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Design of CDM-PI Controller for pH Process

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Abstract: Control of Nonlinear system is considered as a challenging task in process industries. PH control for many process applications was developed and used in many industries particularly in pharmaceuticals, water treatment plant and chemical industries. Several researches are still going on in identifying the appropriate controller for pH process. The main aim of this work is to design the CDM based PI controller for the pH neutralization process which is considered as a highly nonlinear system. Here the CDM-PI controller is compared with the ZN - PI controller and IMC – PI controller and the performance of the controllers are compared and analysed. The results obtained by various control algorithms are discussed.
Keywords: ZN - PI, IMC – PI and CDM-PI.

I. INTRODUCTION

In many process industry control of pH is the major problem. The control of pH in process industries has shown dramatic increase in last few years. The pH control is employed in many industries such as chemical, pharmaceutical, food and wastewater treatment. Still research is going on in identifying the best appropriate control for pH process which is considered as a benchmark problem. Extensive researches in the identification of pH process have been done by many relative experts for many years. An extensive research in the identification of pH process has been done by many relative experts for many years. The ionic product of H2O is given by HCl+NaOH=NaCl+H2Oand its pH neutral (ie.7). Since in pure water the concentration of H+ ion is equal to the concentration of hydroxide ion OH− any addition of H+ ion will make it acidic and OH− ion will make it base. The addition of H+ may be due to the addition of acids and acidic impurities to the water stream by the industries manufacturing acids or industries using acids in most of their manufacturing stages. Similarly the OH− may be from the industries manufacturing alkalis such as KOH, NaOH, etc. and also from those industries using alkalis in most of their manufacturing stages. To make the pH within specific limit the acidic water the alkaline should be added and vice versa [1].CDM is based on algebraic approach which is used to control the complex systems. It is polynomial approach so there will be no occur of pole zero deletion. This technique provides good robustness to the process system with uncertainty in the plant parameters. The settling time can be determined at the start of the process is most significant approach in CDM controller. In this work the CDM–PI controller is compared with ZN–PI and IMP–PI controller and their time domain specifications and the performance index of different PI controller's are compared and the results are discussed.

A. *Description of the process taken for the study.*

A pH process station is considered to conduct the study. The selected system consists of nonlinearity, control of nonlinearity is considered as a major problem in industries. Here the acid stream and alkaline stream with 0.1 normality is feed into 4 lit constant volume stirrer tank and the pH is measured using the pH transmitter which is located in the collecting tank. The acid flow rate is kept at a constant level and a step change is given to the base flow rate and the computer is interface with the data acquisition and control and use the Matlab simulation toolbox to obtain the first order plus dead time transfer function model.

$$G(s) = \frac{k_p e^{-t_d s}}{\tau s+1}$$

$$G(s) = \frac{0.34811\, e^{-0.576s}}{0.17416\, s+1}$$

B. *Proportional Integral Controller*

PI controller is a conventional method of controlling major of the process in industries. Advantage of PI controller is that it will preserve a steady state error to a zero for a step change. It will eliminate forced oscillations and steady state error resulting in operation of on -off controller and proportional controller respectively. It is generally used in the area where speed of the system is not an issue.

$$C(s) = k_p + \frac{k_i}{s} = k_p\left(1+\frac{1}{T_i s}\right)$$

Wherek_p= Proportional Gain,k_i =Integral Gain,T_i= Reset Time =k_p/ k_i.

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The PI controller is designed to identify two gains, Proportional Gain (k_p) integral gain (k_i) [2, 3].

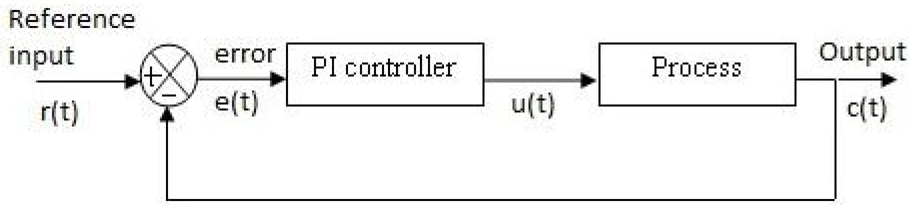

Fig 1: Block Diagram of PI Controller

PI controller is tuned using Ziegler Nichols tuning. The tuning parameter is shown in table 1.
The tuning parameters are shown in table 1.

