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Closed Loop Speed Control of Permanent Magnet Synchronous Motor fed by SVPWM Inverter

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Abstract*— This paper presents very basic closed loop speed control by using PID controller and inverter switching is provided by space vector pulse width modulation (SVPWM) technique. The scheme consist of PID controller, Permanent Magnet Synchronous Motor, Inverter. The stability of the proposed control system is also proven. Simulation block diagram and Simulation results are presented to verify that how the proposed scheme can achieve speed control at desired speeds. Harmonic content in stator current is negligible.
***Keywords*— Closed loop speed control , PMSM, Space Vector Pulse Width Modulation (SVPWM).**

I. INTRODUCTION

The PMSMs are gradually taking over the IMs owing to their high efficiency, low maintenance cost, and high power density. However, the PMSM system is not easy to control because it is a nonlinear multivariable system and its performance can be highly affected by parameters variations in the run time. Therefore in this paper speed control of PMSM under disturbances and load varying conditions using PID controller in closed loop is presented. With its three-term functionality covering treatment to both transient and steady-state responses, proportional-integral-derivative (PID) control offers the simplest and most efficient solution to many real-world control problems. Since the invention of PID control in 1910, and the Ziegler–Nichols (Z-N) straightforward tuning methods in 1942, the popularity of PID control has grown tremendously. However, more than 90% of industrial controllers are still implemented based around PID algorithms, particularly at lowest levels, as no other controllers match the simplicity, clear functionality, applicability, and ease of use offered by the PID controller. A standard PID controller is also known as the “three-term” controller. The “three-term” functionalities are highlighted by the following.

The proportional term—providing an overall control action proportional to the error signal through the all-pass gain factor.

The integral term—reducing steady-state errors through low-frequency compensation by an integrator.

The derivative term—improving transient response through high-frequency compensation by a differentiator. The proposed scheme is not only simple and easy to implement, but also it guarantees an accurate and fast speed tracking.

II. PROPOSED CLOSED LOOP SPEED CONTROL OF PMSM BLOCK DIAGRAM

The gate pulses for inverter are generated by using space vector PWM method. Error is calculated from feedback of speed taken by speed sensors and reference speed and speed control is done by using PID controller. The block diagram for closed loop speed control of PMSM motor is shown below in Fig.1

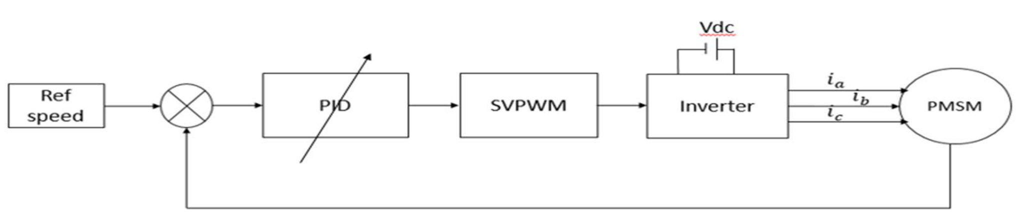

Fig.1 Closed loop speed control of PMSM block diagram

III. SPACE VECTOR MODULATION

The space vector PWM method is an advanced, computation-intensive PWM method and is possibly the best among all the PWM techniques for variable-frequency drive applications. Because of its superior performance characteristics, it has been finding widespread applications. The PWM methods like sinusoidal PWM, Hysteresis band current control PWM, sinusoidal PWM with

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instantaneous current control PWM have only considered implementation on half- bridge of three phase bridge inverter. If load neutral is connected to centre tap of DC supply, all three half-bridges operate independently, giving satisfactory PWM performance. With a machine load, the load neutral normally isolated, which causes interaction among the phases. This interaction was not considered in other PWM techniques. The space vector PWM method this interaction of phases and optimizes the harmonic content of three-phase isolated neutral load. For Space vector PWM technique we need to know the concept of rotating space vectors.

