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Optimal turning of a 2-DOF proportional-integral-derivative controller based on a chess algorithm for load frequency control

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ABSTRACT

Load frequency control is necessary for power system management. The power system must maintain a frequency range to ensure power supply stability. System faults and demand fluctuations may cause frequencies to change quickly. System stability and integrity suffer. We are optimizing the two-degree-of-freedom (2-DOF) proportional-integral-derivative (PID) controllers chess algorithm. This article addresses electrical load frequency regulation. We employ classical control theory and current adjustment. It aims for electrical system efficiency and dependability. It checks for errors using integral absolute error (IAE), integral squared error (ISE), integral of time multiply absolute error (ITAE), and integral time squared error (ITSE). Particle swarm algorithm (PSO) compares performance. The IAE of 0.03364, nearly identical to it, shows that chess trumps other algorithms in many scenarios. The chess algorithm's ISE was 0.00035, like PSO's 0.03363. The ISE was 0.00036, indicating PSO's error-reduction capabilities. For the chess algorithm, PSO is 0.07929, and ITAE is 0.07647. This indicates the PSO responds faster to system breakdowns and load changes. Finally, the chess algorithm's ITSE is 0.00072, below the PSO 0.00076. The chess algorithm is better at managing long-term load frequency.

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1. INTRODUCTION

The main objective of load frequency control (LFC) [1] in a power system is to maintain the system frequency within predefined limits by adjusting the power output of generators in response to changes in demand. [2] Governors on generators manage primary control [2]. Fluctuations in demand, such as a surge in power use, may lead to a decrease in the system frequency [3]. In order to restore the frequency to its intended level, the governors make prompt adjustments to either the fuel input or the power output of the generators. This reaction is swift and automated, offering an initial adjustment to the frequency variation, but it lacks the adequacy for long-term stability [4]. Secondary control, also known LFC [5], has a crucial function in accurately managing the frequency of the power system after the main control has taken action. It entails making precise changes to generators' power output in response to data received from the central control system. LFC consistently monitors the system's [6] frequency and power flow. The LFC system regulates the power output of generators to maintain the appropriate frequency range in the event of a frequency deviation or power flow imbalance between various locations. The significance of LFC: i) system stability [7]: maintaining a consistent frequency [8] is critical for ensuring the power system's overall stability. Significant frequency fluctuations may have a detrimental impact on electrical equipment and the quality of electricity; ii) energy balance [9]: LFC helps the system maintain an equilibrium between power production and consumption; and iii) emergency prevention: maintaining the frequency within prescribed limits mitigates the likelihood of catastrophic events [10], such as widespread power outages. LFC is a vital and intricate procedure that ensures the stability and dependability of a power system. It operates in tandem with the main control to efficiently adapt to fluctuations in power requirements, guaranteeing that the system frequency stays within acceptable parameters.

Industrial control systems use a proportional-integral-derivative (PID) [11] controller as a feedback mechanism. The combination of its simplicity and efficacy makes it a widely favored option for overseeing diverse operations [12]. The PID controller computes the error value by subtracting the intended setpoint from the observed process variable [13] and then adjusting it using proportional, integral, and derivative terms. A two-degree-of-freedom (2-DOF) PID controller enhances the capabilities of the conventional PID controller. The system has two distinct sets of PID parameters [14]: one specifically designed for accurate monitoring of the desired setpoint, and another aimed at effectively rejecting disturbances. This innovative setup enables enhanced precision and efficiency in control. When things get complicated in the workplace, a 2-DOF PID controllers can make the whole system work much better by finding the best way to respond to changes in the setpoint and disturbances. This results in improved stability and responsiveness.

