Chaotic red-tailed hawk algorithm to optimize parameter power system stabilizer

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ABSTRACT

This article introduces a recently created adaptation of the red-tailed hawk (RTH) algorithm. The proposed approach is a modified version of the original RTH algorithm, incorporating chaotic elements to enhance its integrity and performance. The RTH algorithm emulates the hunting behavior of the red-tailed hawk. This article demonstrates the adjustment of the power system stabilizer using the suggested technique in a case study involving a single-machine system. The suggested method was validated by benchmarking against known functions and evaluating its performance on a single-machine system in terms of transient responsiveness. The essay employs the original RTH algorithm as a means of comparison. The simulation results demonstrate that the proposed technique exhibits promising performance.

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1. INTRODUCTION

The utilization of renewable energy and distributed generation, in conjunction with diverse power semiconductor devices, has an impact on the stability of the power system [1]–[3]. The resilience of the electric power system's interconnection will diminish due to the impact of suboptimal submergence of low-frequency oscillations [4]–[6]. This will result in disruptions in the distribution of electricity, which will indirectly impose technical and economic burdens on the system. The emphasis on reducing the intensity of low-frequency oscillations becomes a crucial factor in power systems [7]–[9].

The power system stabilizer (PSS) is a commonly used device for addressing low-frequency oscillations. This gadget is utilized in various system situations [10]–[13]. The design of conventional PSS is based on a linear model. This model regards the optimal operating point as the foundation for adjusting PSS settings [3], [14]–[16]. An electric power system that exhibits non-linear and variable properties throughout a broad spectrum. This renders traditional PSS suboptimal. The advancement of technology and computing techniques is progressing rapidly. This has an impact on and infiltrates the power system stabilizer. Multiple research have reported conclusions about this issue[17], [18]. The application of computational methods in optimization is one of the very important approaches in various fields of science, including engineering, economics, management, physics, biology, and others. Optimization itself aims to find the best solution to a problem by maximizing or minimizing a certain objective function, while meeting the existing constraints [19]. Over the years, various computational methods have been proposed for adjusting PSS parameters. These include mayfly algorithm (MA) [20], particle swarm optimization (PSO) [21], [22], Harris hawk optimizer (HHO) [23], [24], Jaya algorithm (JA) [25], and manta ray foraging (MRF) [26].

This article introduces the tuning approach for power system stabilizers utilizing the modified red-tailed hawk algorithm (RTH) method [27]. The RTH algorithm replicates the predatory behavior of red-tailed hawks. The RTH modification approach involves the integration of a chaotic algorithm. The objective is to enhance the proficiency of RTH. The research has made the following contributions:

a. Adapt the red-tailed hawk algorithm approach, known as chaotic red-tailed hawk algorithm (CRTH), to achieve an optimal equilibrium between exploration and exploitation.
b. The CRTH approach is applied to optimize PSS settings by assessing performance and comparing it with conventional methods (PSS-Conv) and PSS based on the red-tailed hawk algorithm (PSS-RTH).

The organization of this article is as follows: The second section provides an explanation of the red-tailed hawk algorithm, the modification technique for the red-tailed hawk, and its use in the power system stabilizer. The third portion provides a presentation of the results and analysis. The final section presents the findings derived from the investigation.

2. METHOD

2.1. Red-tailed hawk algorithm

The red-tailed hawk (RTH) algorithm mimics the hunting behavior of red-tailed hawks. The actions taken at each stage of the hunt are presented and modeled. This algorithm includes three stages, soaring high, soaring low, and bending and diving. RTH has the advantages, namely fewer parameters, simple setup, easy implementation and accurate calculations. Mathematical modeling of the natural behavior of red-tailed hawks during hunting is used in the design of the proposed RTH approach as follows:

