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Level Control of a Non-Linear Spherical Tank System using GA based Controller

S. Babushanmugham[1], S.Srinivasan[2], A.Ganeshram[3], S.M. Girirajkumar[4], E.Sivaraman[5]
[1, 2, 3, 4, 5] *Department of Electronics and Instrumentation Engineering, Department of Instrumentation and Control Engineering*
Annamalai University, Sranathan College of Engineering

Abstract: In the modern eras of chemical industries, automatic soft computing based controllers are more competent and cost effective for fine tuning of non-linear process parameters when compared to conventional controllers. The main objective of this research work is to show that genetic algorithm based PI controller tuning approach provides optimal performance to control and maintain the level of the non-linear process in a spherical tank system. The simulated end results proves that GA based PI controller contributes best tuning catalogues in terms of servo, regulatory problems when compared with these of ZN PI and internal model controller(IMC) PI.
Keywords: Spherical tank, ZN tuning method, IM Controller, Genetic algorithm, PI controller.

I. INTRODUCTION

Dealing and controlling a chemical process requires intelligent control and monitoring schema due to the dynamic nature of the chemical reactions and non-linear functional relationships between the input and output variables. In control engineering, control of non linear process is a complex task and it is outbreak to use process models obtained from linearization instead of complete nonlinear models. Increased investigation efforts are now concentrated on the development of nonlinear process models and decision making. In order to guarantee the stability and proper functioning of a linear model due to linearization, a painstaking justification is required. Therefore, techniques are needed to assess the nonlinear degree of a process to decide whether a process is sufficiently nonlinear to rationalize a nonlinear controller.

Controlling the level of a process in a spherical tank is one of the most significant and critical entities in chemical industries which exhibit high nonlinear behavior because the change in shape gives rise to the non -linear characteristics. The control of level, temperature, pressure and flow are important aspects in evaluating a PID controller in chemical process industries. The chemical process industries require process liquids to be pumped and stored in another tank or process vessel. Most of the time the liquid will be processes by mixing treatment in tanks, but the level of the liquid in tank to be controlled at some desired value as per the set point or output requirements. Spherical tank is considered as an optimum shaped vessel to carry out chemical reactions and processing the chemicals in many aspects. But, it exhibits high nonlinearity during the level control of the process and it is very hard to control it by conventional methods[5].

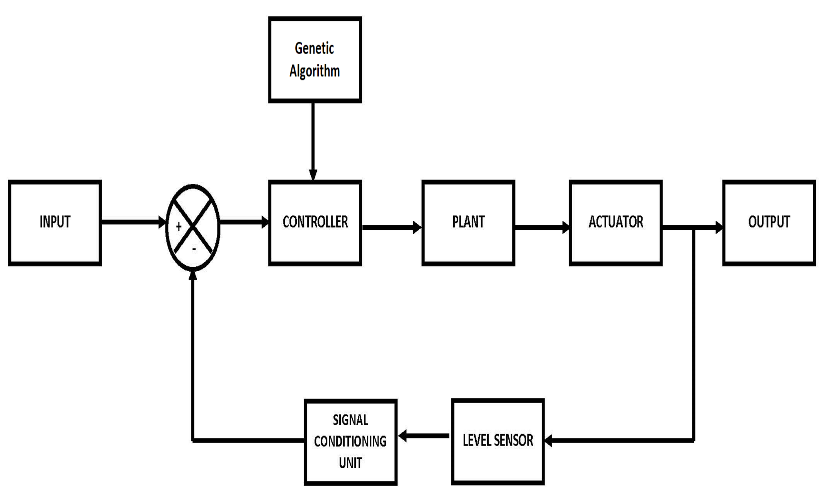


Fig. 1 Block diagram of proposed approach

Presently Genetic Algorithm (GA)[8] has been receiving a lot of attention due to its efficient and cost effective results when compared to many conventional methods and other soft computing technologies. Application in the area of control engineering has also developed tremendously. In spite of this fact, more research has been done to study the behavior of genetic algorithm in many linear and nonlinear process control applications. Genetic algorithm is a random search method used to solve nonlinear system and optimize complex problems which uses probabilistic transition rules instead of deterministic rules and handles a population of potential solutions iteratively known as individuals or chromosomes. Each iteration of the algorithm is termed a generation. The conventional PI controller parameters can be found using GA. In control system design, issues such as performance, system stability, static and dynamic index and system robustness have to be taken into account. For the PI controller design, it is ensured the controller settings estimated results in a stable closed loop system.

