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Power Quality Improvement using Dynamic Voltage Restorer(DVR)

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Abstract: This paper discusses the mitigation of power quality disturbance in low voltage distribution system due to voltage swells using one of the powerful power custom devices namely Dynamic Voltage Restorer (DVR). The DVR normally installed between the source voltage and critical or sensitive load. The new configuration of DVR has been proposed using improved d-q-o controller technique. The simulations are performed using MATLAB/Simulink's SimPower Toolbox. The simulation and experimental results demonstrate the effective dynamic performance of the proposed configuration.
Keywords: Dynamic Voltage Restorer, d-q-o controller, voltage swells, distribution system, sensitive load.

I. INTRODUCTION

Recently the growth in the use of sensitive loads in all industries has caused many disturbances such as voltage sags, swells, transient and unbalance. These types of disturbances which caused malfunction or shut down and tend to revenue losses. Several methods are available to prevent equipment mal operation due to voltage swells. One of commonly used methods is the use of DVR in order to mitigate voltage swells condition.

DVR is an important tool to mitigate disturbances related to power quality problems in the distribution network. One of the crucial disturbances in the electrical network is voltage swells. The existing DVR as shown in Figure 1Consists of a Voltage Source Inverter (VSI), series injection transformer, filtering scheme and an energy storage device may that be connected to the dc-link [2-3].

Voltage sags/swells can occur more frequently than other power quality phenomenon. These sags/swells are the most important power quality problems in the power distribution system. IEEE 519-1992 and IEEE 1159-1995 describe the voltage sags/swells as shown in Figure 2[1-4].

The main objective of this paper is to investigate and proposes a new configuration of DVR in order to develop such device for voltage swells mitigation in the network. The capacity of the developed device is about 5KVA. This prototype is evaluated and tested in the laboratory and later it will be tested in the industry.

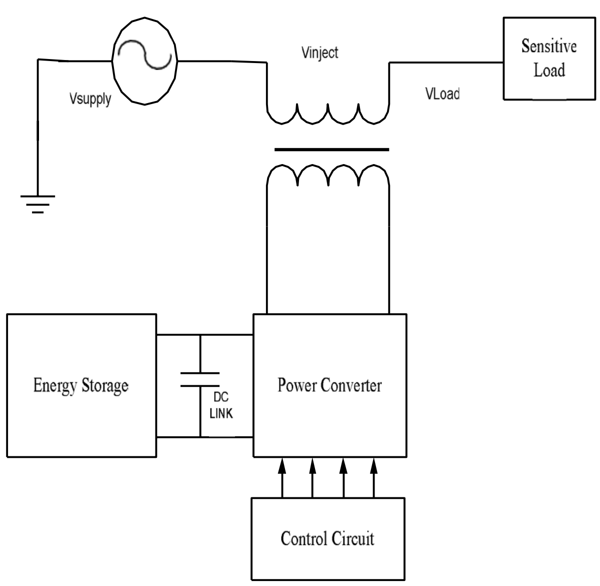

Figure 1: Schematic diagram of Conventional DVR

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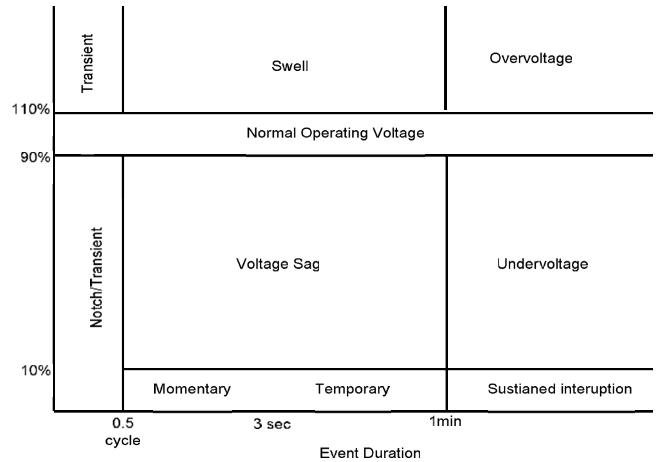

Figure 2 Voltage Reduction Standard of IEEE Std 1159-1995T

This paper is divided into four sections. The explanation of each sections are as follows: Description of DVR and explain of its functioning are discussed in section I. Section II describes a new configuration of DVR's controller. The Simulation results are discussed in Section III.

