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Optimization AVR Response Based on Intelligent Cheetah Algorithm

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Abstract. *This research paper is interested in studying how to obtain the best response to the (AVR) Automatic Voltage Regulator, which is an essential device because of its clear effect on maintaining the stability of the voltage in various circumstances through researching to find the best values for the parameters of the Proportional Integral Derivative (PID) which are (Kp, Ki, Kd). After several experiments and studies by researchers to improve the AVR response, we discuss here another new study by applying the cheetah Optimization (CO) algorithm and knowing the extent of its ability to find the best solutions by comparing results by time limits, namely delay time (td), rise time (tr), peak time(tp), stalling time(ts), and Overshot (OS) as well as determining fitness function for Integral Squirrel Error (ISE). Where excellent results were obtained when implementing the (CO) algorithm when comparing the values of time limiters and error criteria, it is also worth mentioning that one of the most important properties of this algorithm is the speed of performance, as it is within the limits of seconds, so that it is the fastest algorithm among other algorithms.*

Keywords: *Automatic Voltage Regulator (AVR), Cheetah Optimization (CO), Integral square of error (ISE), and Proportional Integral Derivative (PID).*

1. INTRODUCTION

One of the most important devices used for several decades is the automatic voltage regulator (AVR) device, which began its journey with manual modification of the voltage of transformers until it reached our current time, automatic control through smart technologies. (Rodrigues, Molina, & Araujo, 2020) We observe the importance of AVR by protecting electrical devices from damage, reducing energy consumption, stabilizing the electrical system, and reducing maintenance costs. In nature, this device works in the alternating current, where it contains a sensor, which is one of the components of the device that senses voltage fluctuations in the state of high or fall so that the AVR, in turn, evaluates the voltage and returns it as stable energy to the system. (Ali, 2024) This device is based on intelligent circuit electronic control techniques, this research paper used the Proportional Integral Derivative (PID) controller to improve the AVR response by obtaining global solutions for its parameters (Kp, Ki, Kd). (Micev, Ćalasan, & Radulović, 2021) There are two methods to adjust this controller to the best values. The first is to follow the classical techniques, including the gradient, Ziegler Nichols(ZN), and other methods. However, the Tuning method is one of the fastest classic methods for manually adjusting the wave. However, these methods have become somewhat old, and with the development of technology, they have been replaced by smart technologies, such as metaheuristic algorithms (MA). (Çavdar, Şahin, & Sesli, 2024) The **(**MA**)** are techniques Inspired by nature, artificial intelligence, and machine learning. It's one of the most powerful smart technologies for its accuracy, flexibility, and speed in solving the most difficult complex and non-linear problems by finding almost perfect improvement solutions in addition to the advantage of adapting them to different types of issues. Among these algorithms, in general, and used to improve AVR, in particular, are the bee colonies algorithm (ABC), the ant search algorithm (CS), and artificial intelligence algorithms like Artificial Neural Network (ANN). One of the additional features of (MA) is the possibility of implementing it in a hybrid form, combining more than one technical feature to achieve better performance. In this work, we will touch on an algorithm that is one of the elite of excellent algorithms in optimization. (Oladipo, Sun, & Wang, 2020) At the same time, this is the first time it has been implemented in the field of improving the AVR response, which is the Cheetah algorithm(CO). We execute them and find the results of each (ISE, tr, td, ts, tp, OS) and then compare them with the results of the system and the classical control methods. The summary of this research paper is graded by defining AVR, PID, and CO Algorithm performance, then comparing the results and mentioning the conclusion. (Akbari, Zare, Azizipanah-Abarghooee, Mirjalili, & Deriche, 2022).

