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Design of fractional order PID for voltage regulation of an isolated power system using artificial rabbits' optimization

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Abstract

Voltage instability has a detrimental impact on economic productivity as the interruption of essential electrical power equipment leads to unwanted shut down. This instability results from variations in voltage at the generator terminal, which is normally brought on by a change in reactive power at the load center. A well-designed voltage regulation scheme has been devised to ensure that volatility instabilities-related power issues are addressed and mitigated through the Automatic Voltage Regulator (AVR). An intelligent Fractional Order Proportional-Integral-Derivative (FOPID) controller that was properly tuned for optimal parameters has been integrated to the AVR for better performance. The optimal FOPID gains are obtained by minimizing the selected Fitness Function (FF) that is chosen as Integral Time Absolute Error (ITAE) in this study, an AVR system equipped with FOPID controller was designed for voltage regulation of an Isolated Power System in a MATLAB/Simulink environment. Artificial Rabbits Optimization (ARO) technique was used in determining the optimal parameters of the FOPID; the results were compared to that of a Genetic Algorithm (GA) tuned FOPID and Particle swarm optimization (PSO) tuned FOPID controller. The voltage profile response obtained for FOPID using ARO have shown a lower overshoot of 20.7% and a faster-settling time(ts) of 1.25s as compared to that of GA and PSO-tuned controllers. The proposed ARO-FOPID AVR design has proven to be effective and essential, as the results demonstrated; it offers the most optimal dynamic response and increased stability among the AVR designs under consideration.

Keywords: Artificial Rabbits Optimization; Automatic Voltage Regulator; Fractional PID Controller; Isolated Power System

1. Introduction

Due to the dynamic nature of the power system, maintaining a constant real and reactive power demand is not achievable. While real power resulting from variable load demand has an impact on the system frequency, the reactive power component greatly affects the voltage stability of the network. In this context, voltage stability control and load frequency control are two crucial issues that must be addressed for quality power delivery [1].

Voltage quality is generally regarded as a key reliability index in modern power supply operations [2]. Enhancing power quality and resolving pertinent problems related to voltage stability can be achieved by incorporating a good automatic voltage regulator (AVR) [3]. The AVR controls the generator excitation system and ensures that the generator terminal voltage is well regulated for the desired stability [4].

However, inefficient oscillated transient response, maximum overshoot and steady-state errors are some of the major setbacks associated with the AVR system. Thus, implementing a closed-loop AVR control goes a long in improving the

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performance of the voltage regulation process [3]. Currently, a variety of controllers, including PID and PSS controllers are used for controlling automatic voltage regulation. The Proportional Integral Derivative (PID) controller, however, is recurrently used owing to its efficacy, straightforward design, ease of implementation, resilient nature, and a limited number of tuning parameters [3]. In various industrial operational loops, about 90% of the control systems employed are PID-based [5].

The objectives for designing controllers are stability, reference tracking, and disturbance rejection for the steady domain response [6]. The controller gains are available as tuning parameters for the Proportional Integral Derivative (PID) controller [7]. The error signal is quantified as a difference between the output signal and a reference signal used for the control process.

Large power distribution networks must keep the overall voltage profiles at an acceptable level at all times. Particularly for industrial processes, the connected equipment's are designed for a certain nominal voltage and frequency of operation and any aberration from the nominal case generally leads to a decrease in performance and reduction in life time of these equipment. Frequent fluctuations in the load of the power network affects the voltage profile and hence the power utility companies employ a wide range of devices like capacitor banks, on-load tap changing transformers [8]. In power generation systems, automatic voltage regulator (AVR) is utilized to maintain the terminal voltage of a synchronous generator at a specified level. The AVR controls the consistency of the terminal voltage by varying the exciter voltage of the generator [8]. Traditionally the PID controller has been used in the AVR loop due to its simplicity and ease of implementation [8]. importance of topic, making general statements about the topic and presenting an overview on current research on the subject. Your introduction should clearly identify the subject area of interest.

FOPID is a generalization of the PID controller using fractional order operators (integral and derivative). It is characterized by five parameters; the proportional gain, the integrating gain, the derivative gain, the integral and the derivative orders [9],[10]. The parameter tuning of FOPID controller is an important and critical issue compared to conventional PID controller. The FOPID ($PI^{\lambda}D^{\mu}$) controller was designed by Podlubny [11] in 1998. In addition to the three common tuning parameters (K_P, K_I, K_D) of the conventional PID controller, the FOPID ($PI^{\lambda}D^{\mu}$) controller possesses two additional control parameters, i.e., the order of fractional integration (λ) and order of fractional derivative (μ). These additional parameters in FOPID provide increased control flexibility and an added advantage of tuning the control system using respective error information at the cost of complex control strategies. On one hand, it possesses more degrees of freedom to design the controller, and, on the other hand, it means that it is more complex in its synthesis [12], [13]. In literature, several tuning methods have been proposed for the tuning of process control loop. The most popular tuning methods are: Ziegler- Nichols, Cohen-Coon, and Astra-Hagglund. Unfortunately, in spite of this wide range of tuning techniques, the optimum performance cannot be achieved. Several new intelligent optimization techniques have emerged in the past two decades like: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Simulated Annealing (SA), and Bacterial Foraging (BF) [12],[14],[15].

Recently, many authors have proposed fractional order PID (FOPID) controller designs for the automatic voltage regulator (AVR) [8], [16], [17]. In this work, a novel nature-inspired optimization paradigm is proposed called Artificial Rabbits Optimization (ARO) algorithm. The ARO-based tuning method is applied here to estimate the parameters of a PID controller. The obtained simulation results by ARO algorithm are compared with other algorithms reported in most recent literature. It is expected that the proposed method will be proficient in producing good solutions for optimization problems of fractional PID controller parameters.

2. Oscillations and stability encountered in power system

The ability of a power system network to regain its operational equilibrium state even after being subjected to disturbing forces is termed power system stability. In case the forces which hold the machines in synchronism with one another are sufficient to overcome the disturbing forces, then the system is said to be stable or in synchronism Stability problems are generally classified into two major categories; steady-state stability and transient stability [23].

i. Steady-state stability: refers to the ability of the power system to regain synchronism after small and slow disturbances, such as gradual power changes. An extension of steady-state stability is known as dynamic stability. Dynamic stability is concerned with small disturbances lasting for a long time.

ii. Transient stability: studies deal with the effect of large, sudden disturbances such as the occurrence of a fault. The sudden outage of a line or the sudden application or removal of loads [23].

When a steady-state power system encounters a disturbance, no matter how strong or weak, for an extended or brief period, it enters a transient state and begins to oscillate around the equilibrium point. A stable system reaches a new equilibrium point following the oscillation. Even if it reaches a different equilibrium position than it did before the disturbance, it is still referred to as stable. The capacity of the system to maintain synchronism after a disturbance is known as stability.

When oscillations occur during the transient period are persistent and undamped, a power system is classified as unstable. Weakly damped oscillation that lasted long enough could disconnect generators or continuously lessen bus voltage and prevents the power system from optimal performance. A different kind of instability which even occur without losing synchronism is due to the collapse of voltage due to the presence of large induction motor in the bus.