This research work, Along with GA based controller design, Ziegler and Nichols-PI [1] controller parameters and IMC found using spherical tank in different operating regions. All possible regions set of controller values are estimated as First Order Process with Dead Time (FOPDT). For the PI controller design, it is ensured the controller settings estimated results in a stable closed loop system.

In this paper section 2 deals with process description, section 3 deals with control approaches briefly, section 4 shares results and discusses about the research work.

II. PROCESS DESCRIPTION

The Spherical Tank is one of the fluids handling system find its application in many chemical industries, exhibit high nonlinear behavior reasonably. The nonlinearity present in the system imposes complication in the design of conventional PID controllers. The linear model for entire operating regions of the Spherical Tank is obtained and controllers are designed as Spherical Tank liquid level system.

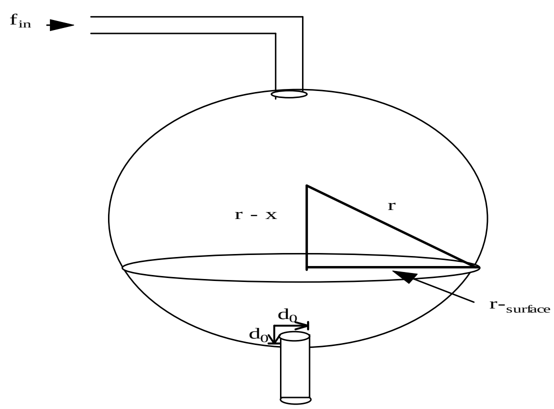


Fig.2 Spherical tank

The first step in the studying of the dynamic behavior and control of spherical tank is to develop a mathematical model depending on mass and energy balances that can be considered as the gate for all works. The specification of the spherical tank is corresponding to nominal operation point is given in Table 1.

TABLE I
SPECIFICATION OF THE SPHERICAL TANK IN NOMINAL OPERATION POINT

Part Name	Details
Spherical Tank	Material: Stainless Steel Diameter: 50 cm Volume: 102 Liters
Storage Tank	Material: Stainless Steel Volume: 48 Liters

Differential Pressure Transmitter	Type: Capacitance Range: (2.5-250)mbar Output: (4-20) mA
Pump	Centrifugal 0.5HP
Control Valve	Size: ¼'' Pneumatic Activate Type: Air To Close Input: (3-15) Psi
Rotameter	Range: (0-18) lpm
Air Regulator	Size: ¼'' BSP Range: (0-2.2) Bar
I/P Convertor	Input: (4-20) mA Output: (0.2-1) Bar
Pressure Gauge	Range: (0-30) Psi Range: (0-100) Psi

The spherical tank level process model referred in Fig 2, in which the control input fin is the input flow rate (m3/s) and the output x is the fluid level (m) in the spherical tank. Let, r, d0 and x0 is the radius of spherical tank, thickness (diameter) of pipe (m) and initial liquid level height respectively.[6 & 11]

Assume 'rsurface' radius on the surface of the fluid varies according to the level of fluid in the tank.

Length2 + Height2 = Hypotenuse 2 (By Pythagoras theorem)

Where,

Length $= r_{surface}$; (1)

Height = radius of tank (r) – fluid level (x)

Hypotenuse = radius of tank (r)

Therefore,

$$(r-x)^{2n} + r_{surface} = r^2 \quad (2)$$

$$r_{surface}^2 = r^2 - r^2 + 2rx - x^2 = 2rx - x^2 \quad (3)$$

$$r_{surface} = \sqrt{2rx - x^2}$$

Now the Dynamic model of the spherical tank is given by

$$\frac{\delta}{\delta t}\left[\int_0^{x_1} A(x)\,\delta x\right] = \text{fin}(t) - a\sqrt{2gx - x_0} \quad (4)$$

where $A(x)$ = area of cross section of tank = $\pi\, r_{surface}^2 = \pi\,(2rx - x^2)$

a = area of cross section of pipe = $\pi \left(\frac{d_0}{2}\right)^2$

Rewriting the equation (4) at time t + δt

$$A(x)\,\delta x = f_{in}\,\delta t - a\sqrt{2g(x - x_0)}\,\delta t \quad (5)$$

Where, $A(x)\,\delta x$ = Amount of water

$f_{in}\,\delta t$ = Input flow rate and $a\sqrt{2g(x - x_0)}\,\delta t$ = Output flow rate