2. MODELLING OF AVR

The mathematical model of AVR consists of the reference voltage Vref, the Amplifier that enhances the weak signals coming from the sensor, the Exciter, which provides the magnetic field required to generate the voltage, the generator maintains the stability of the voltage at a certain level, finally, the sensor that provides feedback on the light of which the voltage is adjusted.(Sikander & Thakur, 2020) Also, there is gain in each block, and its value varies from one part to another, as shown in Table 1 of the system, but its guest is one, which is to enhance the output signal and get accurate measurements.

a. Amplifier equation

$$\frac{V_r}{V_e} = \frac{K_a}{T_a s+1} \quad (1)$$

b. Generator equation

$$\frac{V_t}{V_f} = \frac{K_g}{T_g s+1} \quad (2)$$

c. Exciter equation

$$\frac{V_f}{V_r} = \frac{K_e}{T_e s+1} \quad (3)$$

d. Sensor equation

$$\frac{V_s}{V_t} = \frac{K_s}{T_s s + 1}$$

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(4)

The $\frac{\text{Ka Ke Kg}(1+T_s s)}{(1+T_a s)(1+T_e s)(1+T_g s)\,\text{Ka Ke Kg Ks}}$ transfer function of the general AVR system is equal to the following:

T.F= (5)

In this research, We implemented the optimization on the fourth-order generator; it can increase orders by adding other ranks of $\boldsymbol{Tg}$ and $\boldsymbol{Tp}$. (Abdullah & Amir, 2018)

$$T.F= \frac{\text{Ka Ke Kg}(1+T_s s)(1+T_{g_1} s)(1+T_{g_2} s)(1+T_{g_3} s)(1+T_{g_4} s)}{\text{Ka Ke Kg Ks}(1+T_a s)(1+T_e s)(1+T_{p_1} s)(1+T_{p_2} s)(1+T_{p_3} s)(1+T_{p_4} s)} \quad (6)$$

3. PID CONTROLLING

It is one of the common control systems used to maintain the system's stability by reducing error. (Borase, Maghade, Sondkar, & Pawar, 2021) It has several uses in different applications and consists of three parameters for the proportional controller Kp, the integrative controller Ki, and the Kd differential controller. (Mahmud, Motakabber, Alam, & Nordin, 2020) These parameters are adjusted in several ways, but it is worth mentioning that there are classic methods of adjusting, which are old. It depends on manual calculations such as the Ziegler-Nicholas method, Tuning, and other modern technologies. (George & Ganesan, 2022) This has become common recently when metaheuristic algorithms have been implemented to obtain global solutions for PID parameters.
It can obtain of T.F. for PID by:

$$P_{(s)} = K_p \quad (7)$$

$$I_{(s)} = \frac{K_p}{s} \quad (8)$$

$$D_{(s)} = K_d . s \quad (9)$$

$$C_{(s)} = K_p + \frac{K_p}{s} + K_d . s \quad (10)$$

The K_f filter constant is added to the differential part to reduce noise and other rapid changes.

$$C_{(s)} = K_p + \frac{K_i}{s} + \frac{K_f K_d s}{K_f + s} \quad (11)$$

2.1. CO Algorithm

It is one of the metaheuristic algorithms inspired by natural cheetah-hunting behavior. It aims to find the best solutions from a group of local solutions to provide better system performance. (Kumar et al., 2025) It has the ability to deal with the most difficult problems and smoothly solve them due to its enormous properties derived from the features of cheetahs. (S. Chen, Y. Ji, & X. J. E. Sun, 2024) We have the flexibility and speed to find solutions, focus on research, and reduce error to a large extent. The latter may be considered very accurate because, taken from a natural case, cheetahs must complete the hunting task within a specific time, and there is no room for error because they cannot continue running at their high speed, reaching 120 km/h. After all, it feels exhausted with increasing heartbeats, and therefore, its speed decreases significantly to 90 km/h, 50 km/h, and even 15 km/h. (Akbari et al., 2022) Cheetahs follow strong strategies to manage the hunting process. They start by monitoring the place, setting targets, and calculating the amount of time needed to implement, then waiting at the right moment for the green light and thus attacking with all their strength on the target. (Keyimu, Tuerxun, Feng, & Tu, 2023) If the hunt is successful, they will have the best solutions; if not, they will look for another solution or return home. (Arvaneh, Zarafshan, & Karimi, 2024).