The variety of ways a disturbance can develop, which results in many types of oscillation leading to instability, created a necessity for establishing a classification for stability [19]. Based on the three primary power system parameters, the stability of the power system is widely categorized as follows; Active power support (frequency stability), Reactive power support (voltage stability) and Maintenance of synchronism (rotor angle stability).

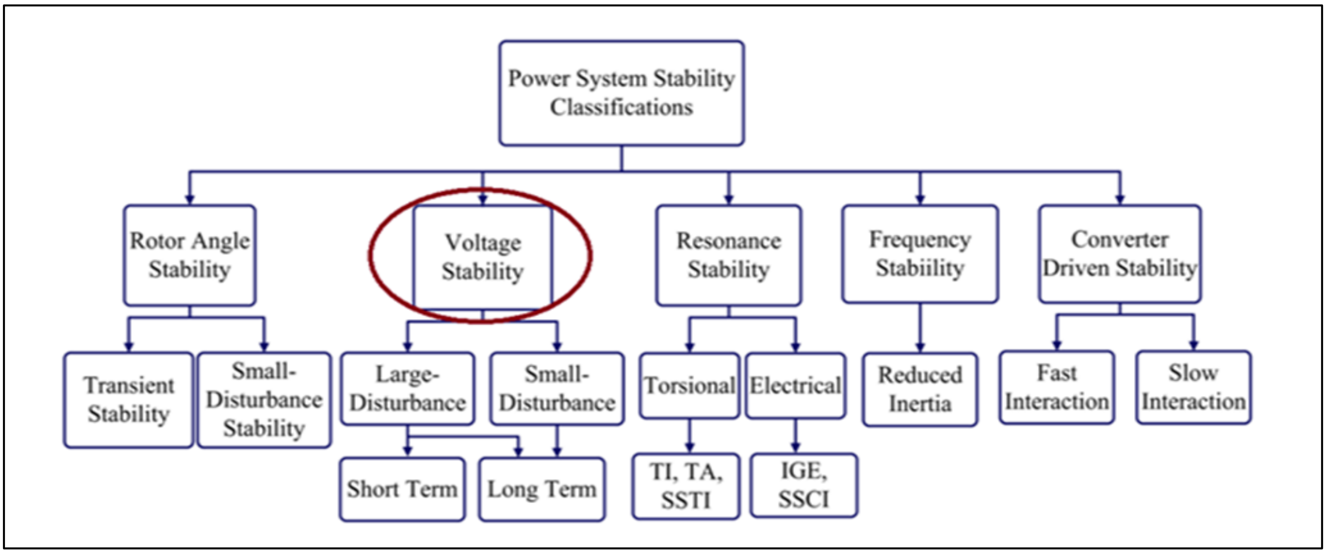

Figure 1 Types of Stability Encountered in Power System [19]

2.1. The automatic voltage regulator (AVR) system

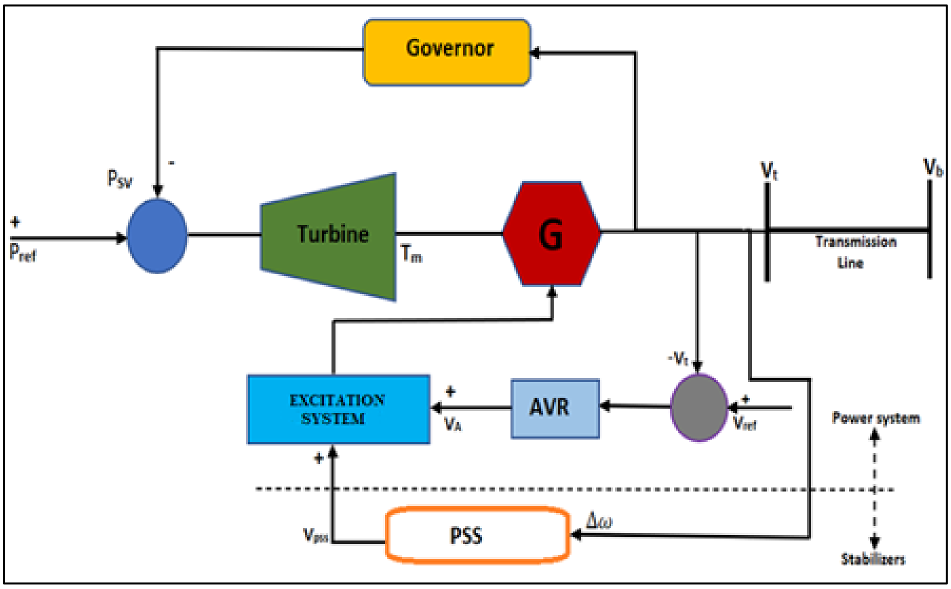

Figure 2 A Synchronous generator coupled to an AVR [20]

An automatic voltage regulator (AVR) is a solid-state electronic device for automatically maintaining generator output terminal voltage at a preset value. It does this as the generator is loaded or operating temperature varies. The AVR is part of a generator excitation system. The fundamental purpose of an AVR system is to use the excitation system to keep the generator's terminal voltage constant. However, a synchronous generator does not always operate at the equilibrium point because of various power system disturbances. The entire stability of the power system may be seriously impacted by these oscillations around the equilibrium state, which can result in variations in voltage and frequency. Excitation systems that are AVR-equipped are used to improve the power system's dynamic stability and to give consumers high-quality energy. Given its significant function, designing an AVR system is an essential and challenging undertaking. A controller, amplifier, exciter, generator, sensor, and generator constitute a typical AVR system. A schematic diagram of an AVR coupled to a synchronous generator (G) is illustrated in Figure 2.

2.2. The fractional order PID (FOPID) Controller

In the last decade, fractional-order dynamic systems and controllers are being studied widely in many areas of engineering and science. The concept of the fractional-order PID(FOPID) controllers was proposed by Podlubny in 1998. He also demonstrated the better response of this type of controllers, in comparison with the classical PID controllers, when used for the control of fractional order systems. Fractional order control systems are described by fractional order differential equations. The FOPID controller is the expansion of the conventional PID controller based on fractional calculus [11]. The orders of integration and differentiation are respectively λ and μ (both positive real numbers, not necessarily integers). Taking λ=1 and μ =1, we will have an integer order PID controller. So, we see that the integer order PID controller has three parameters, while the fractional order PID controller has five. It can be seen from the comparison that while using the FOPID controller tuned by Ziegler Nichols the overshoots obtained is less as compared to the case when the PID Controller was tuned via conventional methods i.e. Ziegler Nichols and Cohen Coon method. The settling time is also lesser in case of the FOPID controller, also the rise time is reduced. The FOPID controller tuned by Z-N tuning rule tends to faster response of AVR. It can be observed [30] that the PID controller tuned by Ziegler Nichols and Cohen Coon have larger overshoot than FOPID controller attain a steady state with larger settling time. A block diagram of an AVR coupled to a FOPID ($PI^{\lambda}D^{\mu}$) is illustrated in Figure 3.

