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Direct current control based bidirectional AC/DC single phase converter in a Grid-Tied Micro grid Systems

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Abstract: ***This paper presents a novel simplified direct current control strategy for the bidirectional ac/dc single phase converter in a micro grid system. Based on the simplified Pulse Width Modulation (PWM) strategy, a feasible feed forward control scheme is developed to achieve better rectifier mode and inverter mode performance compared with the conventional dual loop control scheme. The proposed simplified PWM strategy with the proposed feed forward control scheme has lower total harmonic distortion. The features of the proposed converter will be verified by the simulation using MATLAB.***

Keywords—direct current control, PWM strategy, feed forward control, Total Harmonic Distortion.

I. INTRODUCTION

THE single-phase ac/dc pulse PWM converter is widely used in many applications such as adjustable-speed drives, switch-mode power supplies, and un- interrupted power supplies. The single-phase ac/dc PWM converters [1],[2],[4] are usually employed as the utility interface in a grid-tied renewable resource system, as shown in Fig. 1. To utilize the distributed energy resources (DERs) efficiently and retain power system stability, the bidirectional ac/dc converter plays an important role in the renewable energy system. When DERs have enough power, the energy from the dc bus can be easily transferred into the ac grid through the bidirectional ac/dc converter. In contrast, when the DER power does not have enough energy to provide electricity to the load in the dc bus, the bidirectional ac/dc converters can simultaneously and quickly change the power flow direction (PFD) from ac grid to dc grid and give enough power to the dc load and energy storage sys- tem. There are many requirements for ac/dc PWM converters as utility interface in a grid-tied system; for instance, providing power factor correction functions [1], low distortion line currents [20], [21], [22], high-quality dc output voltage [1], and bidirectional power flow capability [6], [7]. Moreover, PWM converters are also suitable for modular sys- tem design and system reconfiguration. In this paper, a novel PWM control strategy with feed forward control scheme of a bidirectional single-phase ac/dc converter is presented.

In the existing PWM control strategies of a single-phase ac/dc converter, the converter switches are operated at higher frequency than the ac line frequency so that the switching har- monics can be easily removed by the filter [20], [21], [22]. The ac line current waveform can be more sinusoidal at the ex- pense of switching losses. Until now several PWM strategies have been utilized in a single-phase ac/dc converter such as bipolar PWM (BPWM), unipolar PWM (UPWM) [8]–[10],

HPWM [11]–[14], and Hysteresis switching [15],[16]-[19]. UPWM results in a smaller ripple in the dc side current and significantly lower ac side harmonic content [10] compared to the BPWM. The UPWM effectively doubles the switching frequency in the ac voltage waveform harmonic spectrum al- lowing the switching harmonics to be easily removed by the passive filter. The HPWM [12]–[14] utilizes two of the four switches modulated at high frequency and utilizes the other two switches commutated at the (low) output frequency to re- duce the switching frequency and achieve better quality output. However, the switching loss in the HPWM is still the same as that of the UPWM [12].

The hysteresis switching method uti- lizes hysteresis in comparing the actual voltage and/or current to the reference Although the hysteresis switching method has the advantages of simplicity and robustness [15],[16]-[19] the converters' switching frequency depends largely on the load parameters, and consequently, the harmonic ripples are not op- timal. Hysteresis control methods [15], [16]-[19] with constant switching frequency have recently been presented. Those are usually based on the voltage and/or current error zero-crossing time to achieve a constant switching frequency. However, the capacitor ripple voltage and inductor ripple current are assumed to be ignored and the implemented inductor and/or capacitor are not very practical. The switching frequency

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jitter [15] problem would occur during the inverter dead-time control

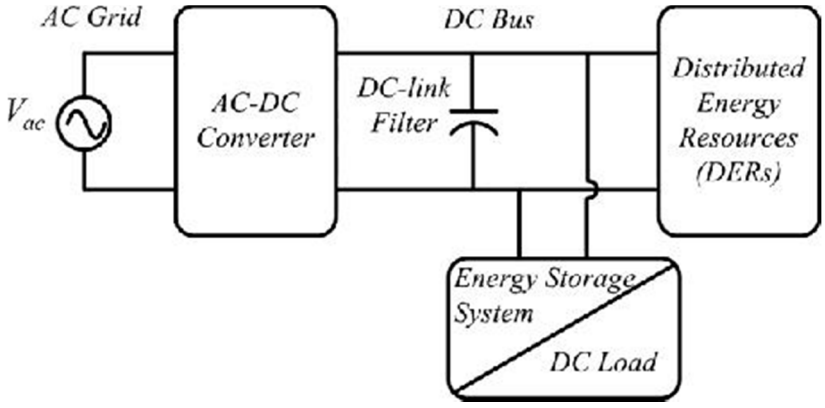


Fig. 1 Distribution Energy System.