Algorirhm strategy

a) **Searching:** In this strategy, the cheetah searches for his prey by the following equation:

$$X_j^{(t+1)} = X_j^{t} + r_{Hat.}^{-1} \times alpha \qquad (12)$$

Where:

Alpha: The size of the step taken by the cheetah
$X_j^{(t+1)}$: The location that the cheetah wants to move to in the dimension j
X_j^{t}: The current location of the cheetah
$r_{Hat.}^{-1}$: It is the inverse of the random value that helps to change the movement of the cheetah inversely, sometimes

b) **Sitting and waiting:** In this strategy, the cheetah remains still without changing its movement; therefore, the new site is the same as the current site. (S. Chen, Y. Ji, & X. Sun, 2024)

$$X_j^{t2} = X_j^{t1} \qquad (13)$$

c) **Attacking:** It starts attacking with the following equation when it ensures the prey is in the right place and time.

$$X_j^{(t+1)} = X_{best(j)}^{t} + r_{Check.} \times beta \qquad (14)$$

$r_{Check.}$: A random factor that changes the movement of the cheetahs while searching for better results
$X_{best(j)}^{t}$: It is the best site that the cheetah has reached or the best prey
$beta$: The difference between the place of the cheetah and the other cheetah and helps to know how the cheetahs move relative to their neighbor

d) **Back home:** In this strategy, there are two decisions according to the situation: if the fishing operation is unsuccessful, it leaves the site and returns to its land, and second, when the hunting procedure within a specific period is unsuccessful, it changes the location and goes to another prey. (Du, Zhang, Han, Zhang, & Xu, 2019)

i. Leaders for a new position

$$X_{j+1}^{t4} = X_{B.j}^{t3} \qquad (15)$$

ii. back home: Some group members return to their original positions when the solutions are not good.

$$X_j^{t4} = X_j^{t3} \qquad (16)$$

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As mentioned earlier, this algorithm has an implementation speed of about half a minute compared to classical methods and other modern algorithms that may reach 15 minutes of execution. For comparison, we observe the difference between CO results and classical methods, as well as the results of the system without a controller through time response parameters (td, ts, tp, tr) and error determinants ISE, as we see in Table 2,3. (Mousakazemi, 2021)