DVR is connected in series between the source voltage or grid and sensitive loads through injection transformer. There are several types of energy storage been used in the DVR such as battery, superconducting coil, and flywheels. These types of energy storages are very important in order to supply active and reactive power to DVR. The controller is an important part of the DVR for switching purposes. The switching converter is responsible to do conversion process from DC to AC. The inverter ensures that only the swells or sags voltage is injected to the injection transformer [5-9].

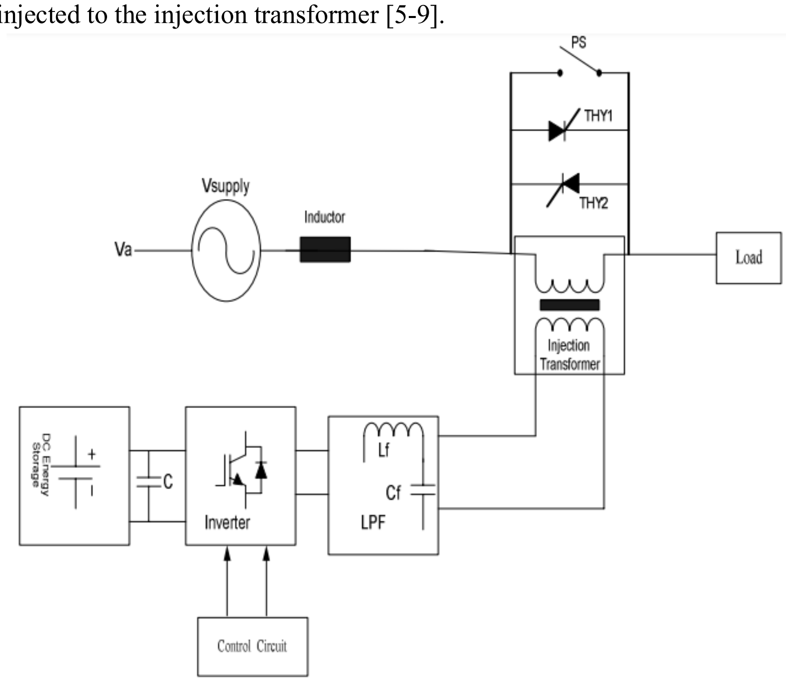

Figure 3: Typical DVR circuit topology (single-phase representation).

Figure 3 shows the existing has a VSI and the injection transformer. The VSC consists of six IGBT's (Insulated Gate Bipolar Transistors), three ac inductors and capacitors respectively, one dc capacitor and energy storage. The selection of IGBT's, interfacing inductor; dc capacitor and the filter is as per the design for a dynamic voltage restorer [10- 12]. In order to protect DVR from any disturbances a hybrid switch been used and its operation will be discussed later.

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As noted in the previous section, the function of DVR is to inject the difference voltages between the voltage source and the sensitive load. The sources of injection voltages are available from the energy storage device which is capable to supply real and reactive power. The DC energy storage rating determines the maximum injection capability of the DVR. The injection transformer consists of the high and low voltages side. The booster voltages can occur through injection transformer which consists of high and low voltages. The source supply is connected in series with the high voltage side where as the converter is connected at the voltage side [13-14].

