RESEARCH ARTICLE

SAMRIDDHI Volume 15, Issue 3, 2023 Print ISSN: 2229-7111 Online ISSN: 2454-5767

Design of FOPID Controller for Optimizing AVR System using Harris Hawk Algorithm

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ABSTRACT

The Automatic Voltage Regulator (AVR) system takes care of maintaining the terminal voltage of the generation unit within safe limitations. But the performance is irregular and delayed. A controller is used in conjunction with the AVR system to improve this. In Automatic Voltage Regulator the FOPID Controller is the main component. FOPID beats the other controllers in terms of its control capabilities and tuning adaptability. The basic role of this examination is to decide how best to utilize this idea while making automatic voltage regulators(AVR), But the Tuning is more complicated due to FOPID's additional parameters (λ and μ). To overcome complexity in this research, the Harris Hawk optimization (HHO) technique is based on a bionic intelligent optimum tuning approach. Gains in FOPID efficiency may be maximized by eliminating absolute error in integral time (IATE), or Fitness Function. MATLAB/SIMULINK is used to double-checkthe findings, which the findings of a comparison between the suggested HHO-based optimum AVRdesign and a previously published GBO-based optimal design of AVR demonstrate that the former delivers the superior dynamic response andincreased stability.

Keywords- Automatic voltage Regulator, Fractional Order PID Controller, HHO Optimizer,Optimal control design**.**

SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology (2023); DOI: 10.18090/samriddhi.v15i03.01

INTRODUCTION

An Automatic Voltage Regulator (AVR) is a major component of any synchronized generator- based power infrastructure, serving to maintain a constant output voltage regardless of the load. If voltage fluctuations are not managed, they may shorten the life of connected devices, trigger malfunctions in those devices, and, in the worst- case scenario, bring the whole power grid to its knees. Failure of the power system might result if the appropriate control component does not dampen such oscillations. Therefore, maintaining the system voltage at the specified value with adequate regulation is critical for the stable functioning of any power grid. To achieve favourable outcome with an AVR system, it is essential to use appropriate controller gains. As a result of its dependability and simplicity of implementation, the Proportional, Integral, and Derivative (PID) controller is often employed in AVR control systems. In addition to these, controllers are positioned from the control system, making the system a closed-loop system that can conduct the job precisely. The controller adjusts the system's output to the desired output by comparing the input and output to provide an error signal. One device that can reduce the error signal and provide it to the system is a controller. In the control system, there are various controllers are there. Combinations and/or isolated uses of the three distinct controller types—Proportional (P), Integral (I), and Derivative (D)—are common. PID controllers are one that can be used frequently and have an advantage over all three separate P, I and D controllers, thus they may produce better results than usual. Using fractional calculus, we constructed a fractional order PID controller and supplemented the control system with a FOPID, which may provide more reliable results and be more useful for complicated systems. Fractional calculus has a connection to both past and present time. criteria that follow.

The primary priority of optimizing an AVRsystem is to limit transient changes in its output voltage for nominal input and stabilize the output within safe limits even when noise, load disturbances, and modeling errors are introduced to the system. Numerous researchers have attempted to enhance the AVR system using various optimization methods.

In order to optimise the AVR system, the majorobjective of this research is to create an optimal FOPID controller based on the Harris Hawk Algorithm (HHA), which is based on a bionic intelligent optimum tuning approach was used to optimise the FOPID-AVR system, and the outcomes were compared to those of other techniques that had already been used.

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How to cite this article: Samasani, J.S.V., Krishna, B.T. (2023). Design of FOPID Controller for Optimizing AVR System using Harris Hawk Algorithm. *SAMRIDDHI : A Journal of Physical Sciences, Engineering and Technology,* 15(3), 276-281.

Source of support: Nil

Conflict of interest: None

The paper is divided into four sections for its possesses. This work is introduced in Section I, Block diagram representation of AVR System in Section II., FOPID Controller based AVR System discussed in Section III.a brief description of HHO tuning of a FOPID controller for AVR system optimization is provided in Section IV. The outcomes of the HHO-based FOPID controller and the GBO-implemented technique are discussed and compared in Section V. This paper is concluded in Section VI.

