iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** IV **Month of publication:** April 2016

DOI:

Volume 4 Issue IV, April 2016
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

An Overview of Control Strategies of an APFC Single Phase Front End Converter

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Abstract— Increase in the use of power electronic equipment has resulted in greater need for regulating the harmonic distortion level in the power system. This is satisfied using some form of power factor correction (PFC) circuits to shape the input currents so that they are sinusoidal in nature and total harmonic distortion (THD) remains within the limit specified by 1EEE standard 519. This paper provides a review of the most commonly used active power factor correction (APFC) technique, boost type PWM rectifier for AC-DC converters and their control strategies. Simulation of the converter using APFC circuit is done and the results are analyzed.

Index Terms— Harmonic distortion, power factor correction, converter, THD.

I. INTRODUCTION

PFC can reduce the harmonics in the system currents and hence increase the efficiency and capacity of power systems. Single phase diode rectifiers are widely used in industrial and commercial applications. It rectifies the AC input voltage and filters the output using large electrolytic capacitors. Since capacitors draws current from the source in the form of short pulses, it generates harmonics in the line current. Also the increased use of non-linear loads such as televisions, computers, faxes, adjustable speed drives have increased the harmonic distortion level in the system. Increased harmonic distortion results in voltage distortion, low efficiency and poor power quality which in turn reduces the reliability and causes deregulation of the power system [1]. Therefore it is necessary to improve the power quality of the supply system so that the electrical equipment operates correctly and reliably without being damaged or stressed and the efficiency of supply system increases.

Many methods have been proposed to improve the power factor which can be classified as passive and active methods [2]. Passive power factor correction methods involves shaping of line current using passive elements such as inductor, capacitor. Active power factor correction (APFC) methods involve shaping of line current using semiconductor switches such as MOSFETs and IGBTs.

Passive methods of power factor correction have certain advantages such as simplicity, reliability and ruggedness, insensitivity to noise and surges, no EMI and no switching losses. But they possess a poor dynamic response, lack of voltage regulation, sensitive to changes in load. Hence for low power applications (typically less than 50 W) passive methods are preferred and for high power applications (above 50W) active methods are preferred as they possess some desired features such as

A. Close to Unity Power Factor (UPC) operation.

B. Less than 10 % Total Harmonic Distortion (THD) in line current

C. Reduced number of feedback signals for controller implementation

Single phase and three phase controlled and uncontrolled rectifiers form a major source of current harmonics in power system. They are used in a large number of equipment and hence pose a serious harmonic threat to the system. In addition, current harmonics injected to the system has dominant third harmonic content in them which results in overloading of neutral conductor as the third harmonic neutral current will be three times the third harmonic phase currents. Hence power factor correction (PFC) is necessary for ac-dc converters in order to comply with the requirements of international standards such as IEC 61000-3-2 and IEEE-519 [3]-[8].

II. SINGLE PHASE BOOST TYPE APFC CONVERTER

A. Working

Fig 2.a.shows a schematic of a single phase boost type PWM rectifier. Using conventional diode rectifier the AC voltage is rectified into DC voltage and the rectified output is applied to the boost converter which provides a constant DC voltage against the variations in input AC voltage and DC side load.

When switch Q is turned on the current in the inductor starts increasing from the initial value. When the switch Q is turned off, the inductor current is made to flow into the capacitor Co through the diode D as current through the inductor cannot change instantaneously. But when diode D starts conducting, the voltage across the inductor changes polarity and the inductor current starts decreasing

.Hence the inductor current can be increased by closing the switch Q and decreased by opening the switch Q. The inductor current can be made to follow a prespecified wave shape by suitably controlling the switch on/off periods. Using this strategy current in L is made to follow a Full wave rectified wave shape. If the current in L is full wave rectified in shape, then the line current in AC side will be pure sinusoidal and in phase with supply voltage. Also the harmonic distortion can be reduced to a very low value.

Let PF_T be the true power factor. It is expressed as the product of displacement power factor and distortion power factor:

$$PF_T = PF_D \; x \; DPF$$

The distortion power factor term is introduced by the harmonics and is given by:

$$DPF = \frac{1}{\sqrt{1+THD^2}}$$

The purpose of power factor correction is to minimize the input current distortion and make the current in phase with the voltage.