II. PROPOSED CONFIGURATION OF DVR

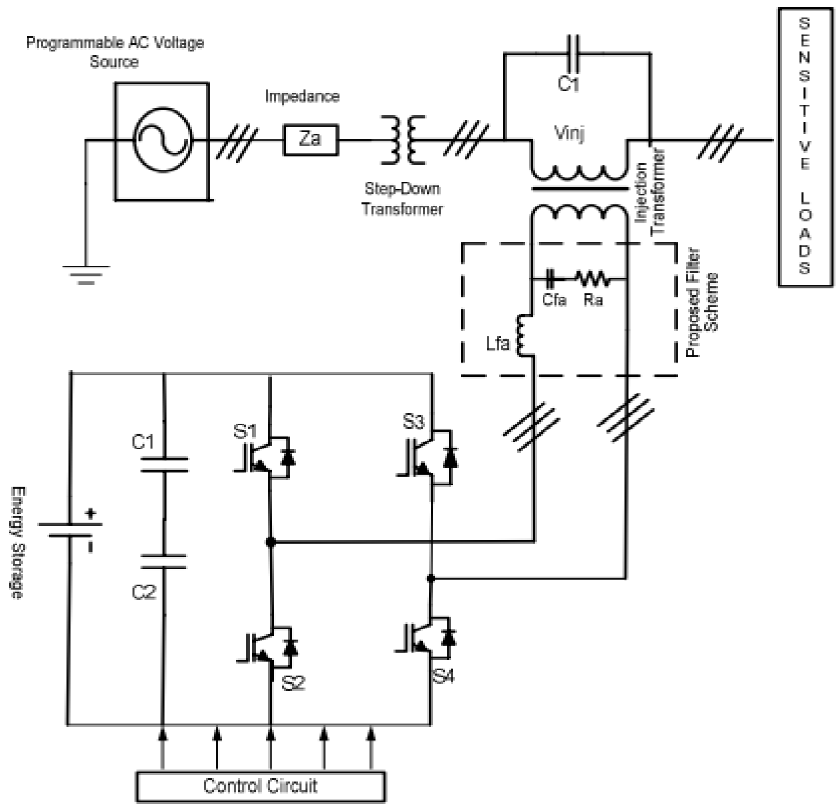

Figure 4: The Proposed Configuration of DVR

The proposed DVR is shown in Figure 4. By using the three single phase of the injection transformer. The injection transformer can be connected either in delta/open or star/open configuration. In this the series injection transformer was configured as delta/open. The DVR power circuit consists of the 3-leg inverter which has 6 IGBT switches and the battery as a dc energy storage. The low pass filters are used to convert the PWM inverted pulse waveform from DC to AC conversion in the VSI. In this configuration, the filters are installed in both the high voltage side and the low voltage side.

When it is place in low voltage side, high order harmonics from the three phase voltage source PWM inverter is by pass by the filtering configuration and its impact on the injection current rating can be ignored [15]. The type of this filtering configuration can also eliminate switching ripples produced by the converter.

When it is place in low voltage side, high order harmonics from the three phase voltage source PWM inverter is by- pass by the filtering configuration and its impact on the injection current rating can be ignored [15]. The type of this filtering configuration can also eliminate switching ripples produced by the converter. As for the filtering configuration is placed in the high voltage side. In this case, high order harmonic currents will penetrate through the injection and it will carry the harmonic voltages. When compensate the voltage sag/swell at the critical load, DVR produce a harmonics distortion fed from series transformer as an injection voltage to the critical load.

III. THE CONTROL of DVR SYSTEM

The Control of the proposed configuration of DVR system using d-q-o Park's transformation technique. Figure 5 show the main components of the control system The control system consists of 6 blocks and each, block has its function and can be described as follows:

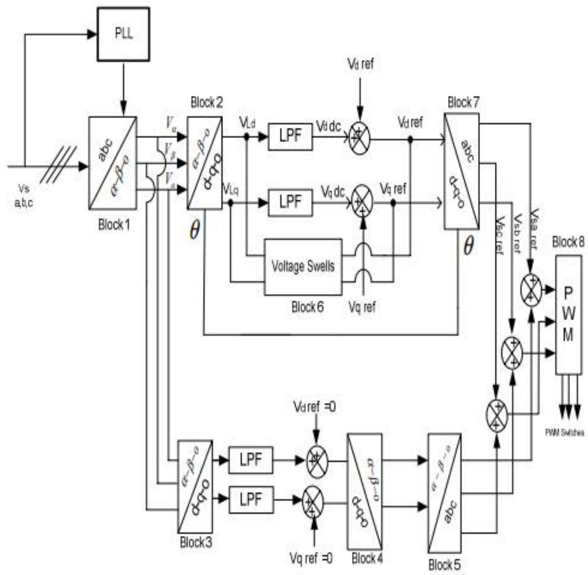

Figure 5: Block Diagram Control Scheme of DVR for Voltage Swells

Block 1 is used to convert the three phase load voltages (V_{sa},V_{sb}, V_{sc}) into the α-β-o coordinates as in equation (1)

