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Analysis of Converter-Fed Rotor Based Induction Machine

Prawej Alam
Electrical Engineering Department, DR. VRK Womens College of Engineering and Technology, Hyderabad, India

Abstract: This paper presents the analysis of an induction-machine with a concept of the rotor-fed by a converter. Stator-winding configured in star and connected to the input-side of the three-phase voltage-source, whereas rotor-windings are fed by back-to-back converter by means of DC-link capacitor. For this, the Induction-machine is modelled in MATLAB/Simulink and simulated with and without a converter. The rotor circuit is magnetized with the help of back-to-back converter which in turns supply the variable-reactive power by setting the different phase-shift angle between the converters. The results depict the enhancement of Power-factor and also presents the dynamic performance of the machine includes the loading and de-loading as well as the starting condition of the machine. Fundamental-frequency variations of the converter enhance capability of machine to operate at a constant-speed with variable-load operation. Impact of variation in phase-shift angles between the converters on the power-factor, reactive-power, stator and rotor-current are also presented.
Keywords: back to back converter, power factor, dynamic performance, MATLAB.

I. INTRODUCTION

The induction machine is basically a rotating machine and it widely used in industry because of its reliability, robustness and cost effectiveness. It has however a drawback of lacking the capability to balance the active and reactive power thereby suffering from poor power factor. Especially when the machine starts or operates with light loads, power factor and efficiency are drastically reduced. Improving the power factor of an induction machine is therefore an attractive topic for research and has been pursued for decades leading to some interesting solutions. The most straightforward solution is to connect a capacitor bank at the machine terminals. The machine system thus becomes bulky. Moreover, the machine might be damaged when it is disconnected from the power supply if an improper capacitance is selected which causes overvoltage because of self-excitation. This approach is not flexible since different capacitances are needed when the loading condition changes. Another approach is used to replace the capacitor bank by a converter, where the induction machine is directly connected to the grid while a three phase pulse width modulation (PWM) converter with a floating capacitor is connected at the induction machine terminals. With a floating capacitor, making it possible to supply variable capacitance to meet the requirements at different operating conditions. However, the improved power factor is realized only for the grid but not for the induction machine itself. Y. Yao et.al [1] reported that the analytical steady-state model which is used to predict the operating range of the induction machine. The result shows that the induction machine can operate at a wide torque and speed range instead of working on the original torque-speed curve. In addition, the relationship between capacitance and capacitor voltage is studied for the constant speed and variable torque operation. It is shown that it is possible to choose a low volume and high capacitance capacitor since the average DC-link voltage is quite low. It is [2-8] reported that the dynamic performance of the system through simulation which is verified experimentally on a 1.8kW induction machine. Good agreement between simulation and experimental results is achieved. Constant speed operation is obtained by simply setting the fundamental frequency of the converter. The stator power factor is effectively improved within a wide range of load torque with the converter-fed rotor. Moreover, the harmonic spectra of the stator and rotor currents are analyzed. It is also [9-15] reported that transient performance of a novel topology of an induction machine with rotating power electronic converter. There are mainly three different methods to control the speed of a wound rotor induction machine. One solution which was common in the past is to connect resistors to the rotor windings. Nowadays this method is mainly used to start large motors in order to obtain a high starting torque and a low starting current drawn from the grid. Due to the low efficiency, this method is very seldom used for speed control in practice. It is [16] reported that induction moor can be analyzed by calculating the inductances and capacitances of the stator winding. The rotor impedance control with different combinations of resistors, inductors and capacitors as well as their connections is investigated. It is [17-21] shown that different schemes are suitable for specific speed settings in order to get good speed regulation performance and high power factor.

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However, this method is preferred for applications where precise speed control is not required and where speeds are close to the synchronous speed. In the present paper improvement of power factor is achieved by magnetizing the machine from the rotor side with the reactive power supplied by the rotor connected converter and meanwhile dynamic performance is improved by the impact of changing the phase –shift angle between the back-to- back connected converter. In present paper an Induction motor is modeled to compute the power factor with and without connecting the converter to the rotor. The main objective of this paper is to improve the power factor with introducing the new concept.

