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Comparison of Performance of Single-Phase Inverter Using Multiple PWM Techniques

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Abstract: Inverters – vitally important in photovoltaic, wind energy, uninterrupted power supply, and motor drive systems – have their operation substantially affected by how their output voltage waveforms are made. For single-phase inverters, Pulse Width Modulation, or PWM, is the method most commonly put to work for creating the needed output voltage waveform. PWM methods cut down on Total Harmonic Distortion, and also on switching losses, as well as raising all-around performance. There are a number of PWM methods – single-pulse, multi-pulse, and sinusoidal PWM amongst them – and each has its own way of dealing with harmonics and lessening switching loss. It is, then, really important to pick the correct PWM method to boost the performance of a single-phase inverter.

In the work reported here, a large number of simulations were run to assess single-phase inverters with the different PWM methods. Also, tests were done in the lab to look at how well these methods worked. The aim was to find the best PWM method, and the best ways of improving it, for single-phase inverters; the main interest of this study was PWM methods, and how they're used in single-phase inverters.

Index Terms: Single Phase Inverter, Total Harmonic Distortion, LC Filter, Single-Pulse Technique, Multi-Pulse, Sinusoidal Pulse Width Modulation, Triangular Carrier Wave, Gate Driver Circuit, ARM Microcontroller, MOSFET H-Bridge.

I. INTRODUCTION

Inverters are at the center of most modern energy systems. Solar panels, motor drives, backup power units — all of them need an inverter to turn DC into AC the equipment can actually use. Clean AC doesn't come automatically. It depends on how precisely the switching is timed, which makes the modulation technique one of the more important decisions in the design. PWM is not one thing. Single-pulse switches once per half cycle — easy to implement, but the output is rough and distortion is heavy, sitting at frequencies where filters don't do their best work. Multi-pulse helps by adding switching events across the cycle, diluting the distortion somewhat. Not a full fix, but an improvement. SPWM works differently — pulse widths follow a sinusoidal reference, so harmonic energy ends up near the carrier frequency rather than in the lower bands where it does the most damage. A simple LC filter handles whatever remains. Hardware starts to matter as switching frequency rises. The ARM7 is a reasonable fit — timer peripherals fast enough for high-frequency carriers, reference-to-carrier comparison handled in software, pulse widths that update each cycle without extra components. Higher frequency means stray harmonics move further up the spectrum, which makes filtering easier and the output waveform cleaner. None of that is free, though. Switch losses go up with frequency, and THD gets harder to control when the load changes, especially at the high end. That's the central tension in this paper. Single-pulse, multi-pulse, and SPWM are each run on a single-phase inverter — the ARM7 generating the pulses throughout — and the three are measured against each other on waveform quality, THD, and efficiency.

II. ABOUT PWM TECHNIQUES

A. Pulse Width Modulation Techniques

Inverter design began with square wave switching. It got the job done and cost little to implement, but the harmonic distortion it introduced was substantial — enough to reduce power quality noticeably and generate heat in connected loads that had no business being there. PWM addressed this directly.

Instead of operating switches in a simple on-off pattern, it controls how long each pulse stays active. That variation in pulse width gives the designer real leverage over the output voltage shape and brings harmonic levels down in a way that square wave switching never could.

B. Single Pulse Width Modulation

With regard to single PWM control, the pulse width changes for adjusting the output voltage of the inverter. This process requires that just one pulse per cycle is generated. In order to create gating signals, the comparison is done between a rectangular reference signal of Ar and a triangular carrier

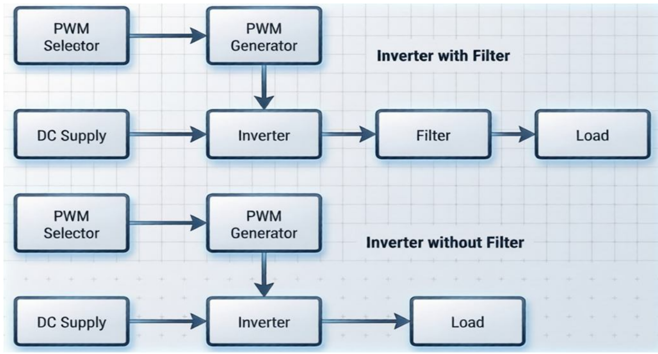

Fig. 1. General block diagram of a PWM-based single-phase inverter system showing DC input, PWM generator, Switching devices, and AC output.