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_O \end{bmatrix} = S \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \qquad (1)$$

Where $S=\sqrt{\frac{2}{3}}\begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{-1}{\sqrt{2}} \end{bmatrix}$

Block 2 and block 3 is the α-β-o to d-q-o transformation blocks which are used to convert the three phase load voltages reference components Vα-ref, Vβ-ref and Vo ref to Vd ref, Vq ref and Vo ref by using equation (2), (3), (4) and (5)

$$V_d = \frac{2}{3}\left[V_a \cos\theta \quad V_b \cos\left(\theta - \frac{2\pi}{3}\right) \quad V_c \cos\left(\theta + \frac{2\pi}{3}\right)\right].(2)$$

$$V_q = \frac{2}{3}\left[-V_a \sin\theta - V_b \sin\left(\theta - \frac{2\pi}{3}\right) - V_c \sin\left(\theta + \frac{2\pi}{3}\right)\right]. \qquad (3)$$

$$V_o = \frac{1}{3}[V_a \quad V_b \quad V_c] \qquad (4)$$

$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (5)$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} \quad (6)$$

Block 4 is used to convert the d-q-o to α-β-o and the transformation of the α-β-o to a-b-c has been done by block 5. The angle θ of the source voltage can be obtained using three-phase PLL. The information extracted from the PLL is used for detection and reference voltage generation. Block 6 is the detection scheme for the voltage unbalance compensator. Figure 5 shows that the synchronous frame variables - Vd and Vq - are used as inputs for low pass filters to generate voltage references in the synchronous frame. Block 7 receives the components of the load voltage vectors Vd ref and Vq ref and transforms them to three-phase coordinates using equation (6). The generation voltages are used as the voltage reference. The DC link error in Figure 5 is used to get optimized controller output signal because the energy on the DC link will be changed during the unbalance voltage. Block 8 is the PWM block which provides the firing for the Inverter switches (PWM1 to PWM6). The injection voltage is generated according to the difference between the reference load voltage and the injection voltage is generated according to the difference between the reference load voltage and the supply voltage and is then applied to the voltage source converter (VSC).

IV. MATLAB BASED SIMULATION OF DVR SYSTEM

The performance of the designed DVR, as shown in Figure 4, is evaluated using Matlab/Simulink. Table I provides the specification of the simulation and experimental results of the DVR.