II. PROPOSED SYSTEM CONFIGURATION AND ITS OPERATION

The configuration of the system is shown in Fig. 1. In the presented configuration, the stator windings are Y-connected and directly connected to the three phase voltage source. The wound rotor windings in each phase are open-ended and short-circuited via a back-to- back power electronic converter, as shown in Fig 2. With this it can be easy for the induction machine to magnetizing from the rotor side. The converter is connected to the rotor windings through slip rings and can be controlled by control unit as show in Fig.1. In this paper sinusoidal pulse width modulation (SPWM) technique is used for generating the switching signals. The generated switching signals are alienated into two groups, one for each converter at same switching frequency and modulation index. The two groups of switching signals for each converter are supplied by the controller. The phase-shift angle θ_{ps}, between the two converters can be varied from −180◦ to +180◦. Zero θ_{ps} indicates that the rotor windings are short-circuited. If θ_{ps} = ±180◦ then it is represents that full voltage is supplied by the converters. The dc-link voltage of the converter is not controlled but automatically balanced depending on the speed and load of the induction machine.

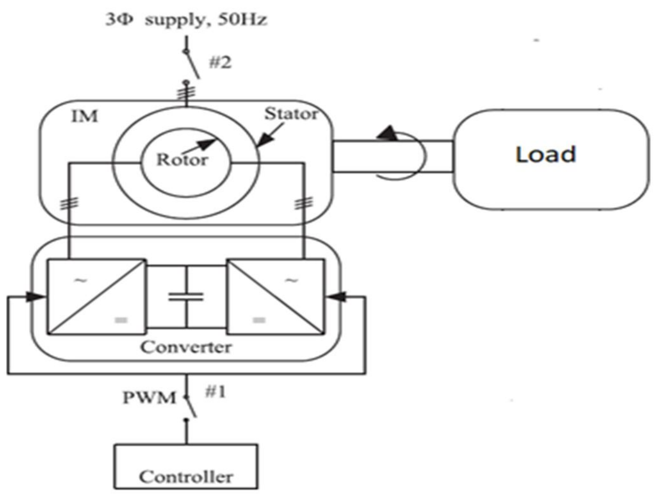

Fig.1 Configuration of the system

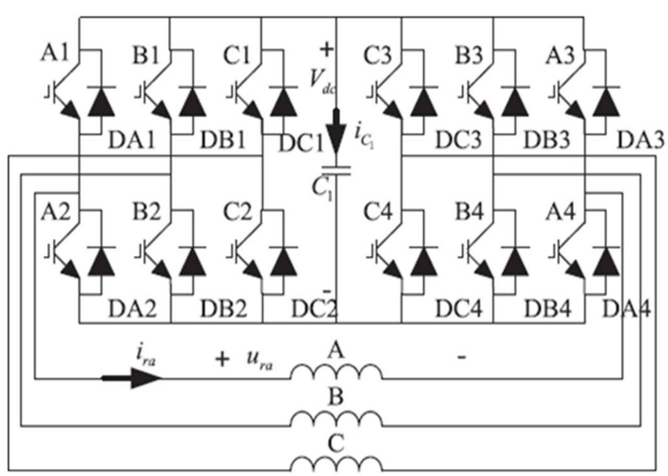

Fig. 2 Connection of back- to-back converter to the rotor windings

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The working of the system may be found out in three steps. First of all, indicated by #1 in Fig. 1, the switching signals are sent to the 12 power electronic valves, in the present paper IGBTs are used as valves. These are indicated by A1–A4, B1–B4 and C1–C4 as shown in the Fig.2. The fundamental frequency of the switching signals can be calculated with the following expression

$$f_2 = \frac{(ns - n_r^*)}{ns} f_1 \text{..................................} \quad (1)$$