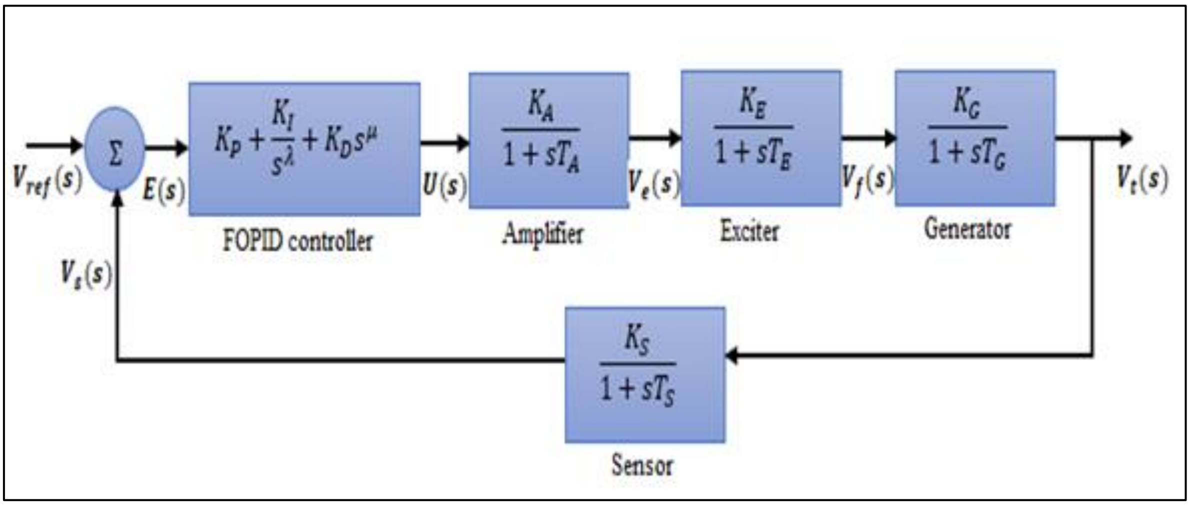

Figure 3 Block diagram of an AVR compensated with FOPID controller [30]

2.3. An overview of optimization techniques

There are numerous optimization techniques in existence and new ones are being developed every day. The discussion here is focused on the techniques that commonly used in engineering optimization applications, it is important to understand that there is no single optimization algorithm in existence that can solve all optimization problems. Some knowledge of various optimization algorithms available will help the researcher to decide the appropriate algorithm for the problem at hand [20,21].

This optimization method was introduced in the 1960's and still gain acceptance due to its effectiveness in providing optimal or near optimal solutions. It is classified into two;

- Heuristic Algorithms: It is an algorithm based on stochastic process which involves finding near-optimal solution to an optimization problem.

- Metaheuristic Algorithms: This technique approaches towards the best solution to a problem; it is inspired by bio-mimicry or other natural entities and is reliable [22].

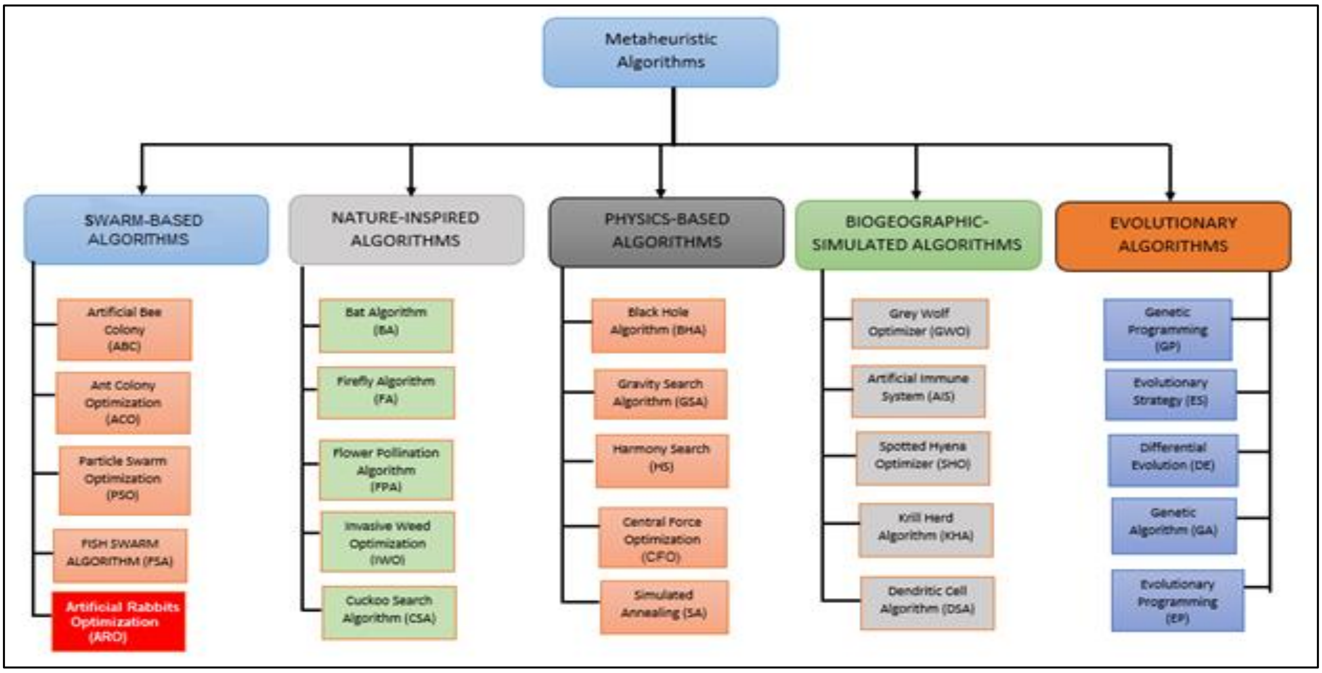

Figure 4 Classification of Metaheuristic Techniques [23]

Figure 4 Illustrates classifications of optimization methods according to the factors that inspired their design and mode of operation, this work is going to employ the use of some of these optimization methods where applicable.

2.4. Artificial rabbits' optimization (ARO)

Artificial Rabbits Optimization (ARO) is a metaheuristic algorithm inspired by bio-mimicry and was first proposed by Wang in 2022. It mimics the foraging habits and predator evasion survival strategies of rabbits in the wild [24]. Wild rabbits effectively utilize detour foraging and arbitrarily chose hiding spots to evade animals that prey on them for food. The detour foraging strategy is considered the explorative phase, the random hiding tactics is referred as the exploitation phase, while objective function is the training error between the desired output and the model output. Energy shrink of rabbits serves as basis for ARO to transition between foraging and hiding tactics, it amplifies both the exploration and exploitation. Initialization is the first step of any search algorithm. Taking into account the size of colony of the artificial rabbit which is denoted by *n, d*(dimension), upper and lower bounds are *ub* and *lb* respectively. The initialization is then carried out as follows;

$$\vec{z}_{i,k} = r.(ub_k - lb_k) + lb_k, k = 1,2...,d \qquad \text{.......................} (1)$$

$$\vec{z}_{i,k} = r.\left(V_{FOPID}^{max} - V_{FOPID}^{min}\right)V_{FOPID}^{min} \quad \dots\dots\dots\dots\dots\dots\dots (2)$$

where $\vec{z}_{i,k}$ denotes the position of the *jth* dimension of the *ith* rabbit and *r* is a random number in (0,1) that we are given along with it. V_{FOPID}^{max} *and* V_{FOPID}^{min} are upper and lower bounds of the FOPID respectively.