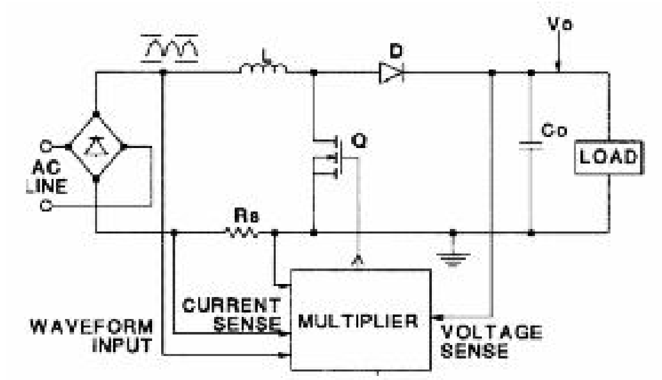

Fig.2.a.Single phase boost type PWM rectifier

III. CONTROL STRATEGIES

A PFC circuit is required to maintain a DC output voltage of constant value and also maintain input current wave shape as pure sinusoidal at U.P.F. In order to obtain a constant DC output voltage, a voltage control loop is used. It ensures that the input power from AC side is equal to output power demand plus losses. The voltage control loop senses the output voltage, increases the current drawn from line if the output voltage tends to decrease and vice-versa.

But a voltage control loop cannot shape the current drawn from the input or the current through the inductor. It can only decide the amplitude of the full wave rectified current wave that is to be made to flow through the inductor. In order to shape the inductor current as a full wave rectified wave, a control loop is used.

Thus in a PFC circuit there should a i)outer voltage loop which monitors output voltage and decides the amplitude of full wave rectified current that should flow through the inductor and ii)an inner current loop which shapes the inductor current.

A. Current Control Strategies

There are four popular current control methods for monitoring the inductor current and forcing it to track the desired wave shape.

1) *Controlled ON time Zero Current Switching Technique*: In this technique the voltage control loop controls the ON period of the switch directly. The voltage control loop senses the output voltage, compares it with the set reference level and generates an error signal which is converted into a proportional pulse width. The width of this pulse decides the ON time of the boost switch in a switching period and will remain constant under steady state. During the OFF period of the switch the inductor current ramps down and is allowed to go to zero. The current zero is sensed (using a current sense resistor) and the switch is switched ON when the current touches zero.

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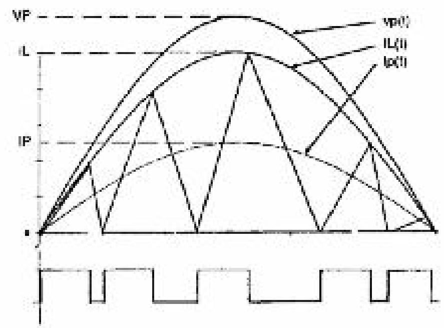

Fig.3.a.Inductor current and switching signal

In every cycle the inductor current increases from zero to a peak value and ramps down to zero directly. Thus over a cycle the inductor current will be a triangle whose average value over one switching cycle will be sinusoidal with amplitude equal to half of peak value. In this way the inductor current can be made to track a full wave rectified wave shape thus making the line current a sinusoidal waveform.

It is the most simple control scheme but causes the peak switch current and diode current to be twice the required line current which in turn increases the stress across them.

2) Peak Current Sensing –Zero Current Switching Technique: In this technique there is a voltage control loop and a current control loop. The voltage control loop maintains a constant DC output voltage and also decides the amplitude of the full wave rectified wave current that should flow through the inductor. The current control loop keeps the Switch ON until the Switch Current reaches a level equal to twice reference current at that instant. At that point Switch is opened and inductor current is allowed to ramp down to zero. The zero current condition is sensed and the Switch is allowed to go ON at that instant. Hence the average inductor current in a switching cycle follows the reference current waveform (which is full wave rectified in shape). But in this technique the switching frequency varies with the line voltage and load and causes high current through switch and diode.