2.1.1. Soaring high

The red-tailed hawk will fly high into the sky looking for the best location in terms of food availability. Equation (1) represents the mathematical model of this stage:

$$X(t) = X_{best} + (X_{mean} - X(t-1).levy(dim).TF(t) \tag{1}$$

$$Levy(dim) = 0.01 \times \frac{\mu.\sigma}{|v|^{1/\beta}} \tag{2}$$

$$\sigma = \left[\frac{\Gamma(1+\beta)\sin(\frac{\alpha\pi}{2})}{\Gamma(\frac{(1+\beta)}{2}).\beta\, 2^{\frac{(1-\beta)}{2}}}\right] \tag{3}$$

$$TF(t) = 1 + \sin(2.5 + \left(\frac{t}{T_{max}}\right)) \tag{4}$$

where $X(t)$ represents the position of the red-tailed eagle at iteration t, X_{best} is the best position obtained in (3), and $TF(t)$ denotes the transition factor function that can be calculated based on (4). Where dim is the problem dimension, β is a constant (1.5), μ and v are random numbers [0 to 1]. T_{max} represents the maximum number of iterations.

2.1.2. Soaring low

The eagle circles its prey by flying much lower to the ground in a spiral line and the model can be expressed as (5) and (6):

$$X(t) = X_{best} + (x(t) + y(t)).Stepsize(t) \tag{5}$$

$$Stepsize(t) = x(t) - X_{mean} \tag{6}$$

where x and y represent directional coordinates which can be calculated as (8):

$$\begin{cases} x(t) = R(t)\,.\sin(\theta(t)) \\ y(t) = R(t)\,.cos(\theta(t)) \end{cases} \begin{cases} R(t) = R_0\,.\left(r - \frac{t}{T_{max}}\right).rand \\ R(t) = A.\left(r - \frac{t}{T_{max}}\right).rand \end{cases} \begin{cases} x(t) = x(t)/\max|x(t)| \\ y(t) = y(t)/\max|y(t)| \end{cases} \tag{8}$$

where R_0 represents the initial value of the radius [0.5–3], A represents the angel gain [5–15], $rand$ is the random gain [0–1], and r is the control gain [1, 2]. This parameter helps the eagle circle its prey with a spiral movement.

2.1.3. Bending and swooping

At this stage, the eagle suddenly bends down and attacks its prey from the best position obtained in the low flight stage. This stage can be modeled as (9)-(13):

$$X(t) = \alpha(t).X_{best} + x(t).Stepsize1(t) + y(t).Stepsize2(t) \quad (9)$$

$$Stepsize1(t) = X(t) - TF(t).X_{mean} \quad (10)$$

$$Stepsize2(t) = G(t).X(t) - TF(t).X_{best} \quad (11)$$

$$\alpha(t) = sin^2(2.5 - \frac{t}{T_{max}}) \quad (12)$$

$$G(t) = 2.(1 - \frac{t}{T_{max}}) \quad (13)$$

The variable α represents the acceleration of the hawk, which increases as time (t) increases in order to improve the pace of convergence. On the other hand, G represents the gravitational effect, which reduces as the hawk gets closer to the prey in order to limit the diversity of exploitation.

2.2. Power system stabilizer

Power system stabilizer (PSS) is a control system installed on generating units that monitors variables such as current, voltage and shaft speed. Its main function is to dampen power oscillations, thereby increasing the stability of the rotor angle and improving the overall stability of the power system. A PSS generally has three important components, namely gain, washout, and phase compensation. The block unit of a PSS can be seen in Figure 1. In conventional PSS, the gain is still used and requires good reset capabilities when operating conditions change. The transfer function can be seen in equation 14. The PSS output (V_s) is the input added to the excited system. PSS input represents the synchronous speed deviation of the system $\Delta\omega_i$.

$$V_s = K_{pss}.\frac{sT\omega}{1+sT\omega}.\frac{1+sT_1}{1+sT_2}.\Delta\omega_i \quad (14)$$

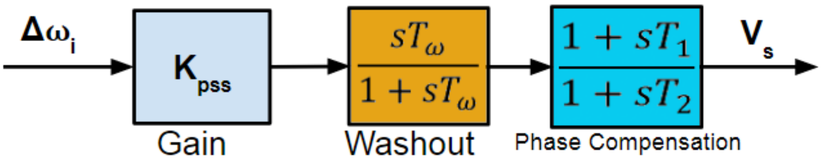


Figure 1. PSS block diagram [3]

