iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** II **Month of publication:** February 2016

DOI:

www.ijraset.com Volume 4 Issue II, February 2016
IC Value: 13.98 ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Incorporating Bidirectional Synchronous-VSC To Enable DC-Link Voltage Regulation With SFCL And Bypassing Circuit

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Abstract—This paper presents a new control topology for voltage source converter (VSC) in the frequency-angle domain which enables DC-link voltage regulation. The proposed controller emulating the behavior of synchronous machine(SM) with proper regulation of DC-link voltage. The superconducting fault current limiter (SFCL) with bypassing circuit is integrated into the circuit in which the fault current interruption can be limited. In order to evaluate the impact of fault current limiter in power system performance, simulation models power system performance with FCL are used. The fault current can be limited by SFCL and the bypassing circuit is used for uninterrupted power supply in the system. And also the controller presents fast DC-link voltage regulation, whereas it can provide frequency support in the ac side during contingencies.
Index terms—Volatge source converter(VSC), Synchronous machine(SM), DC-link voltage regulation, super conducting fault current limiter (SFCL), bypassing circuit.

I. INTRODUCTION

Continuous growth of electrical energy demand resulting in a corresponding increase in the short circuit power system, which results in power quality problems. In dc grids, many generation units such as wind turbines must be interfaced to the utility grid via electronically interfaced (EI) rectifiers. Based on the predictions given in[1]the conventional control topologies for three-phase converters are the voltage oriented vector control and direct power control[2].AN alternative control strategy is to use direct power control in which voltage components are adjusted based on active and reactive power errors. The dq components of current vector are regulated by controller generating values for the voltage components. Controlling VSCs as virtual synchronous machines is proposed for power system frequency stabilization[3] by energy storage to the VSC provides power flow to and from the energy storage device proportional to the variation in grid frequency.FCL is a device that is capable to reduce the fault level on the electricity networks. It may lead to low rated component being used and increasing the capacity in existing system. FCL is a variable-impedance device connected in series with a circuit to limit the fault current[4].The FCL should have very low impedance during normal condition[5] and high impedance for fault condition[6]. Here the bypassing circuit denotes the auxiliary transmission line[7] which is connected across the system. When there is possibility of fault occurring in the primary transmission line, then breaker is opened on that line. Therefore the bypassing circuit helps to supply the power to the load with uninterrupted power supply. The controller has DC-link voltage loops, frequency and angle, it gives additional synchronizing and damping powers.
Therefore the controller offers self-synchronization capability and eliminates the need for PLL. This feature is a continuation of[8],[9] which gives the self synchronization and cooperative droop concepts .The VSCs emulating the behavior with inverting and generative mode. Both the mode is provided with real power, frequency and DC-link voltage.

II. CONTROL OF VSCS WITH SYNCHRONOUS MACHINE BEHAVIOR IN THE FREQUENCY-ANGLE DOMAIN

A. Synchronous Machine Model

One of the main goals in VSC control is to maintain the dc-link voltage regulation .Assuming a lossless VSC ,the input ac power is equal to the dc power Pdc=Vdc*Idc and the reactive power correspond to any real power exchange with the converter side during the mode of operation .If the VSC is used for frequency variation, an energy storage system can be installed at the dc-link to transfer power from the energy storage device to the grid.SM is involved in the excitation and damping mounted on the rotor and three phase winding in the stator. The effect of synchronizing and damping power is emulated by the VSC control function .The

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mechanical dynamics is expressed by

$$J\frac{d^2\theta}{dt^2}+K_m\frac{d\theta}{dt}+K_s\,\theta= P_m - P_{load} \qquad (1)$$

Where θ is the rotor angle,J is the total moment of inertia and Pm and Pload are the input mechanical power SM and the load.