3) *Hysteresis Current Control*

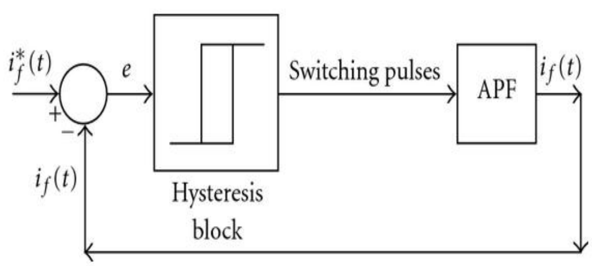

Fig.3.b.Hysteresis control loop

This is a variable switching frequency control technique. The boost inductor is monitored and compared with a reference current obtained from voltage control loop. The error is then given to a hysteresis comparator after amplification. When the actual inductor current goes above the reference current, the comparator changes state. This causes the boost switch to turn off and the current starts decreasing. Similarly when the inductor current goes below a reference value then the hysteresis comparator again changes state which causes the switch to turn on. The current then starts increasing. In this way the inductor current is made to follow the reference current within the hysteresis band.

In this technique the greatest disadvantage is that the switching frequency varies with input line voltage and DC load which makes designing of ripple filter difficult.

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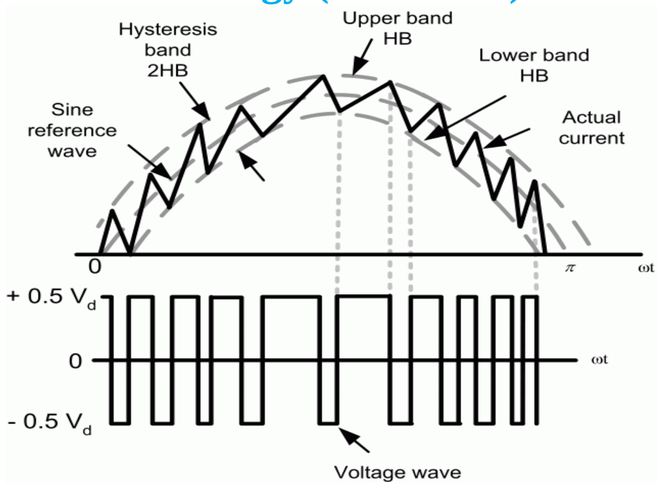

Fig.3.c.Inductor current and switching signal

4) Average Current Control

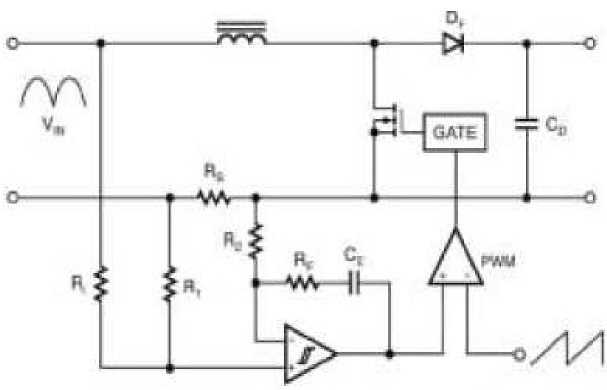

Fig.3.d.APFC converter with Average current loop

This is a fixed switching frequency control strategy. The figure above shows the various components of the control scheme. The negative input of the PWM Comparator is fed with a ramp of frequency equal to desired switching frequency. The boost switch is kept on until the ramp voltage equals the error amplifier output voltage. The error amplifier compares the actual inductor current with the reference current. The capacitor Cf will have a value enough to behave as short at switching frequency and hence at switching frequency the amplifier gain will be Rf/R2. In this way the average value of the inductor current will follow the reference current with almost zero tracking error.