Combining the equations (1) to (5), we have

$$\frac{\delta x}{\delta t} = \frac{f_{in}\ \delta t - \frac{\pi . d_0^2}{4}\sqrt{2g\,(x - x_0)}}{\pi\,(2rx - x^2)\,)} \quad (6)$$

By applying

$\lim_{d \to 0}$ in equation (6), we have $\frac{\delta x}{\delta t} = \frac{dx}{dt}$

Therefore

$$\frac{dx}{dt} = \frac{f_{in}\ \delta t - \frac{\pi . d_0^2}{4}\sqrt{2g\,(x - x_0)}}{\pi\,(2rx - x^2)} \quad (7)$$

Equation (7) shows the dynamic model of the Spherical Tank System and this model representation is considered for simulation studies. The system identification of this non-linear spherical tank system is done by using block box modeling. For fixed inflow rate and outflow rate of the spherical tank, the tank is allowed to fill with water from 0 to 50cm. At each sample time the data from differential pressure transmitter i.e. between 4 to 20mA is being collected and fed to the system through the serial port RS-232 using VMAT-01 interfacing module.[10]

There by the data is scaled up in terms of level(in percentage).The total height of the tank is 0-50cm.It is converted in terms of 0-00%.Using the open loop method, for a given input step change, the output response of the system is recorded with help of PC. In order to find the open loop transfer function model of the spherical tank system at three different operating regions, the level ranges from 20% to 39%, 40% to 59% and 60 to 75% for lower, middle and upper level of the tank respectively. The transfer function parameters at different operating levels for different spherical tank model are given in table II.

TABLE II
TRANSFER FUNCTION PARAMETERS AT DIFFERENT OPERATING LEVELS OF DIFFERENT SPHERICAL TANK MODEL

Model	Level (%)	Kp	τp	td
Model 1	20-39	5.083	620.24	29
Model 2	40-59	5.469	1015.8	30
Model 3	60-75	4.202	1291.2	30

III. CONTROL APPROACHES:

A control system discussed in which the PI controller is tuned using Ziegler-Nichols Tuning Criteria, Traditional methods often do not provide adequate tuning. Internal Model Control is an intellectual approach has been widely used to tune the parameters of PID controller.

A. Ziegler–Nichols Tuning Method

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller. The proportional gain is then increased until it reaches the ultimate gain, at which the output of the control loop has stable and consistent oscillations. Ultimate gain and the oscillation period are used to set the P, I, and D gains depending on the type of controller.

B. Internal Model control Tuning Method:

The internal model control technique is one of the recent traditional tuning techniques that yield better values among the techniques available for the conventional method. Designing a model based controller usually requires a plant model, which is normally obtained from first principles. However, the parameters of the model are normally unknown and need to be estimated from simulated data. The basic PI controller parameters are proportional gain Kp and integral gain Ki.

C. Genetic Algorithm

GA uses a direct analogy of natural evolution to do global optimization in order to solve highly complex problems. It presumes that the potential solution of a problem is an individual and can be represented by a set of parameters. These parameters are regarded as genes of a chromosome and can be structured by a string of concatenated values. The form of variables representation is defined by the encoding scheme and can be represented by binary, real numbers or other forms, depending on the application data.

Its range, the search space, is usually defined by the problem. In the beginning, an initial chromosome is randomly generated. The chromosomes are candidate solutions to the problem. Then, the fitness values of all chromosomes are evaluated by calculating the objective function in decoded form. So, based on the fitness of each individual, a group of the best chromosomes is selected through the selection process. The Genetic operators, crossover, and mutation, are applied to this surviving population in order to improve the next generation solution. The process continues until the population converges to the global maximum or another stopping criterion is reached.

During the reproduction phase, the fitness value of each chromosome is assessed and it is used in the selection process to provide a bias towards fitness individuals. Then crossover algorithm is initiated once the selection process is completed. The background operator in the genetic algorithm is the mutation. The probability of mutation is normally low since high mutation rate will destroy fit strings and degenerate GA into random search. The sequence of evolution is repeated until a termination criterion is reached.