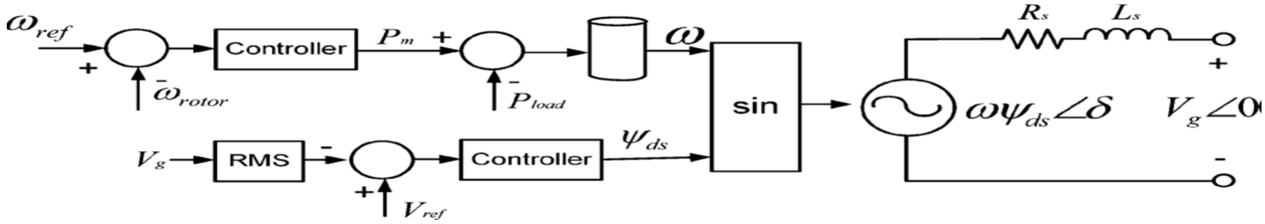

Fig. 1. Operation of principle and control concept of synchronous machine.

The constant K_m and K_s provide synchronizing and damping components given by

$$\text{Damping torque} = \Delta T_{damp} = -K_s\Delta\omega \qquad (2)$$

$$\text{Synchronizing torque} = \Delta T_{syn} = -K_m\Delta\theta \qquad (3)$$

The damping power damp load oscillations, whereas the synchronizing power supports machine grid synchronism.

B. Freuquency Control

The existing topologies for frequency control are presented here. Virtual torque control and direct loop control are the two variants mention in below figure for frequency control. In fig.1 voltage generation principle in a synchronous-VSC which is similar to back emf generation is shown. In fig.2 VSC's frequency regulation and virtual flux is depicted which emulates the behavior of SM with the proper control of the dc-link voltage and frequency therefore the grid assumes the capacitor as virtual rotor .Three cascaded loops are involved in the virtual torque control structure which contains frequency loop, angle loop and the reference torque is equivalent to the generated electrical torque of an equivalent SM in the system.