a) Voltage Control Loop: The output D.C. is sensed and compared with a set reference in the error amplifier. The amplified error is converted into current reference waveform by multiplying it with a waveform template Iac, which represents the desired current wave shape in the boost inductor. This desired shape is that of full wave rectified shape and is readily available at the output of the rectifier bridge. The reference current waveform is then given to the pre-regulator block. The pre-regulator block consists of the boost switch, boost inductor and the current control loop. The current control loop monitors the actual inductor current and compares it with the reference current. It makes the inductor current to track the reference current wave generated by the voltage control loop with minimum tracking error. In case of variations in the input line voltage, the amplitude of the waveform template also changes which in turn changes the output voltage. In order to overcome this, a squarer and a divider are used. The squarer produces a dc output voltage which is proportional to square of peak value of input line voltage. The divider scales the output of the error amplifier by dividing it by output of the squarer. Therefore for a decrease in input line voltage, the output of the error amplifier is increased by a factor Vm^2. Similarly for an increase in input line voltage, the output of the error amplifier is decreased by a factor Vm^2. The main disadvantage of this technique is that in case of load throw off the output voltage rises to a very high value which may damage the load and the PFC, since the output voltage rise is sensed slowly by the

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feedback system due to its low bandwidth. Also it is difficult to bring down the capacitor voltage once it rises to a very high value due to the unilateral flow of current.

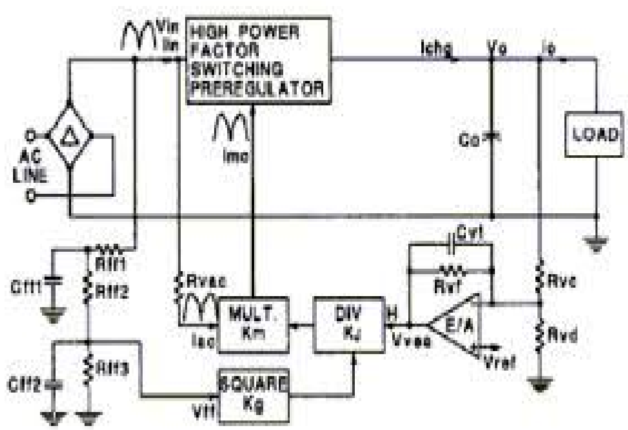

Fig.3.e.APFC converter with voltage control loop

IV. SIMULATION RESULTS

Simulation of the single phase boost type PFC converter was done for an input voltage 250 V. The duty ratio is chosen as 0.35. Average current control technique was used to drive the switch.

The simulink model is shown in Fig.4.a.

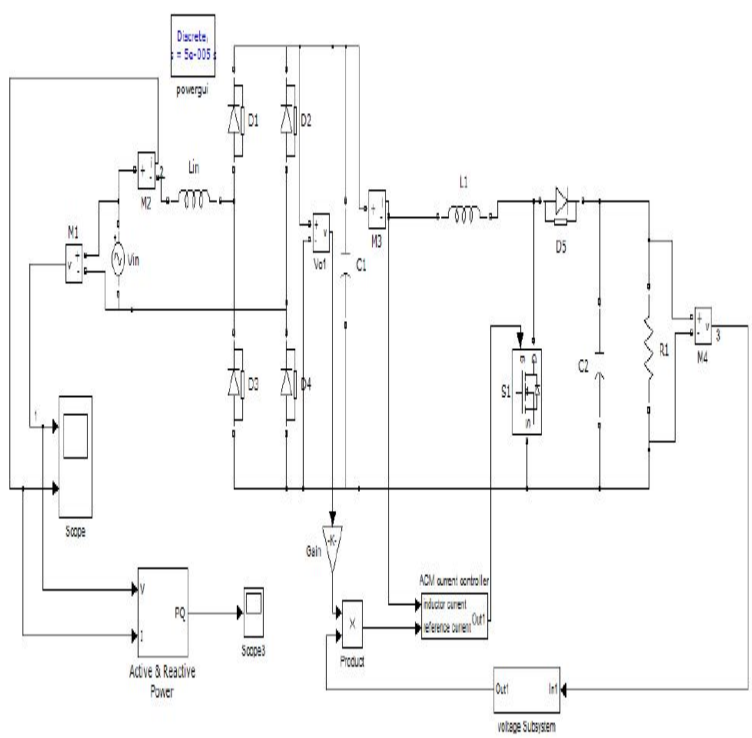

Fig.4.a.Simulink model of APFC converter

The input current was found to be a sinusoidal waveform with THD 4%.

