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Development of a 2 degree of freedom-proportional integral derivative controller using the hippopotamus algorithm

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ABSTRACT

This research project investigates the regulation of autonomous power generation in two interconnected regions using two hydroelectric power plants. It specifically addresses the challenges posed by significant electrical system issues. The hippopotamus optimization algorithm (HOA) has demonstrated enhanced gain value in research and designs of 2 degree of freedom (2DOF)-proportional integral derivative (PID) controllers. The objective is to provide efficient and uninterrupted functioning of the electrical network in both areas. Contemporary technology and methods enable the electrical system to efficiently and accurately fulfill user requirements, resolving any problems related to system balance and stability. This experiment evaluates the efficacy of several algorithms in accurately selecting optimal values. We evaluate performance using the integral of absolute error (IAE) and integral of time-weighted absolute error (ITAE) functions. This experiment evaluates and contrasts different algorithms. Summarizing the analysis using verifiable evidence. Optimization when evaluated using the ITAE measurement, the HOA earned the lowest result of 0.08744 for ITAE. Empirical research has demonstrated that this strategy is the most effective in reducing the ITAE. The sine-cosine algorithm (SCA) and whale optimization algorithm (WOA) have similar ITAE values, with SCA having an error of 0.08967 and WOA having an error of 0.08967. The numerical number is 0.08970.

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1. INTRODUCTION

For the purpose of preserving the reliability and steadiness of power systems [1], it is of the highest essential to guarantee that they will continue to provide energy without interruption, regardless of the varying load needs [2], [3] load frequency control, often known as LFC, is a vital component of the functioning of power systems. Its major function is to regulate the frequency of the system [4] within the parameters that have been specified, and it also ensures that there is an equilibrium between the quantity of electricity produced and the quantity consumed. LFC that is successful results in a reduction in frequency deviations, which in turn decreases the likelihood of blackouts occurring and ensures that the power system remains stable [5].

As a result of its straightforward installation and dependable performance, proportional integral derivative (PID) controllers [6] have discovered widespread use in the field of LFC. In spite of this, the problem of fine-tuning the PID parameters (K_p, K_i, and K_d) continues to be a significant area of concern. Incorrectly calibrated PID parameters may lead to insufficient frequency control, instability, and inefficiency in the power system. These issues might be caused by the power system [7], [8].

When it comes to dealing with complex optimization problems [9], [10] such as the fine-tuning of PID controllers, metaheuristic optimization approaches have grown more popular. There have been tremendous accomplishments achieved via the use of algorithms such as the genetic algorithm (GA) [11], [12], the Bees algorithm [13], [14], and the particle swarm optimization (PSO) [15], [16]. With that being said, the search for optimization procedures that are both more efficient [17], [18] and effective continues, which has led to the research of novel algorithms[19], [20] that are inspired by biological systems [21], [22].

Within the realm of bio-inspired optimization strategies, the hippopotamus optimization algorithm (HOA) [23] is a recently established method that has recently come into existence. For the purpose of resolving optimization challenges, HOA, which takes its cues from the social behavior, territorial instincts, and cooperative hunting strategies of hippopotamuses, provides a highly promising approach. In order to enhance the effectiveness and dependability of power systems, the purpose of this research is to investigate the possibility of integrating a two degree of freedom (2DOF) PID control system [24] with HOA for LFC [25].

In this paper, the development of a PID control system [26] with 2DOF is described. For the purpose of regulating the LFC in power systems, the system makes use of the HOA. There was an improvement in system performance as a result of the introduction of HOA into the 2DOF-PID controller. This demonstrates the power of bio-inspired algorithms to enhance complex control systems. By doing more research, it may be possible to investigate the use of HOA in different control system domains and develop hybrid approaches that combine HOA with other optimization techniques.

2. RESEARCH METHODOLOGY

2.1. Two degree of freedom proportional integral derivative control system

Due to the fact that they are uncomplicated and have the ability to deliver results that can be relied upon, controllers have been utilized for a considerable amount of time currently. For the purpose of the study, the LFC controller was a modified version of the PID controller that was referred to as the 2DOF-PID controller [27]. As a result of its capacity to quickly reject disturbances without generating a large rise in overshoot during set-point tracking, this option has been selected, in Figure 1 illustrates structure 2DOF PID control.