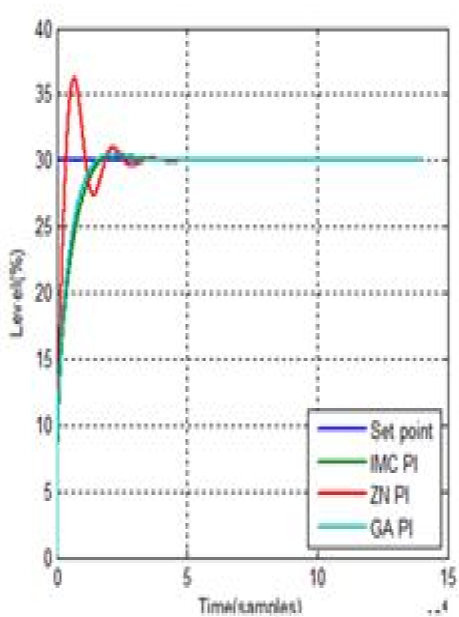
TABLE III

CONTROLLER PARAMETER FOR THREE MODELS

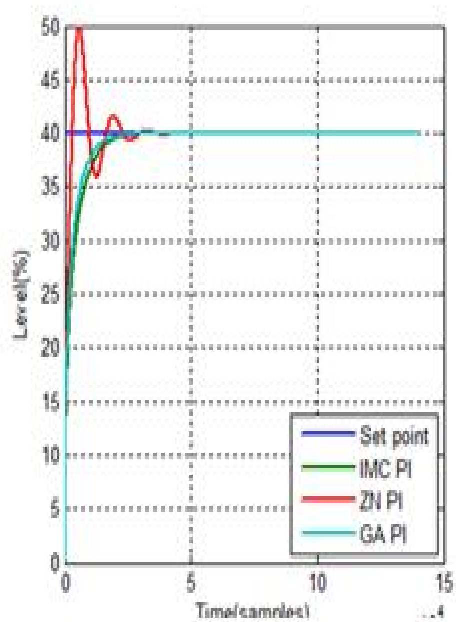
Models	GA-PI		IMC-PI		ZN-PI	
	kp	*ki*	*kp*	*ki*	*kp*	*ki*
Model 1	3.9713	0.006519	3.4856	0.00562	3.3234	0.03196
Model 2	5.9974	0.005971	5.0199	0.004941	4.4360	0.04484
Model 3	7.9936	0.007026	8.3049	0.006431	10.3018	0.07366

IV. RESULTS AND DISCUSSION

The PI controller values obtained by GA based controller are compared with those of the results derived from IMC-PI and ZN-PI methods are compared in various perspectives, viz. set point changes and regulatory changes. A tabulation of the time domain specifications comparison and the performance index comparison for the obtained models with the designed controllers is presented in table IV and table V. In this case, the results of servo and regulatory responses of GA tuned controller at various set point changes are presented.



At 30% operating point



At 40% operating point

Fig.3 Servo Response of Spherical tank at 30% and 40% operating point respectively.

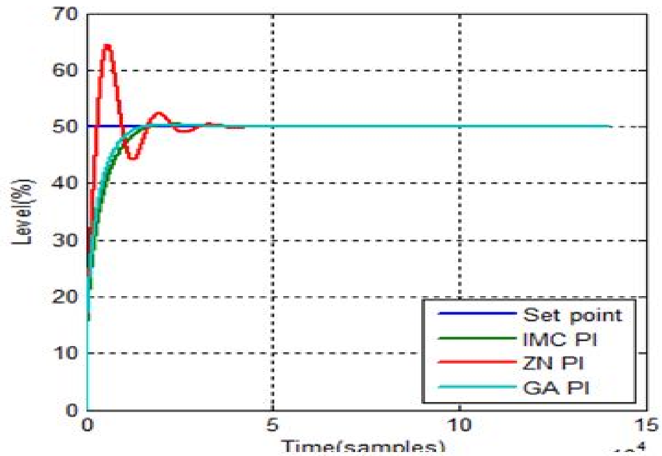
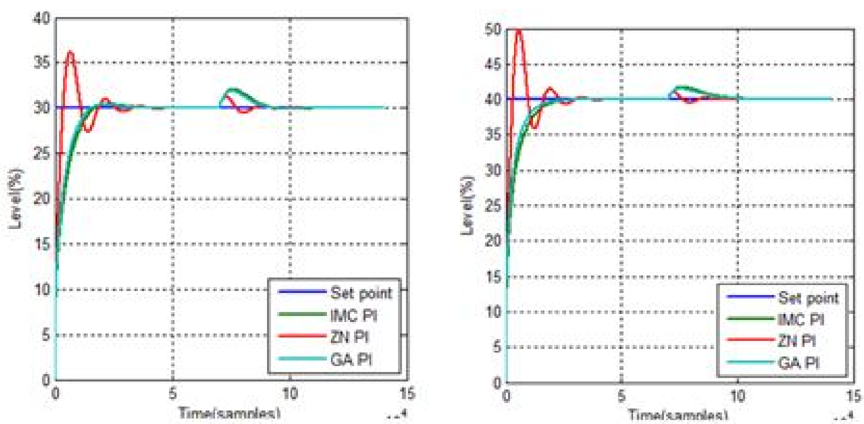