signal of Ac see Figure 1. The fundamental frequency of the output voltage depends on the frequency of the reference signal. The ratio between the two amplitudes, Ar and Ac, is referred to as the amplitude modulation index, ma [1].

A first advantage of this technique is that even harmonics do not exist since the output voltage is symmetrical along the x-axis. Moreover, the nth harmonic is eliminated by setting the pulse width to 2pi/n. One disadvantage is that the harmonic content in the output voltage is significant; this becomes very problematic if the output voltage is low.

C. Multiple Pulse Width Modulation

For multiple PWM, more pulses that are equally spaced per half cycle are produced. Through the use of more pulses for each half cycle of the output voltage, harmonic distortion can be lowered. With this method, the amplitudes of the lower harmonics are minimized, as well as the distortion factor, in comparison with the single pulse modulation technique. On the other hand, the amplitude of the fundamental output voltage is lowered, the amplitudes of the higher harmonics are increased considerably, and switching losses are also increased due to the increased number of switching operations [2].

D. Sinusoidal Pulse Width Modulation (SPWM)

Several pulses, which are spaced evenly, are generated per half cycle in the case of multiple PWMs. With the use of several pulses per half cycle of the output voltage, harmonic content could be minimized. In this modulation method, the amplitude of the lower order harmonics is decreased, and hence the distortion factor is minimized considerably in com-parison to the single pulse modulation method. Nevertheless, the amplitude of the higher order harmonics increases drasti-cally in multiple PWMs and the amount of switching loss is higher. Due to an increased number of switching operations [6].

E. Unipolar PWM Inverter

The unipolar PWM technique involves an inverter output voltage with three voltage states:+Vs,0,-Vs. Comparison takes place between two sinusoidal waveforms with a phase differ-ence of 180° and a high frequency triangular wave carrier. The individual operation of each inverter leg helps create a cleaner waveform with fewer voltage transitions. This results in a low THD, switching losses, EMI, and output filter size. Because of the above benefits, the unipolar PWM method has become popular in inverter operations where the output voltage is critical. The drawback of this approach is a complex controller design due to the addition of comparators and logic circuits for creating pulses.

F. Bipolar PWM Inverter

In case of Bipolar PWM, the voltage level switches from:+Vs,-Vs. The comparator compares one single sinusoidal reference wave with the triangular carrier wave for generation of switching pulses. During bipolar PWM, switching pulses of the two legs of the inverter occur at the same time, and the inverter generates the output waveform at two levels. Bipolar PWM system is relatively easier to implement and hence results in cheaper control circuitry. However, due to the abrupt shift of voltage levels from positive to negative, harmonic distortion becomes more.

G. Trapezoidal Modulation

Comparing a triangular carrier waveform (Vc) with a trape-zoidal reference waveform (Vr) provides the switching points for semiconductor components. The advantage of such modu-lation is that the maximum fundamental component voltage at the output is increased to 1.05 Vd, however, the output voltage waveform consists of low order harmonics [7].

H. Harmonic-injected modulation

With the help of this type of modulation technique, the output signal is generated by superimposing certain harmonics on top of the sine wave, as depicted in Fig. 3.7. As such, the output waveform becomes flat-topped, which leads to the prevention of overmodulation. Using this technique, the output voltage has high-amplitude fundamental components but very low distortion levels. The amplitude of the fundamentals is approximately 0.15 greater compared to SPWM. Because each phase is switched off for one-third of the period, thermal losses are significantly reduced [2].