Where n_s is the synchronous and n_r^* is the reference speed. In above equation f_1 represents frequency of stator. The number #2 as shown in Fig.1is clearly shows that the stator is connected to a three-phase voltage supply and the machine is made started at no load. It is known that generated flux in the stator causes ac currents in the windings of the rotor. Initially, even though the switching signals are offered, the IGBTS did not conduct since the dc-link voltage is zero. These currents can only flow through the anti-paralleled diodes thereby charging the capacitor. The value of capacitor voltage will depend on the phase-shift angle θ_{ps} which is there in between the two converters. If $\theta_{ps} = 0°$, the capacitor voltage will rise to a very high level because no discharge of capacitors through the IGBT. Whereas if $\theta_{ps} = 180°$, the capacitor may not charge due to this reason voltage will be very low which makes it difficult to magnetize the machine from the rotor side. In this paper standard angle θps = 60◦ is used during the start of the machine. Besides, the high starting rotor current will speedily discharge the capacitor during the acceleration of the induction machine. Thus, the capacitor voltage cannot be maintained and the converter is not capable to supply a voltage at constant frequency to the rotor windings. Consequently, the machine accelerates to the no load speed instead of the reference speed n_r^*. Once the machine stabilizes to its no-load steady-state speed, load torque is applied, indicated by #3 in Fig. 1. The capacitor will be charged to a certain voltage according to the applied load and then maintain stable. Thereafter the converter can provide a three-phase voltage with slip frequency of f_2 to the rotor windings. Consequently the speed of the induction machine settles to n_r^*.

III. MODELING OF THE CIRCUIT IN MATLAB

The dynamic performance of the proposed system is simulated using MATLAB/Simulink. For this a 1.8 kW induction machine is selected. In the present work Simulink models are with and without converter connected to rotor of a wound rotor induction machine has been considered. In this paper the Simulink models primarily consists of a wound rotor induction machine, a mechanical load, a three-phase voltage source and two back-to-back connected converters fed by a PWM generation block. The reference speed of the machine should be set to 1400rpm which can be done by controlling the fundamental frequency of IGBTs at 3.3 Hz. The dynamic performance of the induction machine includes the starting, loading and load changing, rotor speed, Capacitor voltage, Rotor current, Stator current, Active power, and reactive power are analyzed by simulating in MATLAB/Simulink. The simulation has been performed without rotor connected converter and with rotor connected converter.

A. Simulink Model without Rotor Connected Converter

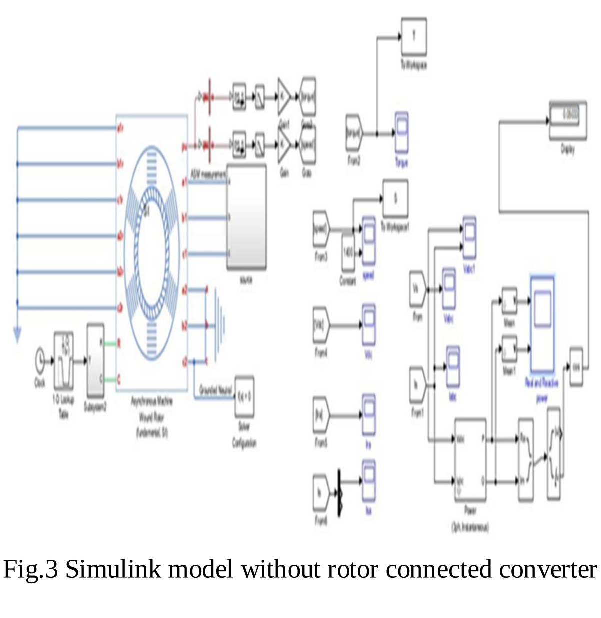

Fig.3 Simulink model without rotor connected converter

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This Simulink model is mainly consists of the wound rotor induction machine, a three-phase voltage source and a mechanical load source. The rotor windings are short- circuited. The machine operating without the converter and follows its original torque-speed curve, which implies that the speed changes with load as can be seen in simulated result without connected converter as shown in the figure 4