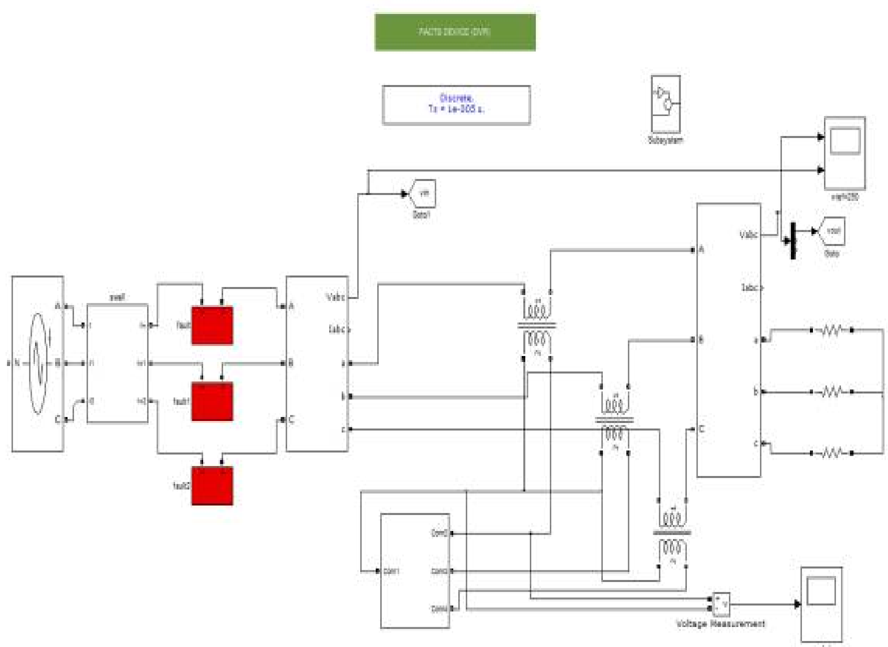

Figure 6: The Proposed Configuration of DVR using Matlab/Simulink

Investigation on the DVR performance can be observed through testing under various disturbances condition on the source voltage. The proposed control algorithm was tested for balanced and unbalanced voltages swells in the low voltage distribution system. In case of balance voltage swell, the source voltage has increased about 20-25% of its nominal value. The simulation results of the The DVR voltage which is injected in to the transmission line during sag condition is shown in Figure 7(a). The function of the DVR will injects the missing voltage in order to regulate the load voltage from any disturbance due to immediate distort of source voltage. The output voltage, which is obtained by using DVR in the distribution system can be seen in Figure 7(b). The Figure shows the effectiveness of the controller response to detect voltage swells quickly and inject an appropriate voltage.

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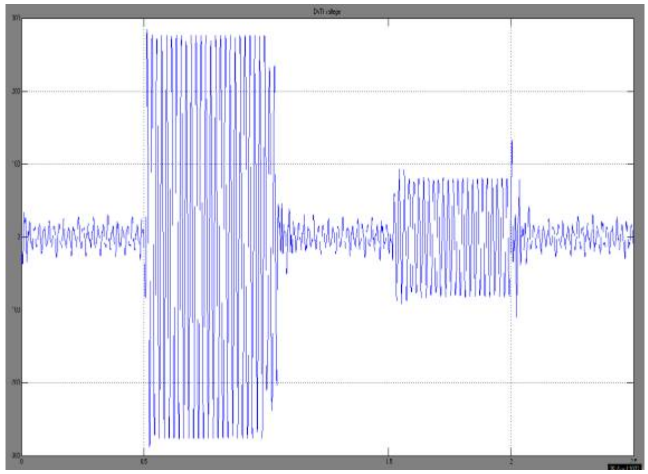

Figure 7(a): The DVR voltage which is injected in to the transmission line during sag condition.

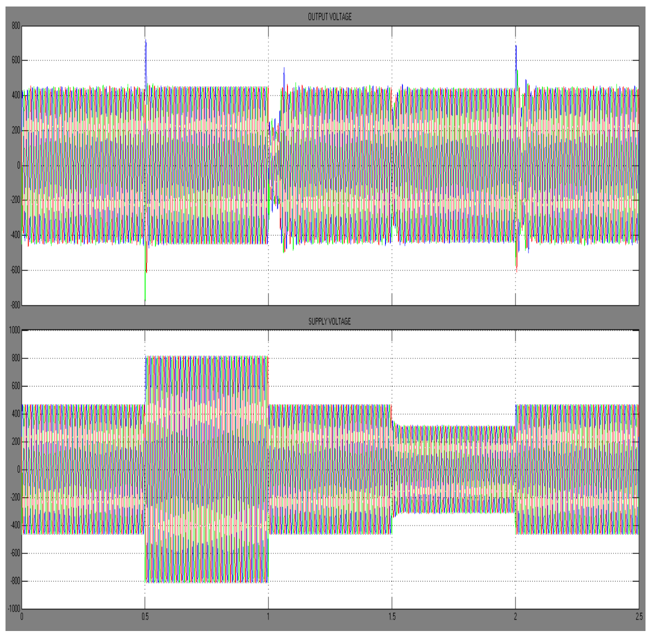

Figure 7(b): The output voltage, which is obtained by using DVR in the distribution system

Table 1: MAIN SPECIFICATION OF THE DVR

PARAMETER	VALUE
Nominal grid voltage	200V (L-L)
Nominal load voltage	120V(L-L)
Maximum series voltage Injection	100V(L-L)
Switching/sampling frequency	10 KHz
Max. inverter dc-bus voltage	120V
Capacitor of dc- bus	26uF
Filter inductance	2.7mF
Filter capacitance	50uF

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V. CONCLUSION

The problem of voltage sags and voltage Swell and its severe impact on sensitive loads is well known. To solve these problem custom power devices are used. One of those devices is the Dynamic Voltage Restorer (DVR), which is the most efficient and effective modern custom power device used in power distribution networks. Its appeal includes lower cost, smaller size, and its fast dynamic response to the disturbance. This paper describes DVR principles and voltage restoration methods at the point of common coupling (PCC). The simulation results clearly show that the performance of DVR in mitigating voltage sags and swells. It handles both balanced and unbalanced situations without any difficulties and injects the appropriate voltage component. It corrects rapidly if there is any variation in the supply voltage and keeps the load voltage balanced and constant at the nominal value.