Controller	k_c	τ_i	τ_d
P	$0.5k_p$	-	-
PI	$0.45k_p$	$\frac{\tau}{1.2}$	-

Table 1: Ziegler Nichols Closed loop Oscillation method tuning parameters

The obtained gain values of PI controller based on Ziegler Nichols Closed loop Oscillation method
K_p= 0.16
K_i= 0.15
The Simulink model for conventional PI controller is shown in Figure 2.

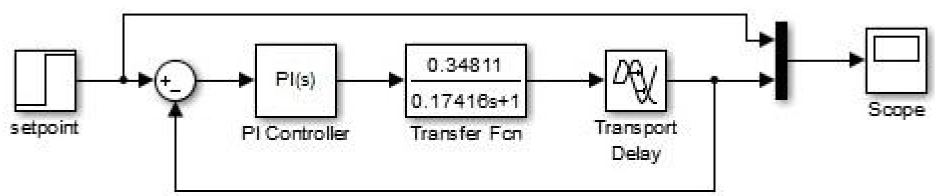

Fig 2: Simulink model for conventional PI controller

C. IMC based tuning for PI controller

Internal Model Control system design based on Q-parameterization. This Q-parameterization technique is the basic technique for internal model control. The main objective of the internal control is to obtain the desired set point and eliminate the disturbances. The IMC controller is designed with prominence on its implications on Pi controller for this study. It is based on Q-parameterization structure. It basically involves two steps design procedure that provides best suitable trade off between performance and robustness. It is mainly designed to achieve the perfect control of the process.

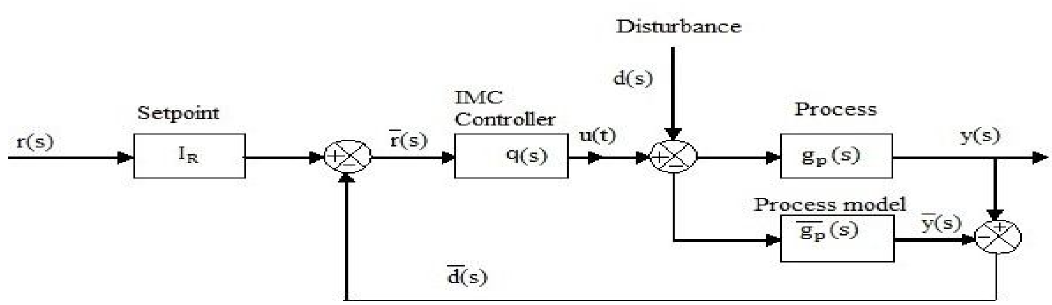

Fig 3: IMC structure

Here we have to develop a feedback equivalent to IMC from the above given block diagram using block diagram manipulation q(s). Represents the controller $g_p(s)$ represents the actual process and the $\bar{g}_p(s)$ represents model of the process. [2]

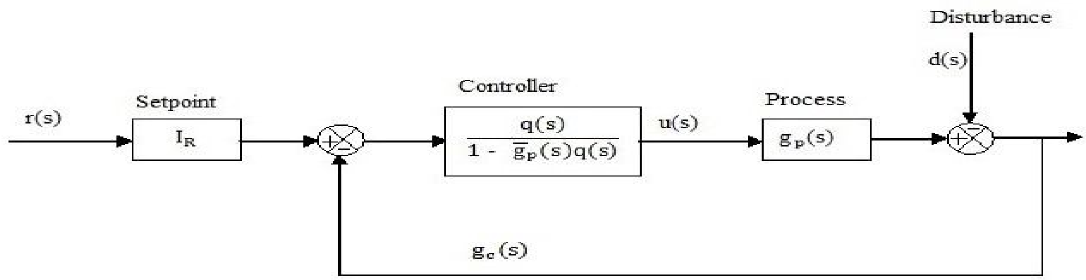

Fig 4: Standard feedback Equivalent to IMC

The standard feedback controller which is equivalent to IMC is

$$g_c(s) = \frac{q(s)}{1-\bar{g}_p(s)q(s)}$$

By using first-order Pade approximation

$$g_p(s) = \frac{k_p}{\tau s+1}e^{-t_d s}$$

$$e^{-t_d s} = \frac{1+\frac{t_d s}{2}}{1-\frac{t_d s}{2}}$$

$$g_p(s) = \frac{0.34811(1-0.288s)}{(0.17416s+1)(1+0.288s)}$$

IMC controller transfer function, q(s)