Fig.5 Servo Response of Spherical tank at 50% operating point.



At 30% operating point

At 40% operating point

Fig.6 Regulatory response at 7% constant load, at 30% and 40% operating point respectively

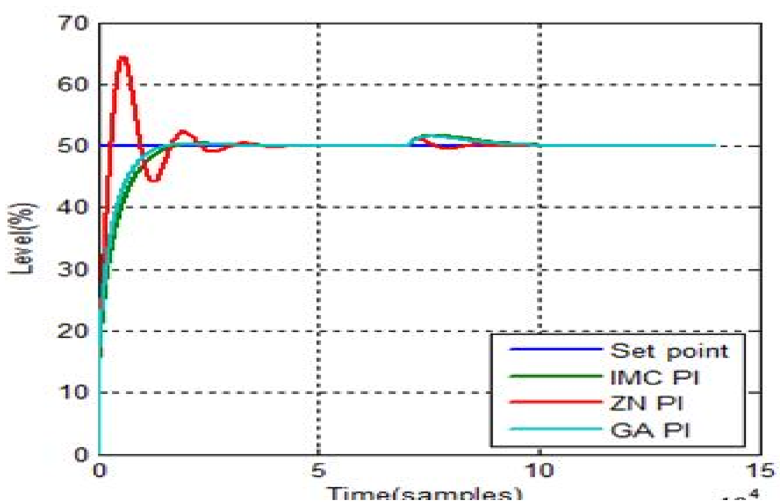


Fig.8 Regulatory response of 50% operating point and 7% constant load applied.

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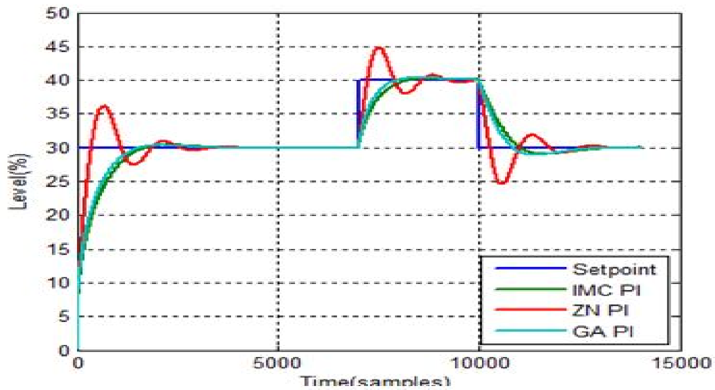

Fig.9 Set-point tracking - 30% positive step changes from 30 % of level and 10% constant load applied

TABLE IV
COMPARISON OF TIME DOMAIN SPECIFICATION FOR DIFFERENT OPERATING LEVELS

Level in Percentage	Specification	GA-PI	IMC-PI	ZN-PI
30%	Rise Time(tr)	8429.3	9683.2	2899.5
	% overshoot	1.2596	1.4002	20.8797
	Settling Time (ts)	12915	14466	23888
40%	Rise Time(tr)	7408.9	9148.6	2455.1
	% overshoot	0	0.0257	24.8024
	Settling Time (ts)	15197	17576	21604
50%	Rise Time(tr)	6892.5	8366.8	2545.4
	% overshoot	0.5846	0.7428	29.1518
	Settling Time (ts)	11653	13712	22157

TABLE V
PERFORMANCE INDEX FOR SERVO RESPONSE

Models	GA-PI		IMC-PI		ZN-PI	
	ISE	*IAE*	*ISE*	*IAE*	*ISE*	*IAE*
30%	26160	4658	30930	5413	19660	4380
40%	36140	5313	45020	6436	33300	5698
50%	59940	6389	73660	7780	60990	8079

V. CONCLUSION

In the present work the design and implementation of GA based PI controller, ZN based PI controller and IMC tuned PI controller for spherical tank liquid level control have been presented. Based on the simulation results it is concluded that for spherical Tank, the performance of the GA controller is much superior when compared to the IMC controller and ZN tuned controller. GA based controllers agree to have a faster and more precise control of the process, both for set-point and disturbance step changes. The simulation responses reflect the effectiveness of the GA based controller in terms of time domain specifications. The performance index under the various error criterions of the GA based PI controller is always less than IMC based controller and ZN tuned controller.

