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Pitch Controlled PMSG Based Wind Energy Conversion System with Control of DC Link Voltage and Load Voltage Variations

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Abstract: In this paper, a novel algorithm, based on dc link voltage, is proposed for a standalone permanent magnet synchronous generator (PMSG)-based variable speed wind energy conversion system. Moreover, by maintaining the dc link voltage at its reference value, the output ac voltage of the inverter can be kept constant irrespective of variations in the wind speed and load. An effective control technique for the inverter, based on the pulse width modulation (PWM) scheme, has been developed to make the line voltages at the point of common coupling (PCC) balanced when the load is unbalanced. Pitch angle control of wind turbine under higher wind speed also implemented with the reference of generator speed. Based on extensive simulation results using MATLAB/SIMULINK, it has been established that the performance of the controllers both in transient as well as in steady state is quite satisfactory and it can also maintain maximum power point tracking.

Index Terms: DC-Side Active Filter, Permanent Magnet Synchronous Generator (PMSG), Pitch Controller, Unbalanced Load Compensation, Variable Speed Wind Turbine, Voltage Control.

I. INTRODUCTION

In wind energy application, variable speed wind turbines are popular mainly because of their capability to capture more power from the wind using the maximum power point tracking (MPPT) algorithm and improved efficiency. Presently, doubly feed induction generators (DFIGs) are widely used as the generator in a variable speed wind turbine system. The reliability of the variable speed wind turbine can be improved significantly using a permanent magnet synchronous generator (PMSG). PMSG has received much attention in wind energy applications because of its self-excitation capability, leading to a high power factor and high efficiency operation. In many countries, there are remote communities where connection with the power grid is too expensive or impractical and diesel generators are often the source of electricity. Under such circumstances, a locally placed small-scale standalone distributed generation system can supply power to the customers. Autonomous wind power systems are among the most interesting and environment friendly technological solutions for the electrification of remote consumers. The control of an inverter to present the customers with a balanced supply voltage is the main challenge in a standalone system. Moreover, voltage variations, flickers, harmonic generation, and load unbalance are the major power quality (PQ) problems that occur in the wind energy conversion system (WECS). The voltage variations are mainly due to the change in load. Flicker or voltage fluctuations are primarily caused by variations in the power from WECS which comes into existence, owing to the fluctuations in the wind speed. Unwanted harmonics are generated due to the power electronics interface (rectifier, inverter and dc–dc converter) between the wind generator and the load. Those power quality problem may not be tolerated by the customers and hence require mitigation techniques [1]. The schematic of the standalone system using PMSG-based wind turbine is shown in Fig. 1. Due to unbalanced load, the voltages at point of common coupling (PCC) become unbalanced. Moreover, unbalanced load will create pulsation in the generator torque which will reduce the life of the turbine shaft.

In this paper a small scale standalone power supply system based on wind energy is considered. Our objectives are:

Implementation of Pitch angle control of wind turbine for control of generator under higher wind speeds.

To maintain constant and balanced voltages at the ac bus (or load bus) as three phase dynamic loads need a balanced three-phase supply for their proper operation.

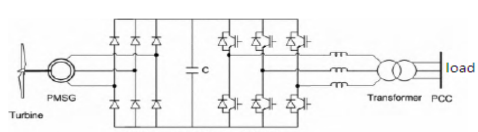

Figure 1: PMSG Based Wind Turbine

II. MODELLING OF WIND TURBINE

The power in the wind is proportional to the cube of the wind speed and may be expressed as [3]:

$$P = 0.5\rho A v_w^{\,3} \tag{1}$$

Where ρ is air density, A is the area swept by blades and **Vw** is wind speed. A wind turbine can only extract part of the power from the wind, which is limited by the Betz limit (maximum 59%). This fraction is described by the power coefficient of the turbine, **Cp**, which is a function of the blade pitch angle and the tip speed ratio. Therefore the mechanical power of the wind turbine extracted from the wind is