I. Comparison of PWM Techniques

When square, trapezoidal, and sinusoidal PWM are tested side by side, the results are consistent: SPWM produces the lowest THD and the cleanest output waveform of the three. The control logic is more demanding than what sim-pler methods require. That added complexity, though, buys genuine improvement in harmonic performance and operating efficiency — a trade most applications are willing to make.

J. Microcontroller-Based SPWM Generation

Generating SPWM through software has become the practi-cal standard. When the reference-to-carrier comparison runs in code rather than analog circuitry, switching frequency, modu-lation index, and output voltage become adjustable parameter none of which require hardware changes to modify. The LPC2148, based on the ARM7 core, has seen broad adoption for this purpose. It produces PWM pulses with the accuracy the application demands, manages feedback from the output, and keeps the inverter operating correctly — all without the additional components that analog-based control requires.

K. Role of Filters and Switching Frequency

Whatever harmonic energy survives the switching process falls to the LC filter to deal with. Higher switching frequencies push that residual energy further up the spectrum, which simplifies the filter's task and produces a cleaner output. The downside is that switching losses climb alongside frequency, and that penalty is real enough to matter. The optimal point between these two competing factors is not fixed — it shifts with the load characteristics and the priorities of the specific design.

III. DESIGNING GATE DRIVER CIRCUIT

The idea behind SPWM is simple: a sine wave reference runs against a faster triangular carrier. Where they cross, a switching event fires. The pulse at each point is wide when the sine is near its peak, narrow near zero — so the pulse train encodes amplitude information across the cycle. A low-pass filter downstream pulls the sine back out.

On the ARM7, sine samples are preloaded into a lookup table. Each output cycle steps through them in order. The carrier is just the on-chip timer, set to toggle at whatever rate the reload register specifies. Want a different switching frequency? Change one value. Output voltage is handled the same way, by scaling the reference amplitude relative to the carrier in firmware.

A. Level Shifting and Signal Conditioning Circuit:

As mentioned above, the LM339 comparator requires a 3.3V digital signal input. Yet, this signal will not be enough to run the next set of circuits. As can be seen from the given circuit diagram, it is the comparator which compares the input signal with the particular reference point and provides a digital output as a result. The resistive network providing a certain point will consist of a few resistors at the point. Another resistor from the given network will get rid of excessive high frequency components of the signal connected in parallel with the capacitor.

B. Circuit for short pulse Suppression:

It is picked up by another circuit which is designed to delay and reshape it. The circuit was connected with the RC network and the inverter in order to cause delay in switching circuits where it was essential that two power devices should not conduct at the same time. For better logic signals, the inverter should reshape it.

C. Circuit for Complementary delay and ANDing of protection signals:

Its an input of Clocked delay output to a CD4013 Flip-Flop (PWMod Circuit) PWM (pulsed wave modulator) as in our circuit. The Flip-flop itself provides without additional hardware interstage, two opposition phase pulses. Resistors and capacitors can be added to stabilise the flip-flop and prevent stability problems when loaded. Two complementary inputs are used as it is a sequential power applied at both ends of the circuit.

The gates will only output after the inputs (the PWM pulses and control signals), to which the gates receive, match together. This means that no switch signals will develop till the system is turned on. This simple method could be extended also for disable operation the power switch activation at any unwanted instant like boot-up time/abnormal conditions. And at this point we have two controlled and inversely PWM output for direct application to gate side of switching MOSFET, which is very much what we all want out of a bridge or a class-D amplifier.

IV. RESULTS AND DISCUSSION

Single-pulse PWM was the worst of the three by a clear margin. Heavy harmonic content, the filter only knocked it down partway, output still visibly distorted. Multi-pulse spread the transitions around more evenly and improved things somewhat, but "somewhat" is about as far as it went — not good enough for anything sensitive.

SPWM was a different story. Because each pulse is individ-ually shaped to the sine amplitude at that moment, harmonics stack up near the carrier frequency rather than scattering across lower-order components. That puts them exactly where the filter is most effective. Post-filter waveforms were close to si-nusoidal. THD was substantially lower than either alternative. Pushing switching frequency higher continued to improve THD — more spectral separation, better filter performance. Efficiency moved in the opposite direction. At the upper end of the tested range, temperatures were high enough that continuous operation would be a problem. You don't get both at once.