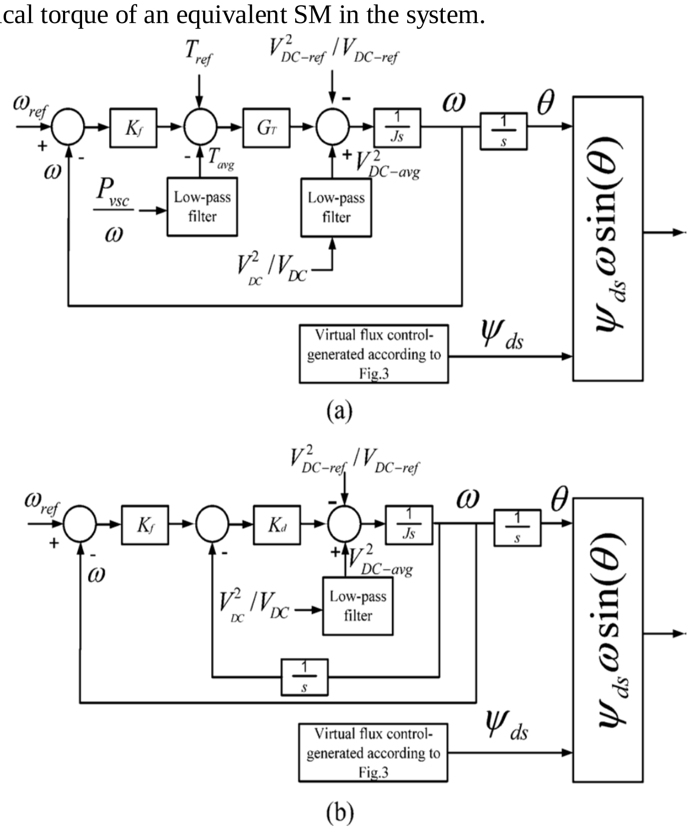

Fig.2 Virtual torque control and direct loop control

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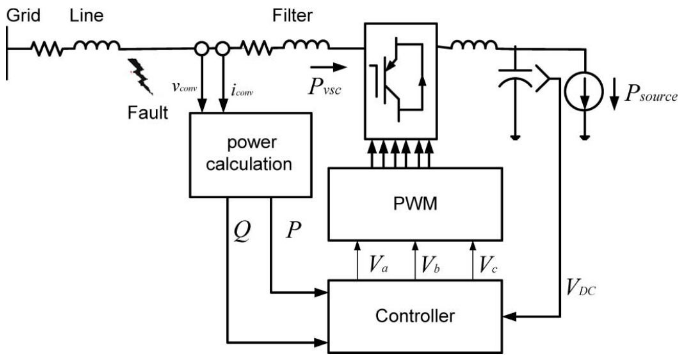

Fig. 3. Schematic view of the system without SFCL and bypassing circuit.

III. ROLE OF SFCL AND ITS OPERATION

SFCL is a device which is used to reduce the fault level on the system and may lead to low rated components being used. The static and dynamic stability denotes the enhancement of power system reliability. The dynamic stability of the system restores the initial state after long scale disturbances. The static stability restores the initial operative mode after a low disturbance. Therefore SFCL and SMES are the basic requirements for achieving the power system reliability.

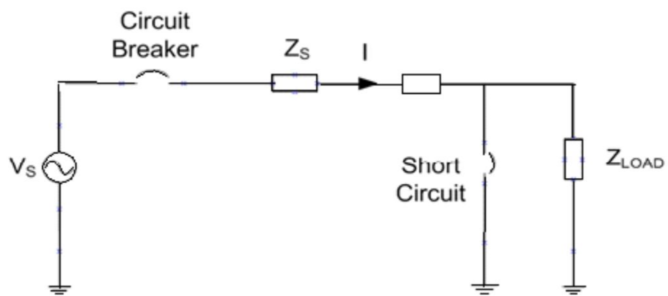

Fig. 4. Principle scheme of the general FCL.

FCL consists of a series tuned net frequency (50/60 HZ) and a MOV in parallel with the capacitor. During normal operation the circuit seems to be almost transparent. Only a small changes in the downstream of short circuit power which is given by the resistance of series natural reactor. The product of the current with reactance is given by 'X'=$\omega L/\omega$c.Infinite values of X are possible to meet resonance condition. Higher the reactances X, slower the increase in the large independently with the smaller value of X. Also voltage on both L and C during short circuit will lead increase in large value of X. In the below figure each of the circuit breaker has its own SFCL in the form of superconducting transmission line connected to the load in series which is connected as a s fast acting switching device. SFCL impedance is minimal at the normal mode and it is acting as a switching device during the fault condition.

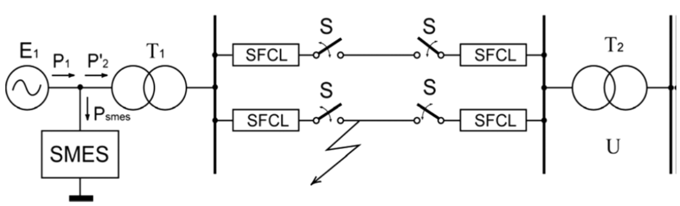

Fig. 5. Representation of SFCL with bypassing circuit.

In order the stable operation of a system during the short circuit condition(Fig 5), the fault part of the transmission line must be disconnected as soon as possible.

IV. SIMULATIONS AND RESULTS

This section explains the detailed simulation results of the proposed control system. The simulated system is shown in Fig.6. MATLAB/SIMULINK tool is used for simulation studies. A different condition in both nodes for the dc-link voltage regulation is

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carried out with the help of controller.