In ARO, each rabbit has *d*-burrows, the mathematical representation of the detour foraging is described as

$$\vec{v}_i = \vec{x}_j(t) + R.\left(\vec{x}_i(t) - \vec{x}_j(t)\right) + round\left(0.5.(0.05 + r_1)\right).n_1 \qquad \text{.......................} (3)$$

$$i, j = 1, \dots n \; and \; j \neq i \qquad \text{.......................} (4)$$

$$R = L.c \qquad \text{.......................} (5)$$

$$L = \left(e - e^{\left(\frac{t-1}{T}\right)^2}\right).\sin(2\pi r_2) \qquad \text{.......................... (6)}$$

$$C(k) = \begin{cases} 1 & if\ k == g(l) \\ 0 & else \end{cases}.$$

$$k = 1, \ldots d\ and\ l = 1, \ldots, \lceil r_3 . d \rceil \qquad \text{.......................... (7)}$$

$$g = randper(d) \qquad \text{.......................... (8)}$$

$$n_1 \sim N(0,1) \qquad \text{.......................... (9)}$$

Where $\vec{v}_{i,k}(t+1)$ denotes the new position of the artificial rabbit, $i, j = 1, \ldots n$. $\vec{z}_i$ denotes the position of the *ith* artificial rabbit, and $\vec{z}_j$ represents arbitrary positions of artificial rabbits. The number of maximum iterations is T_{max}. $\lceil \cdot \rceil$ represents the ceiling function, which denotes rounding to the nearest integer, and *randper* represents a stochastic arrangement from 1 to d random permutation of integers. *r1,r2*,and *r3* are stochastic numbers from 0 to 1. *L* represents the running length, which is speed of movement during detour foraging and *c* is the mapping vector. Perturbation is mainly reflected by the normal distribution random number of n_1. The perturbation of the last term of (4) can help ARO avoid local extremum and perform a global search.

In random hiding tactics, which is the exploitation phase, rabbits randomly generate burrows to evade predators is first defined. The *ith* rabbit produces the *jth* burrow *b* by the expression;

$$\vec{b}_{i,j}(t) = \vec{z}_i(t) + H.g.\vec{z}_i(t), \qquad \text{...........(10)}$$

$$H = \frac{T_{max} - t + 1}{T_{max}}.n_2 \qquad \text{...........(11)}$$

$$n_2 \sim N(0,1) \text{.............. (12)}$$

$$g(k) = \begin{cases} 1 & if\ k == j \\ 0 & else \end{cases} \quad k = 1, \ldots d \qquad \text{............} \qquad (13)$$

where $i = 1, \ldots, N$ and $j = 1, \ldots, d$, and n_2 follows the standard normal distribution. *H* represents the hidden parameter that decreases linearly from 1 to ${}^1/_{T_{max}}$ with stochastic perturbations. H generally decreases during the iteration, hence maintaining a balanced transition from exploration to exploitation.

In an optimization algorithm, populations prefer to perform the exploration phase in the early stages and an exploitation phase in the middle and late stages. ARO depends on the energy of the rabbits to define a search scheme: the energy of rabbits reduces over time, thus causing the transition from exploration to exploitation. Energy factor in ARO can be defined as;

$$A(t) = 4\left(1 - \frac{t}{T_{max}}\right).\ln\frac{1}{r} \qquad \text{.........(14)}$$

where r is a given random number in *(0, 1).* Analysis indicates that the value of *A* decreases throughout the iterations, thus maintaining a balanced transition from exploration to exploitation [24].

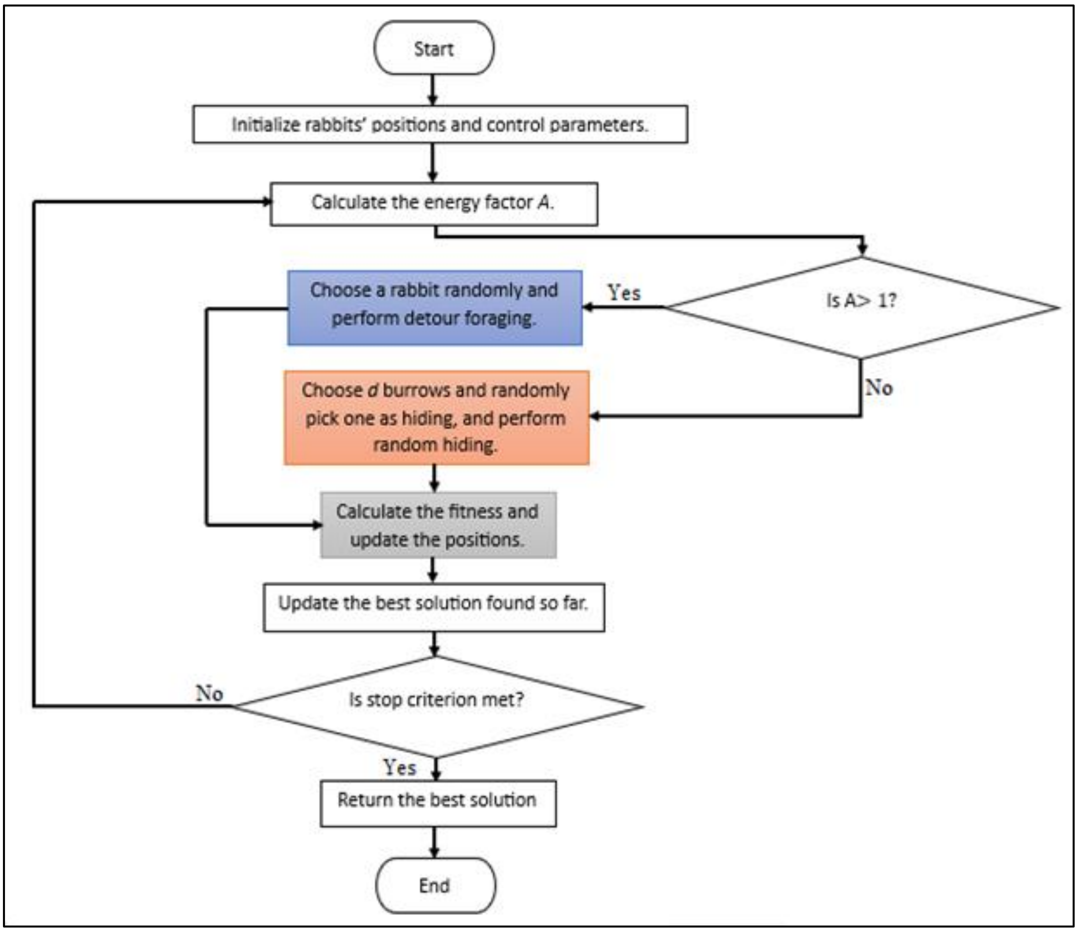

Figure 5 Detail flowchart of the proposed ARO algorithm [24]

2.5. Modelling of the isolated power system

In modelling the isolated power system for AVR study, the major parts of the system include; Controller Amplifier, Exciter, Generator and Sensor which are discussed in the following pages. An isolated power system is a power system that operates independently, without connection to a larger electrical grid or external power source. Figure 6 is a depiction voltage control mechanism for a conventional synchronous generator (SG) through an AVR for an Isolated Power System connected to a Mini Grid.