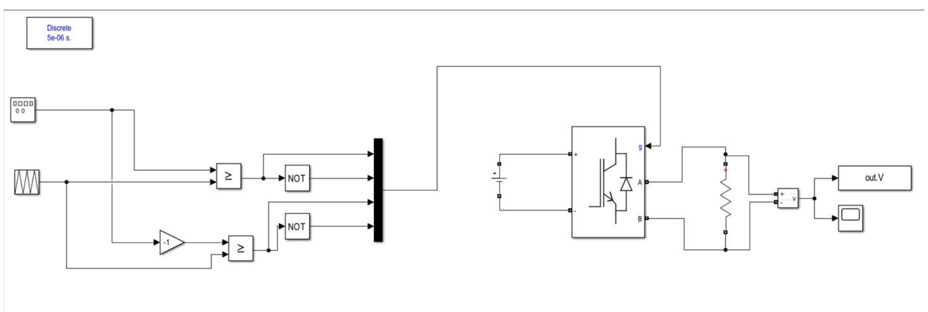

Fig. 2. Circuit Diagram of Bipolar PWM Topology

A. Output Voltage Waveforms for M.I of 0.9

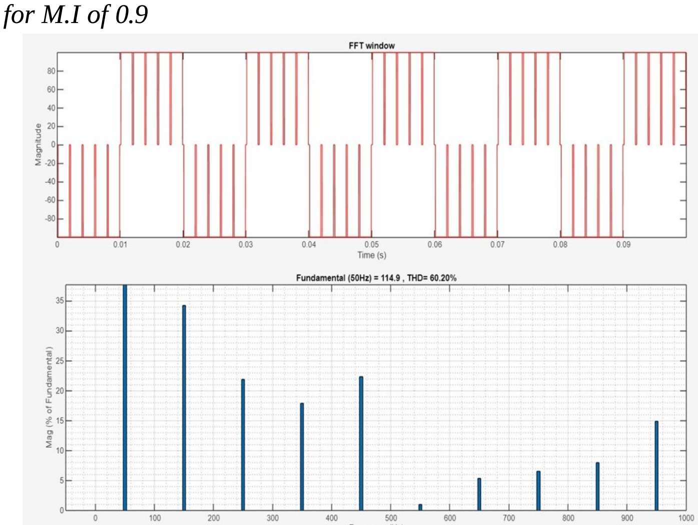

Fig. 3. FFT Analysis of Multi Pulse Output Waveform

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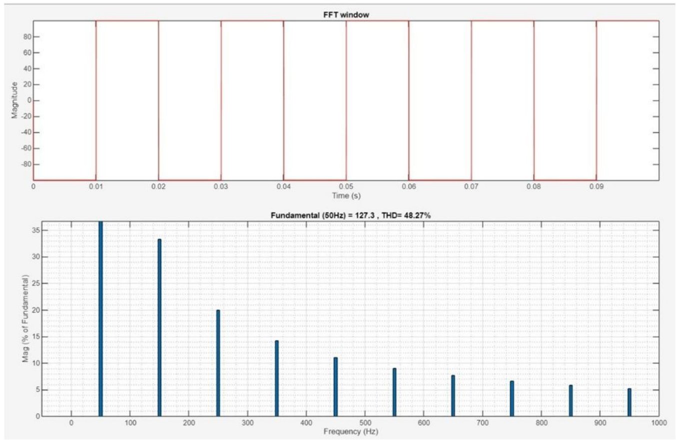

