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A Fuzzy based Direct Torque Control System to Improve the Induction Motor Performance

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Abstract: The Induction Motor is most widely used owing to its high reliability, robust in operations, relatively low cost, and modest maintenance requirements. In order to improve the performance of the Induction Motor P, PI, PID controllers were used. But these controllers provide more distortion in the system. Hence to overcome this, a new controller is introduced as Direct Torque Controller (DTC). In this paper DTC is a method which is employed to control flux and torque of an Induction Motor. The Fuzzy Based Direct Torque Controller is proposed to reduce the torque and flux ripples. Therefore the proposed controller is used as a solution for the improvement in the performance of Single Phase Induction Motor apart from using conventional Controllers.
Keywords: Direct torque control (DTC), Fuzzy logic controller, Field oriented control (FOC), Induction motor, Proportional integral direct torque control (PIDTC), Simulation

I. INTRODUCTION

The induction motor is most widely because of its high reliability, robust in operations, relatively low cost and modest maintenance requirements. But they require much more complex methods of control, more expensive and higher rated power converters than DC and permanent magnet machines. Three phase induction motor is widely used in industrial drive because they are reliable and rugged. Single phase induction motors are widely used for heavier loads for example in fans in household appliances. The fix speed service, induction motors are being increased with variable frequency drives. Induction motor achieves a quick torque response, and has been applied in various industrial applications instead of dc motors. It permits independent control of the torque and flux by decoupling the stator current into two orthogonal components FOC (Field Oriented Control). However it is very sensitive to flux, which is mainly affected by parameter variations. It depends on accurate parameter identification to achieve the expected performance. The vector control of IM drive for speed control is mainly classified into two types such as field oriented control (FOC) and direct torque control (DTC). In FOC, the speed of the induction motor is controlled like a separately excited dc-motor with more transformations and complexity involved in the system. In order to control the induction motor speed in simple way without required any transformations the DTC is used. In the middle of 1980 direct torque control was developed by Takahashi and Depenbrock as an alternative to field oriented control to overcome its problems. Direct torque control is derived from the fact that on the basis of the errors between the reference and the estimated values of torque and flux it is possible to directly control the inverter states in order to reduce the torque and flux errors within the prefixed band limits. Direct torque control is a strategy research for induction motor speed adjustment feeding by variable frequency converter. It controls torque on the base of keeping the flux value invariable by choosing voltage space vector.

The conventional DTC is having high torque ripples and slow transient response to the step changes in torque during start-up. Numerous techniques have been proposed to improve the torque performance and speed trajectory. However using fast error limiters can reduce the torque ripples by selecting high optimal switching frequencies or to the change in the inverter topology. For this fuzzy controller could be better solution to develop high performance motor drives applications to get high degree of accuracy and can pursue the command smoothly and quickly.

The name direct torque control is derived from the fact that on the basis of the errors between the reference and the estimated values of torque and flux it is possible to directly control the inverter states in order to reduce the torque and flux errors within the prefixed band limits. Direct torque control is a strategy research for induction motor speed adjustment feeding by variable frequency converter. It controls torque on the base of keeping the flux value invariable by choosing voltage space vector.