2.3. Proposed method

The suggested approach combines the chaos algorithm (COA) with RTH. This strategy is suggested as a means to enhance the efficiency of the green space optimization algorithm. COA utilizes chaotic variables rather than random variables. Chaos exhibits non-repetitive and unpredictable qualities. Furthermore, the system search exhibits superior velocity in comparison to stochastic search methods or those that depend on probability. This study employs a one-dimensional non-reversed map, specifically the logistics map, as an algorithm for generating chaotic sets. Modifications are employed to expedite the convergence rate of the curve till it attains the ideal point. In most COA methods, chaotic variables are generated by logistic maps. The illustration of CRTH can be seen in Figure 2. The equation is as follows:

$$ylog_{(i+1)} = a \times ylog_{(i)}(1 - ylog_{(i)}) \quad (15)$$

This research makes modifications to (1), (5), and (9) by adding (15). So it becomes (16), (17), (18).

$$X(t) = X_{best} + (X_{mean} - X(t-1).levy(dim).TF(t) \times ylog_{(i+1)} \quad (16)$$

$$X(t) = X_{best} + (x(t) + y(t)).Stepsize(t) \times ylog_{(i+1)} \quad (17)$$

$$X(t) = \alpha(t).X_{best} + x(t).Stepsize1(t) + y(t).Stepsize2(t) \times ylog_{(i+1)} \quad (18)$$

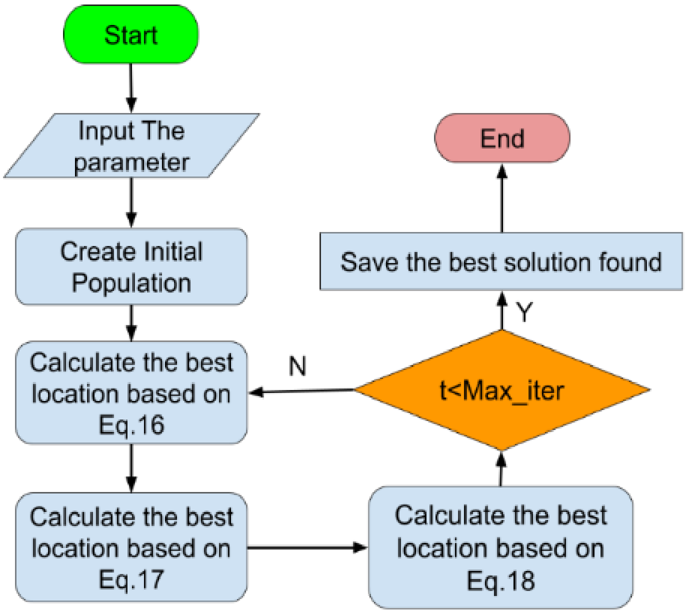


Figure 2. The flowchart CRTH

3. RESULTS AND DISCUSSION

3.1. Convergence curve profile

The CRTH's performance is evaluated by utilizing the benchmark function. This paper utilizes benchmark functions, which are comprehensively detailed in Table 1. The benchmark function consists of 23 functions as shown in Figure 3. The mathematical function consists of seven unimodal functions (F1–F7) in Figure 3 (a)-(g), six multimodal functions (F8–F13) in Figure 3(h)-(m), and ten fixed-dimensional multimodal functions (F14–F23) in Figure 3(n)-(w).

The statistical analysis compares the performance of CRTH with that of competing algorithms to see if CRTH has a statistically significant advantage over the other algorithms. The average rank value of any algorithm can be determined by knowing the rank of each function. The statistical analysis for each function is presented in Table 1. A rating is a numerical representation of the highest average value. The value of CRTH is 1, as seen by the cumulative rank value for each algorithm. The average rank value is 1.043478261. Table 2 displays a comparison of the rankings of unimodal algorithm functions. In the field of multimodal analysis, the CRTH has a ranking of 1.1666667. Table 3 displays a comparative analysis of the various multimodal functions utilized, focusing on their ranks. Table 4 displays a comparison of fixed-multimodal ranks between RTH and CRTH.