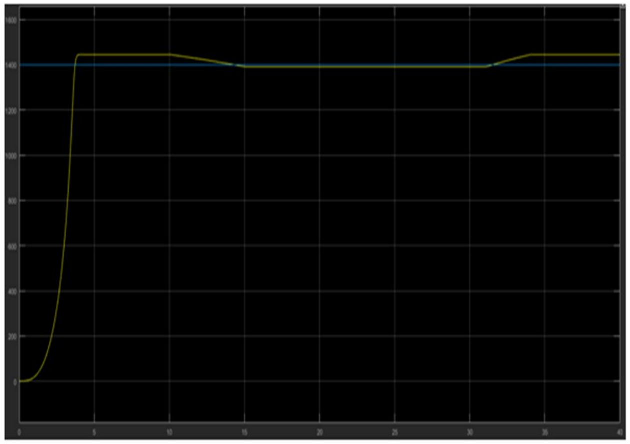

Fig. 4 Rotor speed without converter.

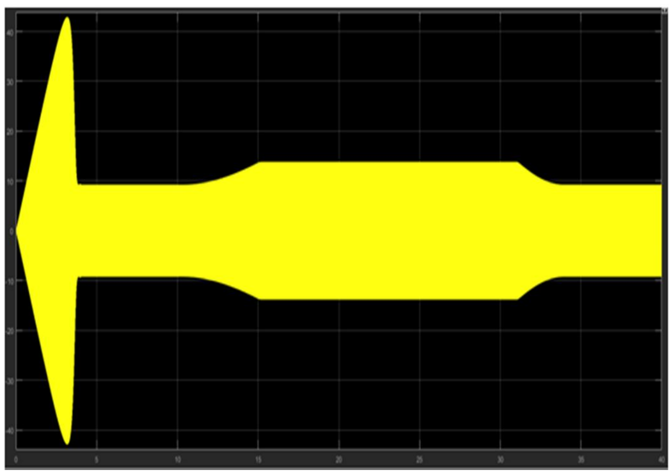

Fig. 5 Stator current without converter

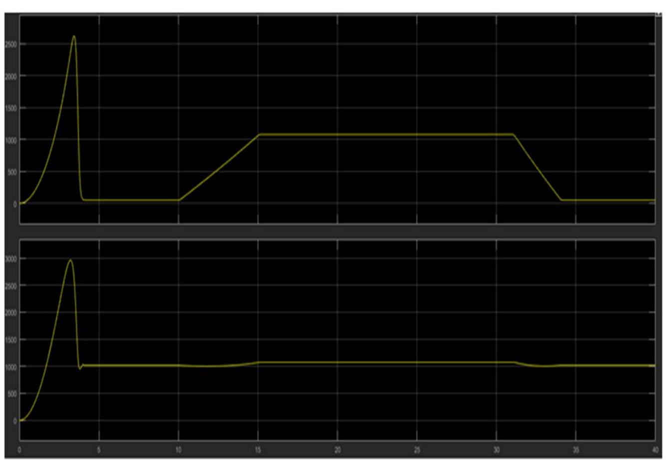

Fig.6 Active and reactive power without converter

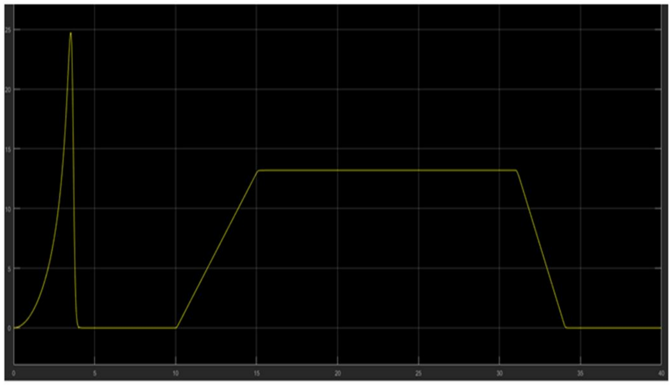

Fig. 7 Torque without converter

The simulated results including Rotor speed without converter, capacitor voltage and currents in the rotor and the stator are shown in Figs. 4 and 5, respectively. Figure 6 depicts the active and reactive power without converter. The reference speed signals is set to 1400 rpm by controlling the fundamental frequency of IGBTs at 3.3 Hz from t = 0s.

