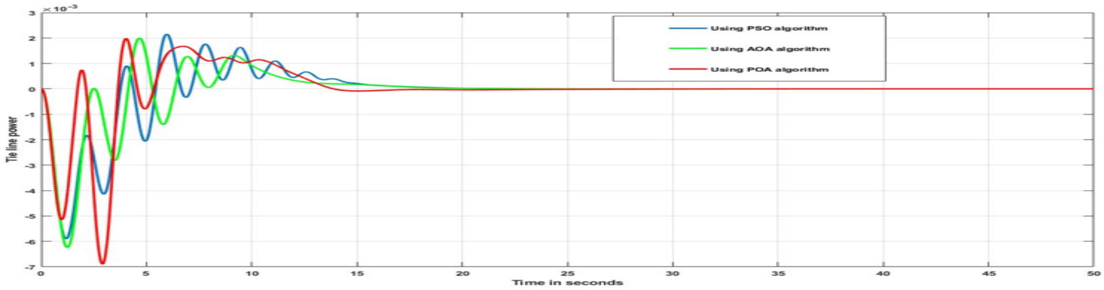

Figure 9: Variation in Tie line power per unit (ITAE)

Table 3

Summary of the dynamic performance through the application of various optimizations when the objective function is ISE.

Algorithm	Parameters	Overshoot (Hz)	Undershoot (Hz)	Settling time (seconds)
PSO	$\Delta \mathbf{f_1}$	0.020	0.032	20
	$\Delta \mathbf{f_2}$	0.020	0.031	20
	$\Delta \mathbf{P_{tie}}$	0.0019	0.0052	24
AOA	$\Delta \mathbf{f_1}$	0.034	0.036	25
	$\Delta \mathbf{f_2}$	0.024	0.038	27
	$\Delta \mathbf{P_{tie}}$	0.002	0.0065	24
POA	$\Delta \mathbf{f_1}$	0.024	0.031	14
	$\Delta \mathbf{f_2}$	0.018	0.032	13
	$\Delta \mathbf{P_{tie}}$	0.0018	0.0055	18

Table 3

Summary of the dynamic performance through the application of various optimizations when the objective function is ITAE.

Algorithm	Parameters	Overshoot (Hz)	Undershoot (Hz)	Settling time (seconds)
PSO	$\Delta \mathbf{f_1}$	0.019	0.035	18
	$\Delta \mathbf{f_2}$	0.026	0.036	19
	$\Delta \mathbf{P_{tie}}$	0.0021	0.0058	21
AOA	$\Delta \mathbf{f_1}$	0.025	0.036	17
	$\Delta \mathbf{f_2}$	0.035	0.033	16
	$\Delta \mathbf{P_{tie}}$	0.002	0.0063	23
POA	$\Delta \mathbf{f_1}$	0.045	0.039	16
	$\Delta \mathbf{f_2}$	0.015	0.031	15
	$\Delta \mathbf{P_{tie}}$	0.002	0.0068	16

VI. CONCLUSIONS

In this research, tuning of a TID controller is done with the POA, and the parameters of the controller are obtained, on which a comparative analysis is done concerning the overshoot, undershoot, and the settling time. The controller in question has been validated on a two-area diverse-unit power system to produce useful results, taking into account the physical constraints of both the GRC and GDB. POA algorithm has been utilized to minimise the ITAE and ISE performance index to achieve the most optimal set of configurable parameters and to utilise the controller's full capacity. By contrasting its performance with that of a few other algorithms from the literature, the AOA algorithm's efficacy has been confirmed.

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