$q(s) = \bar{q}(s)\, f(s)$

$$q(s) = \frac{(0.17416s+1)(1+0.288s)}{0.34811}\frac{1}{\lambda s+1}$$

Where $\bar{q}(s) = \frac{(0.17416s+1)(1+0.288s)}{0.34811}$

$f(s) = \frac{1}{\lambda s+1}$

λ = Filter Tuning Parameter

Equivalent standard feedback controller using the transformation

$$g_c(s) = \frac{\bar{q}(s)f(s)}{1-\bar{g}_{p+}(s)f(s)}$$

$$g_c(s) = \frac{1}{0.34811}\left[\frac{0.05015808s^2+0.46216s+1}{(\lambda+0.288)s}\right]$$

Here $\lambda > 0.8t_d$

$\lambda = 0.7$

The PI tuning paramerers are

$k_c = 1.49$

$\tau_i = 0.57$

The Simulink model for IMC based PID controller is shown in Figure 5.

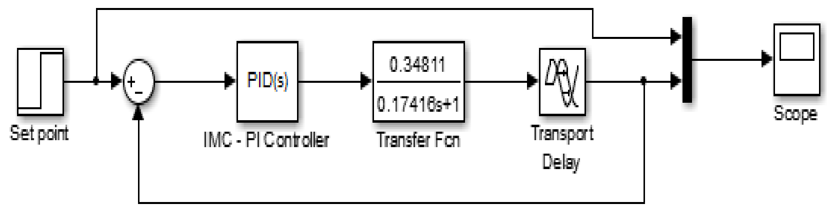

Fig 5: Simulink model for IMC based PID controller

D. CDM based PI controller

CDM uses polynomial approach which is used to obtain the controller and closed loop transfer function. In this approach, the type and degree of the controller polynomials and the characteristic polynomial of the closed-loop system are defined at the start of the process. By taking into consideration of design specifications, coefficients of the polynomials are found at the end. Because of instantaneous design structure, the designer is able to keep a good balance between the intransigence of the requirements and the complication of the controller [4].The CDM – PI controller is designed based on the following steps

1) *Step 1:* The FOPDT transfer function obtained for the pH process station is given by

$$G(s) = \frac{0.34811\, e^{-0.576s}}{0.17416\, s+1}$$

2) *Step 2:* Pade's approximation is obtained for the above mentioned transfer function

$$G(s) = \frac{0.35-0.10s}{0.05s^2+0.47s+1}$$

3) *Step 3:* Defining the CDM controller polynomials (A(s) and B(s))

$$A(s) = I_1 s$$

$$B(s) = K_1 s + K_0$$

4) *Step 4:* The CDM controller stability indices value are defined as γ_1 and γ_2 and the tuning factor is defined as λ

$$\gamma_1 = 2.5$$

$$\gamma_2 = 2$$

$$\lambda = 0.5$$

5) *Step 5 :*Calculate the P(s) = A(s) D(s) + B(s) N(s)

$$P(s) = 0.05I_1 s^3 + (0.47I_1 - 0.10K_1)\, s^2 + (I_1 + 0.35K_1 - 0.10K_0)s^2 + (I_1 + 0.35K_1 - 0.10K_0)\, s + 0.35K_0$$