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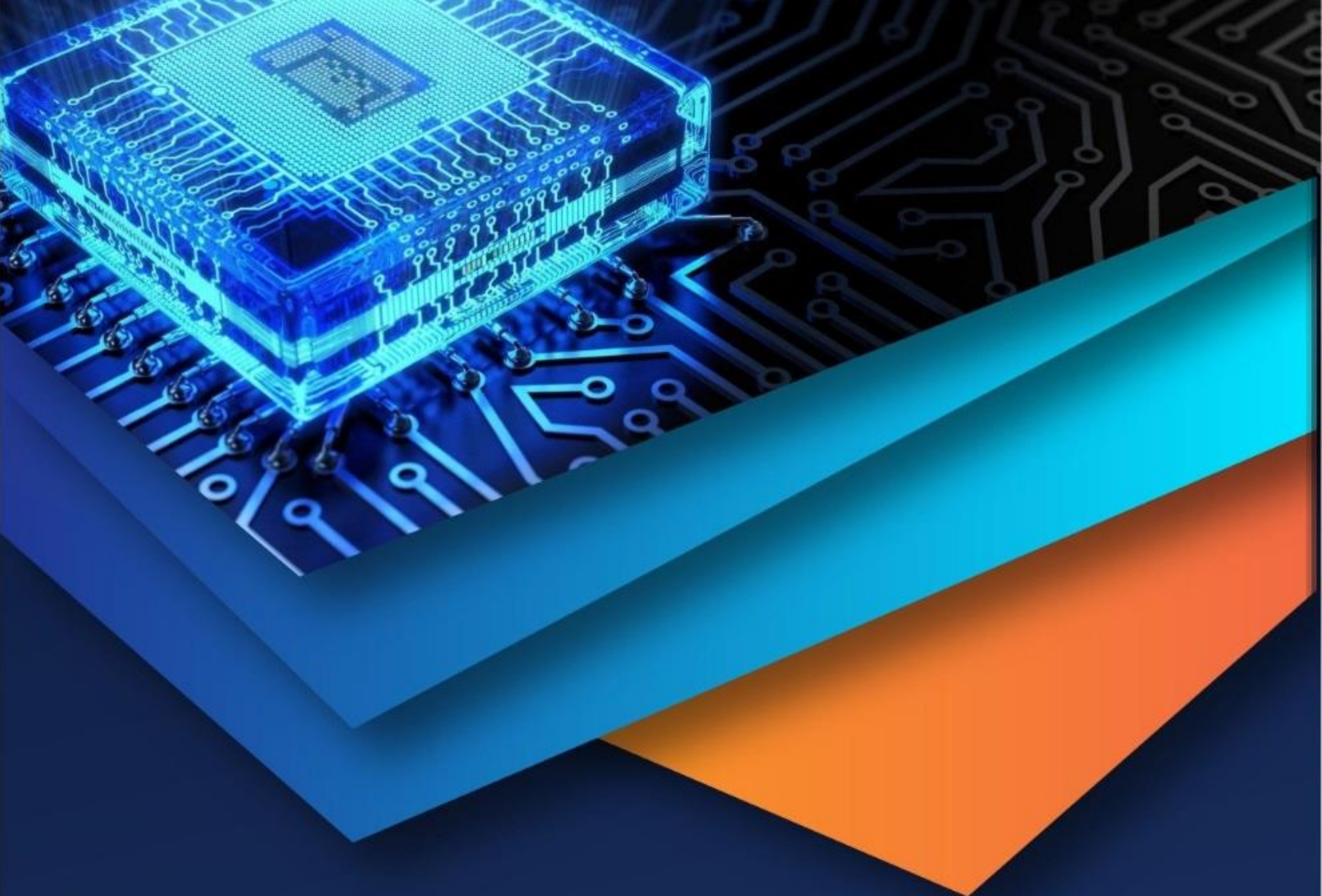

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