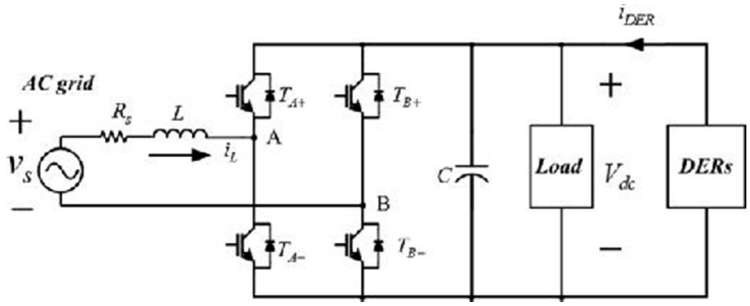


Fig. 2 Application of a bidirectional single-phase ac/dc converter in the renewable energy system.

The proposed simplified PWM reduces harmonic pollution in Distribution power systems and replaces conventional diode front end rectifier stage in order to reduce the total harmonic distortion. This proposed topology follows an active ripple energy storage method that can effectively reduce the energy storage capacitance. A novel feed forward control scheme is also developed so that both the rectifier and inverter mode can be operated in a good manner. It is worth mentioning that the proposed feedforward control scheme is also suitable for the conventional UPWM and BPWM to provide fast output voltage response as well as improve input current shaping.

II. OPERATION PRINCIPLE OF THE PROPOSED PWM STRATEGY WITH LINEAR CONTROL TECHNIQUE

A bidirectional single-phase ac/dc converter is usually utilized as the interface between DERs and the ac grid system to deliver power flows bidirectionally and maintains good ac cur- rent shaping and dc voltage regulation, as shown in Fig. 2. Good current shaping can avoid harmonic pollution in an ac grid sys- tem, and good dc voltage regulation can provide a high-quality dc load. To achieve bidirectional power flows in a renewable energy system, a PWM strategy may be applied for the single-phase full-bridge converter to accomplish current shaping at the ac side and voltage regulation at the dc side. Generally, BPWM and UPWM strategies are often utilized in a single-phase ac/dc converter. In this paper, a novel simplified PWM strategy with linear control technique is pro- posed. In this control scheme, the compensation current or voltage signal is compared with its estimated rated reference signal through the compensated error amplifier to produce the control signal. The resulting control signal is then compared with a saw tooth signal through a pulse width modulation (PWM) controller to generate the appropriate gating signals for the switching transistors. The frequency of the repetitive saw tooth signal establishes the switching frequency. This frequency is kept constant in linear control technique. As shown in Figure, the gating signal is set high when the control signal has a higher numerical value than the saw tooth signal and vice versa. With analogue PWM circuit, the response is fast and its implementation is simple. Nevertheless, due to inherent problem of analogue circuitry,

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the linear control technique has an unsatisfactory harmonic compensation performance. This is mainly due to the limitation of the achievable bandwidth of the compensated error A.PI controllers for DC-bus voltage control

A PI controller used to control the DC-bus voltage is shown in Figure. Its transfer function can be represented as Kp +Ki/S. where Kp is the proportional constant that determines the dynamic response of the DC-bus voltage control, and Ki is the integration constant that determines it's settling time. It can be noted that if Kp and Ki are large, the DC-bus voltage regulation is dominant, and the steady-state DC-bus voltage error is low. On the hand, if Kp and Ki are small, the real power unbalance gives little effect to the transient performance.