6) *Step 6:* The CDM target characteristic polynomial are defined as

$$p_{targer}(s) = \frac{\tau^3}{\gamma_2\gamma_1^2}s^3 + \frac{\tau^2}{\gamma_1}s^2 + \tau s + 1$$

$$p_{targer}(s) = 0.01s^3 + 0.1s^2 + 0.5s + 1$$

7) *Step 7:*Computing the coefficient of the CDM Controller polynomial the value of K_0 and K_1 values are obtained

$$K_0 = 2.85$$

$$K_1 = 1.04$$

8) *Step 8:*PI tuning parameters are

$$k_c = 1.04$$

$$\tau_i = 0.36$$

The Simulink model for CDM - PI controller is shown in Figure 6

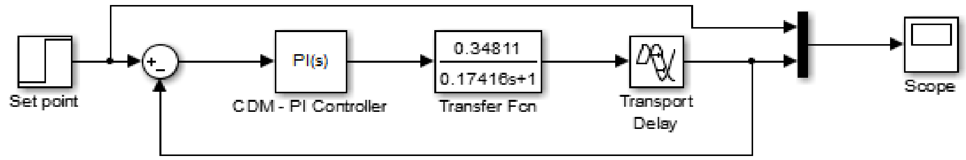

Fig 6: Simulink model for CDM - PI controller

II. RESULTS AND DISCUSSION

The closed loop response of ZN - PI, IMC – PI and CDM-PI controller obtained in MATLAB for Acid, Neutral and Base region and the comparative study has been done and it is shown in Figure 7, 8 and 9.

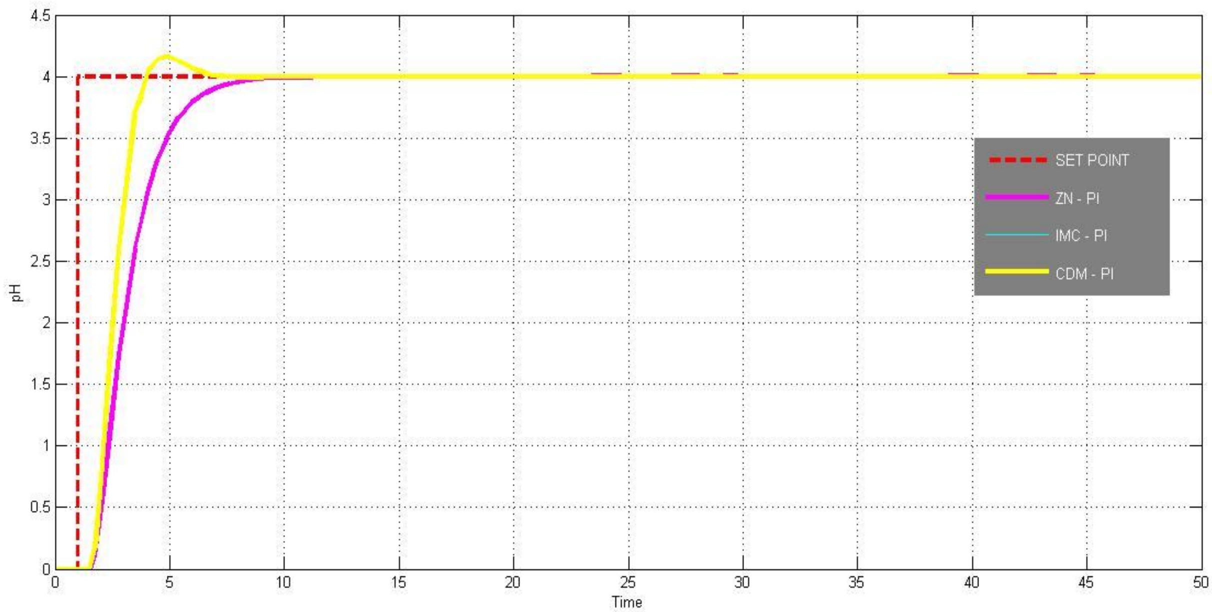

Fig 7: Response of the controllers in Acid region (pH = 4)