The chess algorithm [15] is a bio-inspired optimization technique that utilizes the strategic maneuvers and positional play seen in chess. This algorithm aims to determine the most advantageous solutions by methodically investigating and capitalizing on the search space, using techniques similar to those used in chess. The chess algorithm mimics the cognitive process that chess players employ to make decisions. During a game of chess, players continually evaluate their circumstances and make calculated decisions to outsmart their adversaries. This encompasses both the act of examining new possible possibilities (exploratory actions) [16] and using existing advantages (exploitative maneuvers). using these concepts, the chess algorithm efficiently examines optimal solutions. The algorithm may investigate different areas of the search space by performing exploratory movements, potentially uncovering novel and feasible solutions. Conversely, exploitative strategies allow the algorithm to concentrate on enhancing and fine-tuning these solutions after their discovery. the chess algorithm effectively leverages the dual nature of chess strategy, which entails balancing exploration and exploitation, to navigate complex optimization issues and discover high-quality solutions.

Using the chess algorithm to improve 2-DOF PID controllers in LFC systems leads to a big boost in control performance. A chess algorithm's ability to effectively optimize complicated control systems is due to its capacity to balance exploration and exploitation. Subsequent studies may expand upon this method to include power systems spanning many regions and explore the difficulties associated with implementing it in real-time. The suggested approach combines sophisticated control methods with bio-inspired optimization techniques to improve the resilience and effectiveness of frequency regulation in the power system. This has the potential to enhance the stability and dependability of current power grids.

2. THE MODEL OF THE STUDIED POWER SYSTEM AND CONTROLLER STRUCTURE

2.1. Two-area interconnected thermal power systems

This study focuses on a power system consisting of two linked areas [17], each of which includes a thermal unit with a non-reheat turbine. An abrupt fluctuation in the load in any interconnected part of this system results in a frequency deviation across all regions and a fluctuation in the power transmitted over the tie-lines. Compared to the load frequency control system, the excitation control system has a shorter time constant [18]. This means that the transients in the excitation voltage control fade away more quickly, but they do not change how the load frequency control works [19]. The lack of interaction between excitation control and load frequency control is due to their inability to respond to minor load fluctuations. Thus, we may construct a representation and assess it separately. This vital information simplifies the process of building the model for load frequency control in a two-area power system [20]. The transfer function model for a non-reheat thermal power system consists of two regions, as seen in Figure 1.

Two separate control actions implement load frequency management in two-area power systems. The primary controller is responsible for the first rudimentary frequency modifications. It guarantees that the generators within the control area adjust to changes in load and distribute the load in line with their capacity ratings. Once the primary control takes effect, we initiate a precise control method known as supplementary or secondary control. The goal is to precisely adjust the frequency and restore it to its intended value, or as close as possible. After a load disruption, the main goal of supplementary control is to restore balance between load and generation in each control region. This guarantee ensures the system's frequency and power flows on the tie line remain at their design. As shown in the following equation, the additional controller for the i^{th} area specifically responds to the area control error (ACE_i), which acts as an input to the controller:

$$ACE_i = \sum_J \Delta P_{tie,ij} + B_i \Delta f_i \quad (1)$$

where, ACE_i is area control error of the ith area, $\Delta P_{tie,ij}$ is tit-line power flow error between ith and jth areas, B_i is frequency bias coefficient of ith area, Δf_i is frequency error of ith area.