Automatic Voltage Regulator

Figure (1) depicts the block diagram representation of an AVR, which contains the Regulator, Amplifier, Exciter, Generator, and Sensor. A voltage sensor is utilized to recognize the generator's resultant voltage, which is then shipped off a comparator. The comparator circuit produces the equivalent error signal (e v) after the two inputs are compared. After the signalhas been amplified, the regulated flux required to produce electricity at the required voltage level is generated by the exciter circuit, which the input then enters. Overshoots and undershoots will be larger before the voltage stabilizes at the target value if the controller is not properly connected. So, it is properly connected.

Fopid Controller

Representation of FOPID Controller

FOPID is the extension of PID and it is developed from fractional calculus. The FOPID controllerhas extra parameters compared to PID. Those are λ, μ and these called as fractional parameters. Here K_P = Proportional gain, K_i = Integral gain, K_d = derivative gain, λ, μ fractional components the parameter of FOPID controller is designed by adopting any of the techniques or algorithms.

$$U(s) = E(s)\,[K_P + K_I S^{-\lambda} + K_D S^{-\mu}]$$

FOPID based AVR system

All of the AVR subsystems in Figure (3) have Laplace transformed, frequency domain regulating equations. All five AVR parts are the FOPID Controller, Amplifier, Exciter, Generator, and Sensor have been modelled as transfer functions, which are shown in the following equations.

$$G_{FOPID}(S) = K_P + K_I S^{-\lambda} + K_D S^{-\mu} G_A(S) = K_A / 1+ST_A \; G_E(S) = K_E / 1+ST_E \; G_G(S) = K_G / 1+ST_G \; G_S(S) = K_S / 1+ST_S$$

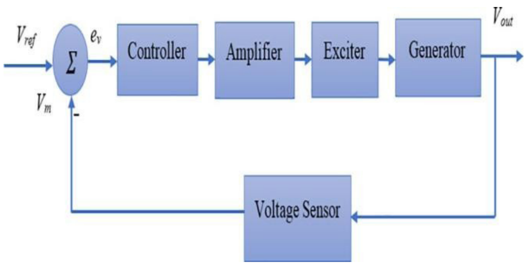

Figure1: Block diagram representation of automatic voltage regulator system

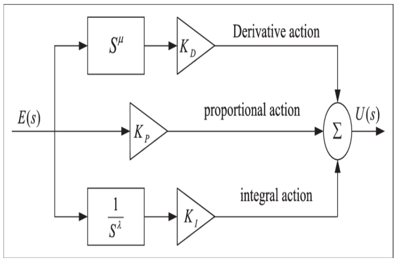

Figure 2: Representation of FOPID controller

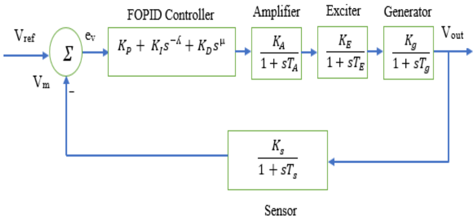

Figure 3: FOPID based AVR system

Table 1: Below table displaying the selected values, gains, Adjustable Valve Timing System Parameters.

Harris Hawk Optimization

Haidari may have been working on a bionic intelligent optimization rule similar to the Harris Hawks optimization (HHO) technique. The rule simulates Harris Hawks' foraging techniques and the stages of exploration, siege, and assault to replicate the gazing behaviors of these two phases. The HHO rule is a powerful optimization approach that does not need a gradient and may be implemented quickly and easily. it's been with success accustomed solveoperate optimization issues and different engineering application issues with smart results.

Table 2: Analysing the proposed work alongside a recently published AVR design that went through 30 iterations.

Simulation Results Internal Parameter Variations

Gain variations

In an AVR, the Amplifier, Exciter, Generator and Sensor all have different time constants, and modifying any one may have

Table 1: Adjustable valve timing system parameters

parameter	Name	Value
K_A	Amplifier gain	10
K_E	Exciter gain	1
K_G	Generator gain	1
K_S	Sensor gain	1
T_A	Amplifier time constant	0.1
T_E	Exciter time constant	0.4
T_G	Generator time constant	1
T_S	Sensor time constant	0.01

drastic effects on the device as a whole, were analyzed and shown graphically. It is crucial to highlight the importance of evaluating a control system's efficacy in delivering stable functioning of the system over a range of parameter fluctuations while discussing its design.