B. Simulink Model with Rotor Connected Converter

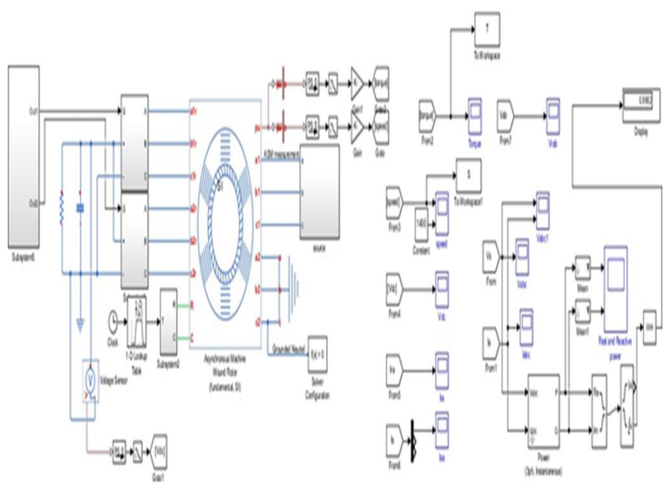

Fig.8 simulation model with rotor connected converter

The Simulink model is mainly consists of a wound rotor induction machine, a three- phase voltage source, a mechanical load and two back-to-back connected converters fed by a PWM generation block. As can be seen in Fig 4.3, a resistor is paralleled with the dc-link capacitor. In reality this resistor is connected in the converter for the reason of safety to protect the capacitor from unwanted transients.