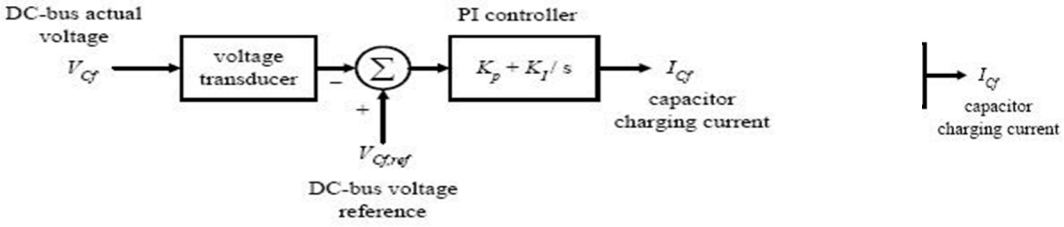


Fig.3. Design of PI Regulator

In the design of single-phase PWM rectifier control system, the general use is dual-loop control, namely, voltage and current loops. The outer voltage loop controls the voltage in DC side, while the current loop as the inner loop, it forces the input current tracking current instruction (gained from the output of the outer voltage loop), in order to achieve sinusoidal current control unity power factor. The current instruction and grid- side voltage have same frequency and opposite phase.

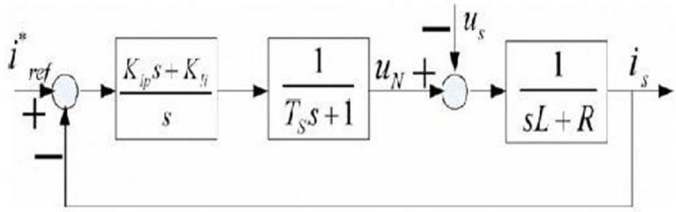


Fig.4.Block Diagram of transfer function in current loop

The control performance of input current is the key of rectifier control, because the essence of the rectifier is an energy conversion system between the AC and DC power, the grid voltage is essentially certain, so the rapid and effective control of the input current is important.

III. PROPOSED DIRECT CURRENT CONTROL SCHEME A. CONVENTIONAL DUAL-LOOP CONTROL SCHEME

In the conventional dual loop control scheme applied to the single-phase bidirectional ac/dc converter, the inner current loop and outer voltage loop are utilized as shown in Fig. 5, where Vdc* is the dc voltage command, Vdc is the actual dc voltage; iL is the ac current command, and IL is the actual ac current. The voltage controller calculates the voltage error and generates the current amplitude command IL multiplied by the unit sinusoidal waveform, obtained from the phase lock loop to generate the current command i*. In general, a proportional-integral controller is adopted as the voltage controller and current controller to achieve power factor correction at the ac side and voltage regulation at the dc B.

Proposed Direct current Control Scheme

Based on the proposed simplified PWM, a novel Direct current scheme is presented in this section. The converter is operated in the rectifier mode and inverter mode. To derive the state-space averaged equation for the proposed simplified PWM strategy, the duty ratio Don is defined as Don = ton /T , where ton is the time duration when the switch is turned ON,

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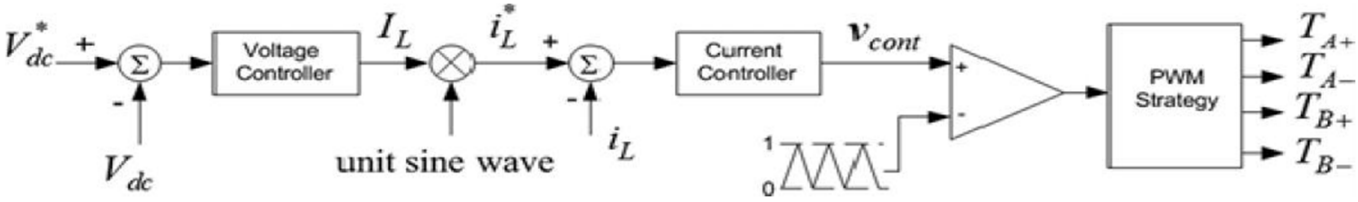


Fig. 5.Conventional dual-loop control scheme for a single phase bidirectional ac/dc converter.

