Design a Fractional Order PID Controller for Reduced Order of Automatic Voltage Regulator System

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Abstract

The lower-order model of fractional-order PID (FOPID) for an automatic voltage regulator (AVR) is reduced by the stability equation method. To improve the AVR system's performance in terms of transient and frequency response analysis, the memory capacity of the FOPID controller is lowered so that it can fit better in the corrective loop. The performance of the proposed Nelder-mead optimization algorithm based LOM-FOPID and FOPID controllers compares with other systems by Step response, root locus, frequency response, robustness test, and disturbance rejection abilities. The simulation results of the LOM-FOPID controller and FOMPID compare with those of other existing controllers by step response, bode and root locus. The proposed method also compares with random output noise for 2% and 20% of the amplitude of the reference input.

Keywords: fractional order proportional-integral-derivative controller (FOPID); low order system automatic voltage regulation (AVR), stability equation method, Noise Attenuation.

1. Introduction

In power systems, an automatic voltage regulator (AVR) is used to maintain the final voltage of the synchronous generator at a suitable level. The AVR system adjusts the terminal voltage constant by adjusting the excitation voltage of the generator [1,2]. Maintaining a constant input voltage in electrical systems has always been a difficult problem. During sudden changes in load due to power demand, AVR system is used to stabilize the voltage value. The AVR system is now attracting a lot of attention in the industry because it keeps the final voltage of the synchronous generator constant under all conditions. Classical-order proportional-integral derivative (IOPID) [3-5], Accelerated proportional-integral derivative (PID) [6], Fractional-order PID (FOPID) [7-9], PID plus second derivative (PIDD2). controller [10], modified neural network (MNN) [11], genetic algorithm (GA) [12], interval type 2 fuzzy logic (IT2FL) [13] and differential evolution algorithm for artificial electric fields (DE-AEFA) [14].

Similarly, the objective function can also be of any kind such as integral of squared error times time (ITSE) [15], integral of absolute error times time (ITAE) [16] , integral absolute error (IAE) [17] and integral square error (ISE) [18]. However, even for the same controllers, several optimization methods are available. Examples: Artificial bee colony (ABC) [15], Random fractal search [19], Whale Optimization Algorithm (WOA) [20], Advanced Whale Optimization Algorithm (IWOA) [21], sin-cosine algorithm (SCA) [22], tree seed algorithm (TSA) [23], particle swarm optimization (PSO) [24], advanced kidney-inspired algorithm (IKIA) [25], cuckoo search (CS) [26], genetic algorithms [12,27], multiple association optimization (MOL) [28], gray wolf optimization (GWO) [18], crow search algorithm (CSA) [29], water wave optimization (WWO) [30], local unilateral sampling (LUS) [31], water cycle algorithm (WCA) [32] and optimized ant colony mapping (ACO) [33], are optimization algorithms that have been proposed to tune the controller parameters of the AVR system. In the introduction. [14, 34].

By using Reduced Equation Method, it is possible to improve the performance of the PID controller in the AVR system. The FOPID controller (FOPID) is a type of classical PID controller that uses fractions instead of integers in the order of derivatives and integrals. Furthermore, compared with the full PID controller, FOPID provides better transient response and is more robust and stable [39–45]. Due to the previously stated

Component of AVR System	**Transfer Function**	**Gain Range**	**Time Constant Range [s]**
Ampifer	Ga = Ka / (1+Tas)	10 < Ka < 400	0.02 < Ta < 0.1
Exciter	Ge = Ke / (1+Tes)	1 < Ke < 400	0.4 < Te < 1
Generator	Gg = Kg / (1+Tgs)	0.7 < Kg < 1	1 < Tg < 2
Sensor	Gs = Ks / (1+Tss)	Ks = 1	0.001 < Ts < 0.06

advantages of FOPID, this study focuses on this type of controller. In this paper, a lower order method (LOM) of fractional order PID (FOPID) based on artificial bee colony (ABC) has been proposed. The IABC/FOPID controller approximation, distinguished by its long memory and integer order transfer function (or higher order approximation (HOA)), is named FOMCON TOOLS and requires the use of multiple parameters. number. To improve the performance of the AVR system in terms of transient and frequency response analysis, the memory capacity of the FOMCON tools controller has been reduced so that it can better fit into the control loop.