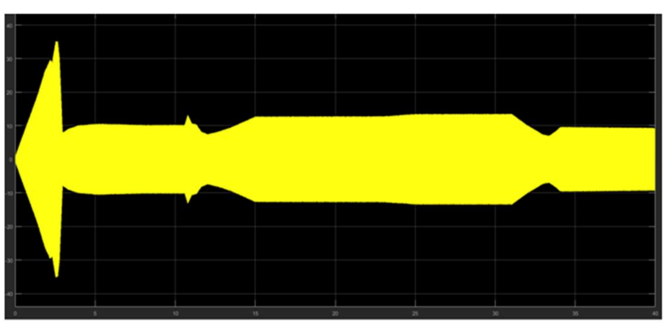

Fig. 9 Stator current with converter

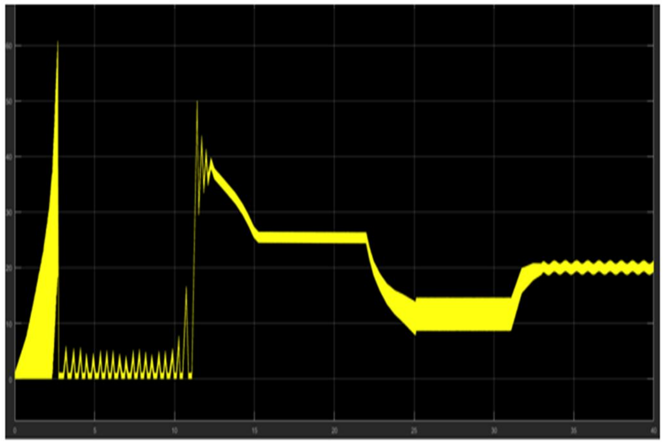

Fig.9 capacitor voltage with converter

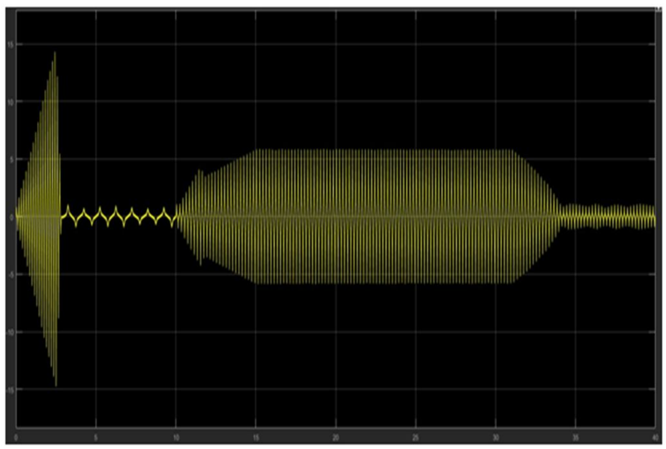

Fig. 10 Rotor current with converter

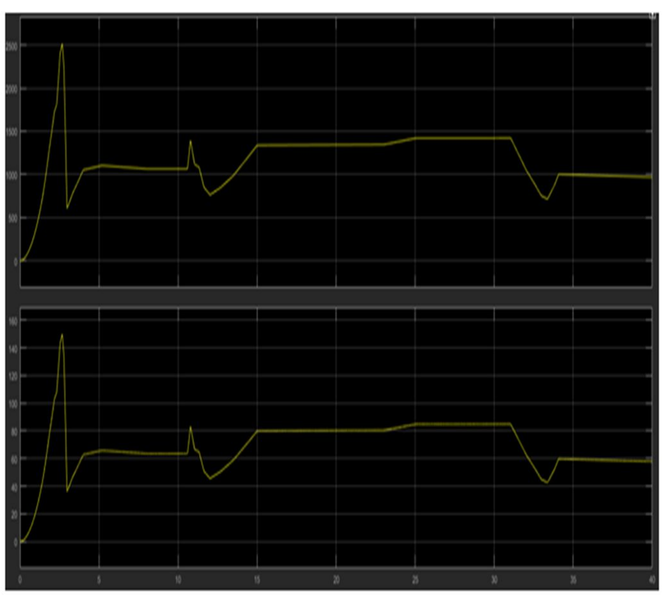

Fig. 11 Active and Reactive power with converter

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IV. DISCUSSIONS OF RESULTS WITH COMPARING WITH AND WITHOUT CONVERTER

Dynamic performance of the machine can be analyzed with the help of following table

Table 1 Dynamic performance of the machine with and without converter

DYNAMIC PERFORMANCE					
Time (sec)	T=0 sec to 10 sec	T=10 sec to 15 sec	T=15 sec to 31 sec	T=31 sec to 35 sec	T= 35 sec to 40sec
Load torque (N-M)	No load	0 to 12.3	12.3	12.3 to 0	No load
WITHOUT CONVERTER					
Speed(rpm)	1445	1389	1389	1445	1445
WITHOUT CONVERTER					
Speed(rpm)	1485	1400	1400	1400	1400

From above table it is clear that dynamic performance of the machine has been improved with converter fed topology. Power factor of the machine also improved with new concept in which converter is fed to the rotor of the machine.

Table 2 Power Factor improvement

POWER FACTOR IMPROVEMENT			
WITHOUT CONVERTER			
Loading condition	Reactive power(VAR)	Capacitor voltage(volts)	Power factor
T=22 sec to 25 sec	1100	0	0.05
WITH CONVERTER			
Loading condition	Reactive power(VAR)	Capacitor voltage (volts)	Power factor
Phase shift Angle=60 to 90 degree	260 to 240	26 to 23	0.9841
Phase Shift Angle=60 to 120 degree	260 to 215	26 to 21	0.9869
Phase Shift Angle=60 to 150 degree	260 to 190	26 to 19	0.9895
Phase Shift Angle=60 to 180 degree	260 to 170	26 to 17	0.9918

V. CONCLUSION

In this paper, a novel concept in which induction motor rotor is fed by the converter is analyzed. MATLAB/Simulink is used to simulate the results. To analyze the induction machine with and without converter has been simulated and depicted in the paper. The results describes that the rotor connected converter enables the magnetization from the rotor side. The converter can provide different amount of capacitive reactive power to the induction machine by setting the phase-shift angle between the back-to-back converters connected to rotor terminals. Thus the power factor of stator is effectively improved as shown in the simulated results and mentioned in the table 2. The power factor has reached to nearly unity. It is also observed from the results that by setting the fundamental frequency of the converter the dynamic performance of the machine like starting, loading and de loading of the induction machine are capable of operating at constant speed and variable load.