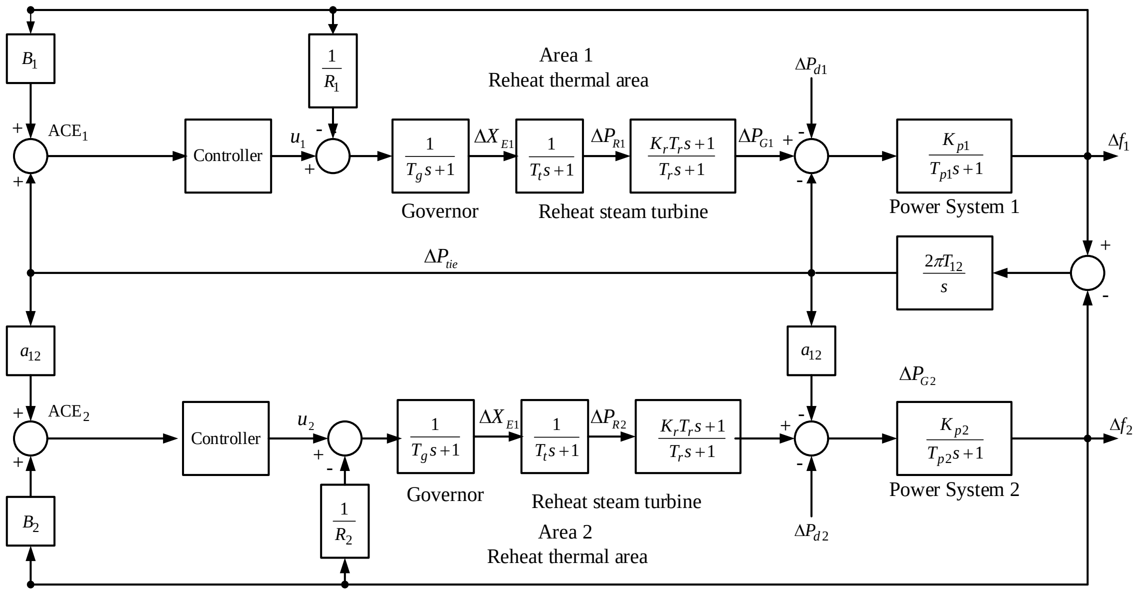


Figure 1. A thermal power system with two linked sections diagram

It is presumable that the load in control areas 1 and 2 will abruptly alter during the simulation process. Based on the data presented in Figure 1, it is clear that T_{f1} and T_{p2} represent power system time constants, K_{p1} and K_{P2} represent power system gains, T_{gl} and T_{g2} represent speed governor time constants, T_{tl} and T_{t2} represent turbine time constants, R_l and R_2 represent regulatory constants, and Δf_1 and Δf_2 represent frequency variations of each control region are being discussed. ΔP_{D1} and ΔP_{D2} are the load demand change in the control areas. The system parameters are displayed in Table 1.

Table 1. Parameters of system

Parameter	Explication	Value
f (Hz)	Nominal frequency of the system	50
K_{pi} (pu/s)	Machine inertia	120
T_{pi} (pu/s)	Load damping factor	20
T_{gi} (s)	Speed governor time constants	0.08
T_{tt} (s)	Turbine time constants	0.3
B_i	Frequency bias parameters	0.425
T_{12} (pu)	Synchronizing coefficient	0.172

2.2. Controller structure

The 2-DOF PID controller [21] enhances the conventional PID control technique by including distinct functionalities for setpoint tracking and noise rejection. This enables enhanced customization, hence enabling the 2-DOF PID controller to more effectively regulate intricate and dynamic systems. As a result, it is considered a very important tool in contemporary control engineering applications. Figure 2 depicts the configuration of this controller [22].

A two-degree-of-freedom (2-DOF) PID controllers [23]. The system has three control loops since it has three degrees of freedom. The ACE of the respective region is represented by $R(s)$ in this instance. The frequency deviation in each area is indicated by $Y(s)$, and the controller's output, $C(s)$, serves as the generating units' input. The basic difference between a two-degree-of-freedom (2-DOF) PID controllers is the disturbance.