2. AVR System Description and Modeling

The basic role of an AVR system is to maintain a constant voltage at the generator terminals through the excitation system. A basic AVR system consists of four main components: amplifier, exciter, generator, and sensor. These components are represented by transfer functions [9,12,15] and modeled in the MATLAB/Simulink environment to study the dynamic performance of an AVR. A first-order transfer function with a gain and a time constant is used to represent each component of the AVR system. Table shows the transfer functions of the aforementioned components. The closed-loop block diagram of the AVR system without a controller is shown in Figure 1 along with the transfer functions.

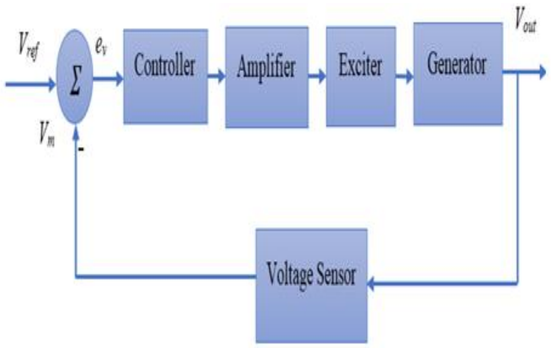


Figure.1 AVR Block Diagram

Table.1 Components of AVR system

To compare the results fairly, in this work, the AVR system's parameters are $Ka = 10$, $Ke = 1$, $Kg = 1$, $Ks = 1$, $Ta = 0.1$, $Te = 0.4$, $Tg = 1$ and $Ts = 0.01$, which are the same as in the research works [12, 15, 21, 23, 26, 28, 31]. The closed loop transfer function for the as the following equation given the model parameter values mentioned above.

$$G(s) = \frac{s^3 + 7s^2 + 24s + 24}{s^4 + 10s^3 + 35s^2 + 50s + 24}$$

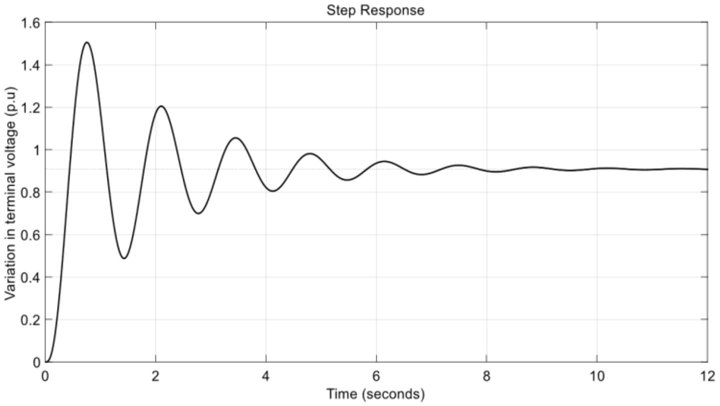


Figure.2 AVR Step response without controller

The AVR system's brief reaction traits most overshoot (**Mp** [%]), settling time (**ts** [**s**])and upward push time (**tr** [**s**]) with inside the absence of the controller.

Table.2 Response of AVR system

$$G(s) = \frac{0.1s+10}{0.0004s^4+0.045s^3+0.555s^2+1.51s+11} \qquad (1)$$

$$G(r) = \frac{0.18273s \quad +18.27273}{s^2+2.7607s+20.1} \qquad (2)$$

Controller Type	**Mp** [%]	**ts** [**s**]	**tr** [**s**]
Avr without controller	65.7226	6.9865	0.2607