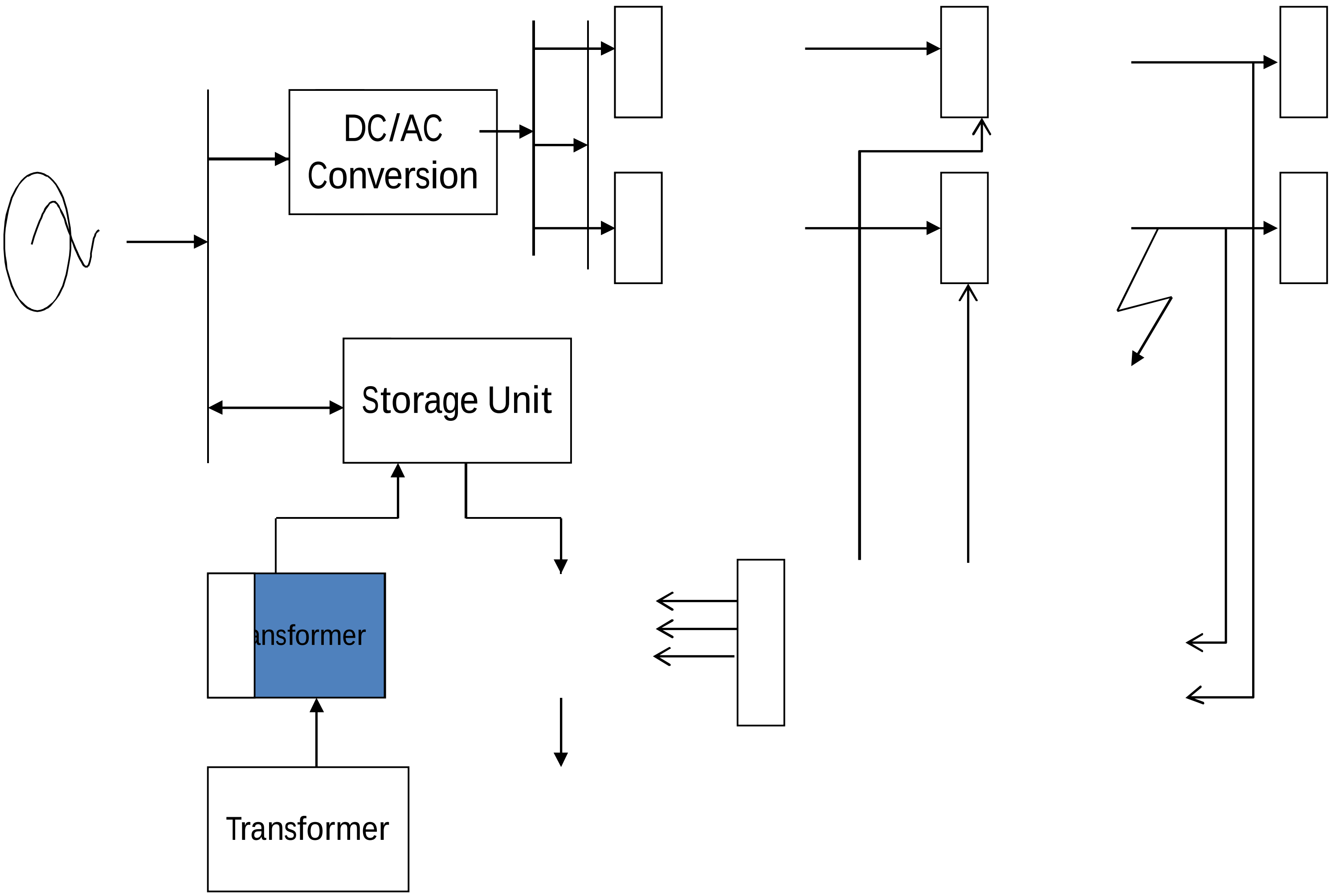

Fig. 6. Schematic view of the simulated system with SFCL

The dc-link voltage and the voltage and current of the load is shown as graphical representation. The system is operated under various operating conditions for providing voltage regulation against dc-link. The stability of the system is obtained by the SFCL which reduce the fault level.

