Comprehensive Journal of Science
Volume (10), Issue (37), (NOV. 2025)
SICST2025, www.sicst.ly
ISSN: 3014-6266

مجلة العلوم الشاملة
عدد خاص بالمؤتمر الدولي الثالث للعلوم والتقنية
المجلد (10)، العدد (37)، (نوفمبر2025)
ردمد: 3014-6266

Stability Analysis of Automatic Voltage Regulator with GA-PID Controller

Ahmed Mohamed Ali Altnazfti 1*, Ibrahim Mohammed Ali Tanazfti 2, Ali Ammar Omar Aburagibah 3 , Suleiman Salem Isa Nghab 4

1*-Higher Institute of Science and Technology-Zliten-Libya,
Email : ahmedaltnazfti@yahoo.com
2-Higher Institute of Science and Technology-Zliten-Libya
Email : eal.tanazfti@yahoo.com
3-Higher Institute of Science and Technology-Zliten-Libya,
Email : abwrgybhly23@gmail.com
4-Higher Institute of Science and Technology-Alazizia-Libya
Email : sulaiman61salem@yahoo.com

Received: 30-09-2025; Revised: 10-10-2025; Accepted: 31-10-2025; Published: 25-11-2025

الملخص

منظمات الجهد الآلية (AVRs) تُعتبر مكونات حيوية في أنظمة توليد الطاقة الكهربائية، حيث تضمن استقرار جهد الخرج لمولدات التيار التزامني. يتحقق هذا الاستقرار من خلال تعديل جهد الإثارة للمولد. ومع ذلك، قد تؤثر عوامل مثل تباينات الحمل وحثّ ملفات المجال في المولد سلبًا على أداء المنظم. تستكشف هذه الدراسة طريقتين مختلفتين لضبط متحكم PID (نسبي–تكاملي–تفاضلي) لتحقيق استجابة مستقرة وسريعة وفعالة للاضطرابات العابرة في الجهود الطرفية. تعتمد الطريقة الأولى على تصميم متحكم PID تقليدي باستخدام تقنية زيغلر – نيكولز، بينما تستخدم الطريقة الثانية الخوارزميات الجينية (GAs) لتحسين معاملات متحكم.PID .

تظهر نتائج المحاكاة أن المتحكم المعتمد على الخوارزمية الجينية يقلل بشكل ملحوظ من ثوابت الخطأ وزمن الصعود وزمن الاستقرار مقارنة بطريقة زيغلر – نيكولز. بناءً على محاكاة أُجريت باستخدام برنامج Matlab/Simulink ، فإن معاملات PIDالمحسّنة بالخوارزمية الجينية تقدّم أداءً أفضل للحلقة المغلقة. علاوةً على ذلك، يمتلك متحكم PID القائم على الخوارزمية الجينية قدرة محسّنة على رفض الاضطرابات ومقاومة أكبر لتباينات الحمل عند تتبع نقاط الضبط والتعامل مع اضطرابات الحمل.

Abstract:

Excitation systems are crucial components in electric power generation systems, ensuring a stable terminal output voltage from synchronous generators. The AVR achieves this voltage stabilization by modulating the generator's exciter voltage. However, factors such as load variations and the generator's field windings induction can negatively impact the regulator's performance. This study investigates two distinct PID (Proportional-Integral-Derivative) controller tuning methods to achieve a stable, rapid, and efficient response to transient disturbances in terminal voltages. The first method involves designing a classical PID controller using the Ziegler-Nichols technique. The second approach utilizes genetic algorithms (GAs) to maximize the parameters of the PID controller. According to simulation data, the controller based on evolutionary algorithms considerably lowers error constants.

, rise time, and settling time compared to the Ziegler-Nichols method. Based on simulations performed in Matlab/Simulink, the PID coefficients optimized by the genetic algorithm provide superior closed-loop output. Furthermore, the controller GA-PID exhibits enhanced disturbance rejection and resilience to load variations when tracking set points and managing load disturbances.

Keywords: (PID) Controller, Disturbance avoid and (GA) Genetic Algorithm, Ziegler-Nichol's method, set point, Mean Squared Error (MSE) Automatic Voltage Regulator (AVR).

1. Introduction

Maintaining a synchronous generator's terminal voltage magnitude at a predetermined level is the principal duty of an AVR. A simplified schematic representation of the AVR is shown in Fig. 1. It has been noted that when the generator's reactive power load rises, the terminal voltage magnitude decreases. A potential transformer in one phase is used to measure the voltage magnitude. After being rectified, this voltage is then contrasted with a reference voltage. The voltage at the exciter terminals rises as a result of the amplified error signal produced by this comparison controlling the exciter field. As a result, the generator's field current is increased, which raises the electromotive force (emf) produced. The generation of reactive power is escalated to a new equilibrium state, thereby fulfilling the requisite terminal voltage (Ula and Hasan, 1992). A brief examination of the components of the simplified AVR system will be undertaken (Saadat, 1999).