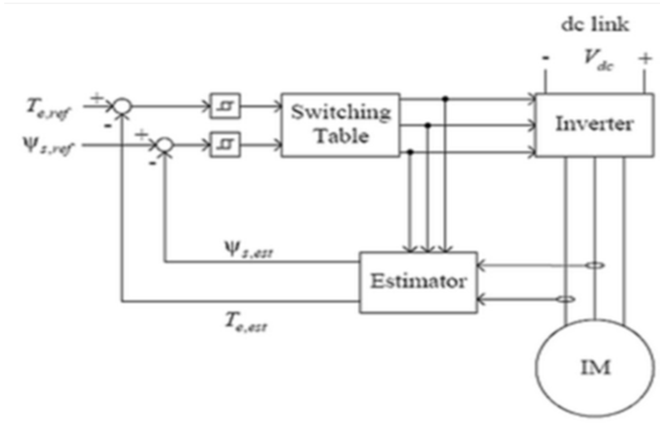

Fig.1. Schematic of Direct Torque Controller

There are two different loops corresponding to the magnitudes of stator flux and torque. The reference values of stator flux modulus and torque are compared to their actual values. The resulting errors are fed to the input of look up table. The DTC require stator flux and torque estimations which can be performed as proposed, by mean of two different phase currents and state of inverter. The basic principle of DTC is to directly manipulate the stator flux vector such that the desired torque is produced. This is achieved by choosing an inverter switch combination that drives the stator flux vector by directly applying the appropriate voltages to the motor windings The direct torque method performs very well even without speed sensors. However, the flux estimation is usually based on the integration of the motor phase voltages. Due to the inevitable errors in the voltage measurement and stator resistance estimate the integrals tend to become incorrect at low speed. If continuous operation at low speeds including zero frequency operation is required, a speed or position sensor can be added to the DTC system. With the sensor, high accuracy of the torque and speed control can be maintained in the whole speed range.

II. FUZZY LOGIC BASED SYSTEM

Conventional DTC of IM drive has the limitations of constant duty ratio for every switching period and high torque ripples. These problems are rectified using fuzzy logic control technique. In it is presented that the implementation of fuzzy logic and neural network reduce the stator flux and torque ripples. A new algorithm for optimized value of stator flux based on the maximum reference value of electromagnetic torque is proposed to operate in conjunction with duty ratio control. The Fig.2 shows the proposed DTC with duty ratio controller. To make the torque and duty ratio variations smaller, the universe of discourse of torque error and duty ratio are divided into five overlapping fuzzy sets. However, to reduce the complexity of design, the stator flux position is defined with three overlapping fuzzy sets only. The universe of discourse of all the variables, covering the whole region is expressed in per unit values.

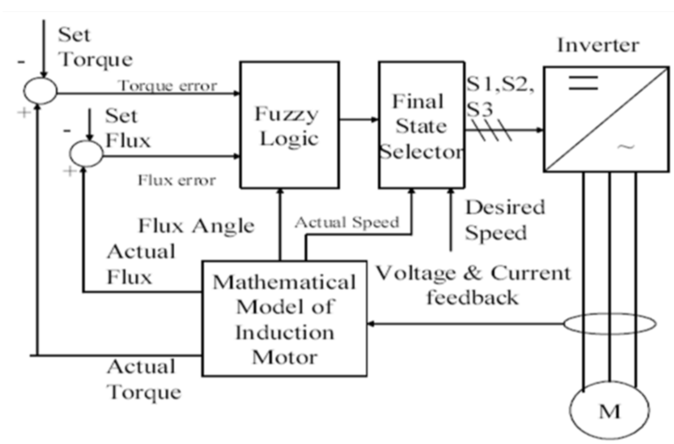

Fig.2. Block Diagram of Direct Torque Control of Induction Motor Using Fuzzy Logic Controllers

The switching state decides the pulse to be applied to the inverter. Depending on the values of flux error, torque error and stator flux position the output voltage vector is chosen based on the fuzzy rules. Using fuzzy logic controller the voltage vector is selected such that the amplitude and flux linkage angle is controlled. Since the torque depends on the flux linkage angle the torque can be controlled and hence the torque error is very much reduced.

Table.1 Linguistic variable of fuzzy logic control

Error e(t)		Change in error Δe(t)		Controller output u(t)	
NB	Negative Big	NB	Negative Big	NB	Negative Big
NM	Negative Medium	NM	Negative Medium	NM	Negative Medium
NS	Negative Small	NS	Negative Small	NS	Negative Small
ZO	Zero	ZO	Zero	ZO	Zero
PS	Positive Small	PS	Positive Small	PS	Positive Small
PM	Positive Medium	PM	Positive Medium	PM	Positive Medium
PB	Positive Big	PB	Positive Big	PB	Positive Big

Table.1 shows the different linguistic variables that are considered for the formation of fuzzy rule. Designing a good fuzzy rule base is the key to obtain satisfactory control performance for a particular operation. Classical analysis and control strategy are incorporated in the rule base. The rule base used in simulation is summarized in Table.2 Each rule has the form IF e(t) is NB AND Δe(t) is NB THEN u(t) is NB. The control literature has worked towards reducing the size of the rule base and finally defuzzified output is obtained from the fuzzy inputs.