where

$$ISE=\int_0^{\infty} e^2(t)\,dt \qquad (17)$$

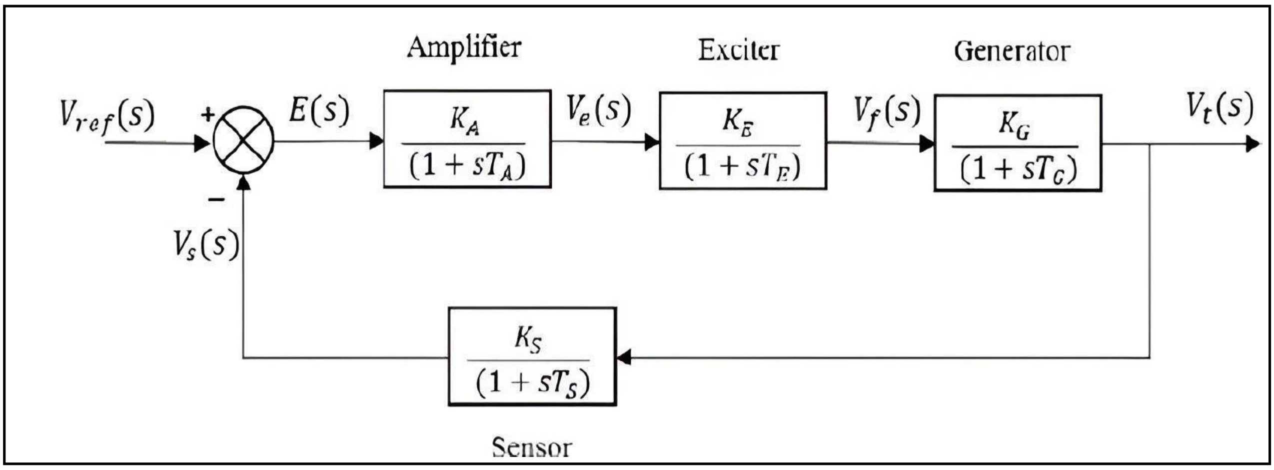

Figure 1 The general AVR model

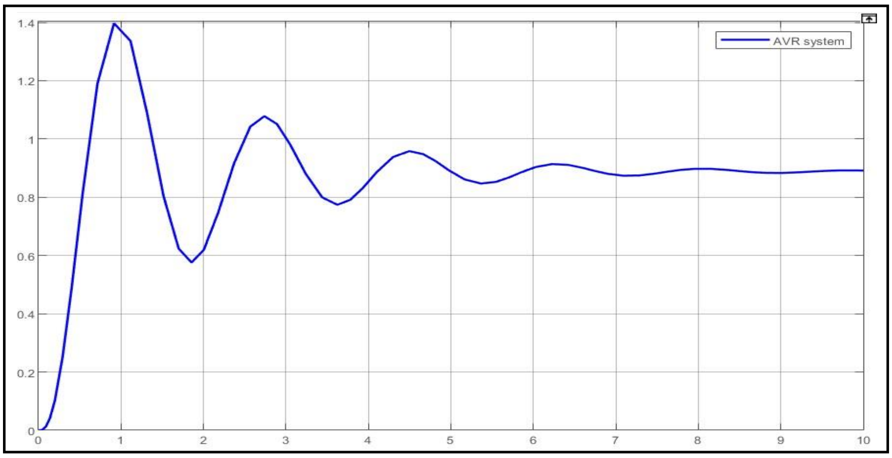

Figure 2 Output response of AVR system

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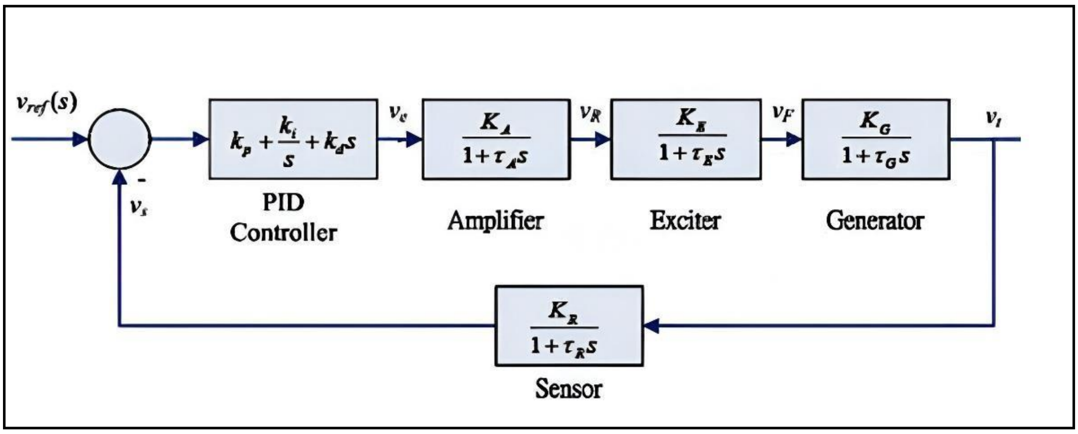