$$P_w = 0.5C_p(\beta,\lambda)\rho A v_w^{\,3} \tag{2}$$

Where **Cp** is the power coefficient of the wind turbine, β is the blade pitch angle and **λ** is the tip speed ratio. The tip speed ratio is defined as the ratio between the blade tip speed and the wind speed **Vw,**

$$\lambda = \frac{\Omega R}{v_w} \tag{3}$$

Where Ω is the turbine rotor speed, R is the radius of the wind turbine blade. Fig. 2 shows that the mechanical power converted from the turbine blade is a function of the rotational speed, and the converted power is maximized at the particular rotational speed for various wind speed.

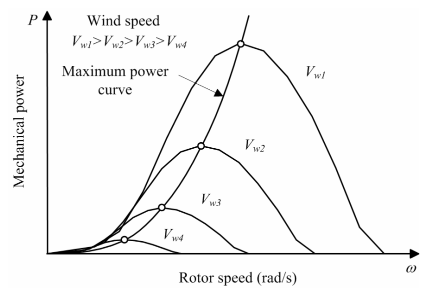

Figure 2: Mechanical Power versus Rotor Speed Characteristics

The typical power control regions of wind turbine are shown in Fig. 3. The turbine starts operating when the wind speed exceeds cut-in wind speed. The power captured by the turbine increases with the wind speed increasing. At the set point of wind speed, the generating power reaches the rated power of the turbine. If the wind speed continues to rise, the generator output power remains constant at the design limit. Due to safety consideration, the turbine is shut down at speeds exceeding cut-out wind speed.

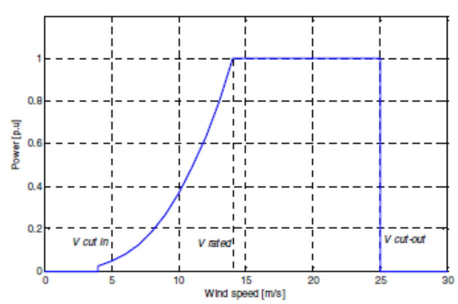

Figure 4: Power versus Wind Speed

III. MODELING OF DRIVE TRAIN

The drive train of a wind turbine generator system consists of the following elements [2]: a blade-pitching mechanism with a spinner, a hub with blades, a rotor shaft and a gearbox with breaker and generator. The acceptable way to model the drive train is to treat the system as a number of discrete masses connected together by springs defined by damping and stiffness

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coefficients (Fig. 5).

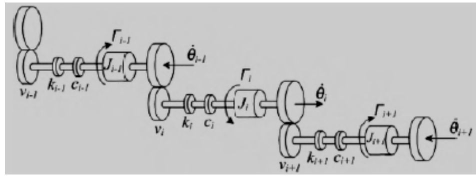

Figure 5: Transmission Model of N Masses Connected Together.

Therefore, the equation of ith mass motion can be described as follows:

$$\frac{d^2\theta_i}{dt^2} = \frac{v_i c_i}{J_i}\frac{d\theta_{i-1}}{dt} - \frac{v_{i+1}^2 c_{i+1} + c_i}{J_i}\frac{d\theta_i}{dt} + \frac{v_{i+1}c_{i+1}}{J_i}\frac{d\theta_{i+1}}{dt} + \\ + \frac{v_i k_i}{J_i}\theta_{i-1} - \frac{v_{i+1}^2 k_{i+1} + k_i}{J_i}\theta_i + \frac{v_{i+1}k_{i+1}}{J_i}\theta_{i+1} \\ + \frac{\tau_i}{J_i} - D_i\frac{d\theta_i}{dt} \qquad \textbf{(4)}$$

where $\mathbf{v_i}$, is the transmission rate between i and i-l masses, $\mathbf{c_i}$ is the shaft viscosity [kg/(m-s)], $\mathbf{k_i}$ is the shaft elastic constant [N/m], **J** is the moment of inertia of the ith mass [kg-m^2] ,$\mathbf{t_i}$ is the external torque [N-m] applied to the ith mass and $\mathbf{D_i}$ is the damping coefficient [N-m/s], which represents various damping effects . For the purposes of the present research, neither viscosity nor damping effects have been considered.