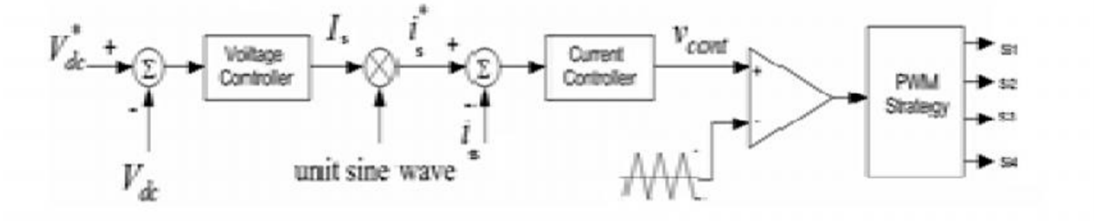


Fig.6. Proposed control scheme block diagram for a single phase bidirectional ac/dc converter.

i.e., Son = 1, and T is the time period of triangular waveform. The duty ratio Doff is defined as Doff = 1 – Don, which is the duty ratio when the switch is turned OFF. By introducing the state-space averaged tech- nique and volt–second balance theory, the state-space averaged equation is derived as follows:

$$Vs - (1 - Don)\, Vdc = O. \quad (1)$$

When the converter is operated in the steady state, the dc voltage is equal to the desired command Vdc* = Vdc ; (1) can also be expressed in the following form:

$$Don = 1 - (Vs/Vdc^*)$$

By introducing the state-space averaged technique and volt– second balance theory, the state-space averaged equa- tion is derived as follows, while the ac grid voltage source is operating in the negative half-cycle vs < O:

$$vs + Don\, Vdc = O.$$

Similarly, when the converter is operated in the steady state, the output voltage is equal to the desired command Vdc = V dc∗. According to the PWM properties, the switching duty ratio can be expressed in terms of the control signal Vcont* and the peak value Vtri of the triangular waveform While the converter is operated in the inverter mode, the control signal v can be obtained using a similar manner in the rectifier mode. Because the control signals Vcont is proportional to Don.

IV. SIMULATION RESULTS

To verify the validity of the proposed PWM strategy and the direct current control scheme, the well-known soft- ware MATLAB was adopted to carry out the simulation process.

A. Direct source current method

Consider that the converter is operated in the rectifier mode. Fig. 7 shows the measured grid voltage Vs and line current iL when the converter is operating the dual loop control scheme in the proposed simplified PWM strategy. The measured THD of the converter ac line current is 34.23% and the power factor is O.92. In contrast, Fig. 1O shows the corresponding measured grid voltage vs and line current iL waveforms with the proposed feed forward control scheme in the proposed simplified PWM strategy operated in the rectifier mode. In the feed forward control scheme, the measured ac line current THD of the converter is 3.34% and the power factor is O.99. Figs. 11 and 12 show the input voltage and source current which are in phase and very low THD. So from this one can find that the proposed source current control method indeed further improves

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the converter ac current shaping com- pared to the dual-loop control scheme in the actual distorted ac grid voltage source.

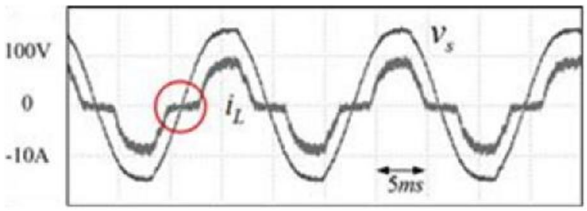


Fig.7. Measured grid voltage Vs and line current iL waveforms of the converter using the dual-loop control scheme in the proposed simplified PWM strategy operated in the rectifier mode.

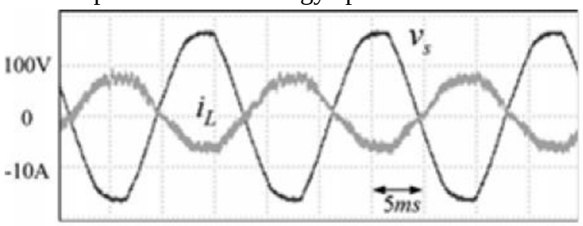


Fig.S. Measured grid voltage Vs and line current iL waveforms using the feed forward control scheme in the proposed simplified PWM strategy operated in the inverter mode.

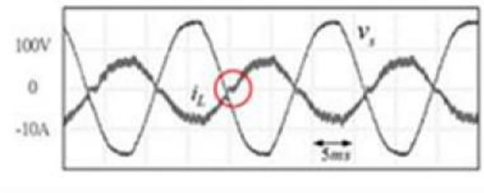


Fig.9. Measured grid voltage Vs and line current iL waveforms using feed- forward control scheme in the proposed simplified PWM strategy operated in the rectifier mode.