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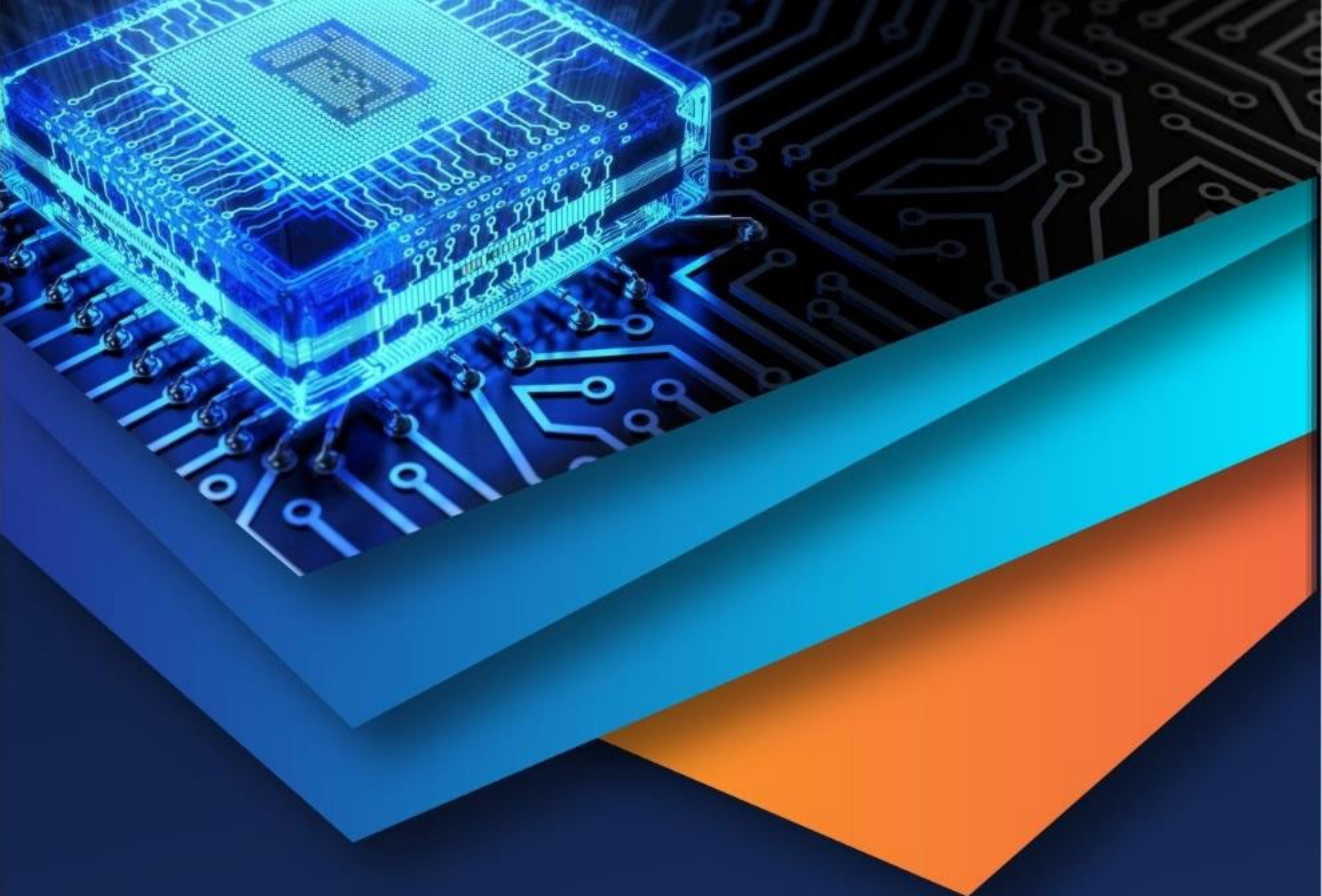

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