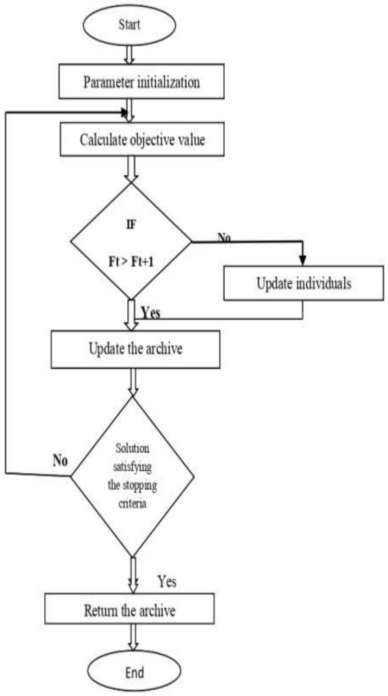

Figure 4: Flow chart for HHO algorithm

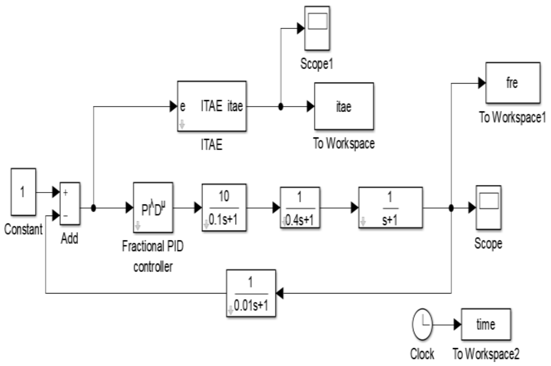

Figure 5: SIMULINK model of HHO based AVR tuning

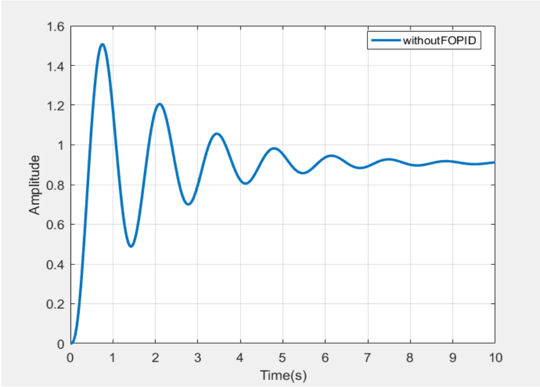

Figure 6: Without FOPID controller in AVR system

Table 2: Analysing the proposed work alongside a recently published AVR design that went through 30 iterations