Despite the widespread application of the (PID) controller within the industrial domain, its parameters are frequently adjusted through trial and error or manual methods in conventional control systems. This limitation precludes the identification of the most effective function capable of encompassing all design objectives with varying characteristics across different processes and disturbances.

It is acknowledged that the dynamic and exceptional requirements of the energy system are incessantly evolving as consumer loads and industrial demands fluctuate. Consequently, the regulation of fuel input to a turbo generator or water input to a hydroelectric generator must be meticulously managed; otherwise, fluctuations in engine speed may ensue, leading to undesirable alterations in the performance of the drive system. In practical terms, while one may theoretically modify a condition to zero, operational constraints render this impracticable. Therefore, in the majority of scenarios, acceptable limits of deviation must be established. Significant alterations in conditions can adversely affect consumers and may inflict substantial damage to industrial equipment. Presently, all systems are inherently interconnected; hence, maintaining a constant frequency poses considerable challenges. The inefficiency of manual commands within expansive network systems has consequently necessitated the development of automated systems to address various issues, including communication delays .

Variability in frequency necessitates the development of a control system that is intrinsically robust and exceptionally adaptable. It is well-documented that over 90% of industries continue to utilize Proportional-Integral-Derivative (PID) controllers due to their straightforwardness, transparent performance metrics, and user-friendly nature. Nevertheless, numerous practitioners have noted that the PID controller conventionally employed does not meet satisfactory performance standards. Consequently, methodologies such as Genetic Algorithms (GA), among others, along with advanced control techniques, initially appeared to offer superior alternatives to conventional PID design; however, it subsequently became evident that these controllers were intricate and encountered significant robustness challenges in practical environments. The prevalence of PID controllers, coupled with inaccuracies in control systems, prompted researchers to recognize the necessity of integrating the simplicity of PID controllers with artificial intelligence. Empirical evidence has demonstrated that such hybrid controllers yield commendable performance under conditions characterized by measurement uncertainty and disturbance rejection. In scenarios involving disturbances and instability, the primary objective of this paper is to ascertain the optimal values for (Kp, Ki, Kd) in the context of PID control for AVR utilizing a Genetic Algorithm-based PID controller. This manuscript is systematically organized into the following sections: the preceding section serves as an introduction to the challenges and control systems addressed herein, while Section 2 delineates the model of the AVR for a single-area power system. Section 3 concentrates on the PID controller, detailing its tuning via the Ziegler-Nichols methodology. A succinct overview of the genetic algorithm is provided in Section 4. In Section 5, a simulation study is presented to illustrate the performance of the closed-loop system employing both of conventionally tuned and GA-PID control strategies. The concluding remarks and recommendations for future research endeavors are articulated in Section 6.

2. Model of AVR in Generation Power Plant

An Automatic Voltage Regulator AVR is designed to maintain the terminal voltage amount of a synchronous generator at a predetermined level. A basic AVR system consists of four primary components: an amplifier, an exciter, a generator, and a sensor.

These components are interconnected as shown in Fig. 1.

The mathematical of model and transfer function analysis, each component is typically linearized, focusing on the dominant time constant and neglecting saturation or other non-linearities.

The components transfer functions can be represented as shown in Fig. 1.

Power systems with multiple control areas, but analyzed as a single control zone, represent a combination of interconnected power systems, incorporating the unique challenges and control structures of each region.

Fig. 1 depicts a single-zone power system block diagram. Within this system, a regulator manages the speed and load of the synchronous generator according to demand.

Here, P_d represents load variation, T_g is the time constant of the speed regulator, T_t is the inlet valve time constant, T_L is the inertia constant in seconds, and R represents the speed regulation coefficient. T

he system is assumed to operate continuously under equilibrium conditions, as illustrated in Fig. 1.

Initially, the system parameters are at a steady-state with no changes. A disturbance, such as a change in load P_D, disrupts the power balance, leading to alterations in both speed and power output.