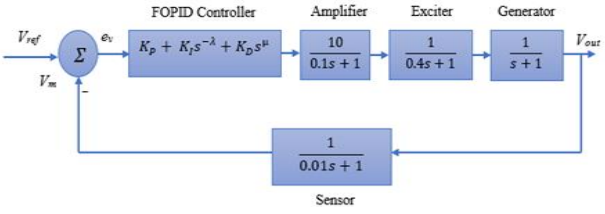


Figure.3 AVR model with values

The essential objective of an AVR framework is to direct the yield voltage of a control source by compensating for variances within the input voltage or stack changes. Usually accomplished through a closed-loop input control instrument. Let's look at the key components and their functionalities inside an AVR framework. The detecting circuit of an AVR framework measures the yield voltage and compares it with a reference esteem. The reference esteem speaks to the specified yield voltage level. The distinction between the measured voltage and the reference voltage is known as the mistake flag. The control circuit gets the blunder flag from the detecting circuit and processes it to produce a appropriate control flag. This control flag decides the alteration required within the yield voltage. The excitation framework is dependable for altering the field current of the generator or transformer to direct the yield voltage. It gets the control flag from the control circuit and alters the excitation level appropriately. Scientific displaying plays a significant part in understanding and analyzing the behavior of AVR frameworks. By speaking to the framework utilizing scientific conditions, engineers can anticipate its reaction to distinctive input conditions and optimize its execution.

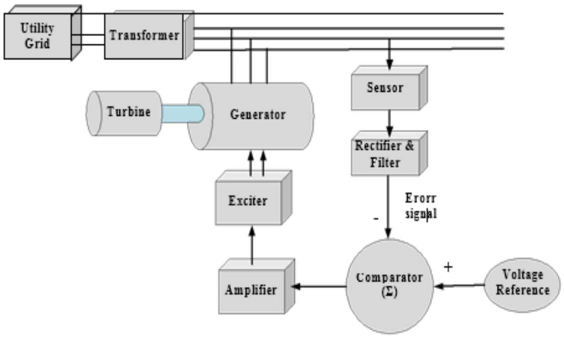


Figure.4 AVR System Conventional

3. Fractional order PID controller

FOPID controller has picked up much consideration both from the scholarly and mechanical point of view, as in rule they are more adaptable in comparison with the standard PID controller, were standard PID controllers have 3 controllable parameters, FOFID presented 2 modern parameters for a add up to of 5 such parameters. FOPID controller can be spoken to as. The two extra parameters of integration and of subsidiary moreover made the tuning of the unused FOPID controller more complex. The Fractional PID controller is the most popular kind of PID controller because of its original characteristics. There are various kinds of FOPID controllers, such as PID (λ = 1, μ = 1), PI (λ = 1, μ = 0), PD (λ = 0, μ = 1), and the P controller (λ = 0, μ = 0). The graphical representation of the various PID controllers is shown in Figure 5.

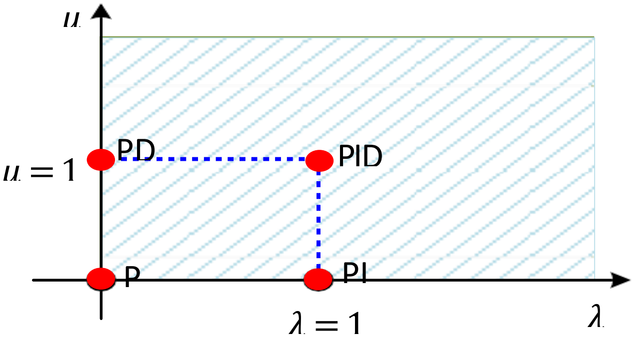


Figure.5 PID/PI$^{\lambda}$D$^{\mu}$ controllers' graphical representation.

4. Design of the FOPID Controller

An AVR system with an LOM-FOPID controller is shown in Figure . The FOPID controller to be optimized has a potential solution represented by a food source location, which is represented by a vector with five components, (X=K_p, K_i, K_d, λ, μ).

Controller Type	K_p	K_i	K_d	λ	μ
Stability equation{reduced}	99.9845	99.9905	100	0.98512	0.82545
proposed	0.00055915	8.7092	0.48257	0.99123	0.89921
PSO-PID [12]	0.6254	0.4577	0.2187	1	1
ABC-PID [15]	0.6352	0.4235	0.2241	1	1
CS-PID [26]	0.6198	0.4165	0.2126	1	1
MOL-PID [28]	0.5857	0.4189	0.1772	1	1
GA-PID [12]	0.8851	0.7984	0.3158	1	1
LUS-PID [31]	0.6190	0.4222	0.2058	1	1
TSA [23]	1.1281	0.9567	0.5671	1	1

Table. 3 Gain parameter of the reduced stability equation and other compared controllers.