Inverter switching states

A three-phase bridge inverter has eight permissible switching states. Table1 gives a summary of switching states and the corresponding phase to neutral voltages of an isolated neutral machine. The fig 2 shows three phase bridge inverter fed PMSM.

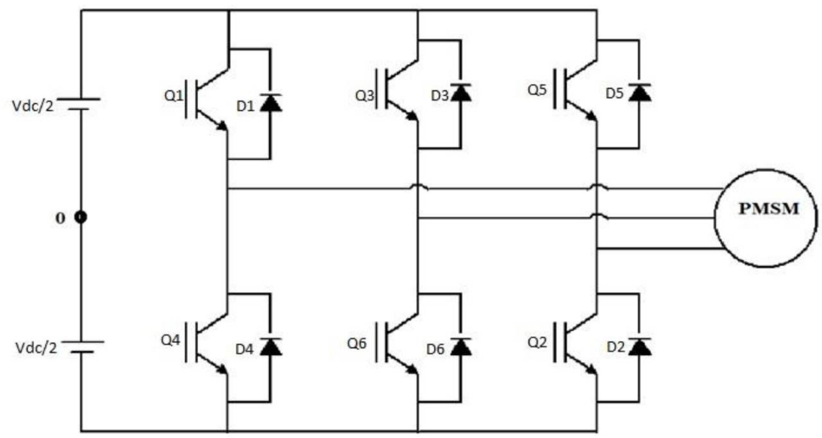

Fig.2 Bridge inverter

Consider for example state 1, when switches Q1, Q6, Q2 are closed. In this state phase a is connected to positive bus and phases b and c are connected to negative bus. The simple circuit solution indicates that Van= 2/3Vd Vbn= -1/3Vd and Vcn= -1/3Vd. The inverter has six active states (1-6) when voltage is impressed across the load, and two zero states (0 and 7) when the machine terminals are shorted through the lower devices or upper devices. The set of phase voltages for each switching state can be combined to derive to corresponding space vectors. The graphical derivation of $V1$ (100) in fig.3 indicates that the vector has magnitude of 2/3Vd and is aligned in horizontal direction as shown. In the same way all six active vectors and two zero vectors are derived and plotted in fig.4 the active vectors are $\pi/3$ angle apart and describe a hexagon boundary. The two zero vectors $V0$ (000) and $V7$ (111) are at origin. For three phase, square wave operation of inverter, it can be easily verified that the vector sequence is $V1$, $V2$, $V3$, $V4$, $V5$, $V6$ with each dwelling for an angle of $\pi/3$ and there are no zero vectors.

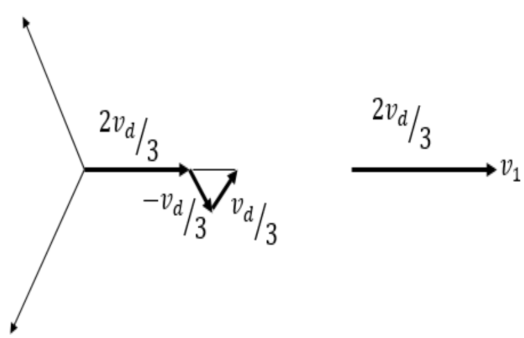

Fig.3 Construction of inverter space vector $V1$ (100)