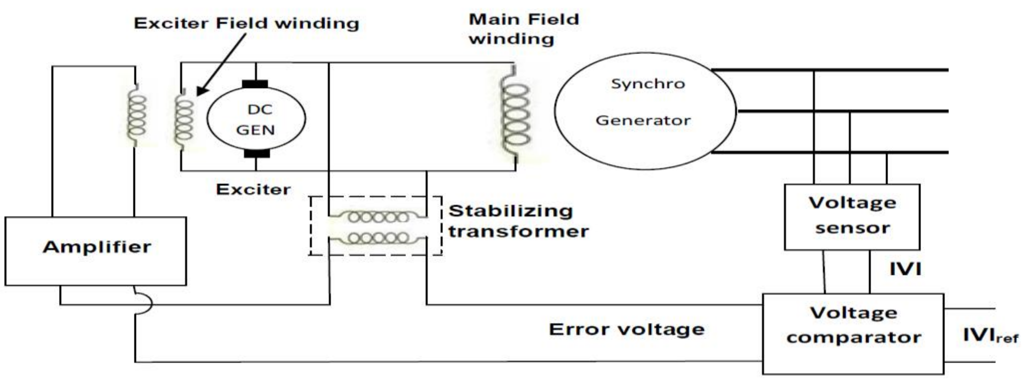


Fig. 1 Automatic Voltage Regulator System

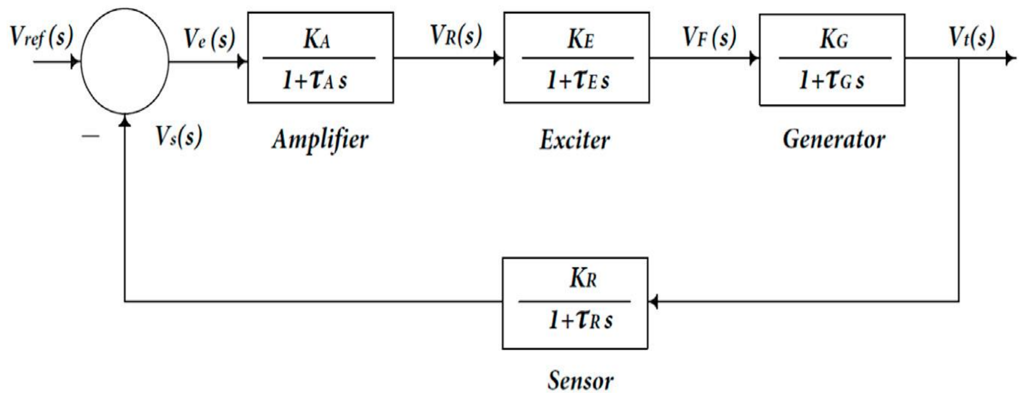


Fig. 2 Block of the AVR for the power plant system.

There are four different blocks of AVR must be consisted as follows.

Amplifier with Dynamic $G_A(s)$:

$$V_R(s) = \frac{K_A}{1+T_A S}\ Ve(s) \quad (1)$$

Exciter with Dynamics $G_E(s)$:

$$V_F(s) = \frac{K_E}{1+T_E S}\ V_R(s) \quad (2)$$

Generator Filed with dynamics $G_{GF}(s)$:

$$V_t(s) = \frac{K_{GF}}{1+T_{GF} S}\ \Delta V_F(s) \quad (3)$$

Feedback Sensor with Dynamics $G_S(s)$:

$$V_e(s) = V_{ref}(s) - \frac{K_{sn}}{1+T_{sn} S}\ V_s(s) \quad (4)$$

Where K_A , K_E, K_{GF} K_{sn}, are the amplifier gain, exciter gain, generator field gain and sensor gain respectively.

And T_A , T_E, T_{GF} $T_{sn},$ are the amplifier delay time constant, Exciter delay time constant, generator field delay time constant and sensor delay time constant respectively.

The open loop transfer function of AVR is:[1]

$$PO_{AVR}(S) = G_A(s)G_E(s)G_{GF}(S) \quad (5)$$

$$PO_{AVR}(S) = \frac{K_A, K_E, K_{GF}}{(1+T_A S)(1+T_E S)(1+T_{GF} S)} \quad (6)$$

$$PO_{AVR}(S) = \frac{8}{(1+0.1S)(1+0.4S)(1+1.4S)} \quad (7)$$

$$PO_{AVR}(S) = \frac{8}{0.056S^3+0.74S^2+1.9S+1} \quad (8)$$

The feedback gain, implemented using droop characteristics (typically represented as $1/R$), is applied in power systems to improve the damping properties of Automatic Voltage Regulators (AVR).

It's generally connected before the AVR control design. Therefore, AVR design can be approached in (at least) two ways, incorporating this droop characteristic.

The closed loop transfer function of Automatic Voltage Regulator (AVR) is :

$$PC_{AVR}(S) = \frac{G_{GF}G_E G_A}{1+G_{GF}G_E G_A G_{sn}} \quad (9)$$

$$PC_{AVR}(S) = \frac{K_A \ K_E \ K_{GF} \ K_{sn} \ (1+T_{sn}S)}{(1+T_A S)(1+T_E S)(1+T_{GF} S)(1+T_{sn} S)+K_A \ K_E \ K_{GF} \ K_{sn}} \quad (10)$$

Table 1: The nominal parameters value of AVR .