Figure 3 Simulink of AVR with PID controller

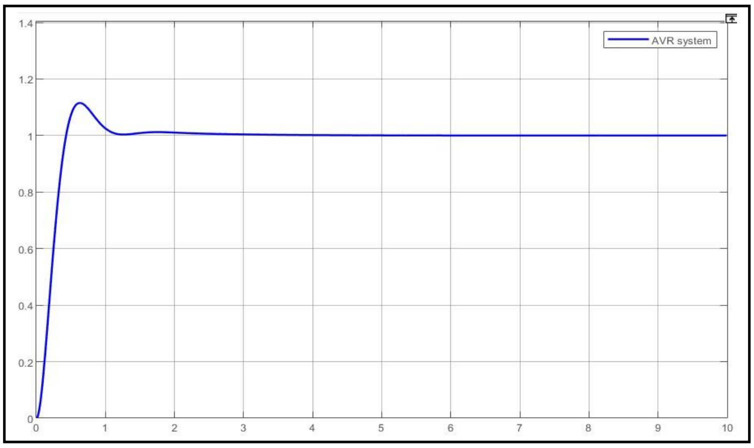

Figure 4 AVR response with PID controller

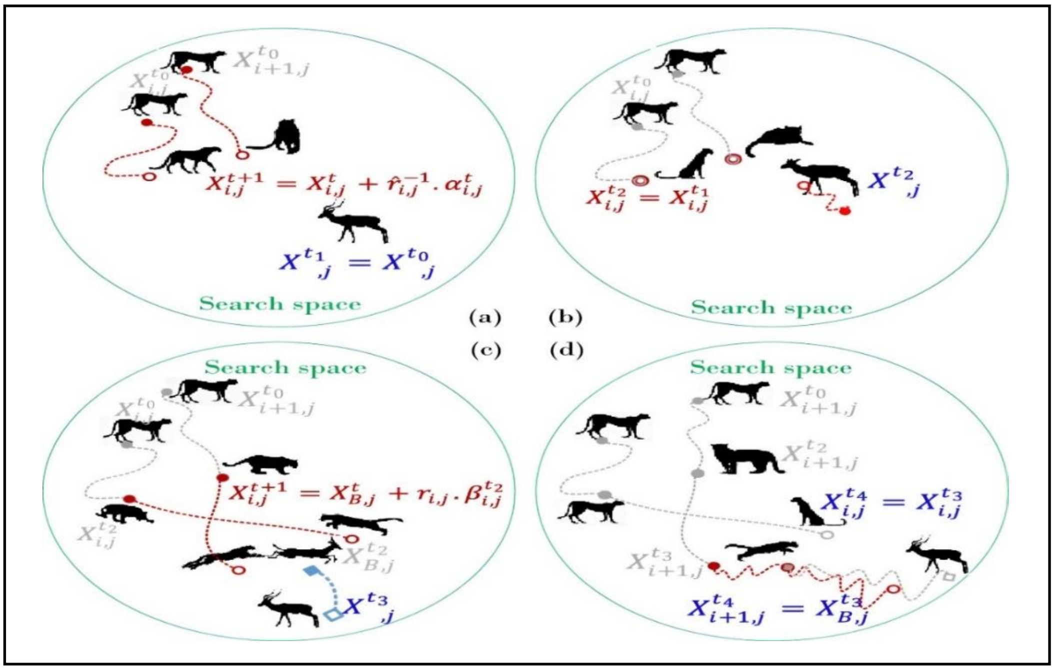

Figure 1 The four strategy of Cheetah

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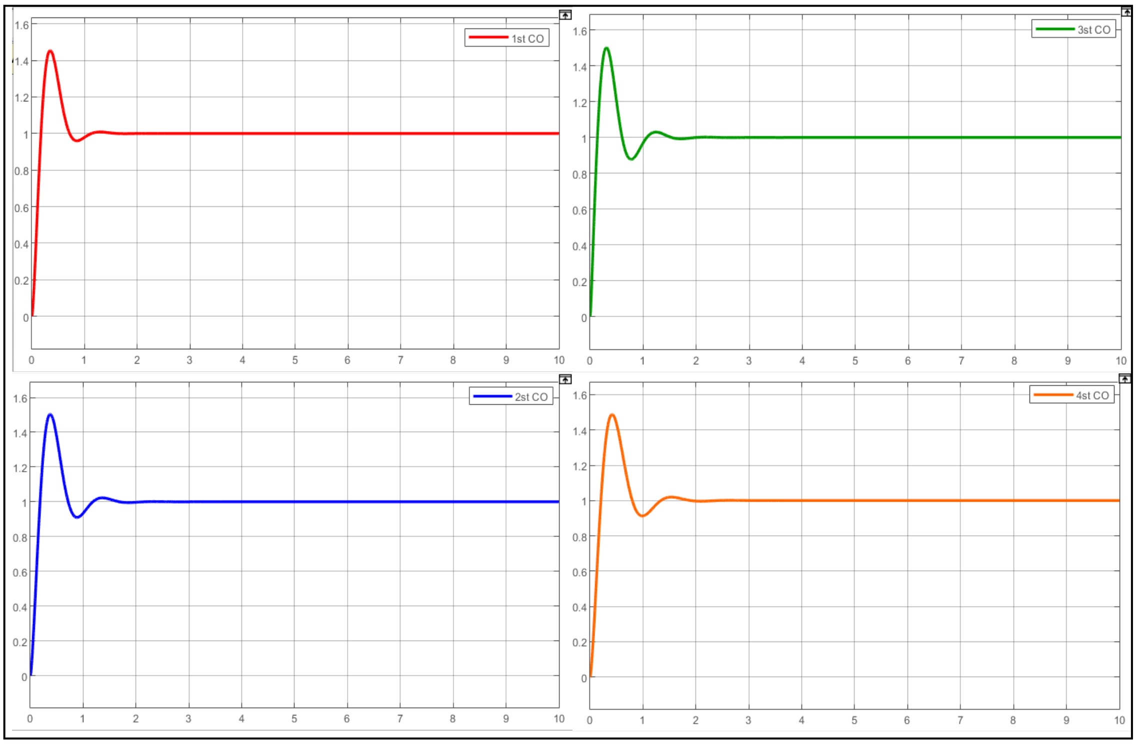