A. Two Modes Of Opertion For Dc-Link Voltage Regulation

Here, the transient behavior of the system is represented for both the modes. The occurs at a time t due to the sudden load increment .The dc voltage encounters -415v sag due to the load power change but the recovery time is less than 0.1s which is a fast response..Load angle is however constant .In spite of integrating the real and reactive power, the controller quickly regulates the reactive power to the pre set value. When the time is increased from its initial value the dc-link voltage reference is reduced.

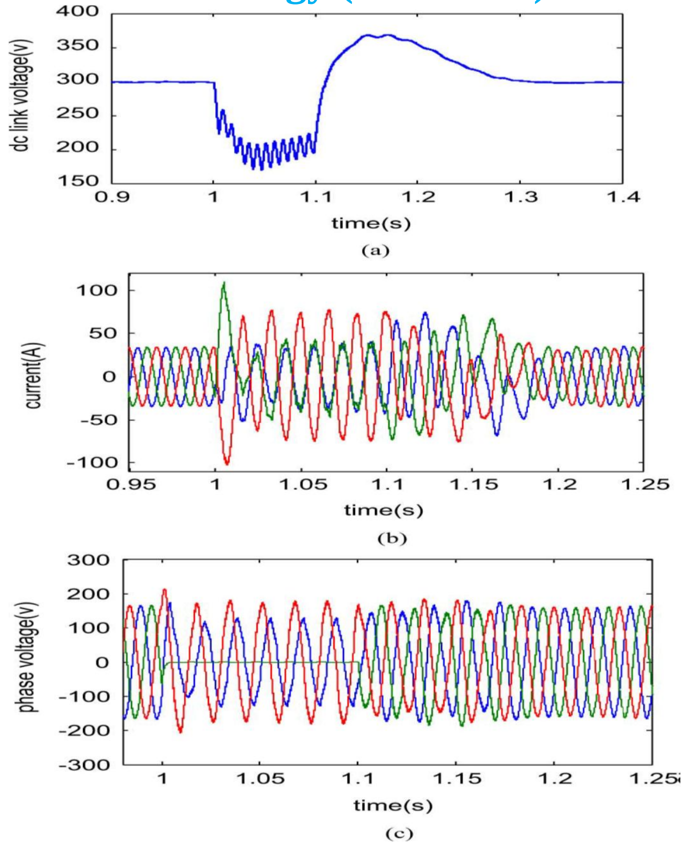

Fig.7.(a)DC-link voltage.(b)Instantaneous current. (c)Instantaneous output

The behavior of synchronous VSC in the inverting mode is also studied which is equivalent to generative mode. If the initial voltage is 415v and at time t=2s,the output dc current is increased from 30 to 40A.After the DG output power is increased, the dc-link voltage reference is reduced to 400v and the VSC tracks the reference value with highly damped transient response.

B. SFCL With Bypassing Circuit

The system with uninterrupted power supply can be achieved with the help of superconducting fault current limiter and the auxiliary transmission line. Times on the horizontal axis are: 0.15–2.0 ms SFCL actuation time, 0.5 s auto reclosing cycle time. With the use of the mathematical model developed, it has been confirmed that the operation of this device only ensures the enhanced stability of power system that is limitation of the fault current. The supply impedance is much lower than the load impedance, the current during the fault are significantly large compared to the normal current. Although circuit breaker will eventually stop its fault current, immediately taking about 2-3 cycles to act. Within this period of time, damage can occur between the supply and load.

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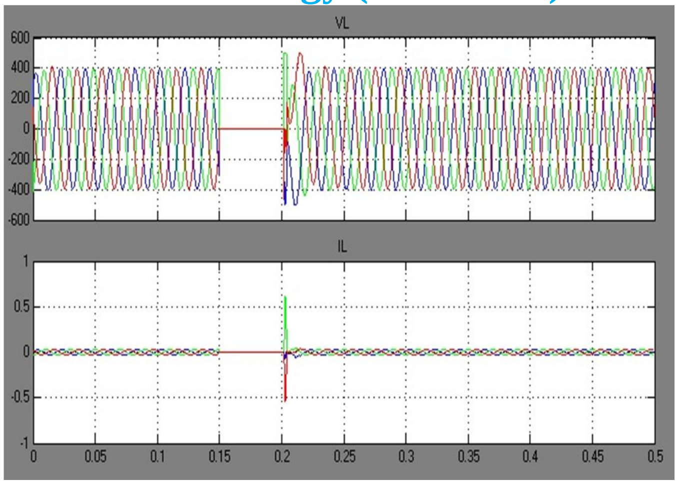

Fig. 8. Without bypassing circuit during fault.