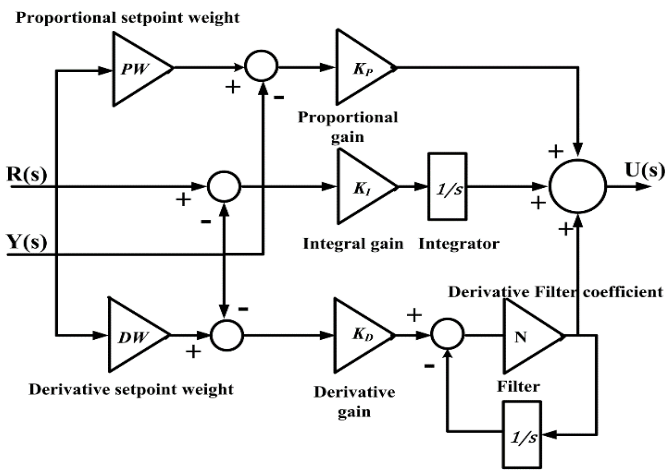

Figure 1. Structure 2DOF PID control [28]

2.2. Hippopotamus optimization algorithm

2.2.1. A mathematical representation of the hippopotamus optimization algorithm

The algorithm continuously monitors and saves the most optimal possible solution throughout its operation. Once the process concludes, the hippopotamus plays a crucial role in revealing the final response, also known as the prevailing solution to the dilemma. The flowchart in Figure 2 illustrates the procedural components of the HOA.