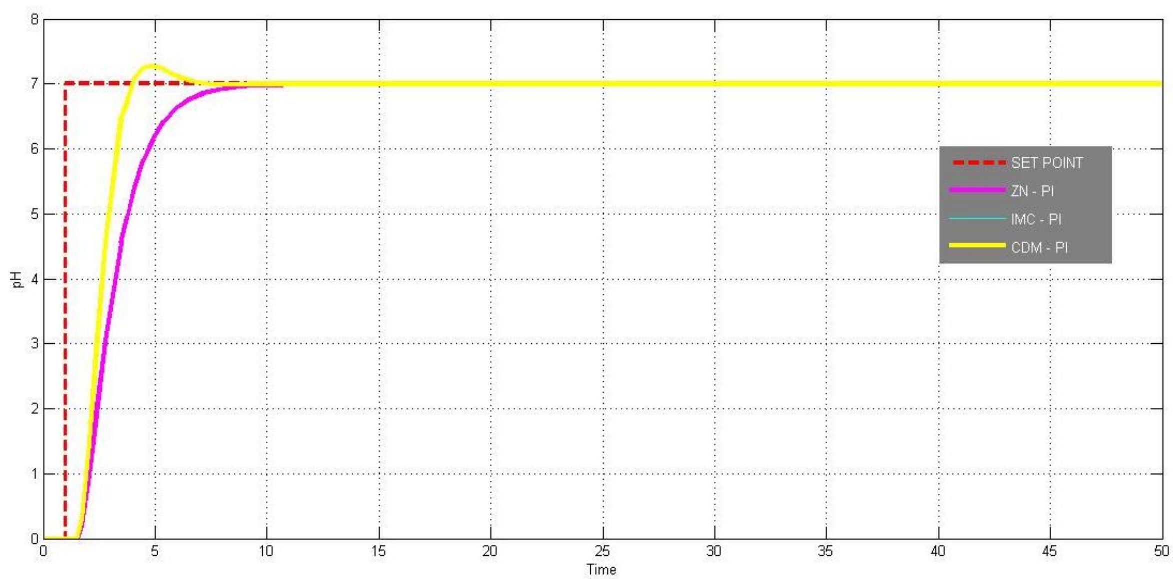

Fig 8: Response of the controllers in Neutral region (pH = 7)

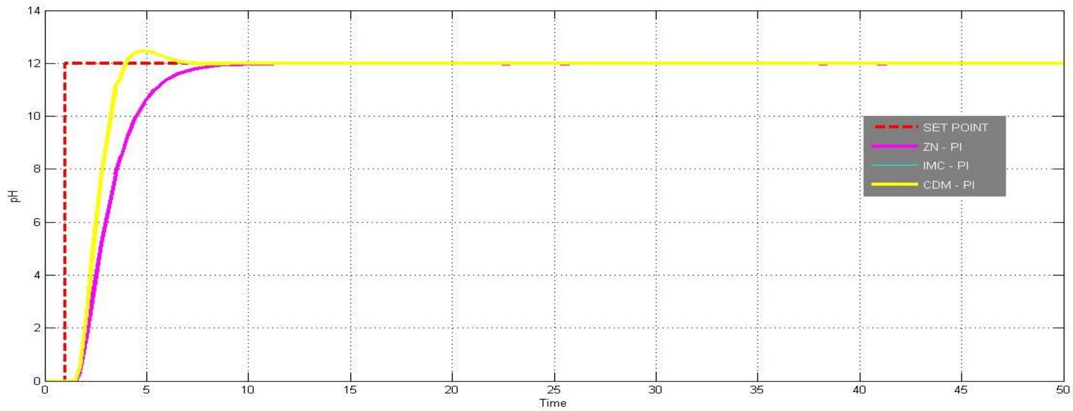

Fig 19: Response of the controllers in Base region (pH = 12)

The comparative analysis of controller performance based on the rise time, settling time, peak time, peak overshoot are identified and listed in table 2. The error indices like Integral Absolute Error (IAE) and Integral Square Error (ISE) are also calculated and tabulated in Table 2 of the proposed system.

Controller	Region	Rise time (sec)	Peak time (sec)	Delay time (sec)	Settling time (sec)	IAE	ISE
Conventional PI controller	Acid	4.05	4.89	2.53	9.90	2.53	2.26
	Neutral	4.05	4.89	2.53	9.90	2.53	2.26
	Base	4.05	4.89	2.53	9.90	2.53	2.26
Internal Model Controller based PI Controller	Acid	4.05	4.89	2.53	9.90	2.53	2.26
	Neutral	4.05	4.89	2.53	9.90	2.53	2.26
	Base	4.05	4.89	2.53	9.90	2.53	2.26
CDM based PI Controller	Acid	4.05	4.89	2.53	9.90	2.53	2.26
	Neutral	4.05	4.89	2.53	9.90	2.53	2.26
	Base	4.05	4.89	2.53	9.90	2.53	2.26

III. CONCLUSION

The controlling of nonlinear system is a very challenging task to perform. The performances of various controllers were tested in simulation. By the analysing the simulation results the IMC – PI controller and CDM – PI Controller gives same response and when it is compared with ZN –PI controller both IMC-PI and CDM-PI gives better response for the pH process.