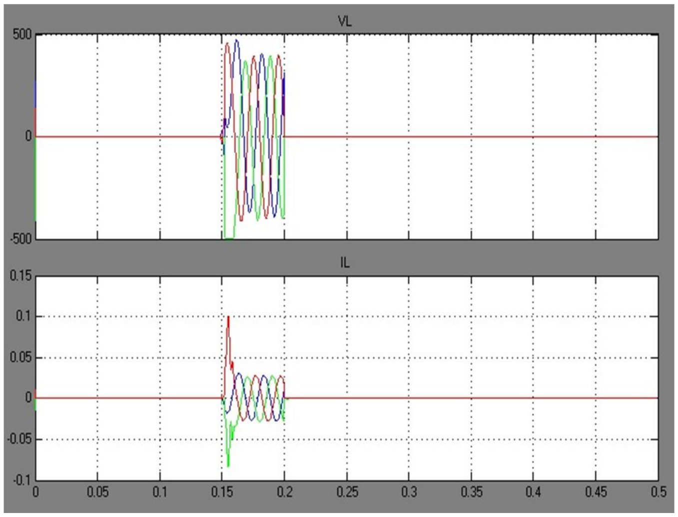

Fig. 9. SFCL with bypassing circuit.

The system is represented as without and without bypassing circuit. In fig.8 and fig.9 the fault period is between 0.15 to 0.2s therefore the voltage and current flow is seen above. During the fault period, the voltage reached zero and the current is varying rapidly. To avoid this situation, circuit breaker in the main transmission line kept open so that the power flow to the load is uninterrupted due to the auxiliary transmission line. The fault current is limited before entering to the load, therefore the limited current is shown in fig.8.

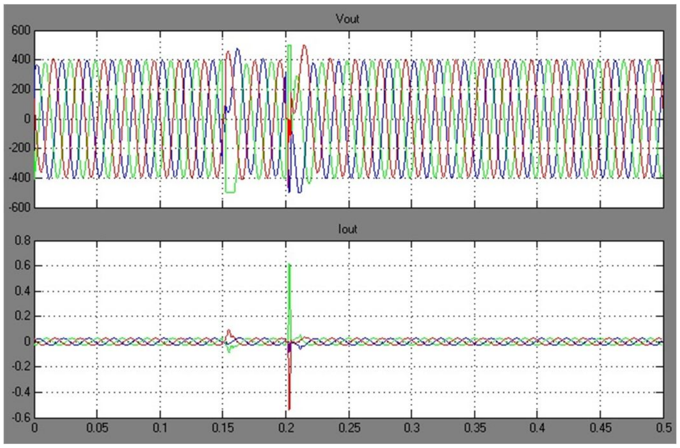

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Fig. 10. Output voltage and current waveform

In fig.10 the voltage and current of the load is denoted. The system with two transmission line are depicted in the form of output current and voltage .Only a slight fluctuation is figured and that too happened only to 2-3 cycles . The SFCL reduce the fault current level and it is limited within few cycles.

V. CONCLUSIONS

In this paper, VSC has been developed to regulate the dc-link voltage while providing 1) damping and synchronizing power components and 2) emulated inertia function to the VSC. The SFCL is used in the system to reduce the fault level and the fault is a three phase to ground fault which is analyzed earlier. SFCL with bypassing circuit is maintaining the system reliability by limiting the fault level in the entire system.