Fig. 4. FFT Analysis of Single Pulse Output Waveform

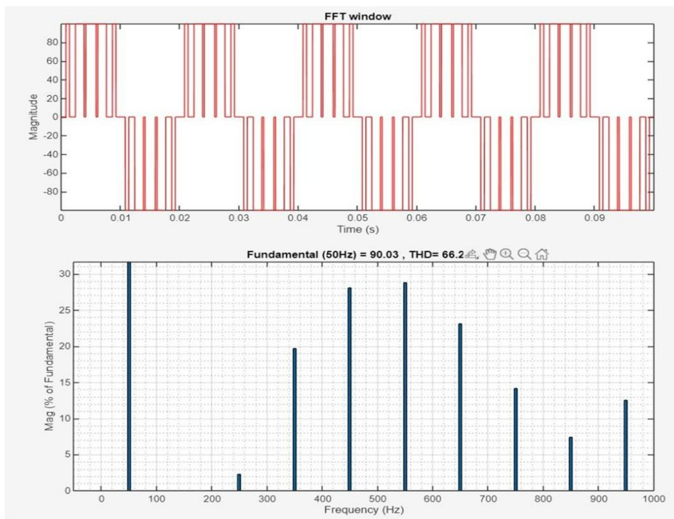

Fig. 5. FFT Analysis of SPWM Output Waveform

B. Output Voltage Waveforms for M.I of 0.8

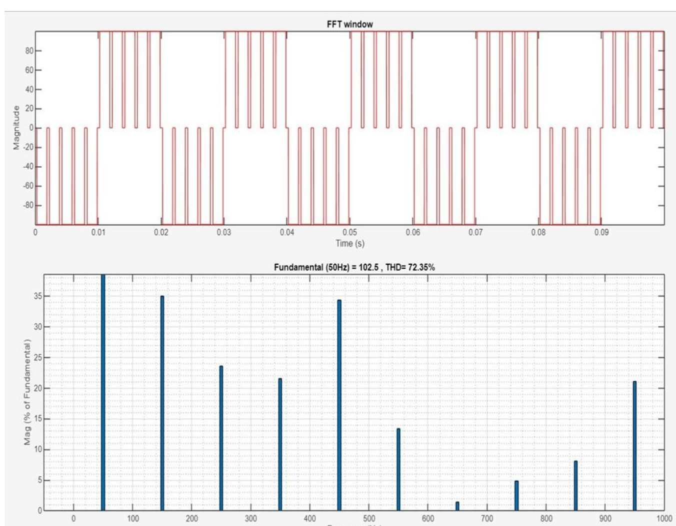

Fig. 6. FFT Analysis of Multi Pulse Output Waveform

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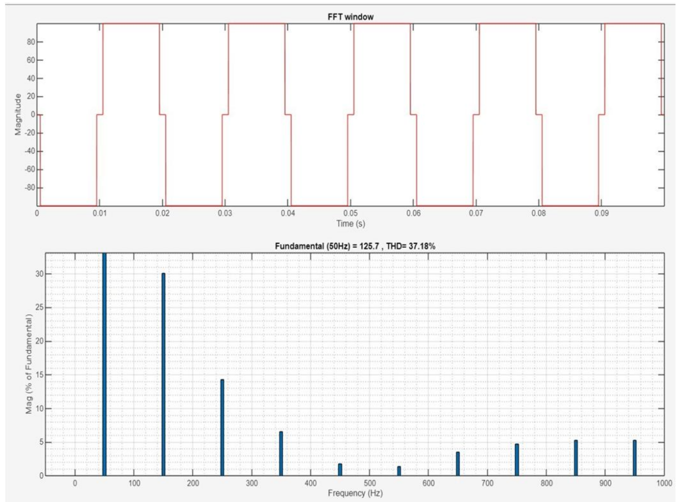