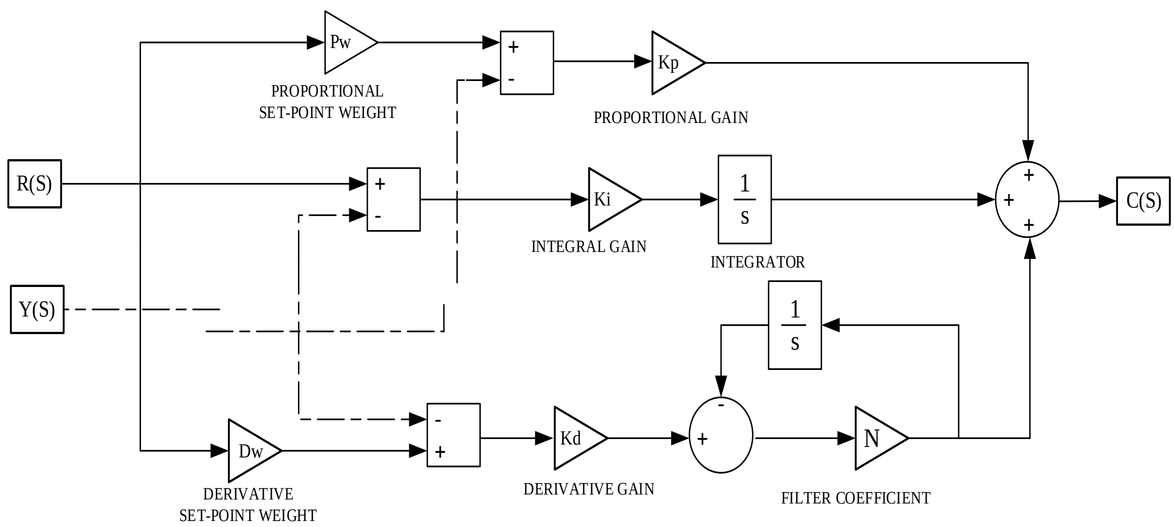


Figure 2. Block diagram three 2DOF-PID controller

3. PROBLEM FORMULATION AND OPTIMIZATION TECHNIQUE

3.1. Problem formulation

System control in power systems [24] aims to reduce frequency discrepancies to zero when loads change is the goal is to reduce the integral of the frequency error and control system characteristics must maintain system stability. Based on the information supplied, control objectives may be stated as equations in the following way:

– Integral absolute error (IAE)

$$IAE = \int_0^\infty [|e(t)|] \cdot dt \tag{2}$$

– Integral squared error (ISE)

$$ISE = \int_0^\infty [e^2(t)] \cdot dt \tag{3}$$

– Integral of time multiply absolute error (ITAE)

$$ITAE = \int_0^\infty [|e(t)|] \cdot t \cdot dt \tag{4}$$

– Integral time squared error (ITSE)

$$ITSE = \int_0^\infty [e^2(t)] \cdot t \cdot dt \tag{5}$$

As a result, the objective function for adjusting 2-DOF PID controllers based on the chess algorithm will be the performance indices represented by (2)–(5) [25]. In short, the goal of chess algorithm-based optimization in this case is to find an exact combination of a 2-DOF PID parameters that would result in the feedback control system having the lowest performance index. The objective function must be accomplished within the parameters' upper and lower bounds [26]. Table 2 shows the parallel a 2-DOF PID controllers, which comprises of the following elements.

3.2. Optimization technique

3.2.1. Chess algorithm optimization technique

The technique described in this work, known as the chess algorithm optimization technique [27], [28], uses the ideas and strategies used in the game of international chess to identify the best value. Furthermore, the user should evaluate each chess piece's particular actions as well as the game's general strategic approach. If the above-mentioned approach is used to determine the optimal value, the player will win the game [29]. This will result in an algorithm with varied properties across several domains. This approach leads to the creation of an algorithm because, depending on the game's style, each chess piece can move in certain ways based on a predetermined set of rules [30]:

Step 1: Divide the eight pawns (np) to randomize the answer. Reactions have to be practical given the limitations. There can be just one iteration because there are so many required requirements.
Step 2: Assess the assignments of pawns at random. Through evaluating the system at every answer. At the function's worst value, the response is ready for classification.
Step 3: Shows the responses in order. Comprises, in that order, two rooks, two knights, two bishops, one king, and one queen.
Step 4: Give each object a unique assignment. Determine the solution locally based on the movements of the components.
Step 5: Assess neighboring answers. Consider the purpose of every answer. locate the best options in your area every single thing
Step 6: Rearrange the parts. Determine which component-environment compatibility solution is optimal.
Step 7: Evaluate all chess pieces against search results. Which response has the maximum function value? Name it the optimal answer for that particular search iteration.
Step 8: Verify the circumstances and include a regional answer. Provided that the conditions are satisfied. Let's break free from constrained answers.
Step 9: Examine the grounds for termination. Search no farther if the requirements are satisfied. Iterate more if necessary if the prerequisites are not satisfied. To obtain the updated value, take the current Iteration value and add 1.
Step 10: Divide the eight pieces equally and begin over.
Step 11: Combine the initial pawn configuration (8 pieces) with the current optimal solution for all chess pieces (1 king, 1 queen, 2 rooks, 2 knights, and 2 bishops), in addition to figuring out the function value of the random pawn pick outcome. The 16 responses were arranged in order of preference.
Step 12: Until the halting condition is satisfied, step 3 is repeated using the top 8 responses.