Quality	Gain/Time constant	Value
Amplifier Gain	K_A	10
Exciter gain	K_E	1
Generator Filed Gain	K_{GF}	0.8
Sensor gain	K_{sn}	1
Amplifier Time Constant	T_A	0.1
(Exciter time constant)	T_E	0.4
(Generator Filed time constant)	T_{GF}	1.4
(Sensor time constant)	T_{sn}	0.01

Numerically the transfer function become

$$PC_{AVR}(S) = \frac{0.08S + 8}{0.00056S^4 + 0.0634S^3 + 0.759S^2 + 1.91S + 9} \quad (11)$$

3- Using Classical Ziegler- Nichols Tuning for PID controller

This section only describes the Ziegler-Nichols PID control method. If incorrect control values are used, an operating system may experience poor performance or even become unstable. Therefore, it is important to adjust the values of the controller to achieve satisfactory performance. Tuning the controller involves selecting the optimal values for kc, Ti and Td (if the PID algorithm is used). This is often a subjective process and really depends on the process. This is the most popular method for integrating PID controllers. The process is simple. Preliminary set the controller to P position only. Then set the controller gain (kc) to the low line. Make small changes to the setpoint (or load) and observe the response of the control variable. If kc is small, the reaction must be slow. Double the Kc and make another small change in position or load. Continue adding kc (twice) until the thread vibrates. Then adjust kc until a solution is found that consistently returns .

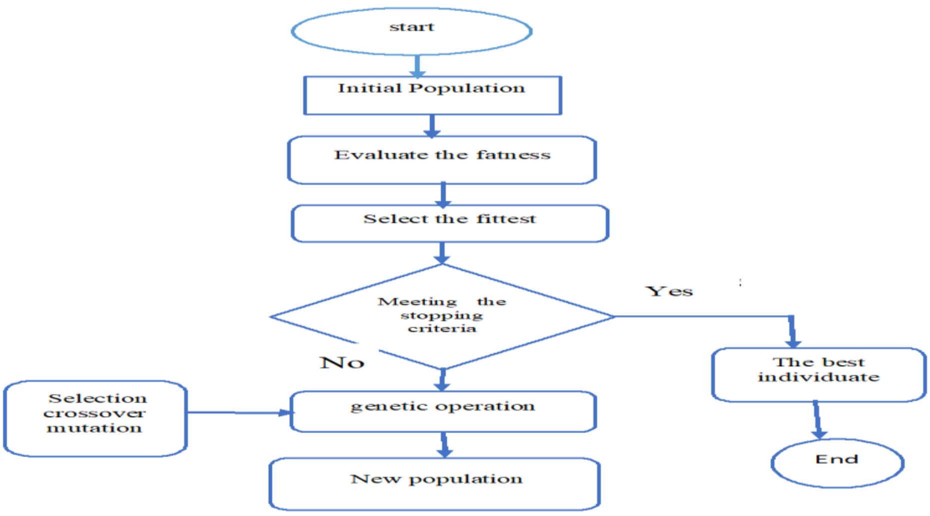
This is called (until) the final victory. Pay attention to the oscillation period (Pu). The steps required for this procedure are given below. We need to set the base and derivative coefficients to zero. Gradually increase the parameters from zero until the system becomes stable. The relative coefficient in this category is called final profit Ku. The oscillation period of this phase is called the final period Pu. Ku = gain of the system and Pu = (2*pi)/wcg. Here, wcg. This is a temporary advantage. It is the inverse of the gain amplitude ratio . Audit rules are now available in Table 1 below and also in the wcg. The PID gain value after simulation is given in Table II below.

Table2: PID -Controller's settings .

Controller	K_p	T_i	T_d
	$\frac{K_u}{2}$		
PI	$\frac{K_u}{2.2}$	$\frac{P_u}{1.2}$	
PID	$\frac{K_u}{1.7}$	$\frac{P_u}{2}$	$\frac{P_u}{8}$

4- Overview of Genetic-Algorithm (GA)

Genetic Algorithm is method that simulates the genetic evolution of a model. It is used to solve many different problems. A genetic algorithm is



used in this paper to find the optimal values of PID controller gain suitable for linear load control in power systems. Also to helps improving the transient of the system. Performance is improved using the fitness function. initially, genetic algorithm consists of the three stages: the selection, the crossover and the transformation. Using these three methods will create new people who can treat their parents well. This algorithm was used over and over for generations and eventually came to an end when people discovered that this was the best solution to this problem. The gain of the PID controller at different loads and speeds is calculated using the algorithm as shown in Fig. 3.

Fig 3: Genetic Algorithms Architecture.

Steps in the Genetic Algorithm

Step 1: The initial population,

The initial population consisting of potential solutions to on the specific issue, is defined in step one.

Step 2: Evaluate Fitness In this step,

Every individual in the population is examined for fitness, and the individuals, who represent potential solutions, are ranked according to their fitness values.

Step 3: Genetic Operations

Genetic operations are similar to natural evolutionary procedures and involve three basic operations that create a new population with the goal of identifying the best solution:

Selection

Individuals (chromosomes) are selected for additional processing from the original population in this operation. Choosing the chromosomes is the difficult part. Darwin's hypothesis states that the fittest people live and create new solutions. In general, parents chosen for crossover are those with greater fitness scores.