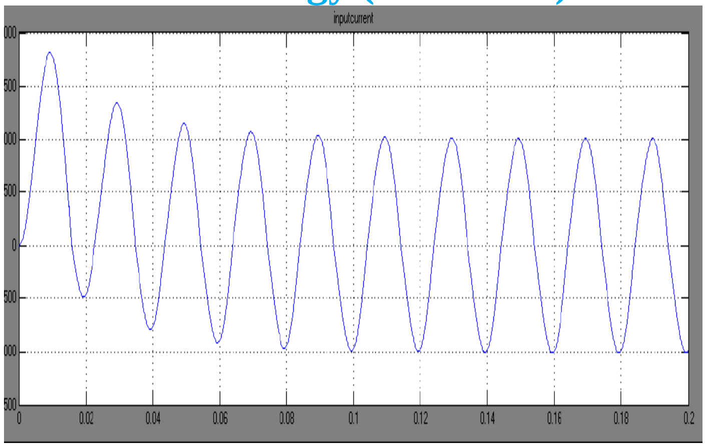

Fig.4.b.Input current waveform

The output voltage was found to be 350 V and is shown in Fig 4.c.

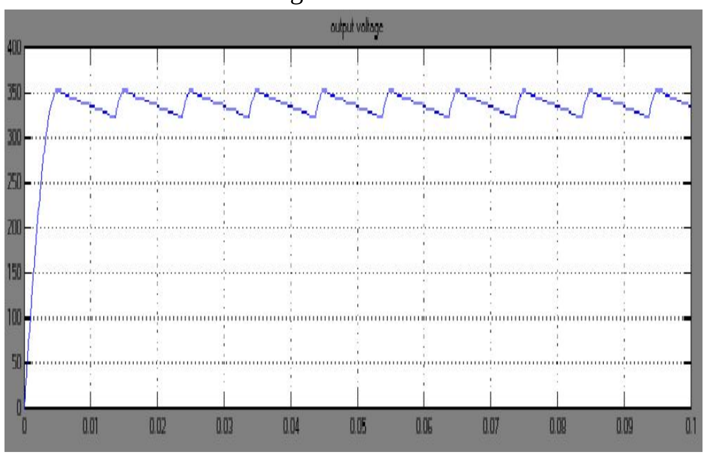

Fig.4.c.Output voltage waveform

Active power and reactive power is shown in Fig 4.d. We can see that the initial transients occurring are suppressed due to the PFC circuit and the controller circuit.

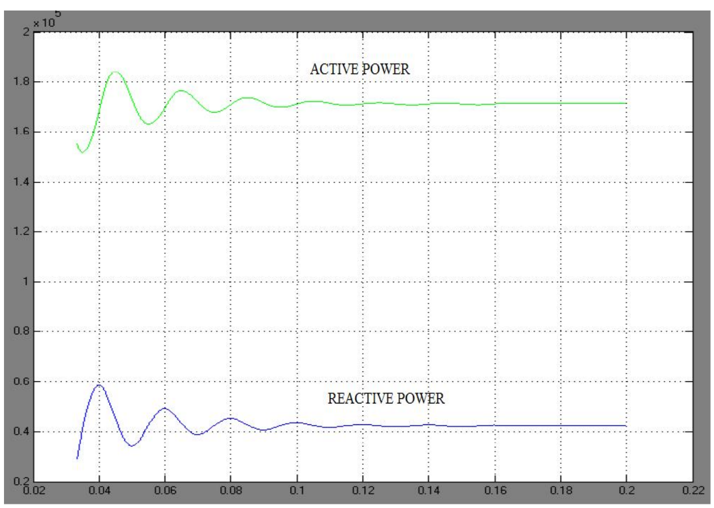

Fig.4.d.Active and reactive power waveforms

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V. CONCLUSION

Low and medium power level AC-DC rectification, based on peak-charging and phase- controlled rectifiers operated at low power factor and injected lower-order harmonics into the utility. The need for techniques to improve the power factor and reduce the harmonic content of the input current was felt. This resulted in the development of different techniques for power factor correction based on power semi-conductor devices like IGBTs and MOSFETs. In this paper the most commonly used PFC technique; Single phase Boost type APFC converter is discussed. Also the different control strategies of the APFC converter is been analysed. Simulation of the APFC converter was done for an input voltage of 250 V and a duty ratio of 0.35. Average current control strategy was used to control the APFC circuit. It was observed that the input voltage was found to be a sinusoidal waveform with THD less than 5 % thus satisfying the IEEE standard 519.