Table 2. Minimum and maximum value of control parameter

Controller Parameter	Minimum	Maximum
K_p	0	1
K_i	0	1
K_d	0	1
N	10	300
PW	0	2
DW	0	5

4. RESULTS AND DISCUSSION

The chess algorithm optimization technique adjusts the parameters of a 2-DOF PID controllers, it controls the power networks. Connection between two sources of Every operation is tested and assessed using the MATLAB R2024A tool. The program runs on a CPU with 16.00 GB RAM and a Core i5 processor that clocks in @ 2.50 GHz. The results of parameter adjustment for 2-DOF PID controller.

The experimental findings compare the performance of 2-DOF PID controllers adjusted using the chess and particle swarm algorithm (PSO) algorithms. The comparison utilizes the system's steady state time (setting time), the peak in area 1, area 2, and the tie line as reference points. Illustration 3 illustrates the division of experimental findings by error values such as IAE and ISE. The experimental results, including Table 3 and Table 4, show that the chess algorithm and the PSO algorithm have different strengths and disadvantages. The chess algorithm reduces peak values in all domains and error types. This shows more control and precision. However, the PSO method has somewhat shorter steady state durations in area 1 and area 2 when considering IAE values. Thus, steady-state duration and peak values should dictate algorithm selection in actual applications. Using a chess algorithm to minimize peak value is better. The PSO technique is suitable for rapid system stabilization. Figures 3(a) to 3(c) illustrates the dynamic power system reaction IAE and ISE of each location: area 1, area 2 and Tie line. These responses are depicted in Figures 3(a) to 3(c).

Table 3. Optimization controller parameter IAE and ISE

Parameter		IAE	ISE
Chess algorithm	K_p	0.70140	0.94460
	K_i	0.99990	0.99730
	K_d	0.19670	0.80020
	N	224.66360	233.45920
	PW	0.41920	1.42350
	DW	4.69440	4.94800
Particle swarm algorithm	K_p	0.58030	0.98190
	K_i	1.00000	0.93730
	K_d	0.18790	0.78260
	N	21.48210	280.52180
	PW	0.37780	1.18510
	DW	3.65870	3.08690

Table 4. Optimization controller parameter ITAE and ITSE

Parameter		ITAE	ITSE
Chess algorithm	K_p	0.69480	0.99120
	K_i	0.99690	0.93310
	K_d	0.42790	0.51170
	N	162.91510	114.44094
	PW	1.80560	1.28640
	DW	1.68150	4.12240
Particle swarm algorithm	K_p	0.36820	0.93670
	K_i	0.89210	0.96320
	K_d	0.23200	0.58630
	N	39.27040	70.58910
	PW	0.79870	1.32700
	DW	1.39870	2.99200