Table.2 Rule Base for Fuzzy Logic Control

u(t)		e(t)						
		NB	NM	NS	ZO	PS	PM	PB
Δe(t)	NB	NB	NB	NB	NB	NM	NS	ZO
	NM	NB	NB	NB	NM	NS	ZO	PS
	NS	NB	NB	NM	NS	NS	PS	PS
	ZO	NB	NM	NS	ZO	ZO	PM	PM
	PS	NM	NS	ZO	PS	PS	PB	PB
	PM	NS	ZO	PS	PM	PM	PB	PB
	PB	ZO	PS	PM	PB	PB	PB	PB

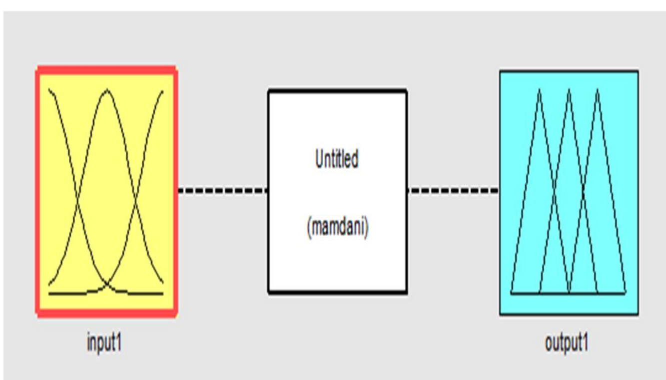

Fig.3. Mamdani fuzzy inference system developed for fuzzy controller

The Fig.3 shows the Mamdani fuzzy inference system developed for fuzzy controller for simulation. The mamdani rule base is a crisp model of a system. That is, it does with the use of user-defined rules on user-defined fuzzy variables.

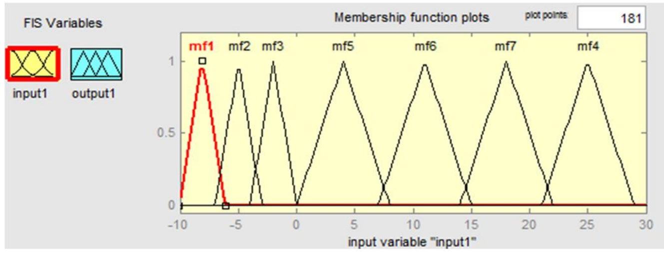

Fig.4. Triangular input membership function for input

The Fig.4 shows the triangular input membership function for input. The membership function fully defines the fuzzy set. A membership function provides a measure of the degree of similarity of an element to a fuzzy set. The Fig.5 shows triangular input membership function for output