Fig. 7. FFT Analysis of Single Pulse Output Waveform

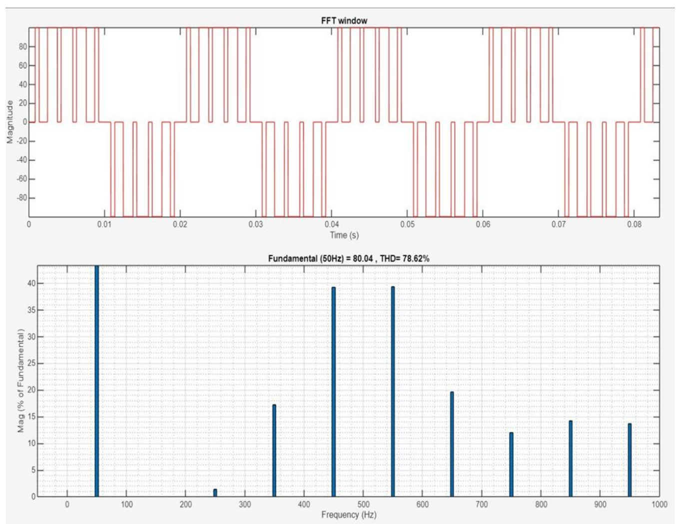

Fig. 8. FFT Analysis of SPWM Output Waveform

C. *Gate Driver Circuit Results*

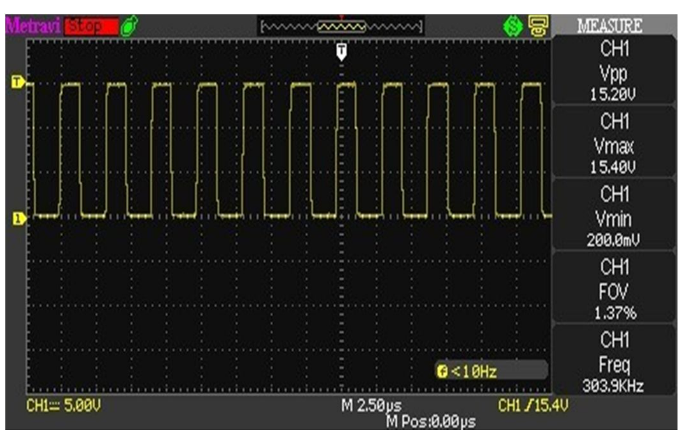

Fig. 9. Clock Output

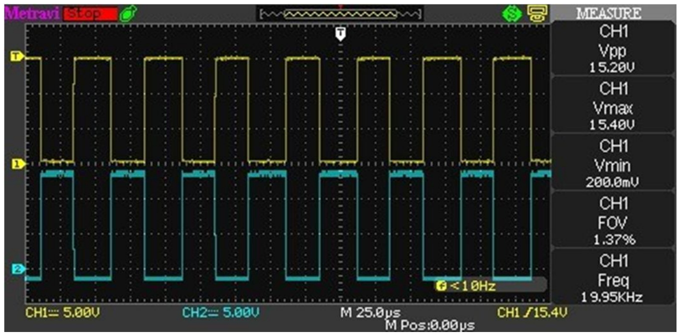

Fig. 10. Output pulses from AND Gates

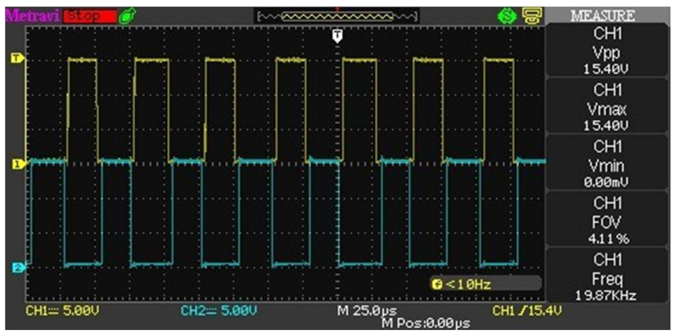

Fig. 11. PWM Pulses from Gate Driver Circuit

V. CONCLUSION

All three methods were tested on the same hardware under the same load. SPWM won, clearly — lowest THD, cleanest output. The other two weren't competitive for applications that care about waveform quality.

Switching frequency is a genuine tradeoff. Higher frequency improves the output; it also stresses the devices. Where you land depends on what the application demands thermally and what THD it can tolerate.

For anything where power quality matters — UPS stages, solar inverters, motor drives — SPWM with a properly de-signed LC filter is the answer. These results support that, though the specific frequency selection needs to be worked out for each design.filter is the answer. These results support that, though the specific frequency selection needs to be worked out for each design.