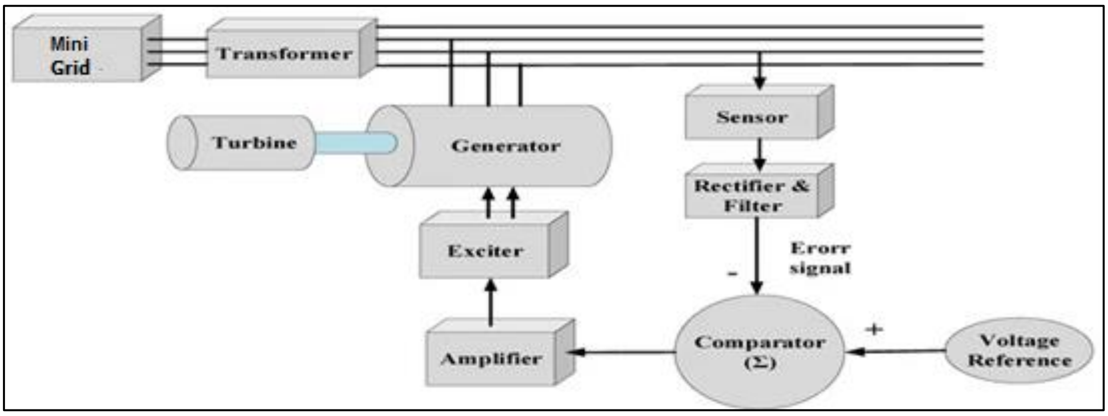

Figure 6 Conventional AVR for an Isolated Power System [29]

The block diagram for the ARO tuned FOPID in AVR for the Isolated system is shown in Figure 7.

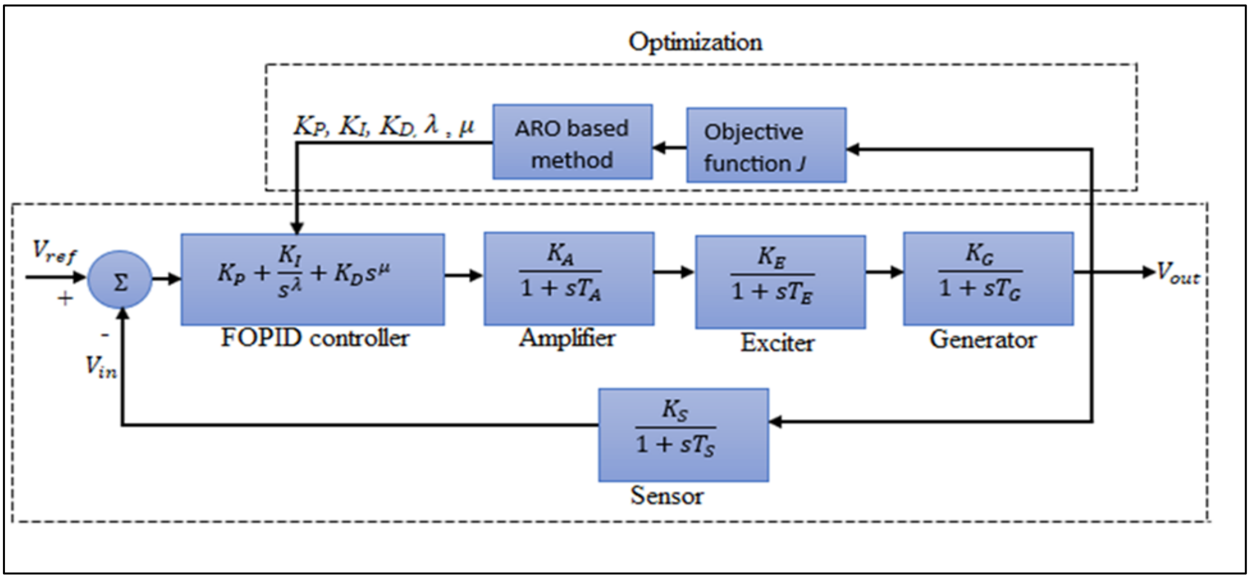

Figure 7 Block diagram of proposed ARO-FOPID optimized controller

2.6. Amplifier modelling

The amplifier might be a magnetic amplifier, rotating amplifier or electronic-based amplifier. The transfer function modelling of the amplifier can be derived from (15) [25].

$$\frac{V_{R(S)}}{V_e(S)} = \frac{K_A}{1+sT_A} \quad \text{.........(15)}$$

Where;
K_A = Amplifier gain
T_A = Amplifier time constant
V_e = Amplifier input signal
V_R = Amplifier output signal.

2.7. Exciter modelling

To design the generator exciter, there are various types of generator exciter models. Although, modern excitation systems are driven by solid-state power electronic devices. The transfer function of the exciter can be formulated from (16) [25].

$$\frac{V_F(S)}{V_R(S)} = \frac{K_E}{1+ST_E} \quad \text{......... (16)}$$

Where;
K_E =Exciter gain.
T_E =Exciter time constant
V_R = Exciter input signal
V_F = Exciter output signal.

2.8. Generator modelling

The model of the generator is derived from the synchronous machine's swing equation, which is described by (17) [25].

$$\Delta\omega\ (s) = \frac{1}{2Hs}(\Delta P_m(s) - \Delta P_e(s)) \quad \text{...........} \quad (17)$$

The voltage sensor is connected via a transformer and a rectifier circuit. The first order transfer function of the generator is formulated from (18) [25].

$$\frac{V_t(S)}{V_F(S)} = \frac{K_G}{1+ST_G} \text{...........} \quad (18)$$

Where;
K_G = Generator gain
T_G = Generator time constant
V_F = Generator input signal
V_t = Generator output.

2.9. Sensor modelling

Voltage is sensed through a potential transformer and rectified with a bridge rectifier. Using a first order transfer function, the sensor is modelled as shown in (19)[25].

$$\frac{V_S(S)}{V_t(S)} = \frac{K_S}{1+ST_S} \qquad (19)$$

Where;
K_S = Sensor gain
T_S = Sensor time constant
V_t = Sensor input signal
V_S = Sensor output signal.

2.10. FOPID controller design

The modelling equation for the FOPID is as shown in (20) [25]. A block diagram of FOPID-Isolated Power System is shown in Figure 8.