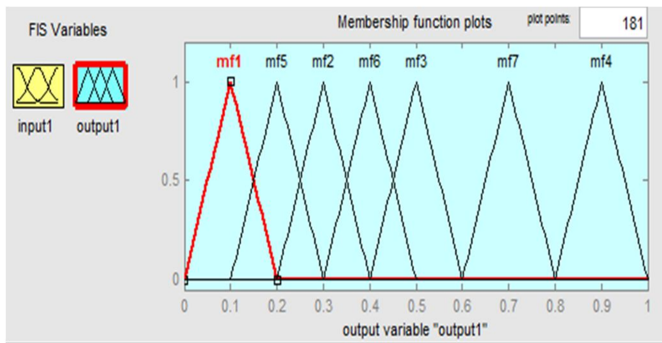

Fig.5 Triangular input membership function for output

III. SIMULATION MODEL

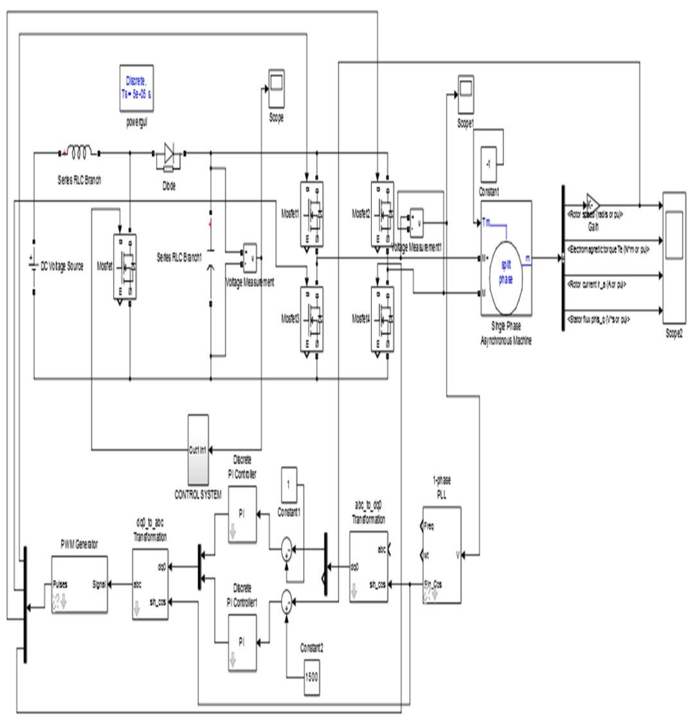

Fig.6. Proposed System Simulation Model

The Fig.6 shows the proposed Fuzzy based Direct Torque Control System Simulation Model for the Single Phase Induction Motor done in MATLAB/SIMULINK. And analyzed the input and output waveforms of proposed system. In the simulation model, the input is taken from the dc source with 50v as dc voltage value. This voltage is given as input to the boost converter. The dc-dc boost converters are used to convert the unregulated dc input to a controlled dc output at a desired voltage level. The 50v dc voltage is

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boosted into 160v dc voltage. The fuzzy controller is implemented for giving gate pulses to the MOSFET switch in the boost converter. The rules are for formulated for fuzzy controller using mamdani method. The dc output voltage from the boot converter is given to the inverter for inverting the dc voltage into ac voltage. The gate pulses to the four MOSFET switches are given by the DTC controller. The DTC controller takes the speed from single phase induction motor as the feedback, it is then given to the phase locked loop. From PLL block the signal fed into the transformation block, the transformed signal is fed to the PI controller where the signal is compared with the constant speed given as 1500rpm and the resultant signal is given to the dq transformation block. The pulses to the inverter switches are generated in the PWM generator. From there the gate pulses are given to the four inverter MOSFET switches. Thus by the switching operation of the switches the dc voltage is inverted to the ac voltage and given to the single phase induction motor as input. The motor used here is single phase asynchronous motor and the speed, torque, rotor current and stator flux waveforms are obtained as output waveform.

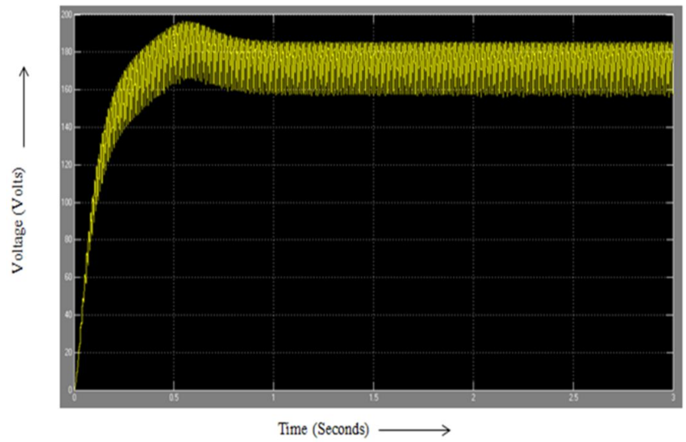

Fig.7. Input voltage waveform

The x axis of the input waveform of the simulation represents the time offset in seconds and y axis represents the dc voltage fed into the inverter in volts.The input dc voltage to the boost converter is 50v. This voltage gets boosted in the converter upto 160v and it is then fed into inverter as input voltage. The dc voltage increases initially with increase in time and the time taken to reach the steady state is 0.75s with 160v as dc voltage.