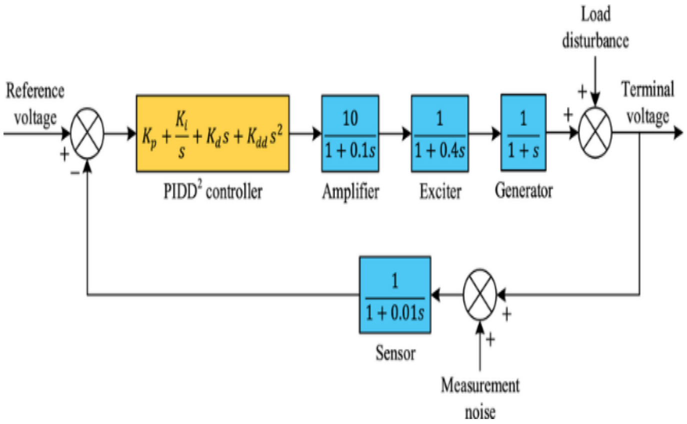


Figure.6 Proposed LOM-FOPID controller applied to the AVR system.

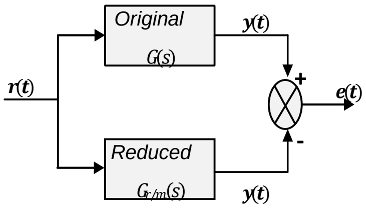
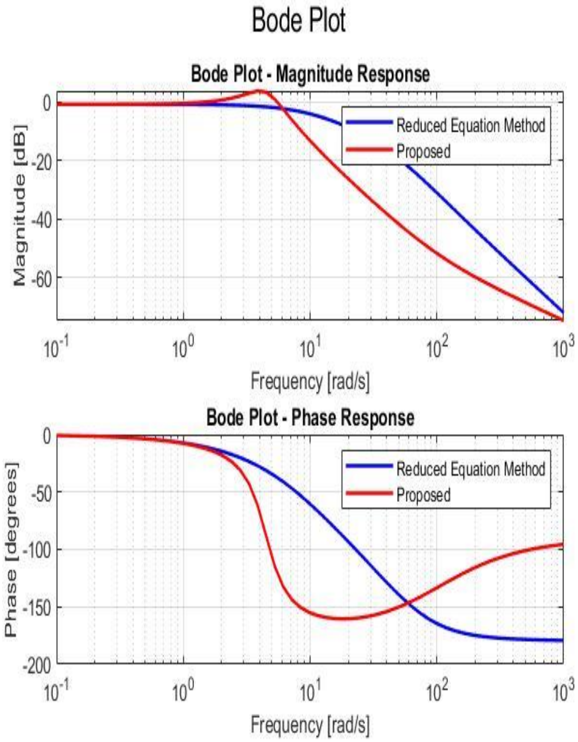


Figure.7 Sub-Optimal Reduction

5. Results and Discussion

Denominator of transfer function (1) reduced by stability equation method. The performance in managing the AVR system specified in Equation (1) is validated by the simulations that follow. The simulations were created using the MATLAB/SIMULINK software. Table 3 provides a list of the proposed and Reduced Equation method parameters with existing technique.



Figuure.8 Bode Diagram approximations

Figure 8 illustrates the bode diagram of reduced by stability equation method and proposed method of model.

$$G(pso) = \frac{0.02187s^3+2.25s^2+6.3s+4.557}{0.0004s^5+0.0454s^4+0.555s^3+3.697s^2+7.254s+4.577} \quad (3)$$

$$G(abc) = \frac{0.02241s^3+2.304s^2+6.395s+4.235}{0.0004s^5+0.0454s^4+0.555s^3+3.75s^2+7.352s+4.235} \quad (4)$$

$$G(cs) = \frac{0.02126s^3+2.188s^2+6.24s+4.165}{0.0004s^5+0.0454s^4+0.555s^3+3.636s^2+7.198s+4.165} \quad (5)$$

$$G(mol) = \frac{0.01772s^3+1.831s^2+5.899s+4.189}{0.0004s^5+0.0454s^4+0.555s^3+3.282s^2+6.857s+4.189} \quad (6)$$

$$G(Ga) = \frac{0.03158s^3+3.247s^2+8.931s+7.984}{0.0004s^5+0.0454s^4+0.555s^3+34.668s^2+9.851s+7.984} \quad (7)$$

Figure 9 present the results of the step response analysis for AVR control systems designed using different approaches. LOM-FOPID terminal voltage comparison with existing technique PSO-PID[12], ABC-PID[15], CS-PID[26], MOL-PID[28], GA-PID[12].