Figure 2 fourth orders of AVR Generator optimized by CO Algorithm

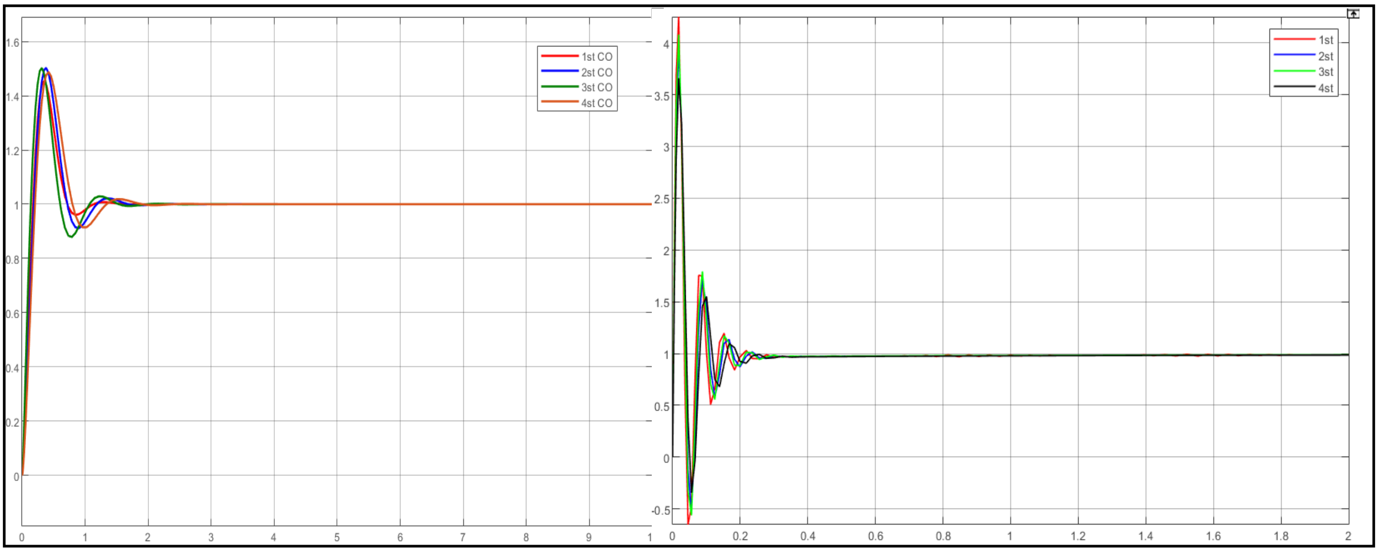

Figure 7 Comparison between AVR system and CO Algorithm

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Table 1 range of parameter and used values