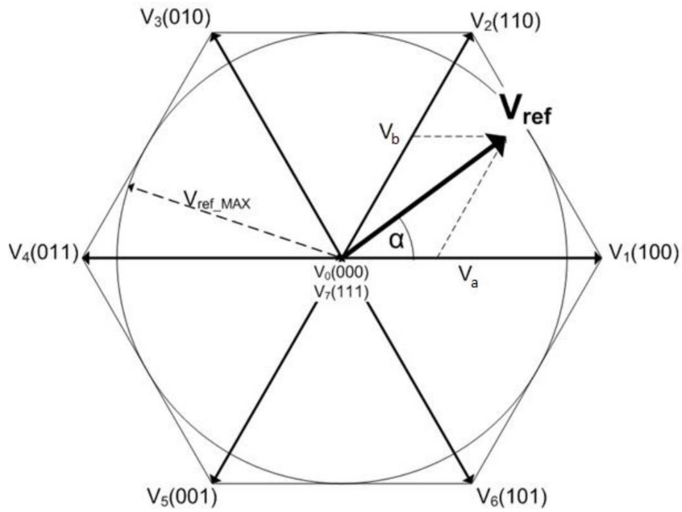

Fig.4 Vector diagram for SVPWM

TABLE 1
Inverter switching states

State	On devices	Van	Vbn	Vcn	space voltage vectors
0	(4,6,2)	0	0	0	$V_0(000)$
1	(1,6,2)	2/3 vd	-1/3 vd	-1/3vd	$V_1(100)$
2	(1,3,2)	1/3 vd	1/3 vd	-2/3 vd	$V_2(110)$
3	(4,3,2)	-1/3 vd	2/3 vd	-1/3 vd	V_3 (010)
4	(4,3,5)	-2/3 vd	1/3 vd	1/3 vd	$V_4(011)$
5	(4,6,5)	-1/3 vd	-1/3 vd	2/3 vd	V_5 (001)
6	(1,6,5)	1/3 vd	-2/3 vd	1/3vd	$V_6(101)$
7	(1,3,5)	0	0	0	$V_7(111)$

IV. BASIC PID CONTROLLER

With its three-term functionality covering treatment to both transient and steady-state responses, proportional-integral-derivative (PID) control offers the simplest and yet most efficient solution to many real-world control problems. Since the invention of PID control in 1910, and the Ziegler–Nichols used for tuning, the popularity of PID control has grown tremendously. More than 90% of industrial controllers are still implemented based around PID algorithms, particularly at lowest levels, as no other controllers match the simplicity, clear functionality, applicability, and ease of use offered by the PID controller. A PID controller continuously calculates an error value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error over time by adjustment of a control variable. The equation for controller output or plant input is given by,

$$u(t)=k_p e(t)+k_i \int_0^t e(T)\, dT+k_d \frac{de}{dt}$$

The below block diagram indicate the basic PID controller with input as error and output as plant input or controller output. The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant k_p, called the proportional gain constant.

The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain k_i and added to the controller output.

The derivative of the process error is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain k_d. The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain k_d.