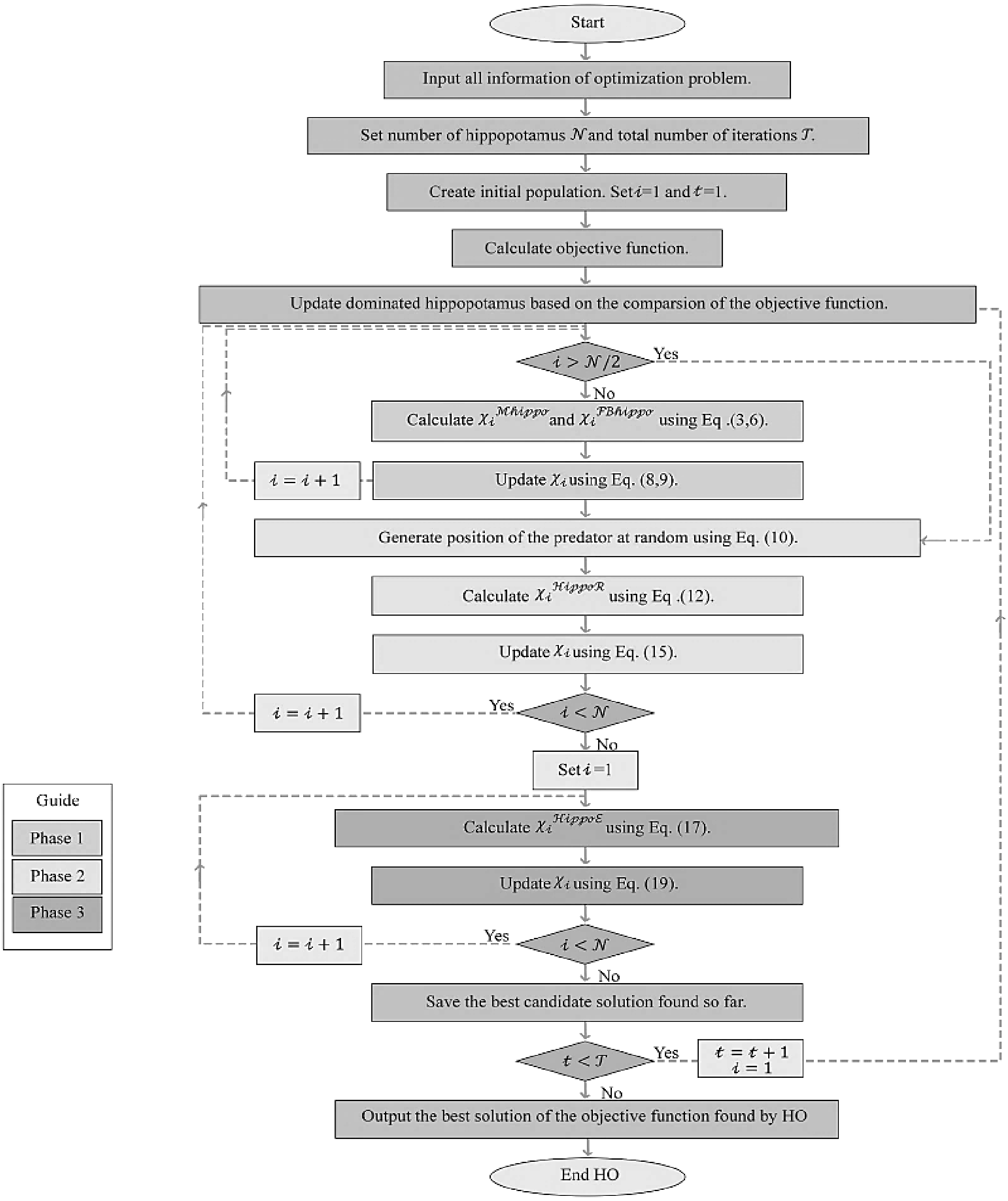

Figure 2. HOA flowchart [23]

2.3. Objective function

Consumer demands and system parameter disruptions have a significant impact on the frequency and power variations of the linked electrical power system. These fluctuations deviate from the specified efficiency values that are acceptable for a stable electrical system. A satisfactory level of stability, fast control response, and reduced fluctuations is desired in the LFC system. These requirements enable the system to quickly restore the frequency deviation (Δf) in each area and maintain the constant power deviation (ΔP) at its original or predetermined value [29].

The study work employs an integral performance index type as the fitness/objective function. The fitness/objective functions of IAE and ITAE utilized in the literature are represented by (1) and (2):

$$IAE = \int_0^{\infty} [|\Delta f + \Delta P|] \cdot dt \quad (1)$$

$$ITAE = \int_0^{\infty} [|\Delta f + \Delta P|] \cdot t \cdot dt \quad (2)$$

Based on the literature study, it is preferred to use IAE and ITAE-optimized controllers in LFC systems. Therefore, this study presents a new approach that utilizes the IAE and ITAE performance criterion to develop and implement a weighted objective technique. This approach serves as the fitness function for optimizing the 2DOF-PID controller's settings.

3. METHOD

This research evaluates the efficacy of the HOA in finding the ideal configuration settings for the 2DOF PID control controller in a thermal power system that consists of two sections that are linked to one another. Within the context of the simulation, each power plant has a load capacity of one thousand megawatts and a production capacity of two thousand megawatts [28]. Currently, the system incorporates a governor-dead band in order to further strengthen the realism of the system. Because of the enhancement, the system became nonlinear, which enabled it possible to take use of it for the purpose of researching the dynamic response of frequency in power plants [29]. To be more specific, it is able to conduct an analysis of the power response of the tie line in response to a 0.01 p.u. Step load perturbation (SLP) disturbance at the thermal power plant located at Figure 3 [30], the range of parameters will be set according to Table 1.

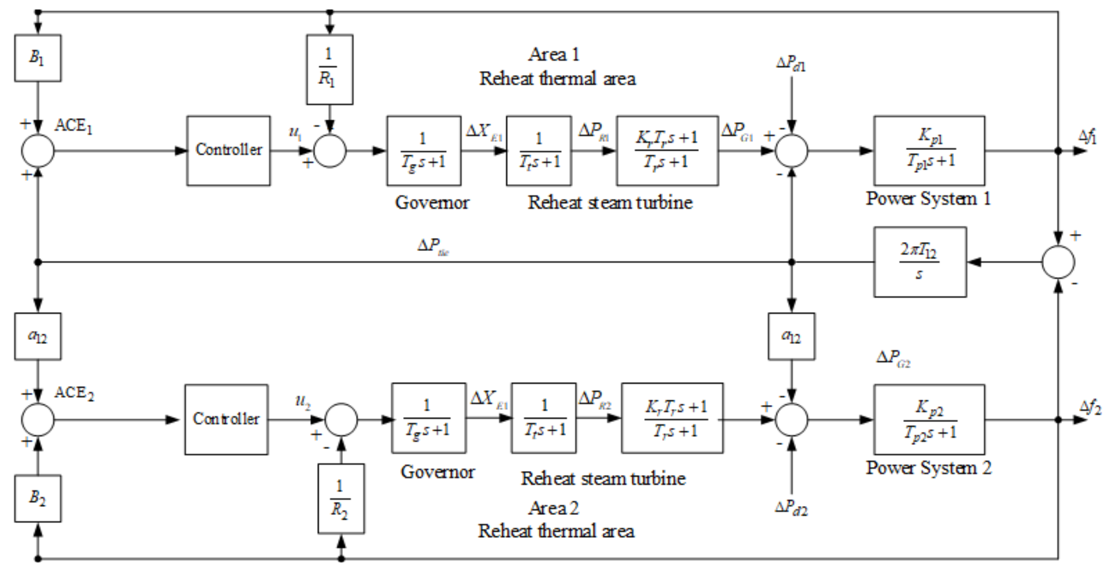

Figure 3. A thermal power system with two linked sections diagram [30]