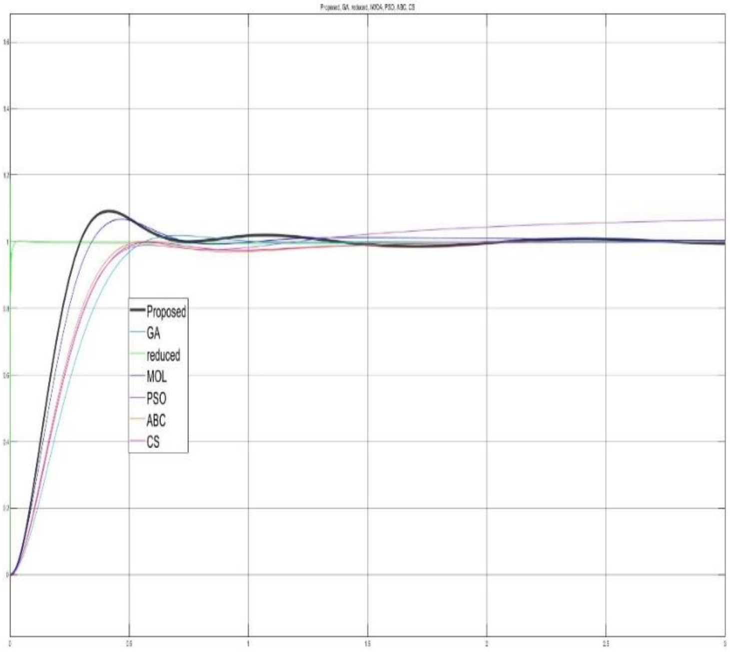


Figure.9 Transient Response Analysis Comparison

According to below figure 10 a superior time response than others. The different parameter such as rise time, settling time, and overshoot percentage has superior output than others technique.

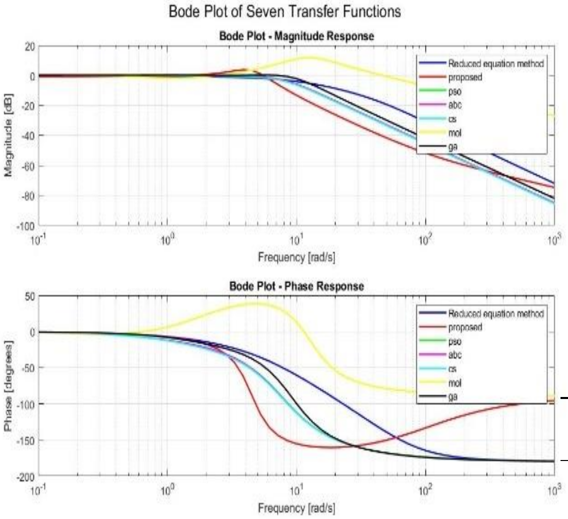


Figure.10 Bode Plots comparison with existing method

The execution records of most extreme overshoot values (Mp [%]) gotten with PSO-PID [12], ABC-PID [15], CS-PID [26] and LUS-PID [31] have less overshoot and motions than the proposed controller. In any case, these controllers are slower in terms of rise time and settling time than other PID controllers. On the other hand, the proposed IABC/LOA-FOPID controller appears prevalent execution over the distinctive optimized PID controllers in terms of settling time and rise time. Moreover, the displayed calculation essentially diminishes the execution file esteem**.**