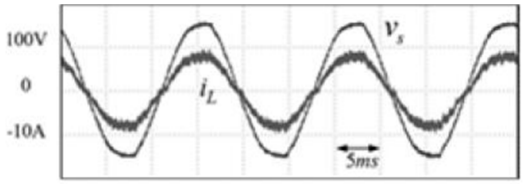


Fig.10. Measured grid voltage Vs and line current iL waveforms of the converter using the dual-loop control scheme in the proposed simplified PWM strategy operated in the inverter mode.

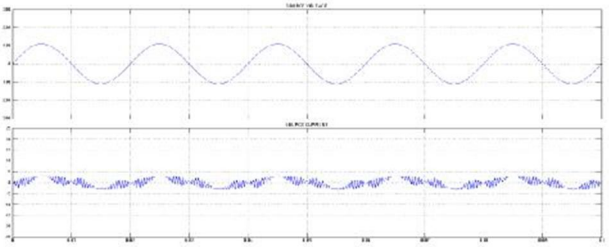


Fig.**11**. simulated source voltage and source current conventional PWM rectifier

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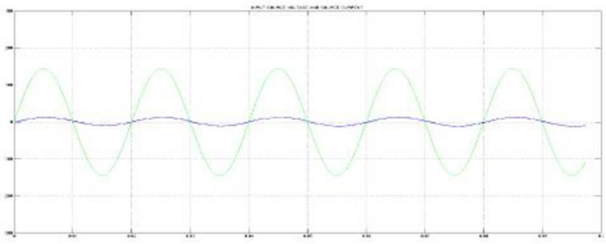


Fig.12. simulation results of source voltage and source current of proposed ac-dc converter

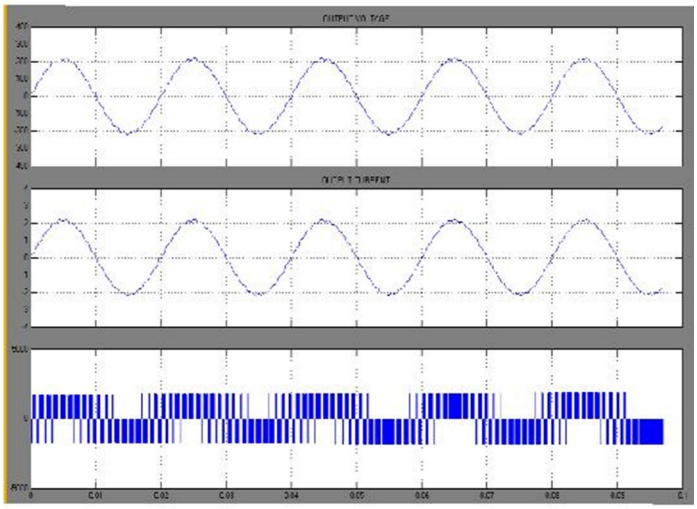


Fig.13. Inverter output voltage, output current and pwm output voltage (during PV supplying power to battery charging system and inverter)

Consider next that the converter is operated in the inverter mode. Fig. 9 shows the measured grid voltage Vs and line current iL of the converter with the dual-loop control scheme in the proposed simplified PWM strategy. When the converter is operated in the dual-loop control scheme, one can find that zero cusp distortion exists near the zero crossing. The serious distortion may occur when the controller is not designed well. The measured THD of the converter ac line current is 6.64% and the power factor is –0.967. In contrast, Fig. 8 shows the corresponding measured grid voltage vs and line current iL waveforms with the feed forward control scheme in the pro- posed simplified PWM strategy operated in the inverter mode. In the proposed feed forward control scheme, the measured ac line current THD of the converter is 4.69% and the power fac- tor is –0.985. Comparing Fig. 9 with Fig. 10, the feed forward control scheme also improves the ac/dc converter current shaping when operated in the inverter mode compared to the conventional dual-loop. By using source current control method the THD level further current and pwm output voltage during PV supplying power to battery charging system and inverter.