Crossover

Two chosen parents are combined in the crossover operation to create offspring (new solutions). Based on a predetermined crossover probability, this technique creates new solutions from preexisting ones.

Mutation

Following crossover, mutation occurs. Mutation refers to the random alteration of bits in the offspring, changing 0s to 1s or 1s to 0s. This process flips bits randomly depends on a small mutation probability.

The process then returns to Step 2 to evaluate fitness again. This cycle continues up to the stopping criteria are met.

Implementation of Tuning Procedure Using Genetic Algorithms

The tuning procedure begins with defining the chromosome representation. Each chromosome is composed of three values corresponding to the gains that need to be adjusted for optimal performance: (K_p, K_i, and K_d)

. These gains are real numbers that characterize the individual to be evaluated. The goal is to adjust these three gains to achieve satisfactory behavior.

In this context, the genetic algorithm (GA) is employed to calculate the optimal values of (K_p, K_i, and K_d) mean squared error (MSE)

for the GA controller. Performance indices, such as the mean squared error (MSE), are typically utilized for optimal controller tuning. This objective function is defined as follows (Eq. 12), that normally applied for optimum controller tuning . This objective function is:

The Mean Square Error (MSE)

$$\mathrm{MSE} = \int_{0}^{t} e(t)dt \tag{12}$$

Where t and e (t) are time and the actuating signal respectively that compute as the difference between the input signal and the output signal.

5– Simulation Results of (Z–N) – PID and (GA)–PID

This section describes two ways for controlling the Automatic Voltage Regulator specified by Equation (11): a Genetic Algorithm (GA)–based PID controller tuning approach and a Classical Ziegler–Nichols (Z–N) tuned PID controller. There are three sections in this section: A, B, and C. While Part B covers the GA–based PID controller tuning method using the Mean Squared Error (MSE) performance indices, Part A concentrates on the Classical Z–N tuned PID controller. The findings of the simulation are examined in Part C. The reference signal is taken to be a unit step signal throughout the duration of the simulations.

A. Classical Method of Ziegler–Nichols Tuned PID Controller

This section focuses on the classical Ziegler–Nichols method for tuning a PID controller. The PID gain values determined using this approach are presented in Table 3. The step response of the closed–loop system is illustrated in Fig. 4a, while the Bode curve response is depicted in Fig. 4b.

Table 3 Controller gain parameters and values

Gain Coefficients	T_D	K_P	T_I
Values	0.6	0.3	1.5

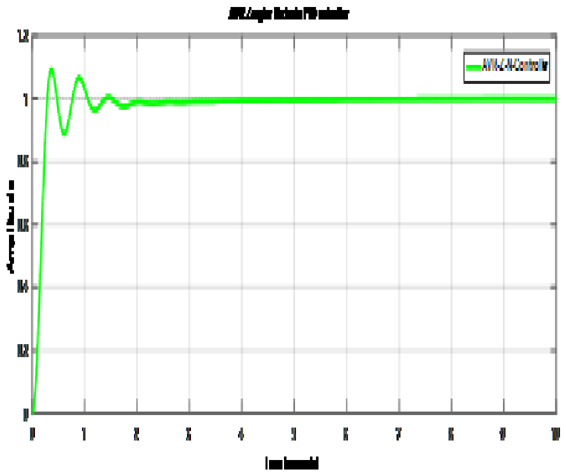


Fig.4a: System response with conventionally tuned PID controller.

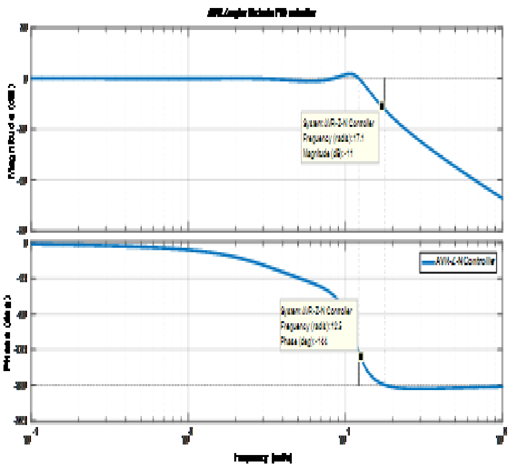


Fig.4b: GM and PM response using Z-N PID controlle

B - Using MSE performance indices for GA-utility PID Controller tuning method.

In this section, simulations were conducted to examine the impact of the Mean Squared Error (MSE) performance indicator on the closed-loop system response. The specifications of the designed Genetic Algorithm (GA) technique, utilizing performance indices, are detailed in Table I.