S. NO	*Criteria (Best Solution)*	*Value*
1.	HHO	0.00072656
2.	GBO	0.005283702

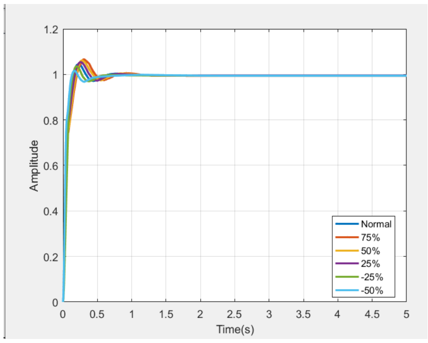

Figure 7: Amplifier Gain changes from -50 to +75%

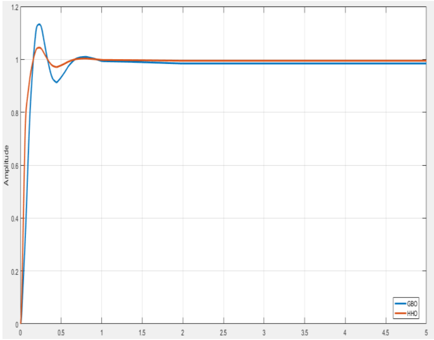

Figure 8: Comparison in Amplifier gain changes

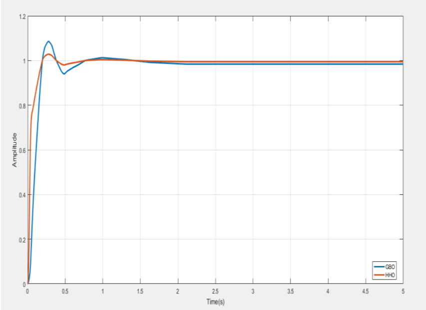

Figure 9: Exciter Gain changes from -50% to +75%

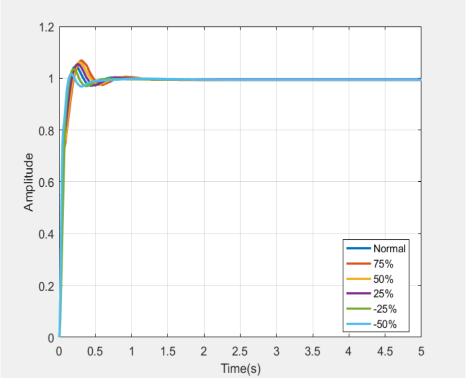

Figure 10: Comparisons in Exciter Gain changes +75%

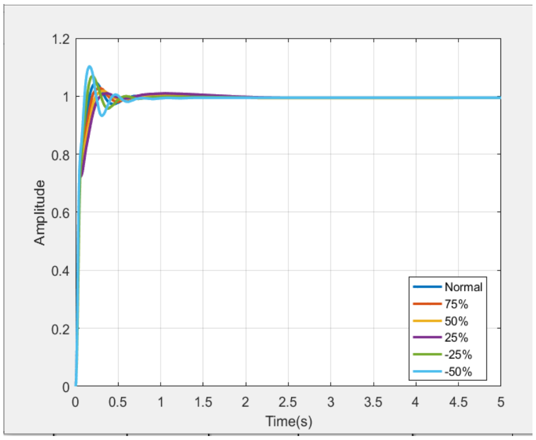

Figure 11: Generator gain changes from -50%

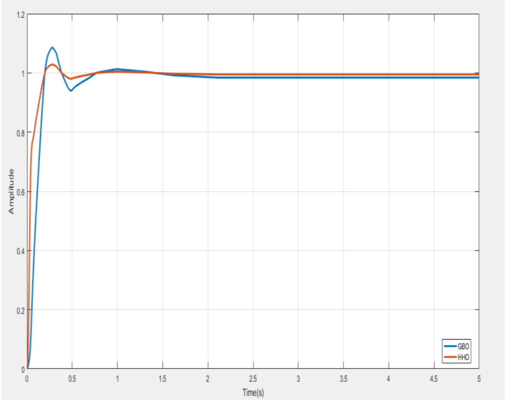

Figure 12: Comparisons in generator gain changes

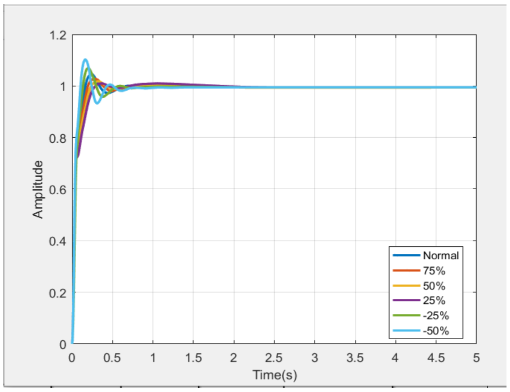

Figure 13: Sensor gain change from -50% to +75%

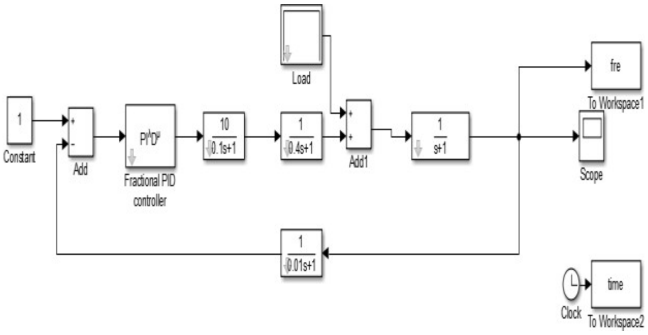

Figure 14: comparison in Sensor gain change

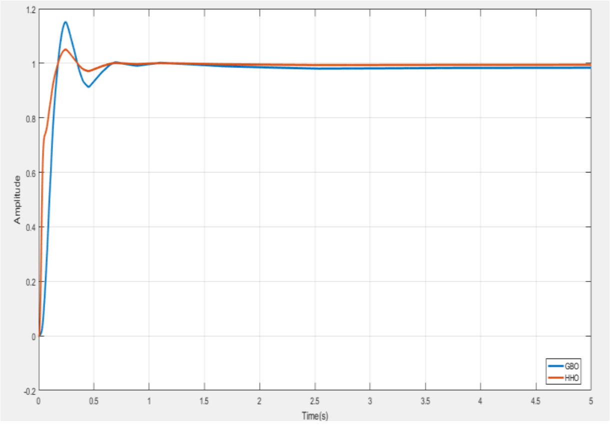

Figure 15: SIMULINK model for load disturbance in AVR system

External Parameter Variations

Effect of load disturbance in AVR system The suggested AVR's stability is put to the test here by subjecting it to varying loads. During the reproduction run, an additional heap of greatness 0.2 is applied and afterward eliminated at 1.5 s and 2.5 s, individually, to do the testing method. A fair correlation with other meta-heuristic based AVR arrangements is introduced beneath in Figure 16, as is the system's equivalent response. As can be observed in Figure 16, under the given loading circumstances, the suggested AVR design achieves the best dynamic response while maintaining the voltage at thedesired level.