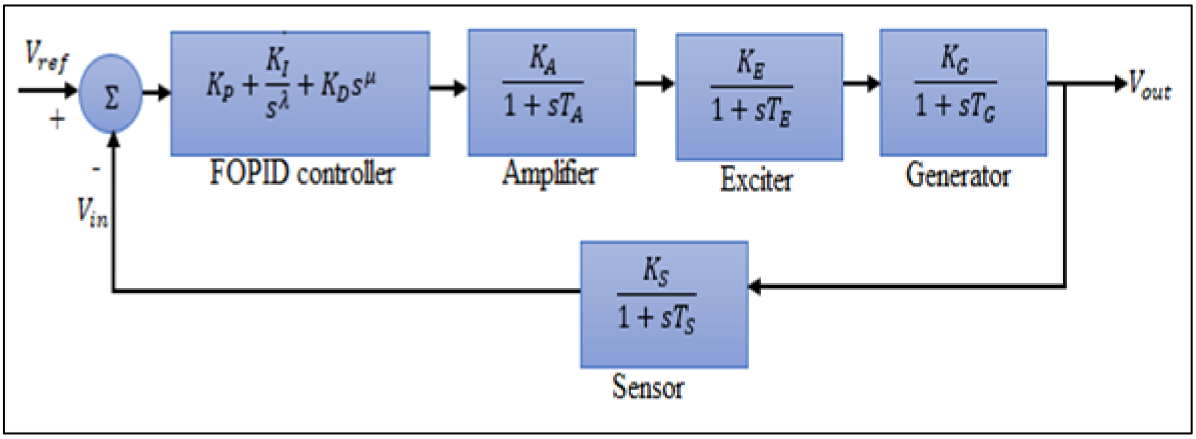

Figure 8 Block diagram of proposed FOPID-Isolated Power System [18]

$$K_P + \frac{K_I}{s^\lambda} + K_D S^\mu \qquad (20)$$

Where;
Kp = Proportional gain
K_I = Integral gain
K_D = Derivative gain
λ = Exponential of the integral
μ = Exponential of the derivative.

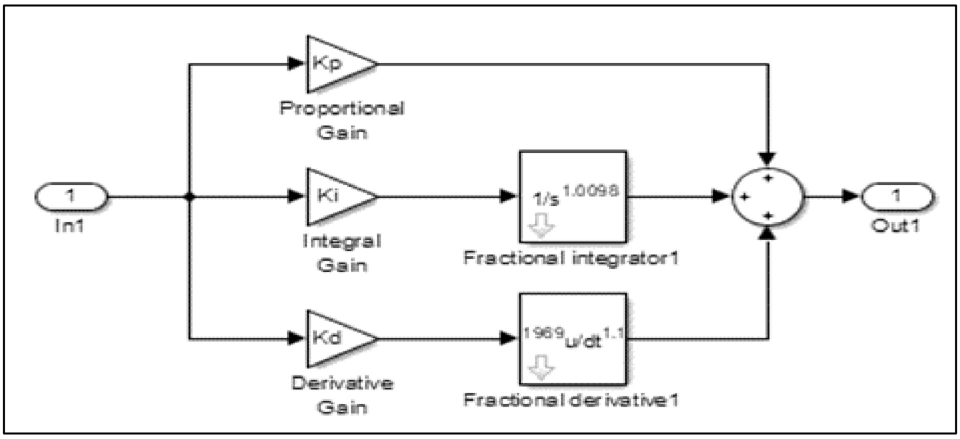

Figure 9 FOPID Controller SIMULINK Model

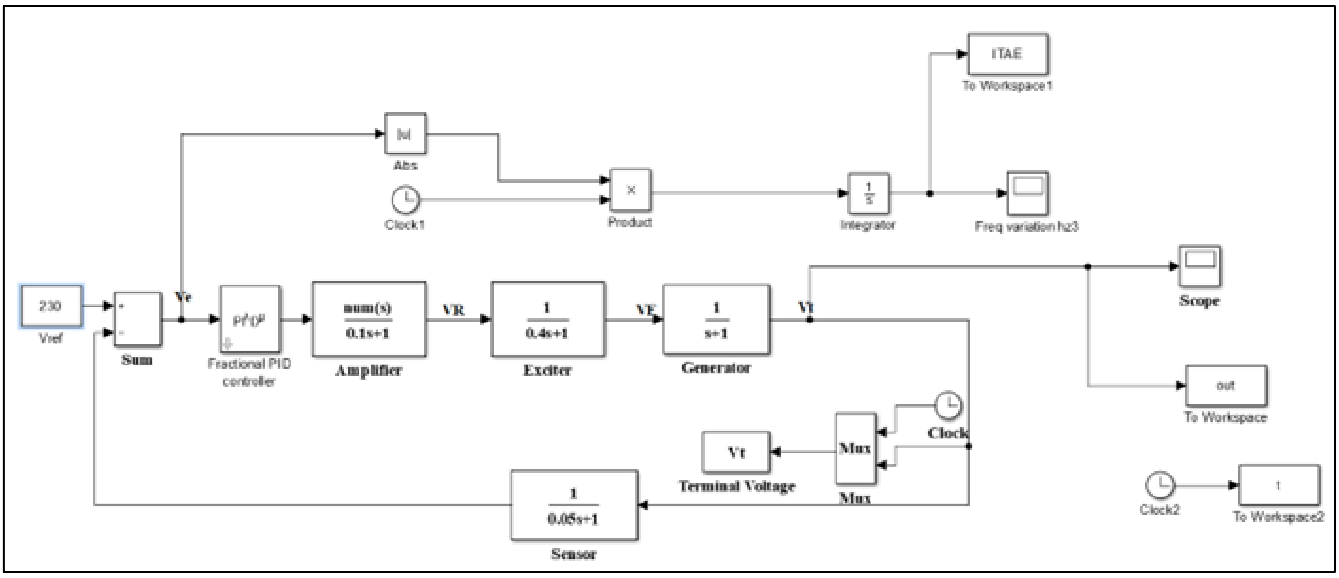

Figure 10 MATLAB SIMULINK AVR Model with FOPID Controller

Thus, for this simulation study, the respective gain and time constant parameters adopted are as presented in Table I [25].

Table 1 Gain and time constant parameters for the AVR system [25]

Components	**Gain Parameters**	**Time Constants**
Amplifier	$K_A=10$	$T_A = 0.1$
Exciter	$K_E=1$	$T_E = 0.4$
Generator	$K_G=1$	$T_G = 1$
Sensor	$K_S=1$	$T_S = 0.05$

2.11. Objective function

In this research work, optimum values of the controller will be calculated by minimizing the indices functions. The objective function is chosen for minimizing the time response characteristics due to the dependency of error on time e(t).

Where;

$$e(t) = V_{ref}(t) - V_{in}(t). \quad \text{..................} \quad (21)$$

The objective function is evaluated using integral time absolute error (ITAE) [18];

$$J = \quad ITAE = \int_0^{t_f} t|e(t)|dt \quad \text{...............}(22)$$

The problem can be represented as Minimize J Subjected to;

$$K_{Pmin} < K_P < K_{Pmax}$$

$$K_{Imin} < K_I < K_{Imax}$$

$$K_{Dmin} < K_D < K_{Dmax} \quad \text{...............}(23)$$

$$\lambda_{min} < \lambda < \lambda_{max}$$

$$\mu_{min} < \mu < \mu_{max}$$

Here, J indicates the objective function, V_{ref} and V_{in} is defined as desired output and the system output respectively.