V. CONCLUSION

This paper presented a Direct current control based bidirectional AC/DC single phase converter in a Grid-Tied Micro grid Systems. The proposed simplified PWM strategy with the proposed feed forward control scheme has lower total harmonic distortion. Based on the proposed feed forward control scheme, both the ac current shaping and dc voltage regulation are achieved in both the rectifier and converter operating modes. The THD of the proposed PWM strategy is very low. The features of the proposed converter were verified by the simulation using MATLAB.

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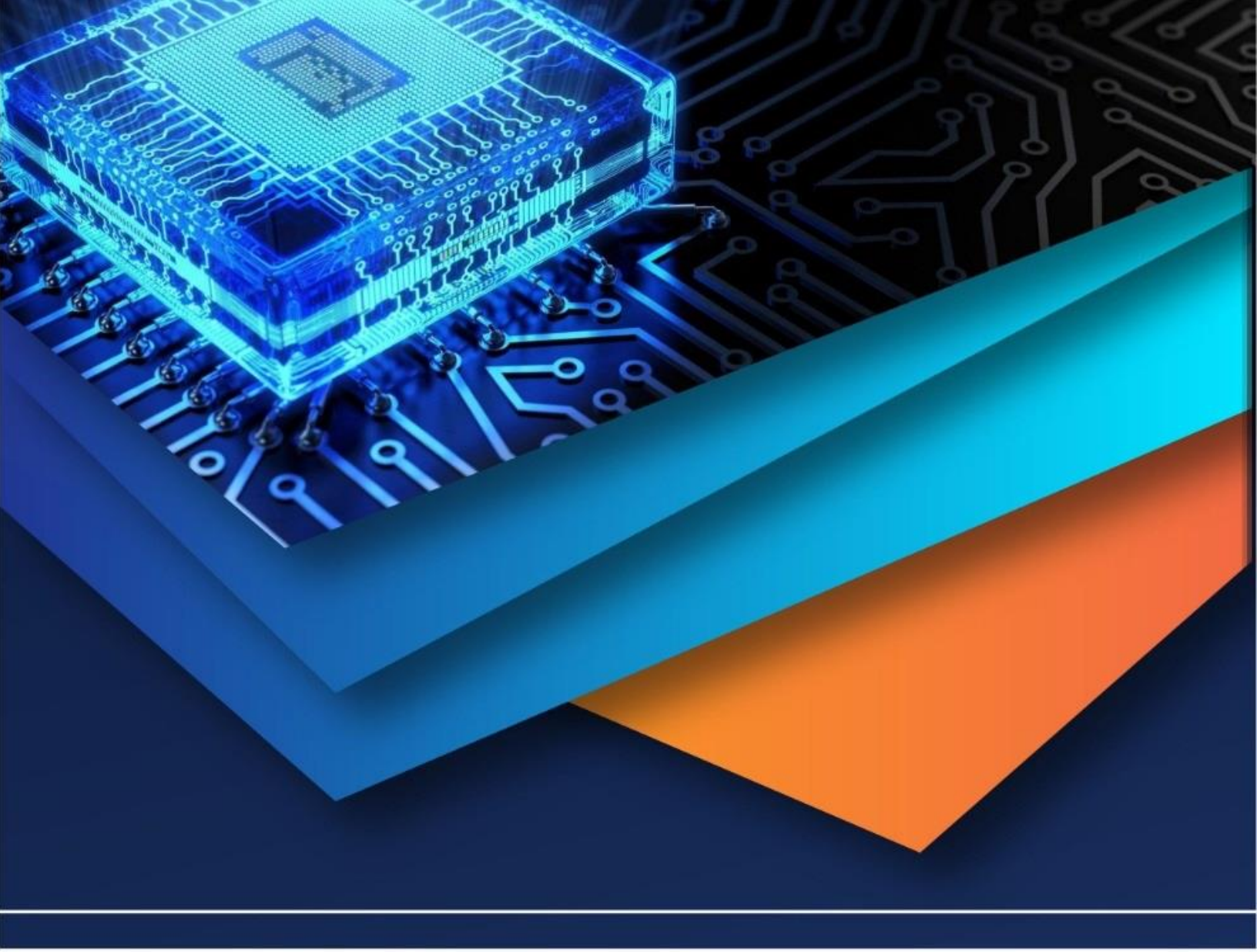
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