Table 1. Minimum and maximum value of the control parameter [30]

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 2-DOF PID controller, which plays a crucial role in power system control, optimizes its parameters using the HOA. The connection between two sources of information. We use the MATLAB R2021A program to conduct tests and assess all operations. The program runs on a central processing unit (CPU) that has a Core i5 processor operating at a clock speed of 2.50 GHz. In addition, it has a random-access memory (RAM) capacity of 16 GB. Changing the settings for a 2DOF-PID controller yields different results.

Table 2 shows that each function has just 6 parameter values, namely the parameters of the 2DOF-PID controller. Concerning the experimental power plant, the paramotor search operational simulation produces an appropriate value for each method. The implementation has been carried out in two domains. A link exists between the two thermal power plants.

Table 2. Optimization controller parameter

Parameter	HOA		SCA		WOA	
	IAE	ITAE	IAE	ITAE	IAE	ITAE
K_p	1	0.3518	1	0.3132	1	0.3463
K_i	1	1	1	1	1	1
K_d	0.1215	0.2338	0.1714	0.1873	0.1188	0.2304
N	21.2966	282.3872	10	10	300	84.8399
PW	0.0123	1.3516	0.2124	0	0.5792	0.192
DW	4.3947	1.1593	0	0	3.2373	0.7401

The frequency response of areas 1-2 and 3 of the IAE was shown in Figure 4. The study revealed that the HOA exhibited more responsiveness compared to the SCA and WOA in parameter search. The setting time consideration value is 2%. Upon analyzing the function's graph, ITAE found that using the HOA yielded a much superior response compared to the SCA and WOA. Additionally, Figure 5 demonstrates that the settling time value at 2%, values of settling time, peak and values of error show in Tables 3 and 4.

Table 3. Values of settling time and peak

Values		HOA		SCA		WOA	
		IAE	ITAE	IAE	ITAE	IAE	ITAE
Settling Time 2%	Area 1	605.928	242.4594	580.07	324.29	612.86	241.623
	Area 2	579.732	302.578	442.86	267.22	469.46	301.951
	Tie line	578.677	354.909	572.79	342.32	585.45	241.623
Peak	Area 1	0.0143	0.0149	0.0141	0.0159	0.0142	0.015
	Area 2	0.0105	0.0096	0.0105	0.011	0.0102	0.0097
	Tie line	0.0035	0.0031	0.0035	0.0036	0.0034	0.015

Table 4. Values of error

Algorithm	HOA		SCA		WOA	
	IAE	ITAE	IAE	ITAE	IAE	ITAE
Error	0.0348	0.0874	0.034	0.0896	0.0348	0.0897