2.12. FOPID optimization setup

The AVR design for the isolated power system requires the setting of a few optimization parameters. The parameter settings for the FOPID-based optimization are displayed in Table 2, and the algorithms under consideration are configured to function according to similar conditions.

Table 2 FOPID parameters configuration for the optimization processes

Parameters	**Settings**
Population	100
Number of Variables	5
Variables	K_P, K_I, K_D, λ, μ
Number of Iterations	100
Upper Boundary	[1.5, 1, 1, 2, 2]
Lower Boundary	[0, 0, 0, 0, 0]

3. Results and discussion

The ITAE criterion was used for this study. Optimal parameters obtained for the GA-FOPID are presented in Table 3, PSO-FOPID in Table 4 and ARO-FOPID in Table 5.

Table 3 GA-FOPID tuning parameters

	GA-FOPID				
	k_p	k_I	k_D	λ	μ
UB	1.5	1	1	2	2
LB	0	0	0	0	0
Gains	1.4981	0.8961	0.3945	1.0378	1.2287

Similarly, the PSO-FOPID gains were obtained based on ITAE criterion and are shown in Table 4.

Table 4 PSO-FOPID tuning parameters

	PSO-FOPID				
	k_p	k_I	k_D	λ	μ
UB	1.5	1	1	2	2
LB	0	0	0	0	0
Gains	1.1527	0.7154	0.3539	1.0076	1.1527

The optimal gains for the ARO-FOPID obtained based on ITAE criterion are also shown in Table 5.

Table 5 ARO-FOPID tuning parameters

	ARO-FOPID				
	k_p	k_I	k_D	λ	μ
UB	1.5	1	1	2	2
LB	0	0	0	0	0
Gains	1.4921	0.9987	0.3379	1.0098	1.1969

At the end of the optimization and simulations, various results were obtained from which the performance of the designed Automatic Voltage Regulator (AVR) control techniques are presented here therein. Design of robust Fractional Order PID (FOPID)-based controller for Voltage Regulation was carried out. Optimization was carried out to obtain optimal tuning parameters using Genetic Algorithm (GA), Particle Swarm Optimization (PSO) and Artificial Rabbit Algorithm (ARO) for an effective control mechanism.

3.1. Tunning parameters results or FOPID optimization

An overlay of the convergence curves for the GA, PSO and ARO using FOPID based on ITAE is shown in Figure 11.

3.1.1. The convergence curves

By comparison, ARO shows the fastest convergence at the 38th iteration, while GA and PSO converged at the 75th and 62nd iterations respectively.

The voltage stability waveforms of the modelled Isolated Power system were obtained from simulating it with FOPID-based tuning parameters presented in Table 3, Table 4 and Table 5.

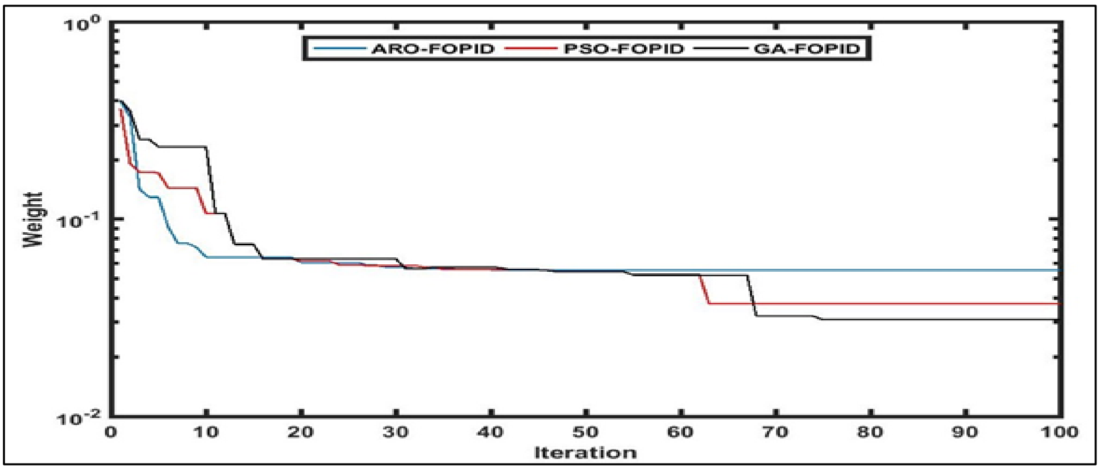

Figure 11 An Overlay of FOPID-Based Convergence Curves

3.1.2. GA-FOPID waveform

Considering the GA-FOPID, result indicated rise-time, (tr) lasted of 0.1239s, with a 25.29% overshoot and settling-time, (ts) of 1.8104s before stabilizing. There was a momentarily voltage spike of 280V before stabilizing at 230V.

After the simulations, the waveform obtained for the GA-FOPID is shown in Figure 12, based on optimal gains shown in Table 3.

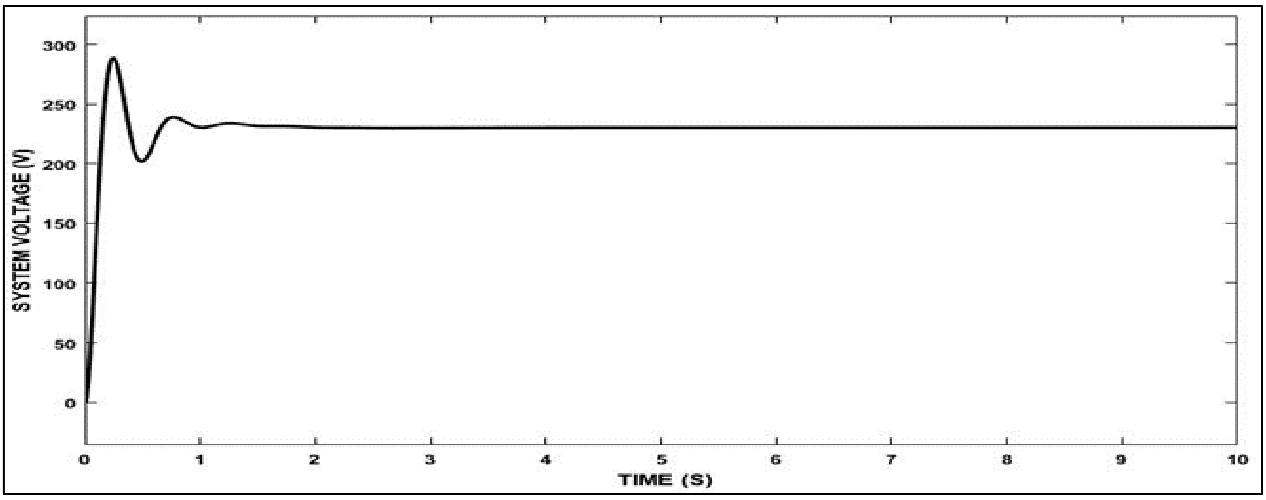

Figure 12 GA-FOPID Voltage Waveform

3.1.3. PSO-FOPID waveform

The PSO-FOPID result indicated (tr) lasted for 0.1325s, with a 25.27% overshoot and (ts) of 1.7132s before stabilizing. There was a momentarily voltage spike of 280V before stabilizing at 230V.