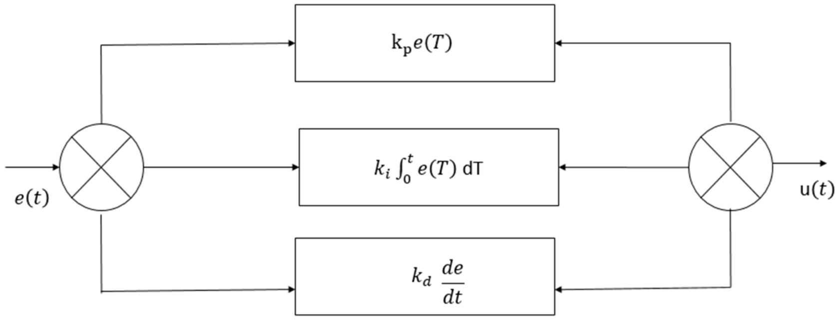

Fig.5 Block diagram for basic PID controller

V. MATLAB SIMULATION

A. Simulink diagram

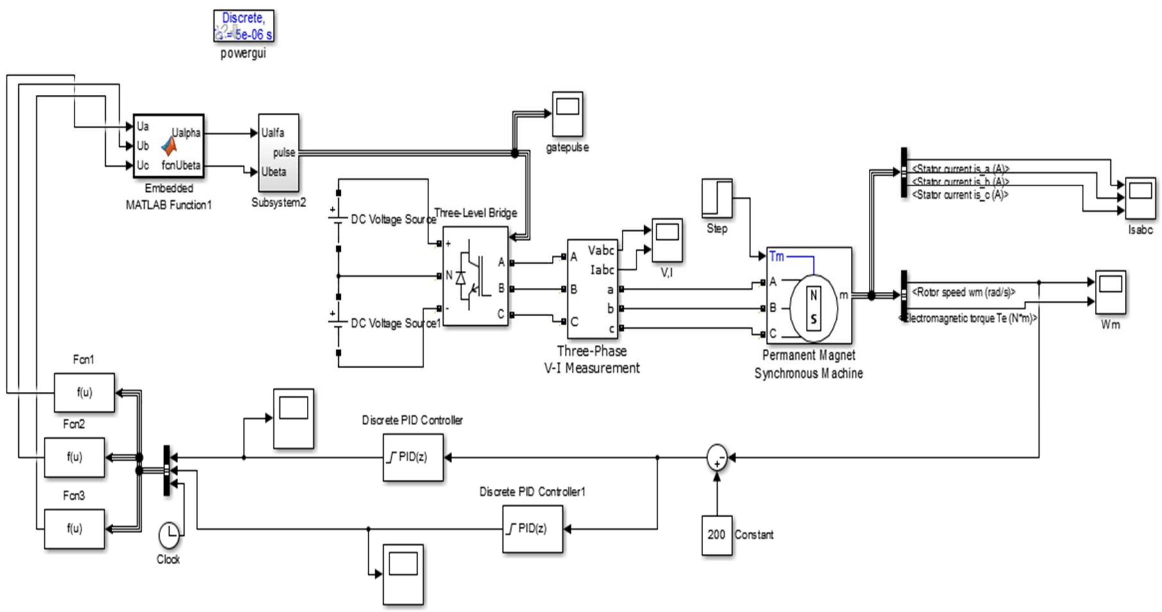

Fig.6 Simulation of closed loop speed control for PMSM

The above fig.6 shows MATLAB simulation for speed control of PMSM fed by SVPWM multilevel inverter. The embedded MATLAB function and subsystem together gives SVPWM technique. Results for above simulation are given below.

B. Simulation results

The below fig.6, fig.7 and fig.8 gives results of rotor speed, electromagnetic torque and stator phase currents with step change of 1.

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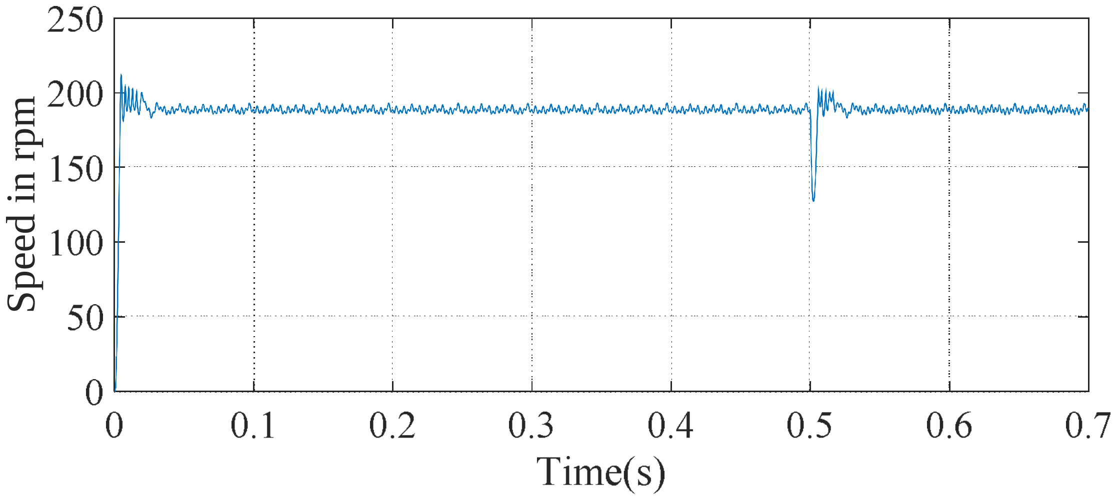