3.2. Implementing CRTH for PSS

This article use tiny signal stability analysis to examine the Heffron-Philips model. CRTH is used to solve the non-linear set of PSS parameters. The collected parameters are utilized to minimize wave oscillations to the greatest extent feasible. This work employs a comparative approach, namely utilizing conventional PSS and RTH as means of validating the performance of the CRTH. The acquired PSS parameters are evaluated by subjecting the system to 100% overload conditions. Performance validation is conducted by comparing the CDO approach with alternative algorithms, as depicted in Figure 4. The response of the speed can be seen in Figure 4(a). Figure 4(b) is the response of the rotor angle. The examination of the temporary reaction is outlined in Table 5.

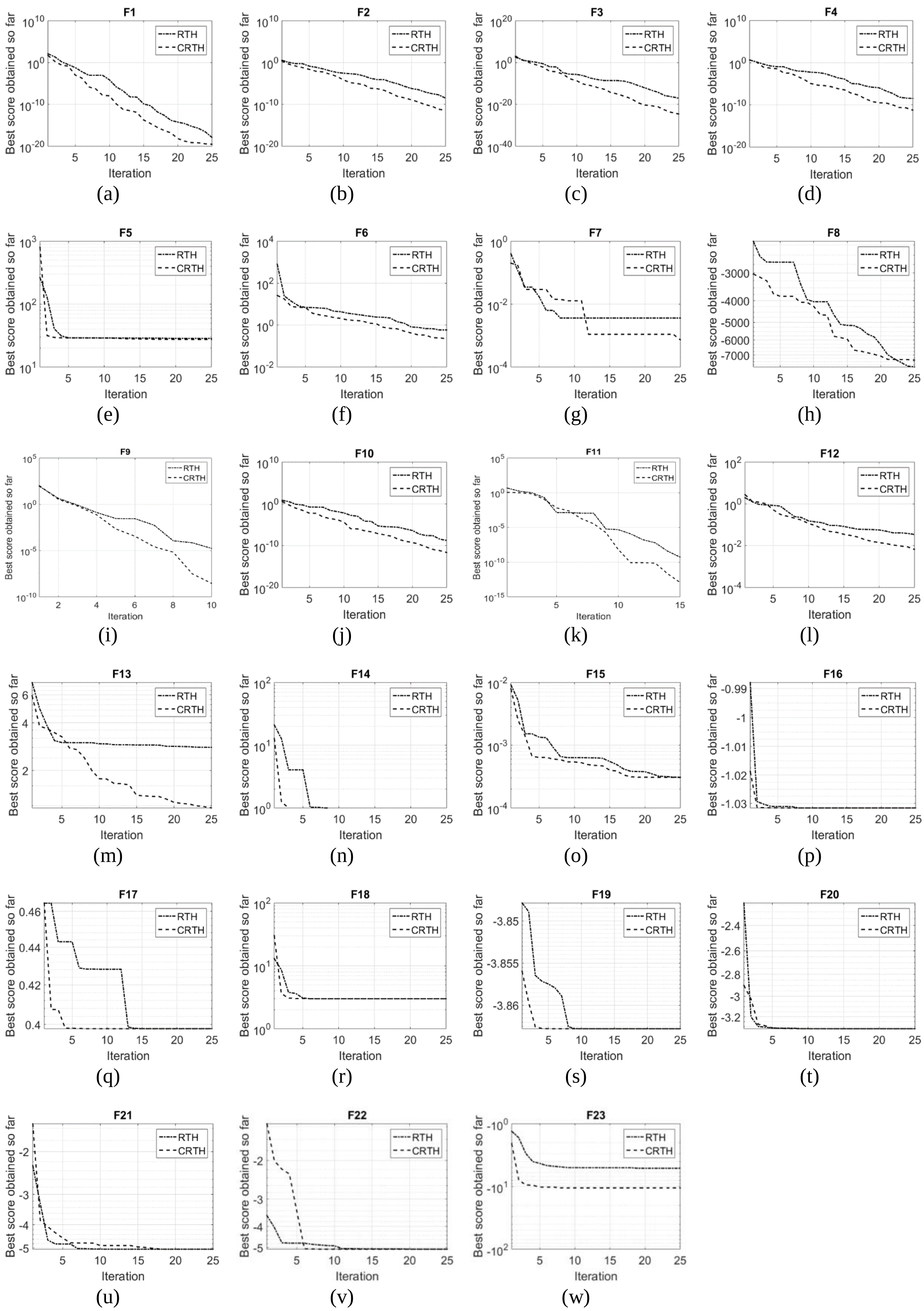


Figure 3. Convergence curve of benchmark function (a) F1, (b) F2, (c) F3, (d) F4, (e) F5, (f) F6, (g) F7, (h) F8, (i) F9, (j) F10, (k) F11, (l) F12, (m) F13, (n) F14, (o) F15, (p) F16, (q) F17, (r) F18, (s) F19, (t) F20, (u) F21, (v) F22, and (w) F23

Table 1. Comparison of RTH and CRTH

Function		RTH	CRTH	Function		RTH	CRTH
F1	Best	5.69E-41	1.90E-46	F13	Best	2.162	0.4808
	Mean	5.69E-41	1.90E-46		Mean	2.162	0.4808
	Worst	5.69E-41	1.90E-46		Worst	2.162	0.4808
	Std	0	0		Std	0	0
	Rank	2	1		Rank	2	1
F2	Best	5.48E-20	8.42E-24	F14	Best	0.998	0.998
	Mean	5.48E-20	8.42E-24		Mean	0.998	0.998
	Worst	5.48E-20	8.42E-24		Worst	0.998	0.998
	Std	0	0		Std	0	0
	Rank	2	1		Rank	1	1
F3	Best	7.98E-43	3.85E-47	F15	Best	0.000307	0.000307
	Mean	7.98E-43	3.85E-47		Mean	0.000307	0.000307