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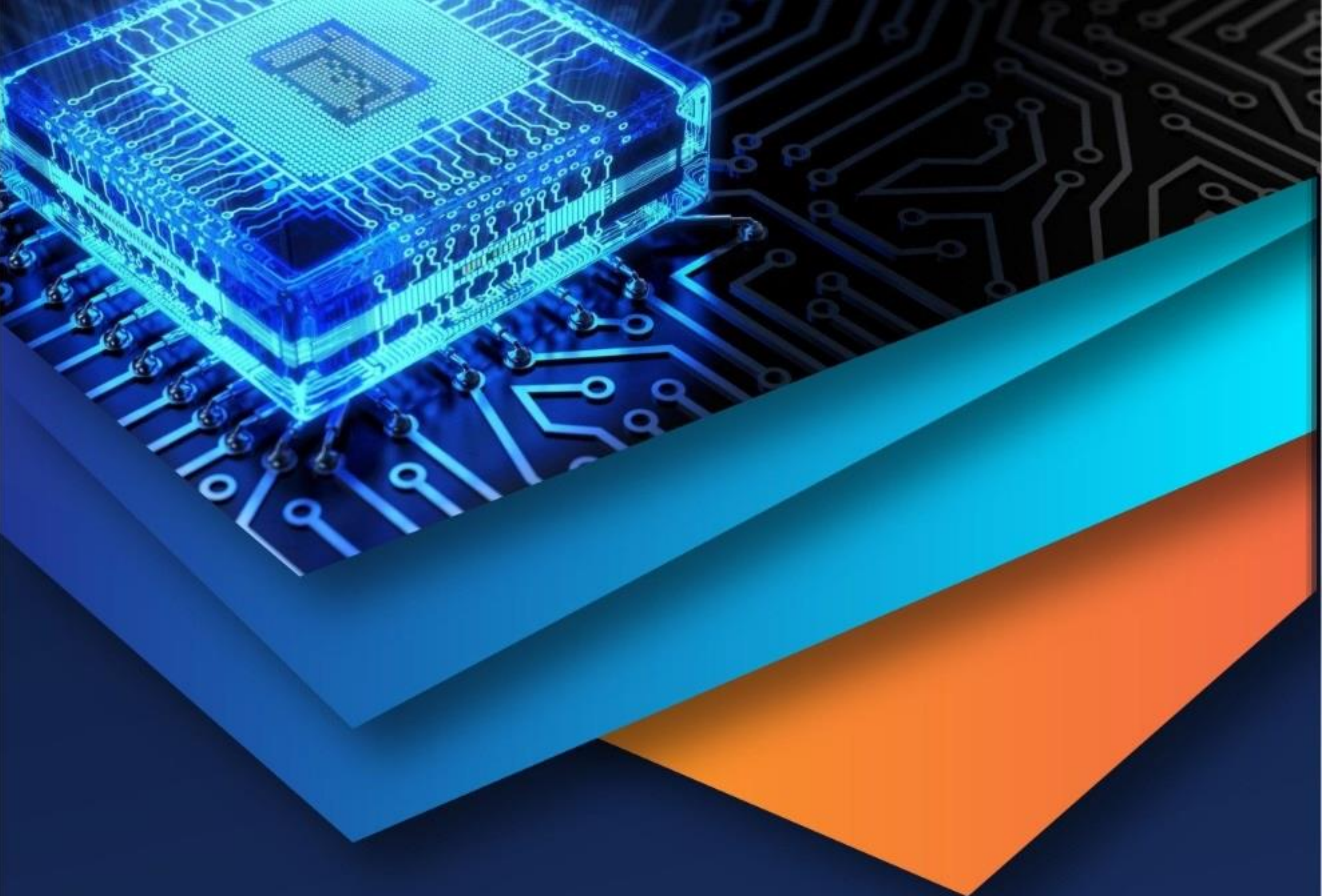

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