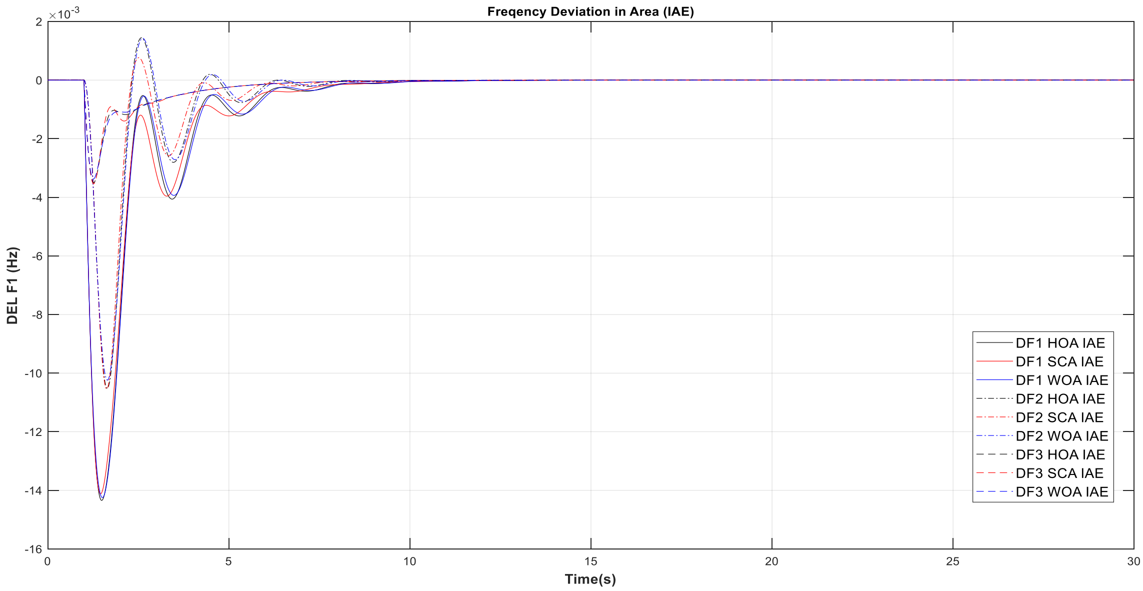

Figure 4. Freqency deviation in area (IAE)

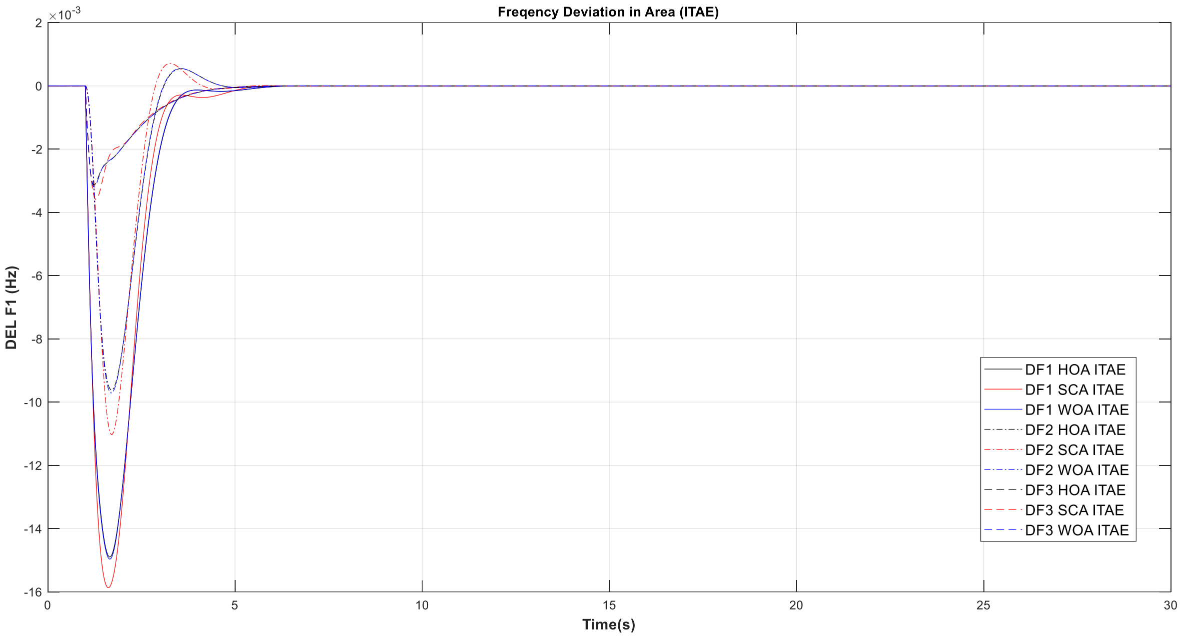

Figure 5. Freqency deviation in area (ITAE)

5. CONCLUSION

The aim of this experiment is to evaluate and compare the effectiveness of several algorithms in determining the optimal values. The IAE and ITAE functions are used for quantifying the results. The algorithms under comparison in this experiment are: According to the empirical data, the analysis may be stated as follows. Effectiveness the SCA has exceptional efficiency in reducing the IAE when assessed using the IAE metric, resulting in a minimum error of 0.034087693541846. SCA has higher optimization skills in comparison to other approaches, particularly in terms of lowering the IAE. The HOA and WOA have similar IAE values, with HOA showing an equal value. The error is 0.034848038938341, whereas WOA has an error value of 0.034846945292738, which exhibits a little disparity. Effectiveness when assessed utilizing ITAE measurement, the HOA attained the minimum ITAE value of 0.087448913139503. Empirical research has shown that this strategy is the most effective in reducing the ITAE. The SCA and WOA have similar ITAE values, with SCA having an error of 0.089673119049235 and WOA having an error of 0.089673119049235. The numerical number is 0.089705069065476.

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