Table 4: Specifications of GA

Genetic Algorithm property	Parameter/Value / Method
Population size	100
Function of fitness	MSE
Selection method	Geometric Selection
Crossover rate	Arithmetic
N. of crossover points	0.5
Mutation rate	Uniform Mutation
Mutation probability	0.1

The response of GA based PID controller using the MSE method is shown in Fig.5a and the GA-based PID controller parameters: Kd= 0.11768 , Kp=0.29362 , and Ki= 0.9672

are shown in Fig.5a. Whereas, the gain margin and phase margin are shown in Fig.5b.

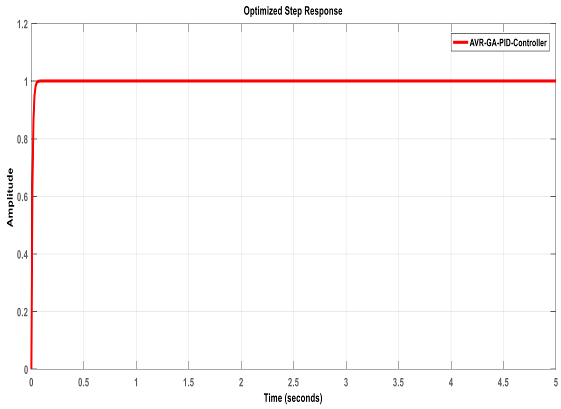


Fig.5a: GA-based PID using MSE method response.

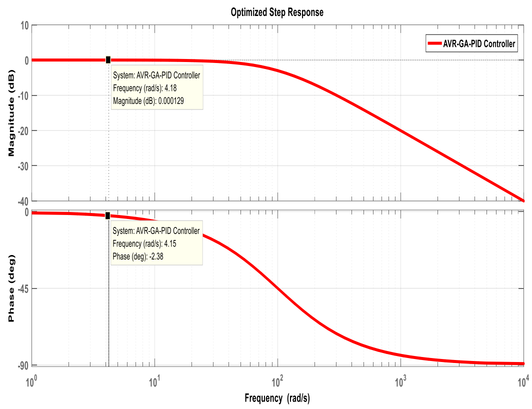


Fig.5b: Convergence graph of the PID gains value in the GA method.

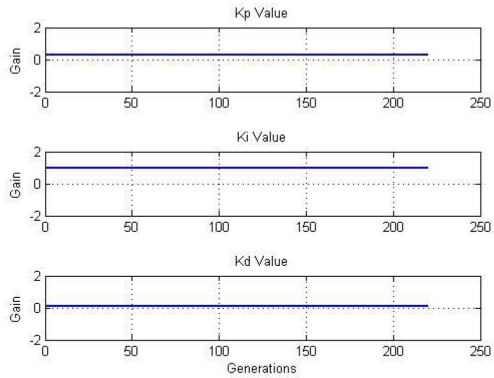
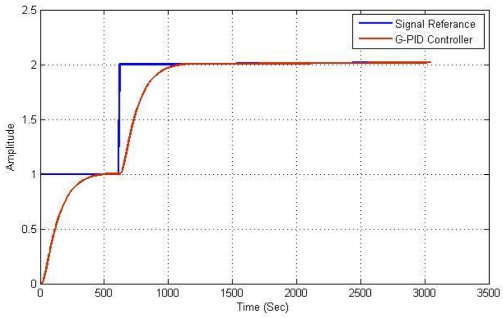


Fig.5c: Gain margin and phase margin response

- **Using GA-based PID controller to investigating the effect of set point change on the performance :**

From Fig. (6.a) and (8.b), the tracking of the PID controller could be observed as acceptable, and the PID controller responds very well.



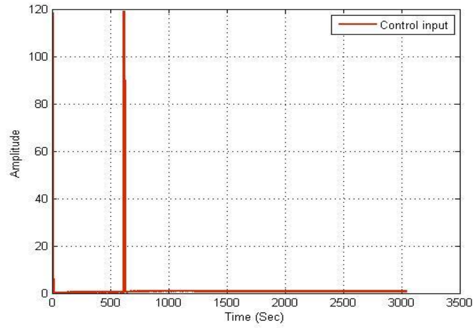
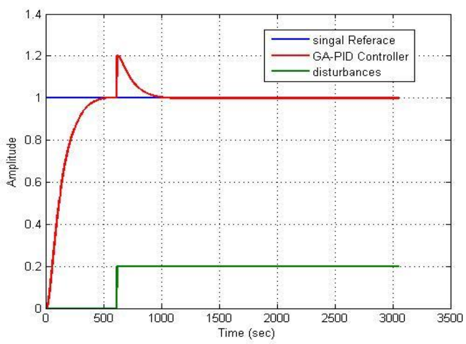


Fig. 6 a: : Change the reference input response of the system by using the GA-PID.