Controller Type	Maximum Overshoot M_p [%]	Settling Time t_s [s]	Rise Time t_r [s]	IAE
Reduced	2.3323	0.3129	0.1373	0.01193
Proposed	6.9064	0.6466	0.2266	0.1911
PSO-PID	0.4349	0.4609	0.3007	0.2917
ABC-PID	0.0081	1.2041	0.2957	0.2892
CS-PID	0.0198	1.1681	0.3082	0.2916
MOL-PID	1.9547	0.5154	0.3432	0.3086
GA-PID	8.6338	0.6055	0.2042	0.3048

Table.4 Comparative analysis of the transient response

Upper table 4 shows that the performance indices of maximum overshoot values (M_p[%]) obtained with PSO-PID [12], ABC-PID [15], CS-PID [26] have less overshoot and oscillations than the Reduced Equation Method. However, these controllers are slower in terms of rise time and settling time than other PID controllers. On the other hand, the proposed LOA-FOPID controller shows superior performance over the different optimized PID controllers in terms of settling time and rise time. Furthermore, the presented algorithm significantly reduces the performance index value.

6. Comparison of Frequency Domain Analyses

Bode plots with different controller settings are compared in Figure 8 and 10 below Table 5 summarizes the results of the comparative frequency response performance study. Gain margin (G_m: in decibels), phase margin (ϕ_m: in degrees) and bandwidth (B_w: in Hertz) are all parts of the performance criteria.

Controller Type	Gain Margin G_m [db]	Phase Margin φm	Bandwidth B_w [Hz]
Reduced	Inf	178.7980	15.7280
Proposed	Inf	161.6094	9.6571
PSO-PID [12]	Inf	173.8067	7.5015
ABC-PID [15]	Inf	180	7.6998
CS-PID [26]	Inf	180	7.3393
MOL-PID [28]	Inf	180	6.3391
GA-PID [12]	Inf	116.3886	10.6594

Table.5 Comparative analysis of frequency response

7. Noise Attenuation

Additive noise is considered in the input of the process to be regulated. Figures.11 depict the temporal response characteristics of different integer order and fractional order PID controllers with random output noise of 2% and 20% of the reference signal amplitude, respectively. The overshoot produced with the various integer order PID and fractional controllers is extremely similar, as shown in Figure11.

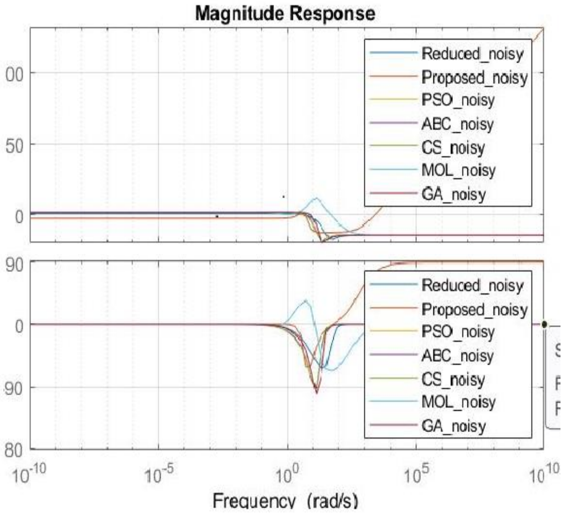


Figure.11Noise response with existing technique

8. Conclusion

In this paper, a low-order method (LOM) version of a fractional order PID (FOPID) primarily based totally Reduced by stability equation method for an automatic voltage regulator (AVR) become proposed. This method stepped forward at the overall performance of the FOPID controller, which necessitates the employment of a massive quantity of parameters. The brief and frequency reaction function parameters of the AVR system, including most overshoot, settling time, upward push time, bandwidth, advantage margin, and segment margin, have been evaluated the usage of the proposed LOM-FOPID and different present controllers including PSO-PID [12], ABC-PID [15], CS-PID [26], MOL-PID [28], GA-PID [12], The consequences display that the proposed controller stronger dynamic overall performance, specifically pace convergence, and is properly suitable for the AVR system. Furthermore, robustness, root locus, and Bode analyses have been used and in comparison to currently posted findings to illustrate the prevalence of the proposed LOM-FOPID reduced by stability equation method. The end result exhibits that the proposed technique has traits of excessive balance for AVR structures and plays higher in phrases of noise attenuation and disturbance rejection.

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