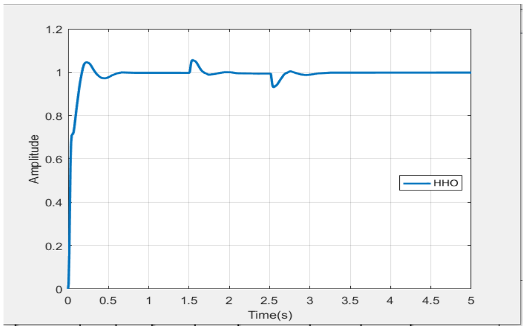

Figure 16: AVR designs under different loading conditions

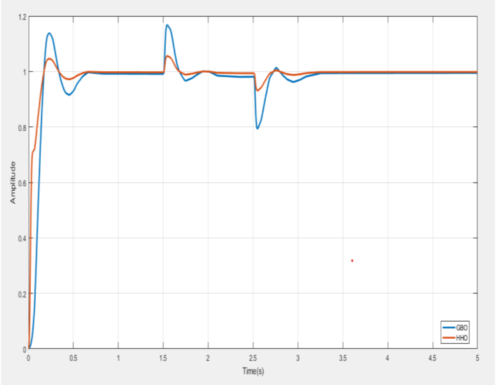

Figure 17: comparison in AVR Designs under various Loading circumstances

Noise test on the system

Evaluation of a control system's ability to reduce the impact of noise signals is crucial to its design, development, and implementation. Here, we simulate the noise in the measurements as white Gaussian noise with a power of 0.05. This is implemented at various stages in the simulation. Figure 18 displays the results of the proposed AVR design and how it stacks up against some existing widely used AVR layouts. Figure 20 shows that the suggested AVR outperforms the other AVR designs investigated by a wide margin when it comes to addressing the noise problem, validating its effectiveness and significance in the context of control engineering.

Convergence Curve

In order to get the most basic possible applied mathematical results from the predetermined algorithmic rule, it was necessary to run 30 simulations of the developed model. Since the centered development method relies on initially erratic product attributes, it is inherently stochastic. Figure 21 displays the results of the applied mathematics for the chosen range of simulation runs, namely the convergence behavior for the simplest run. Shows that the suggested