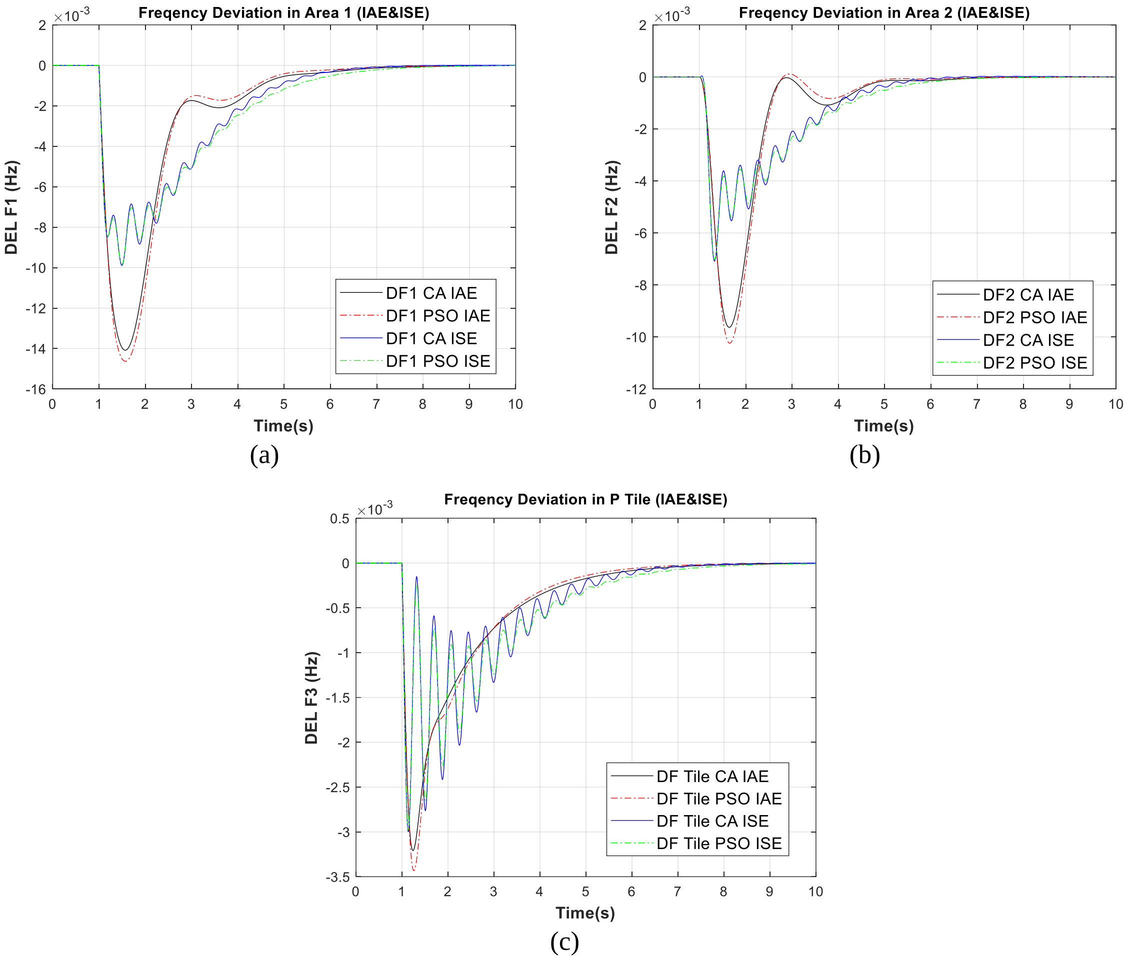
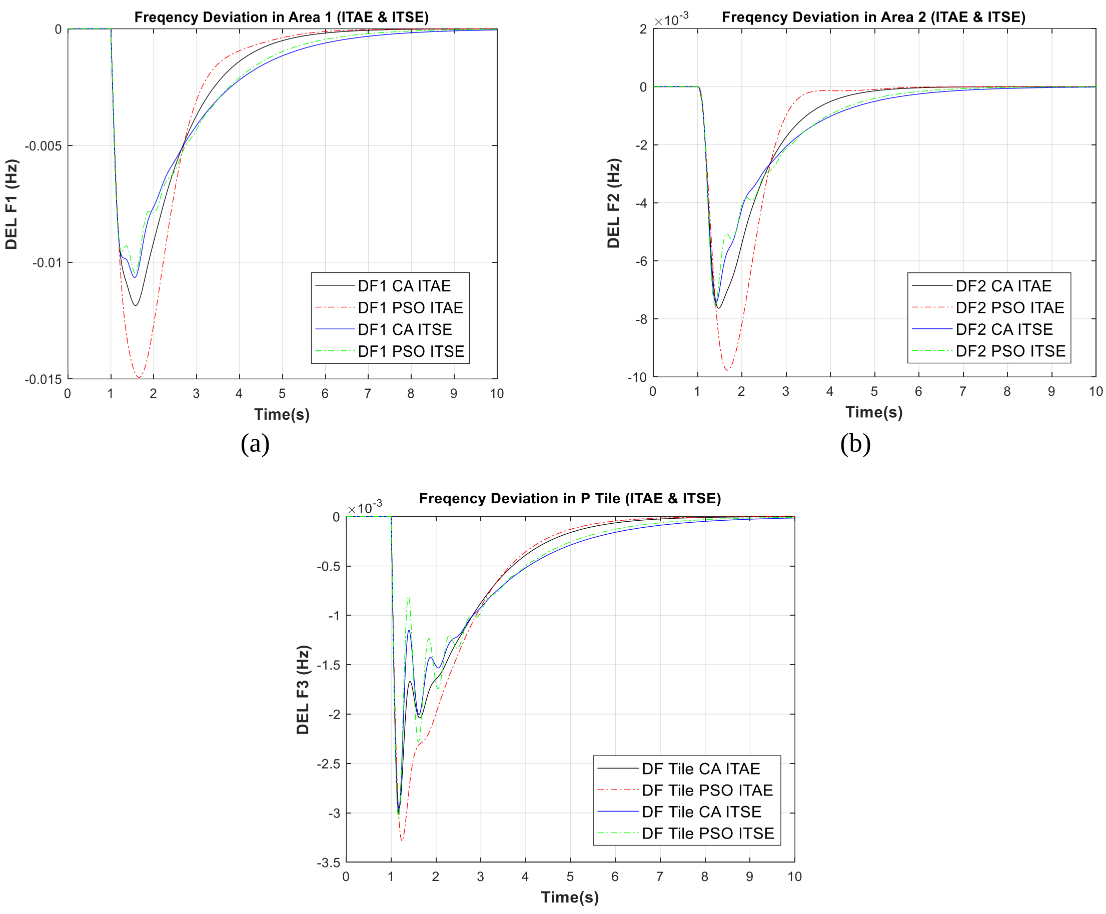