	Worst	7.98E-43	3.85E-47		Worst	0.000307	0.000307
	Std	0	0		Std	0	0
	Rank	2	1		Rank	1	1
F4	Best	1.15E-20	2.74E-24	F16	Best	-1.0316	-1.0316
	Mean	1.15E-20	2.74E-24		Mean	-1.0316	-1.0316
	Worst	1.15E-20	2.74E-24		Worst	-1.0316	-1.0316
	Std	0	0		Std	0	0
	Rank	2	1		Rank	1	1
F5	Best	26.656	26.0654	F17	Best	0.39789	0.39789
	Mean	26.656	26.0654		Mean	0.39789	0.39789
	Worst	26.656	26.0654		Worst	0.39789	0.39789
	Std	0	0		Std	0	0
	Rank	2	1		Rank	1	1
F6	Best	0.035788	0.002554	F18	Best	3	3
	Mean	0.035788	0.002554		Mean	3	3
	Worst	0.035788	0.002554		Worst	3	3
	Std	0	0		Std	0	0
	Rank	2	1		Rank	1	1
F7	Best	0.001951	0.00073	F19	Best	-3.8628	-3.8628
	Mean	0.001951	0.00073		Mean	-3.8628	-3.8628
	Worst	0.001951	0.00073		Worst	-3.8628	-3.8628
	Std	0	0		Std	0	0
	Rank	2	1		Rank	1	1
F8	Best	-9272.72	-8019.71	F20	Best	-3.322	-3.322
	Mean	-9272.72	-8019.71		Mean	-3.322	-3.322
	Worst	-9272.72	-8019.71		Worst	-3.322	-3.322
	Std	0	0		Std	0	0
	Rank	1	2		Rank	1	1
F9	Best	0	0	F21	Best	-5.0552	-5.0552
	Mean	0	0		Mean	-5.0552	-5.0552
	Worst	0	0		Worst	-5.0552	-5.0552
	Std	0	0		Std	0	0
	Rank	1	1		Rank	1	1
F10	Best	8.88E-16	8.88E-16	F22	Best	-5.0877	-5.0877
	Mean	8.88E-16	8.88E-16		Mean	-5.0877	-5.0877
	Worst	8.88E-16	8.88E-16		Worst	-5.0877	-5.0877
	Std	0	0		Std	0	0
	Rank	1	1		Rank	1	1
F11	Best	0	0	F23	Best	-5.1285	-10.5364
	Mean	0	0		Mean	-5.1285	-10.5364
	Worst	0	0		Worst	-5.1285	-10.5364
	Std	0	0		Std	0	0
	Rank	1	1		Rank	2	1
F12	Best	0.001067	0.000163	Sum Rank		33	24
	Mean	0.001067	0.000163	Mean Rank		1.434783	1.043478
	Worst	0.001067	0.000163				
	Std	0	0				
	Rank	2	1				