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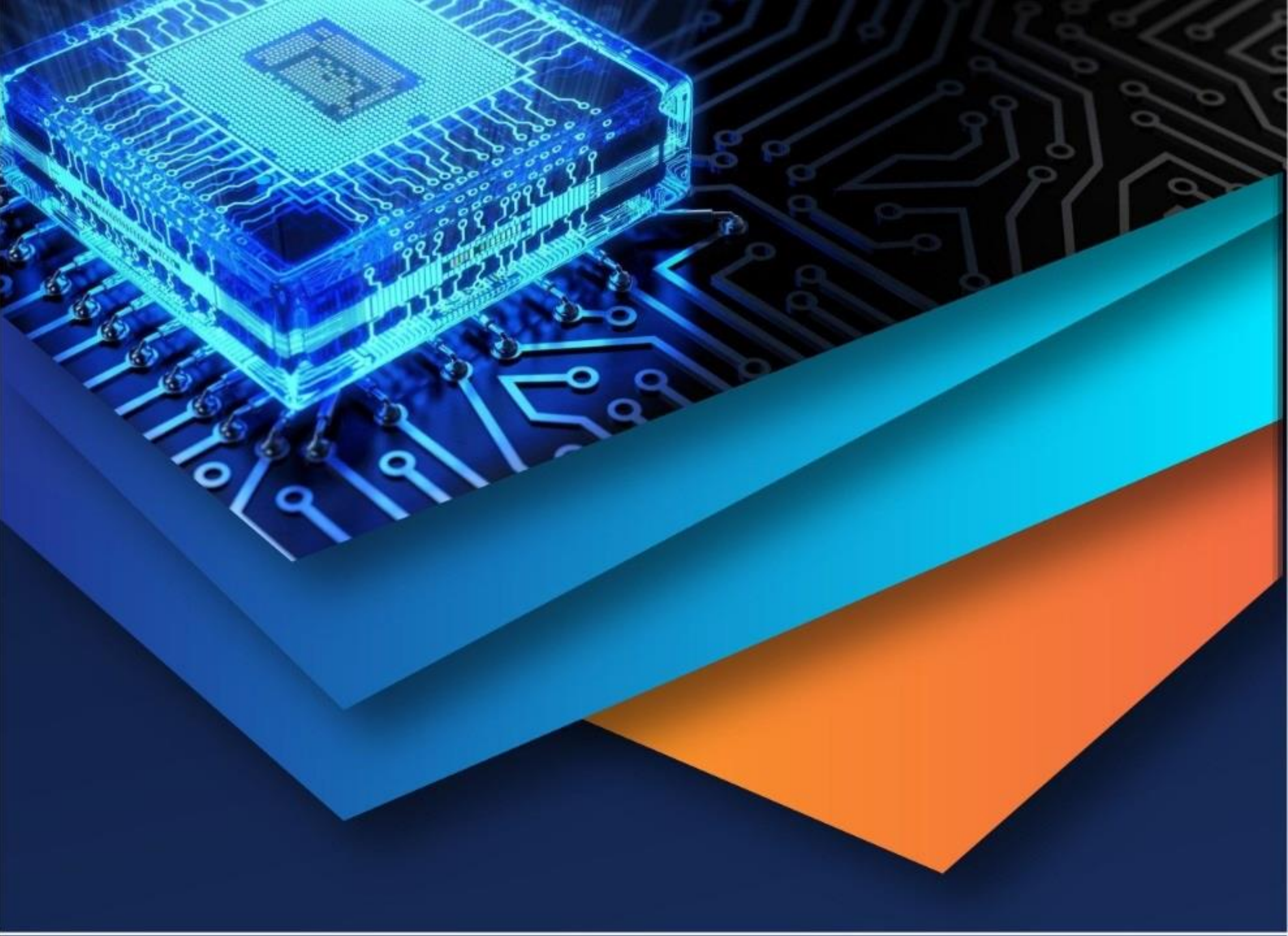

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