Fig. 6c: control input Signal of GA-based PID Controller

- **Using GA-based PID controller to investigating the effect of load disturbance on the performance:**

This study examines the performance of the designed PID controller in mitigating various disturbances. The effectiveness of these controllers was tested under diverse disturbances and parameter changes, accounting for the system's inherent nonlinearity and sudden changes. Load changes were introduced at different times. Figures 7(a) and 7(b) demonstrate that the PID controller successfully mitigated the introduced disturbances while effectively suppressing overshoots within a reasonable timeframe.



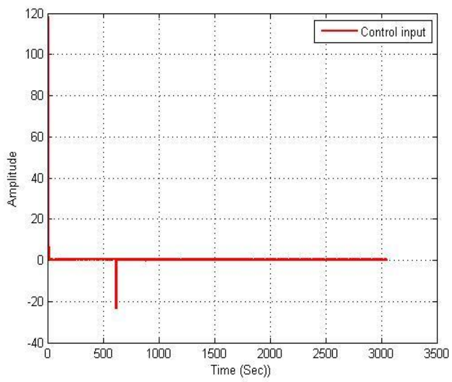
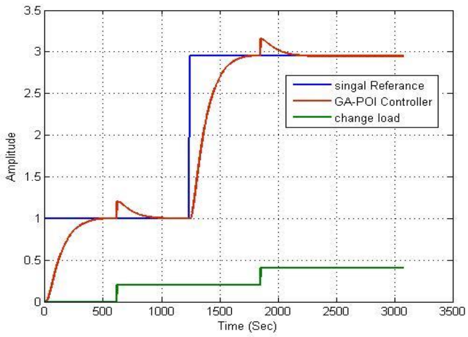


Fig.7a Disturbance Rejection of

Fig. 7b: Control input of GA-based PID GA-based PID Controller Controller.



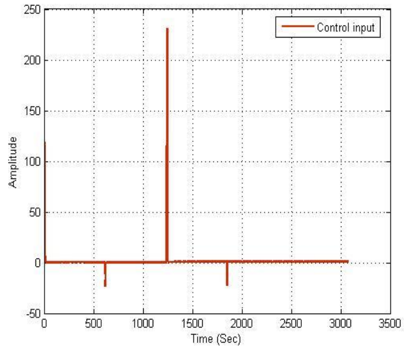


Fig.7a load change Rejection of

Fig. 7b: Control input of GA- based PIDGA-based PID Controller Controller .

C. Simulation Result Analysis of GA- PID

It can be observed from Figures 4a and 5a that the implementation of a conventionally tuned PID controller does not yield accurate results. In contrast, the optimized gain values of the controller, achieved through the implementation of a GA-based PID controller, demonstrate significant improvements. Comparative results are provided for reference.

Table 4. Comparison of results Parameters

Parameters	K_p	K_i	K_d	t_s (Sec)	t_r (sec)	Pt (Sec)	GM	PM deg
Z-N	0.2	1.5	0.71	1.8444	0.1863	0.3765	-11	-144
GA	0.29362	0.9672	0.11768	0.0391	0.0220	0.1055	0.0001	-2.38

6- CONCLUSIONS

The proposed model was simulated in the MATLAB, necessitating the adjustment of three parameters Kp, Ki and Kd of the PID controller for improved performance in controlling the Automatic Voltage Regulator in a power system. As evidenced by the simulation results presented in Section 5, the PID controller designed using Genetic Algorithms (GA) demonstrates superior response characteristics compared to those derived from classical methods. While classical methods provide useful preliminary estimates for the initial PID values, it is clear that the GA-based PID controller significantly outperforms the conventional approach in terms of overshoot and settling time. Furthermore, the results indicate that the GA-based PID controller effectively handles set-point changes and can eliminate step load disturbances. To further evaluate this controller design approach, it is essential to explore its implementation in real-time applications.

References

[1] Modu M. Ibrahim , Jibril D. Jiya , Idakwo O. Harrison Modelling and Simulation of Automatic Voltage Regulator System International Journal of Computer Applications (0975 – 8887) Volume 178 – No.1, November 2017.

[2] Mohamed S. Amin, Mahmoud A. Attia, Amr K. Khamees,S. F. Mekhamer, Hossam Kotb4, Kareem M. AboRas and Amr Yousef Development of AVR controller performance using exponential distribution and transit search PUBLISHED 05 March 2024.

[3] Tayyab Ali , Suheel Abdullah Malik , Amil Daraz , Muhammad Adeel , Sheraz Aslam ,and Herodotos Herodotou Load Frequency Control and Automatic Voltage Regulation in Four-Area Interconnected Power Systems Using a Gradient-Based Optimizer Energies 2023, 16, 2086.

[4] SALIH M. EL SHARIF ABDALLA, COMPARATIVE STUDY OF THE EXCITATION SYSTEM, AVR AND PSS MODELS FOR SYNCHRONOUS GENERATORS UNDER THE PHASE TO GROUND FAULT 2015.