Table 2. Rank comparison of unimodal functions between algorithms (F1-F7)

Function	RTH	CRTH
Sum Rank	12	6
Mean Rank	1.71	0.86
Total Rank	2	1

Table 3. Rank comparison of multimodal functions between algorithms (F8-F13)

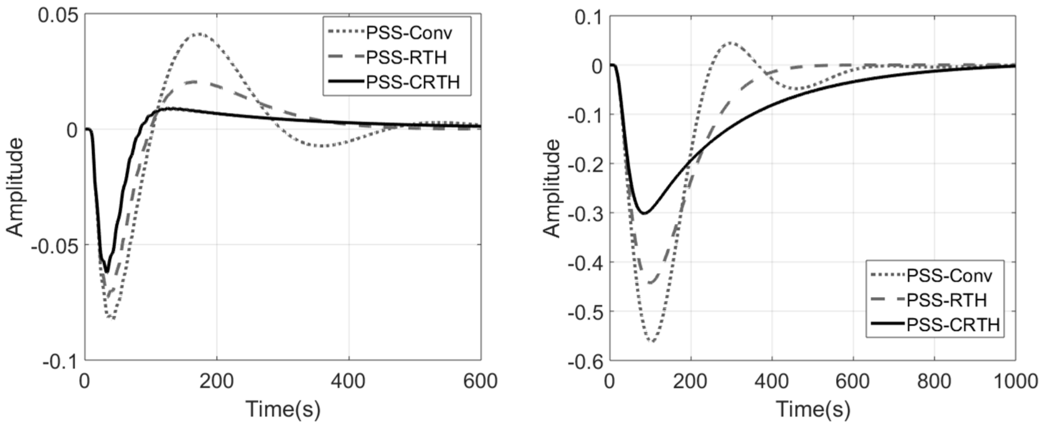
Function	RTH	CRTH
Sum Rank	8	7
Mean Rank	1.3333333	1.1666667

Table 4. Rank comparison of fixed-multimodal functions between algorithms (F14-F23)

Function	RTH	CRTH
Sum Rank	8	8
Mean Rank	1	1

Table 5. Transient response

Algorithm	Rotor Angle Output			Speed Output		
	Overshoot	Undershoot	Settling time (s)	Overshoot	Undershoot	Settling time (s)
PSS-Conv	No Overshoot	-0.562	593	0.0411	-0.0824	601
PSS-RTH	0.01372	-0.44	478	0.0204	-0.073	417
PSS-CRTH	No Overshoot	-0.3016	994	0.009	-0.0622	600



(a) (b)

Figure 4. Transient response (a) speed response and (b) rotor angle response

4. CONCLUSION

This article suggests enhancing the RTH approach by incorporating a chaotic algorithm to achieve optimal settings from the PSS.The RTH algorithm emulates the predatory actions of red-tailed hawks. The experimental results demonstrate that the CRTH approach enhances the capability of PSS under a fully loaded system situation. When the PSS is adjusted with the CRTH, it is possible to achieve a reduction of 78.1% in overshoot speed and a reduction of 46.33% in undershoot rotor angle, as compared to conventional approaches. This research needs to be further developed to obtain deeper performance. Research in more complex and complicated systems can be applied.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL

The research related to human use has been complied with all the relevant national regulations and institutional policies in accordance with the tenets of the Helsinki Declaration and has been approved by the authors' institutional review board or equivalent committee; or: The research related to animal use has been complied with all the relevant national regulations and institutional policies for the care and use of animals.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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