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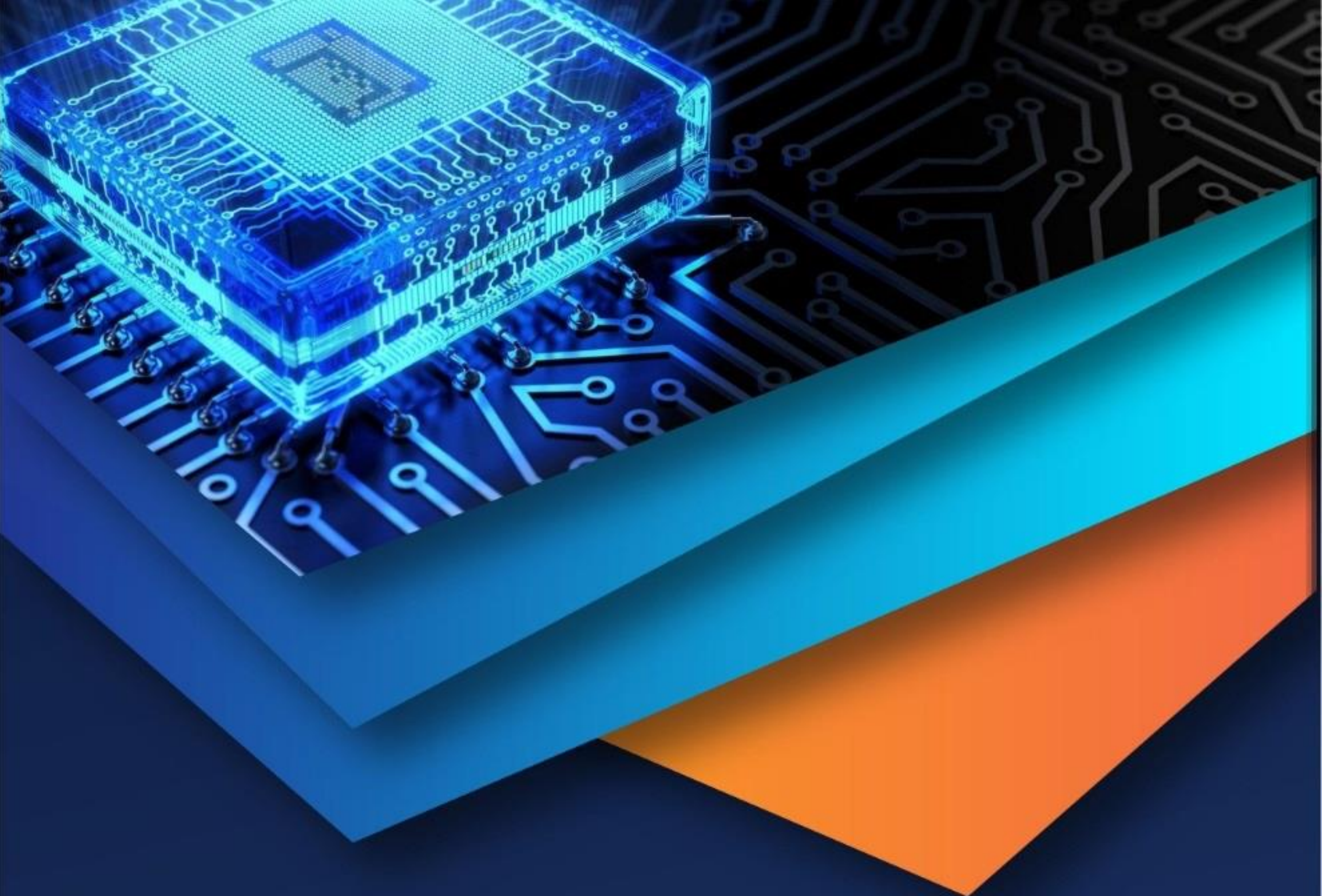

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