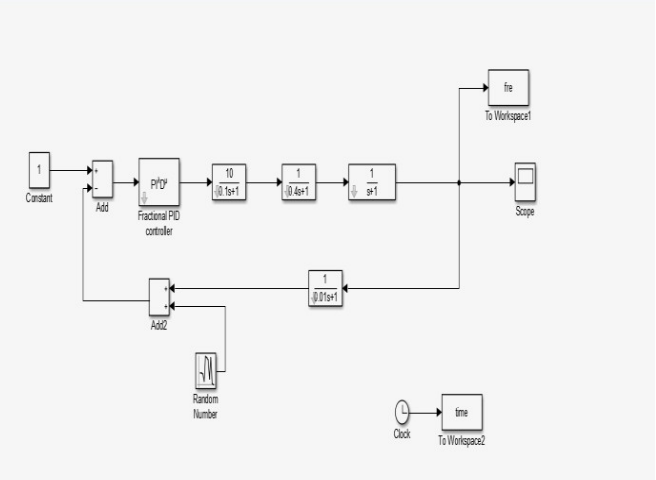

Figure 18: SIMULINK Model for AVR design with Noise effect

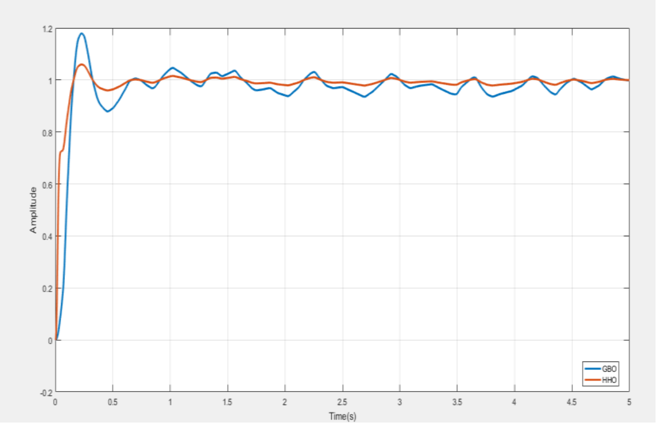

Figure 19: AVR design with Noise effect

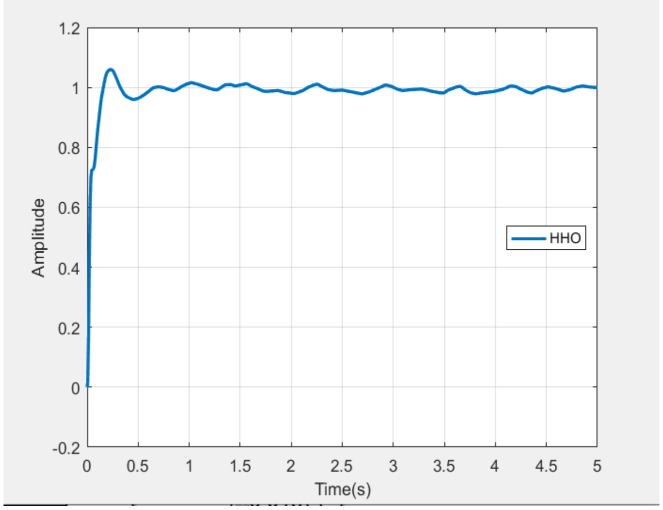

Figure 20: Comparison of AVR Design with Noise effect

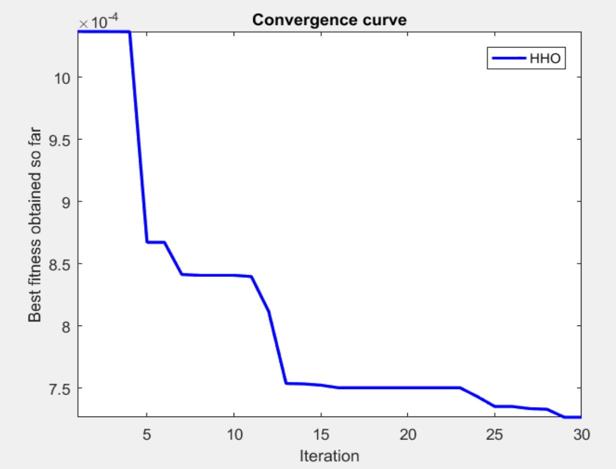

Figure 21: HHO Convergence Curve

Table 3: Optimized FOPID Gains Obtained after 30 iterations.

Parameter	*Value*
K_P	1.2538
K_I	1.0632
K_D	0.8235
λ	0.5347
μ	1.9832

Table 4: Dynamic response evaluation of proposed HHO based AVR Design.

FOPID tuning method	*Peak Value (p_v)*	*Percentage Overshoot (%MP)*	*Rise time (t_r)*	*Settling time (t_S)*	*Peak time (t_P)*
HHO FOPID (Proposed)	1.104	10.5	0.08826	0.463	0.176
GBO FOPID	1.110	11.3	0.0885	0.653	0.161

enhancement approach is able to provide a high-quality image at a fair convergencerate. In precisely thirty iterations of the simulationrun, the HHO algorithmic method produced the minimal value, i.e., 0.000728370, proving its efficacy in determining the present improvement downside.

CONCLUSION

In this study, the HHO algorithm, a cutting- edge optimization method, looks at the information to perceive how it very well might be utilized to assemble the best FOPID-based AVR framework practical. For ideal execution, the FOPID Controller should be fine-tuned using the HHO technique by minimizing the error introduced by the integration of FF. By investigating the proposed AVR plan's dynamic responsiveness and power comparing the findings to those of recently published AVR designs operating under the same conditions, its veracity isestablished. Dynamic responsiveness is improved by the recommended HHO adjusted FOPID-AVR compared to the other AVR systems. All of this emphasizes the significance of continuing study.

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