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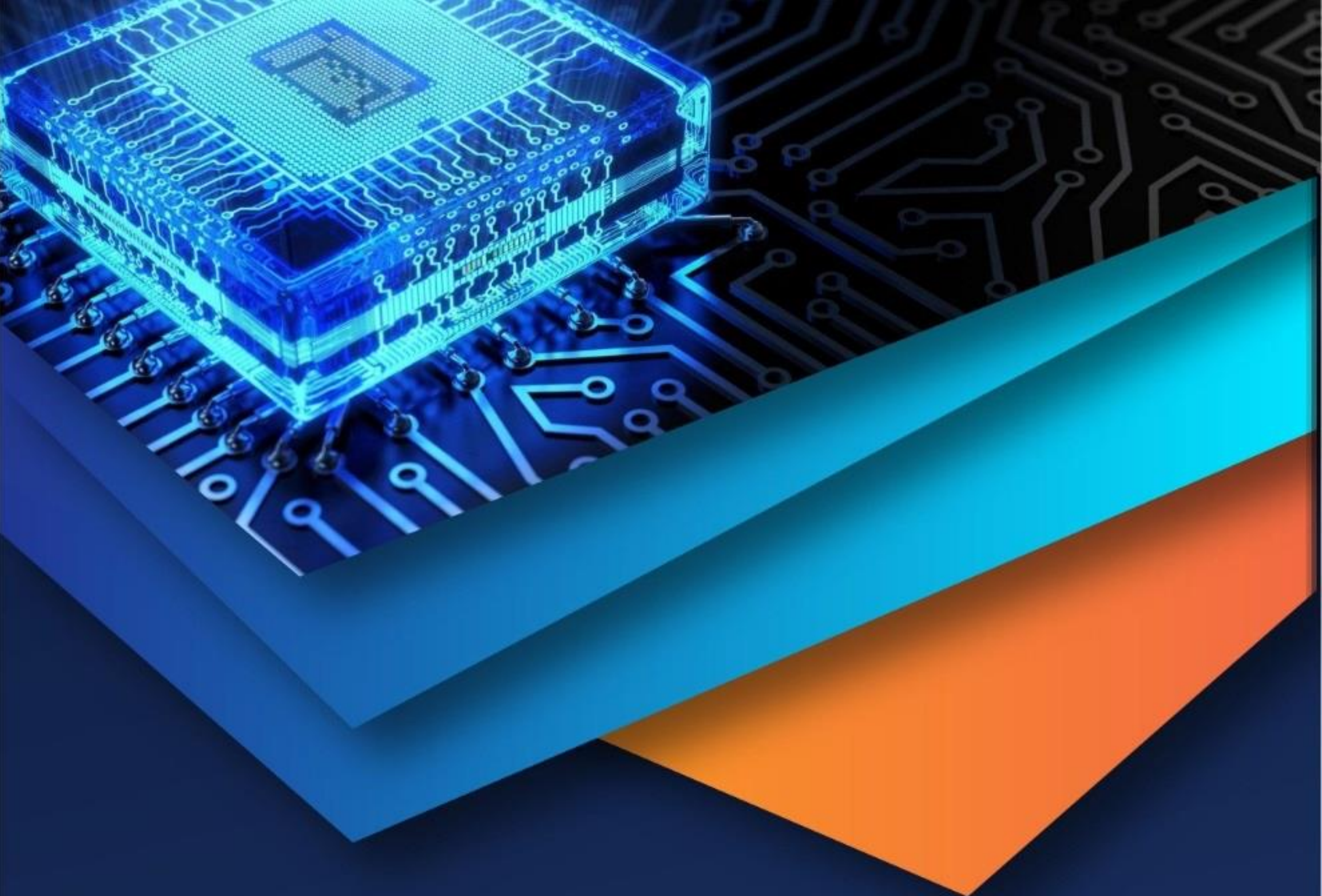

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