[5] Kalyan, C.N.S.; Goud, B.S.; Reddy, C.R.; Bajaj, M.; Sharma, N.K.; Alhelou, H.H.; Siano, P.; Kamel, S. Comparative Performance Assessment

of Different Energy Storage Devices in Combined LFC and AVR Analysis of Multi-Area Power System. Energies 2022.

[6] Fayek, H.H.; Rusu, E. Novel Combined Load Frequency Control and Automatic Voltage Regulation of a 100% Sustainable Energy Interconnected Microgrids. Sustainability 2022.

[7] Mathur P and Joshi S.K (2015) "PID turning of Automatic Voltage Regulator" international Journal of Research and Analytical Reviews. Vol 2, Issue 3 PP 18 – 21.

[8] Muriithi, C. M., & Nyakoe, G. N. (2015). Effect of AVR and PSS on power system transient stability with different wind generation technologies. Journal of Energy Technologies and Policy, 5, 66-71.

[9] Dekaraja, B.; Saikia, L.C.; Ramoji, S.K.; Behera, M.K.; Bhagat, S.K. Impact of RFB and HVDC link on Combined ALFC-AVR Studies of a GTPP Integrated Hydro-thermal Systems Using a Cascade Fuzzy PD-TID Controller. In Proceedings of the 2022 4th International Conference on Energy, Power and Environment (ICEPE), Shillong, India, 29 April–1 May 2022.

[10] Dekaraja, B.; Saikia, L.C.; Ramoji, S.K. Combined ALFC-AVR Control of Diverse Energy Source Based Interconnected Power System using Cascade Controller. In Proceedings of the 2022 International Conference on Intelligent Controller and Computing for Smart Power (ICICCSP), Hyderabad, India, 21–23 July 2022.

[11] Kalyan, C.N.S.; Goud, B.S.; Reddy, C.R.; Bajaj, M.; Sharma, N.K.; Alhelou, H.H.; Siano, P.; Kamel, S. Comparative Performance Assessment of Different Energy Storage Devices in Combined LFC and AVR Analysis of Multi-Area Power System. Energies 2022, 15, 629.

[12] Tabak, A. Maiden application of fractional order PID plus second order derivative controller in automatic voltage regulator. Int. Trans. Electr. Energy Syst. 2021, 31, e13211.

[13] Ayas, M.S.; Sahin, E. FOPID controller with fractional filter for an automatic voltage regulator. Comput. Electr. Eng. 2021, 90, 106895.

[14] Altbawi, S.M.A.; Bin Mokhtar, A.S.; Jumani, T.A.; Khan, I.; Hamadneh, N.N.; Khan, A. Optimal design of Fractional order PID controller based Automatic voltage regulator system using gradient-based optimization algorithm. J. King Saud Univ. Eng. Sci. 2021.

[15] Verma T & Mishra A. K (2014) "Comparative study of PID and FOPID Controller Response for Automatic Voltage Regulation" IOSR journal of Engineering (IOSRJEN) Vol 4, 1ssue 9 PP. 41 – 48.

[16] Patonding H. E, Lobo E. T and Sau M (2015) "Modeling Control of Automatic Voltage Regulator with Proportional Integral Derivative" International journal of research in Engineering and Technology. Vol.4, issue 9, PP 241 – 244.

[17] Lodh B (2014) "Simulink Based Model for Analyzing the Ziegler – Nichols Turning Algorithm as Applied on Speed Control of DC Motor International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. Vol 3, issue 1, PP 6641 – 6645.

[18] Mathur P and Joshi S.K (2015) "PID turning of Automatic Voltage Regulator" international Journal of Research and Analytical Reviews. Vol 2, Issue 3 PP 18 – 21.

[19] Lai J (2007) "Parameter Estimation of Excitation System" Master Thesis, Electrical and Computer Engineering, Graduate Faculty of North Carolina, Raleigh, North Carolina. PP 15 – 17 .

[20] Dabur P, Yadav N. K & Tayal V. K (2011) "Matlab Design and simulation of AGC and AVR for multi Area system and Demand Side Management" international journal of computer and Electrical Engineering Vol 3, No:2, PP 259 – 264.

[21] Tony F. T and Prakash R (2014) "Load frequency Control of a two Area Hybrid System Consisting of a Grid Connected PV system and thermal

Generator" International Journal of Research in Engineering and Technology Vol: 3, issue 7, PP. 573-580.

[22] E. K¨ose, “Optimal control of AVR system with tree seed algorithm-based PID controller,” IEEE Access, vol. 8, pp. 89457–89467, 2020.

[23] M. Calasan, M. Micev, M. Radulovic, A. Zobaa, H. Hasanien,and S. Abdel Aleem, “Optimal PID controllers for AVR

[24] system considering excitation voltage limitations using hybrid equilibrium optimizer,” Machines, vol. 9, no. 11, p. 265, 2021.