Figure 3. Dynamic power system response IAE and ISE (a) area 1, (b) area 2, and (c) tie line

Table 5 and Figures 4(a) to 4(c) show the ITAE and ITSE measures and illustrate the dynamic power system reaction IAE and ISE of each location: area 1, area 2 and Tie line. These responses are depicted in the figure, which are 2% setting time and peak values for the chess and particle swarm algorithms, respectively. We display the data for two distinct areas, area 1 and area 2, along with the tie line connecting them. Definitions are necessary. With the exception of area 1, the particle swarm algorithm's average configuration time is 2% faster than that of both chess algorithms (ITAE and ITSE). In area 1, the chess algorithm (ITAE) achieves the lowest settling time of 2% (0.0119 seconds). The particle swarm method, which is defined as the integral of time multiplied by the absolute error (ITAE) criterion, obtains the lowest settling time of 2% (0.0076 seconds in area 2 and 0.003 seconds in the tie line). The particle swarm algorithm (ITAE) is the second-fastest algorithm in area 2 and Tie Line, with a settling time of 2%. The tie line and area 2 have respective timings of 0.0031 seconds and 0.0075 seconds, respectively. Compared to both particle swarm algorithms (ITAE and ITSE), the chess algorithm has a lower average peak value on the peak side, with the exception of area 1 (ITAE). The particle swarm (ITAE) algorithm achieves the lowest peak value (0.0098) in area 1. The chess algorithm's ITAE criterion exhibits the lowest peak values of 0.0076 and 0.003 in area 2 and the tie line, respectively. The chess algorithm, sometimes known as ITSE, records the second-lowest maximal value in area 2 and the tie line, measuring 0.0074 and 0.003 seconds, respectively.