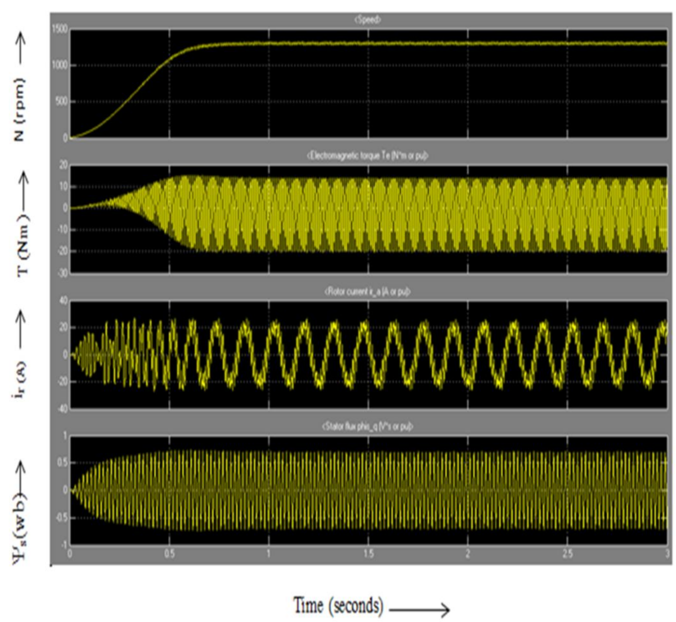

Fig.8. Output wave form

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The Fig.8 shows the output waveform of the proposed simulation. The x axis of the output waveform of simulation represents the time offset and y axis represents stator flux, rotor current, electromagnetic torque and speed of single phase induction motor respectively. The fuzzy based DTC system provides less flux distortion, so in the output waveform the time taken to reach the steady state by stator flux is 0.5s with a stator flux value of 0.75wb. The maximum rotor current value obtained in the output waveform is 25A and it reaches the steady state at 0.5s. The time taken by the torque and speed waveforms to reach steady state is 0.7s with a maximum torque and speed values 15Nm and1400rpm respectively. Thus the implemented fuzzy based DTC system minimizes the ripples and distortion in speed, flux and torque waveforms effectively.

IV. RESULTS AND DISCUSSIONS

Table.3 Performance Comparison of PIDTC and FDTC

SL NO	CONTROL SCHEME	Time Taken to Reach Steady State (Seconds)				THD (%)
		N (rpm)	T (Nm)	$i_{r\,(A)}$	Ψ_s (wb)	
1.	PIDTC (Existing System)	2.5	2.5	2.4	2.5	50
2.	FDTC (Proposed System)	0.7	0.7	0.5	0.5	42
Improvement with FDTC over PIDTC		1.8	1.8	1.9	2.0	8

The Table.3 shows the performance comparison of proportional integral direct torque control (PIDTC) and fuzzy logic control for DTC (FDTC) of a single phase induction motor. The parameters considered are speed (N), torque (T), rotor current (ir), stator flux (Ψs) and the time taken by these parameters to reach steady state in both existing and proposed system are compared. In the PIDTC system, the time taken by the speed and torque waveforms to reach steady state is 2.5s, whereas in the proposed FDTC system the time taken for settling is 0.7s only, which is 1.8s lesser than the existing system. Thus the proposed system provides improvement in the torque distortion and can reach the steady state earlier than that of existing system. In the case of rotor current, the settling time in PIDTC system is 2.4s. But the FDTC needs only 0.5s, which is 1.9s less than the existing system. So the steady state obtained by rotor current is 1.9s earlier than the PIDTC. In the FDTC system, the time taken by the stator flux waveforms to reach steady state is 0.5s but PIDTC needs 2.5s to reach the steady state, which is 2s more than the proposed system. Thus the proposed system improves the stator flux than in existing system. The total harmonic distortion (THD) value of PIDTC is 50%, whereas in the existing system it is only 42%. Therefore the THD value with FDTC is less and it is improved by 42%, which is 8% lesser than PIDTC. Thus when compared with the existing system, the performance of the single phase induction motor was improved in the proposed system than in the existing system and results obtained were satisfactory.

V. CONCLUSION

The simulation of the proposed system was done using MATLAB/SIMULINK. From the simulation waveform it is found that, the Fuzzy Based Direct Torque Control System provides less torque distortion and fast dynamic performance than other conventional control methods. The analysis of voltage and current waveforms were also done by using the simulation results. Thus when compared with the existing system, the performance of the single phase induction motor was improved in the proposed system and results obtained were satisfactory.