The voltage waveform shown in Figure 13 for PSO-FOPID is obtained from the optimal gain parameters in Table 4.

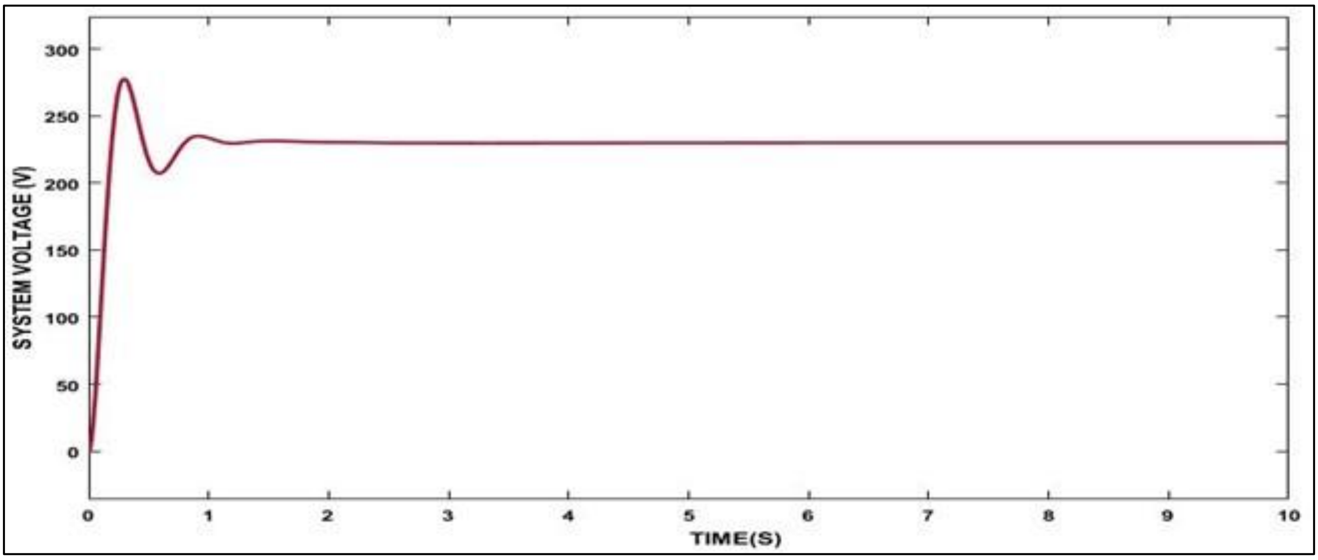

Figure 13 PSO-FOPID Voltage Waveform

3.1.4. ARO-FOPID waveform

The PSO-FOPID result indicated (tr) lasted for 0.1325s, with a 25.27% overshoot and (ts) of 1.7132s before stabilizing. There was a momentarily voltage spike of 280V before stabilizing at 230V.

Similarly, the voltage waveform for ARO-FOPID is depicted in Figure 14 is obtained from optimal gains in Table 5.

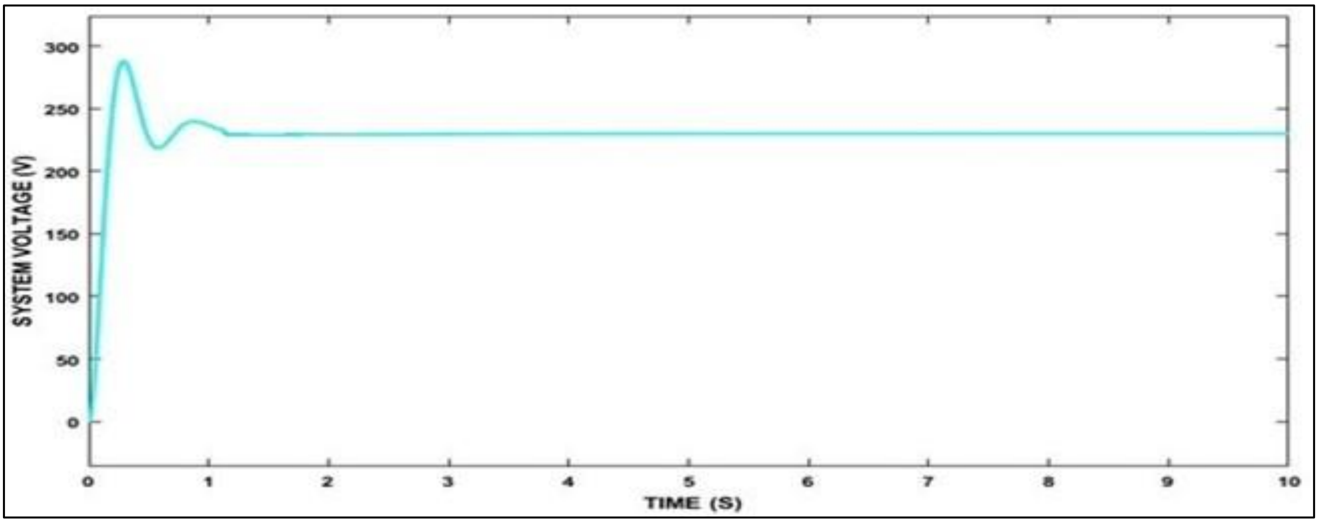

Figure 14 PSO-FOPID Voltage Waveform

The Artificial Rabbits Optimized FOPID controller based on ITAE criterion had the best result with convergence at the 38th iteration and a settling time (ts) of 1.2514 seconds, Genetic Algorithm and Particle Swarm Optimization techniques for the FOPID converged at the 75th and 62nd iterations respectively. Consequently, the Artificial Rabbits Optimization (ARO) technique evaluated based on Integral Time Absolute Error (ITAE) criterion for the FOPID controller surpasses the other optimization cases considered in this work.

Hence, ARO-FOPID had 30.88% and 26.96% improvement on GA-FOPID and PSO-FOPID respectively.

4. Conclusion

An FOPID, AVR of a synchronous generator in an Isolated Power System is modelled on a MATLAB/SIMULINK environment. The optimization problems concerning the design of a well-tuned FOPID controller for voltage regulation of the AVR of an isolated was addressed technically through exploring the use of some metaheuristic algorithms.

Artificial Rabbits Optimization (ARO) was applied for getting the optimal parameters of the FOPID controller, with a reference voltage of single-phase 230V. Results obtained using the Artificial Rabbits Optimization (ARO) was compared to that of Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) based controllers for performance evaluation. Thus, the effectiveness of the Artificial Rabbits Optimization (ARO) based controllers in the repression of voltage fluctuations was established through simulation and convergence profile analysis. This produced the best results in terms of rise time, settling time and overshoot for the AVR of the SGs in an isolated power system.

Hence, it is more effective to use ARO-FOPID controller for voltage regulation in the AVR of synchronous generators (SGs) in an isolated power system.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participant included in this study.

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