Table 5. Values of settling time and peak (IAE & ISE)

Algorithm	Area	Settling time 2%	Peak
Chess algorithm (IAE)	Area 1	476.9806	0.0141
	Area 2	355.0423	0.0096
	Tie line	491.2444	0.0032
Particle swarm (IAE)	Area 1	404.4149	0.0146
	Area 2	344.0657	0.0102
	Tie line	444.4372	0.0034
Chess algorithm (ISE)	Area 1	493.3599	0.0099
	Area 2	437.3881	0.0071
	Tie line	525.7413	0.003
	Area 1	559.5391	0.0098
Particle swarm (ISE)	Area 2	480.6729	0.007
	Tie line	567.2323	0.003



(a) (b) (c)

Figure 4. Dynamic power system response ITAE and ITSE (a) area 1, (b) area 2, and (c) Tie line

Table 6 displays the error values for the four chess and particle swarm algorithms, namely IAE, ISE, ITAE, and ITSE. When comparing the IAE values of the chess and particle swarm algorithms, we see that they are fairly close, with values of 0.03364 and 0.03363, respectively. The chess algorithm has a slightly lower ISE value compared to the particle swarm method, with values of 0.00035 and 0.00036, respectively. The chess algorithm has somewhat reduced ITAE values compared to the particle swarm method, with values of 0.07647 and 0.07929, respectively. the ITSE value of the chess algorithm is somewhat lower than that of the particle swarm method, with values of 0.00072 and 0.00076, respectively. In conclusion, the chess algorithm has somewhat superior overall performance compared to the particle swarm algorithm in terms of mistake rates. the disparity in error levels between the two techniques is minimal. The optimal algorithm for practical use is contingent upon the specific requirements. The chess algorithm is likely to be a more suitable option if a high level of accuracy is desired. The particle swarm method is likely a superior option if you prefer a more straightforward system, The values of settling time and peak (ITAE and ITSE) are shown in Table 7, as may be seen.

Table 6. Values of error

Algorithm	Function	Error
Chess algorithm	IAE	0.03364
Particle swarm algorithm	IAE	0.03363
Chess algorithm	ISE	0.00035
Particle swarm algorithm	ISE	0.00036
Chess algorithm	ITAE	0.07647
Particle swarm algorithm	ITAE	0.07929
Chess algorithm	ITSE	0.00072
Particle swarm algorithm	ITSE	0.00076

Table 7. Values of settling time and peak (ITAE and ITSE)

Algorithm	Area	Settling time 2%	Peak
Chess algorithm (ITAE)	Area 1	434	0.0119
	Area 2	362.9073	0.0076
	Tie line	464.2008	0.003
Particle swarm (ITAE)	Area 1	386.4546	0.0149
	Area 2	234.6018	0.0098
	Tie line	424.462	0.0033
Chess algorithm (ITSE)	Area 1	604.541	0.0107
	Area 2	523.1856	0.0074
	Tie line	604.9475	0.003
Particle swarm (ITSE)	Area 1	546.175	0.0105
	Area 2	465.2253	0.0075
	Tie line	551.1389	0.0031

5. CONCLUSION

This experiment aims to evaluate and compare the efficacy of chess and particle swarm algorithms in system control. The evaluation is based on two primary factors: the setting time of 2% and the peak of the highest deviation, as well as the error value of the setting time of 2%. Overall, the particle swarm method has a 2% faster setting time, except in some cases. When applying IAE to area 1 often results in peak chess methods exhibiting lower peak values, indicating less deviation. ver, this is not the case when employing IAE in area 1. An error has occurred. The chess algorithm has a slightly narrower total margin of error. However, the disparity between the two methods is not very substantial. Simply put, the outcome depends on whose requirements take precedence. The particle swarm algorithm is likely to be a superior option if you need a system that exhibits rapid responsiveness. If you need a system that exhibits high precision and little variance, the chess algorithm would likely be a superior option. Variables such as the manipulated system may influence the experiment's outcome. Parameters and noise in algorithms.

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