VI. FUTURE SCOPE

The future work will focus on the improvement of the total harmonic distortion of the system. It is observed that MATLAB is user friendly software and may be helpful in creating models on and off line. The DTC with Fuzzy logic controller proposed in this paper are able to control motor more sensitively and more reliably. The work can also be extended by various ways and add-on.

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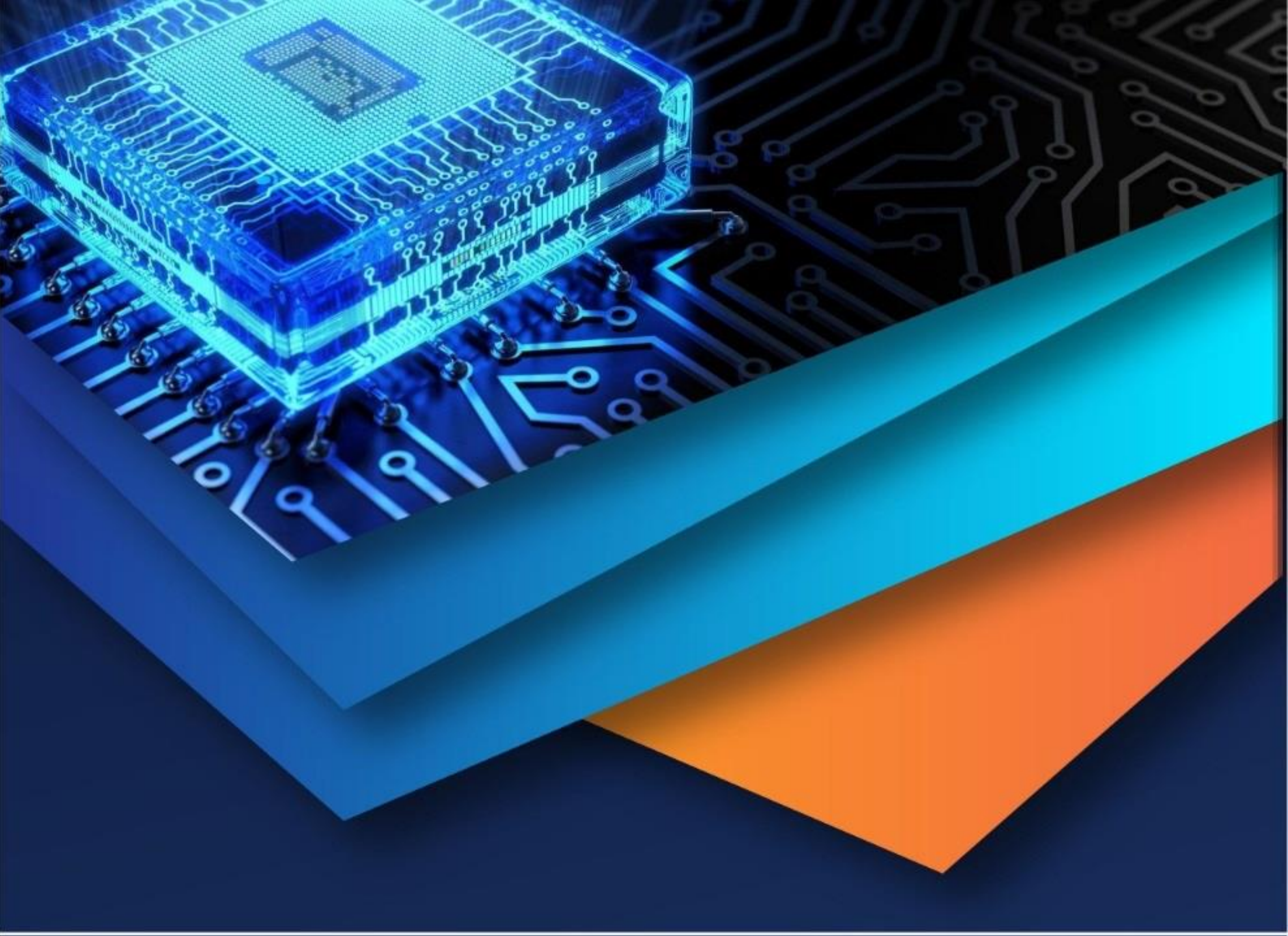

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