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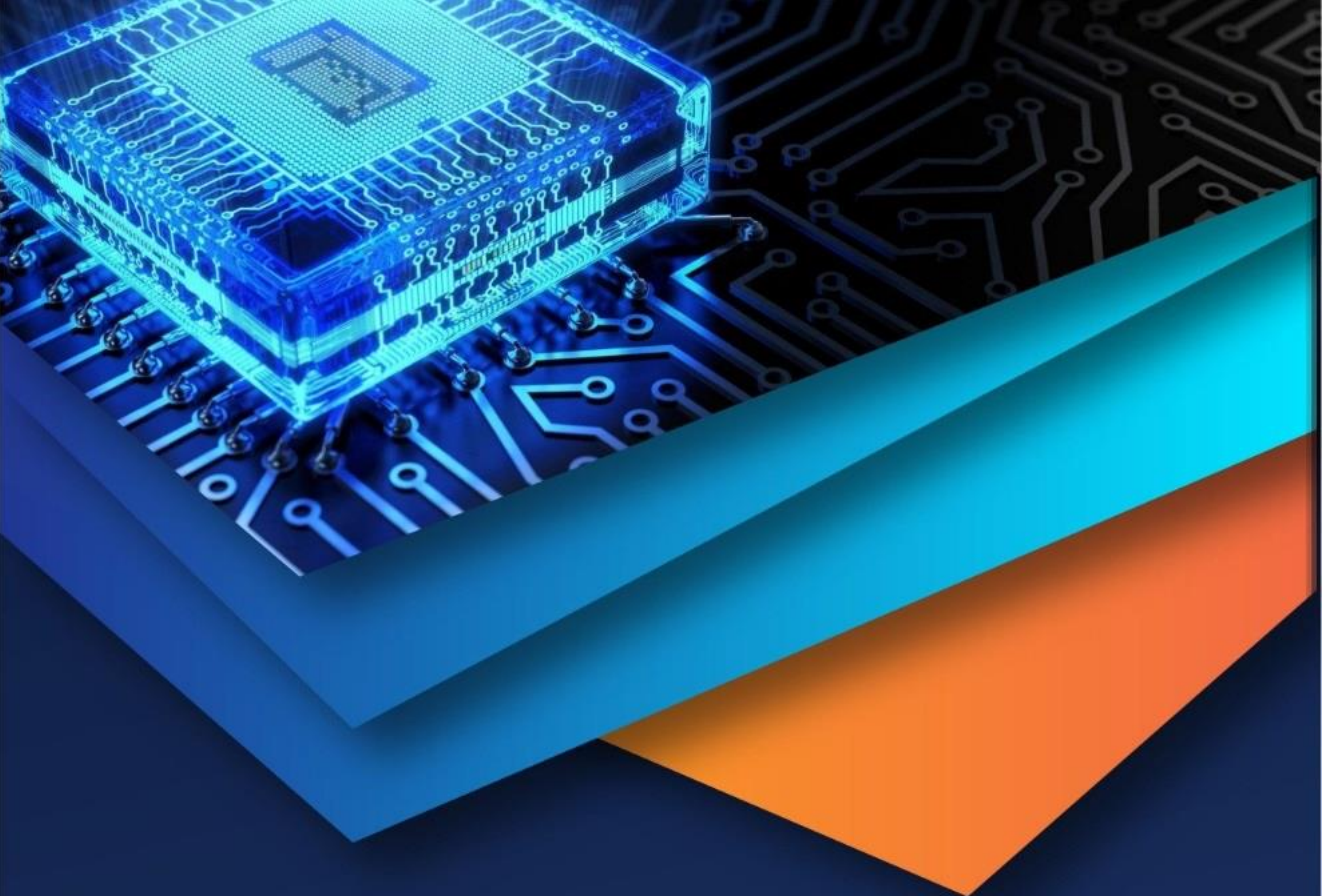

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