Component	Gain & time constant range	Used values	
Amplifier	$10 \leq K_a \leq 400$ $0.02 \leq T_a \leq 0.1$	$K_{ae} = 200$ $T_{ae} = 0.05$	
Exciter	$1 \leq K_e \leq 400$ $0.25 \leq T_e \leq 1$		
Generator	$0.7 \leq K_g \leq 1$ $1.0 \leq T_g \leq 2.0$	$1st$	$T_{g1} = 0.9087$ $T_{p1} = 3.9817$
		$2st$	$T_{g2} = 0.1257$ $T_{p2} = 0.1481$
		$3st$	$T_{g3} = 8.88e^{-3}$ $T_{p3} = 8.38e^{-3}$
		$4st$	$T_{g4} = 7.75\,e^{-4}$ $T_{p4} = 9.37e^{-4}$
Sensor	$1 \leq K_s \leq 10$ $0.001 \leq T_s \leq 0.06$	$K_s = 1$ $T_s = 0.05$	

Table 2 Compares system response specifications for each technique

AVR system	technique	t_s(sec)	t_r(sec)	t_d(sec)	t_p(sec)	OS
First order	without	0.2775	0.008678	0.13875	0.01794	4.252
	With PID	2.5	0.394173	1.25	1.444	1.065
	CO	1.535	0.123864	0.741	0.3479	1.454
Second order	without	0.2356	0.006540	0.1178	0.01794	3.953
	With PID	2.901	0.371739	1.4505	1.433	1.065
	CO	1.681	0.132661	0.8905	0.372	1.502
Third order	without	0.3509	0.006770	0.17545	0.01794	4.079
	With PID	2.257	0.302515	1.1285	1.290	1.61
	CO	1.900	0.101320	0.9765	0.313	1.504
Fourth order	without	0.3242	0.001985	0.1621	0.01794	3.658
	With PID	2.736	0.467662	1.368	1.8	1.063
	CO	1.926	0.148349	0.97	0.422	1.488

Table 3 compares between all technique by Error and ISE.

AVR system	technique	ISE	Error
First order	without	0.0022760951306736	0.012043450067167
	With PID	0.0053618436192083	7.8580968521091e-07
	CO	0.00013190319041077	4.1760594982065e-11
Second order	without	0.0023052897645174	0.01322947349956
	With PID	0.0051990449802828	-0.00010761696033046
	CO	0.00013190275434103	4.3469514654504e-09
Third order	without	00020814398493650	0.012685400822869
	With PID	0.0039071369533832	0.00017600155069664
	CO	4.5901907922402e-05	9.4557739606094e-06
Fourth order	without	0.0029157464967882	0.014608550343257
	With PID	0.0089177518148592	-0.00023651384665202
	CO	0.00014361095668646	4.0426910175695e-05

3. RESULT AND DISCUSSION

This study confirms to us the difference and importance of algorithms in the field of optimisation, as we observe in **Table 2**, and according to the difference between the performance criteria, the CO algorithm excelled in tp, td, and the most important is its speed in the ascending time as well as the lack of stability time. As for Overshot, it is higher than the traditional methods, but compared to the other points achieved by CO, this overrun is considered simple, but **Table 3**, we also observe through which the algorithm excels with the lowest values for error and ISE, where the results of the algorithm can be seen in **Figure 6,7**.

4. CONCLUSIONS

The conclusion of this study is that speed and accuracy are important factors in all fields in general and in engineering fields in particular, so optimisation algorithms are considered as an example of accuracy and speed. We conclude that CO had a clear impact on finding the optimal PID parameters and preferring them over traditional methods because of its flexibility, speed and accuracy.

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