Fig.6 Rotor speed variations

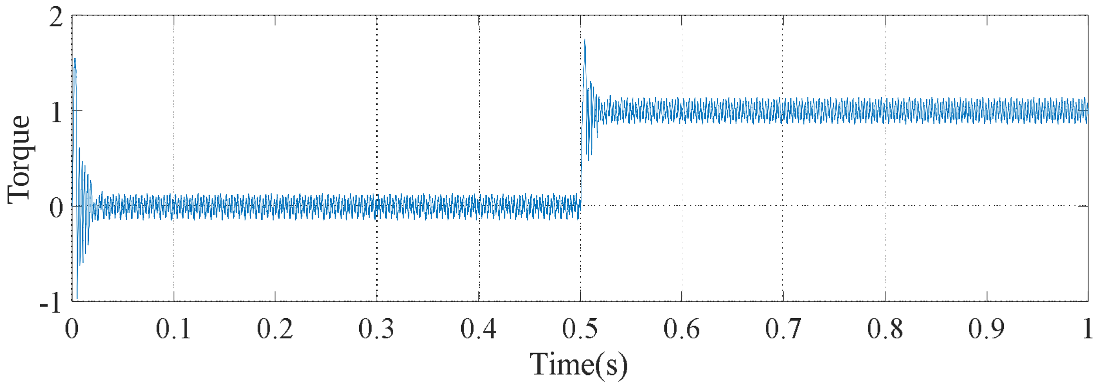

Fig.7 Torque variations

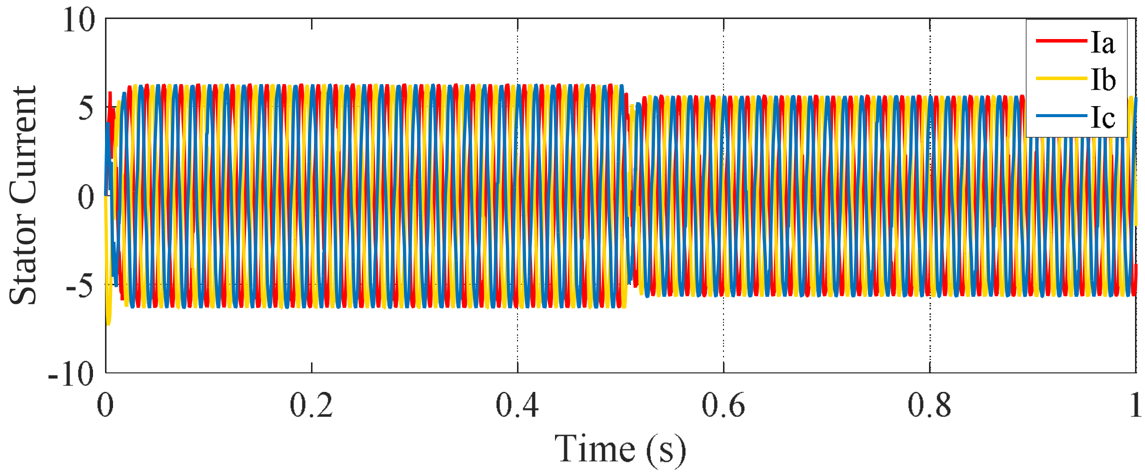

Fig.8 Stator phase current

VI. CONCLUSION

Conclusions are based on simulation results:

The control scheme using SVPWM technique for inverter switching and simple PID controller for speed control has been presented. The PID gain values are chosen by trial and error to make the variations in speed and electromagnetic torque of PMSM are

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negligibly small as shown in fig.6, fig.7. The three phase $Iabc$ is shown in above fig.8, which are almost harmonics free other than step change. Harmonic content in stator current is negligibly small. Also one can operate the system at any desired speed. Proposed control scheme can compensate for variation in frequency. If we have given the step change for torque then there are some variations and after some time the torque and speed settle to given set point. One major drawback for traditional PID controller is that it is sensitive to the disturbances in the system.

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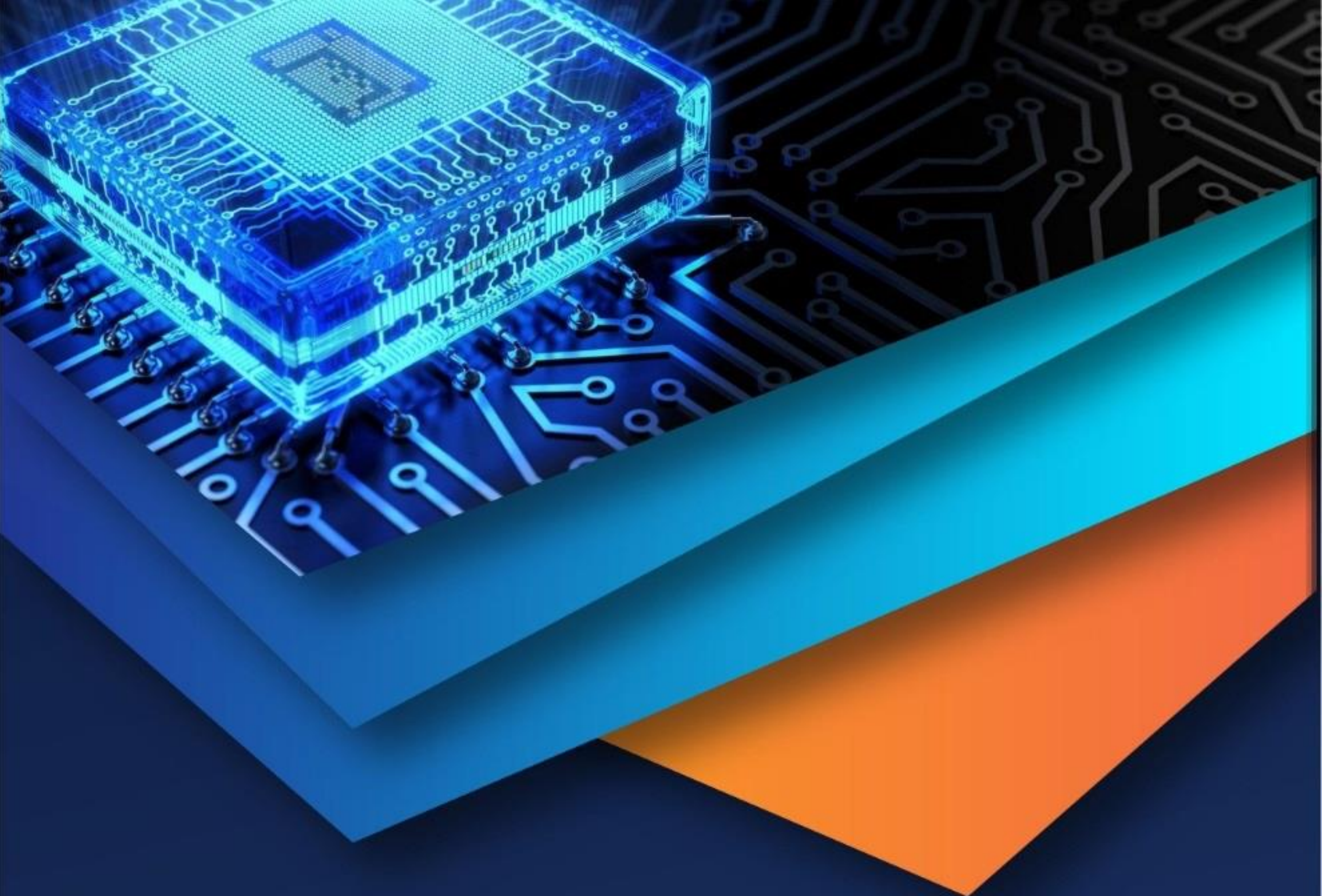

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