When the complexity of the study varies, the complexity of the drive train differs. For example, when the problems such as torsional fatigue are studied, dynamics from all parts have to be considered. For these purposes, two-lumped mass or more sophisticated models are required. However, when the study focuses on the interaction between wind farms and loads, the drive train can be treated as one-lumped mass model for the sake of time efficiency and acceptable precision. The last approximation has been considered in the present study and it is defined by the following equation

$$\frac{d\omega_g}{dt} = \frac{\tau_e - \tau_{w\_g}}{J_{eq}} - \frac{B_m}{J_{eq}}\cdot\omega_g \qquad (5)$$

Where the sub-index g represents the parameters of the generator side, wg is the mechanical angular speed [rad/s] of the generator; Te is electromechanical torque [Nm], T_{w_g} is the aerodynamic torque that has been transferred to the generator side, which is equal to the torque produced in the rotor side because there is no gearbox, and Jeq is the equivalent rotational inertia of the generator [kg-m^2], which is derived from,

$$J_{eq} = J_g + \frac{J_w}{n_g^2} \qquad \textbf{(6)}$$

Where Jg and J; are the generator and the rotor rotational inertias [kg-m^2] respectively, ng is the gear ratio, which is equal to I, because no gearbox is utilized. The model of the two mass drive train implemented in Simulink is depicted in Fig.6.

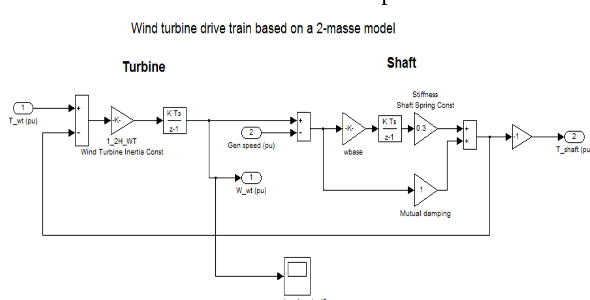

Figure 6: Simulink Model of Drive Train

IV. PITCH ANGLE CONTROL OF WIND TURBINE

Pitch angle control is the most common means for adjusting the aerodynamic torque of the wind turbine when wind speed is above rated speed and various controlling variables may be chosen, such as wind speed, generator speed and generator power. As conventional pitch control usually use PI controller, the mathematical model of the system should be known well. Pitch angle regulation is required in conditions above the rated wind speed when the rotational speed is kept constant. Small changes in pitch angle can have a dramatic effect on the power output. The purpose of the pitch angle control might be expressed as follows [4]:

Optimizing the power output of the wind turbine. Below rated wind speed, the pitch setting should be at its optimum value to give maximum power.

Preventing input mechanical power to exceed the design limits. Above rated wind speed, pitch angle control provides a very effective means of regulating the aerodynamic power and loads produced by the rotor.

Minimizing fatigue loads of the turbine mechanical component. It is clear that the action of the control system can have a major impact on the loads experienced by the turbine. The design of the controller must take into account the effect on loads, and the controller should ensure that excessive loads will not result from the control action. It is possible to go further than this, and explicitly design the controller with the reduction of certain fatigue loads as an additional objective.

A. Conventional Pitch Angle Control

Adjusting the pitch angle of the blades provides an effective means of regulations or limiting turbine performance in strong wind speeds. To put the blades into the necessary position, pitch servos are employed which may be hydraulic or electrical systems. During normal operation, blade pitch adjustments with rotational speeds of approximately 5-10% are expected. Here the chosen pitch rate is 8% which avoids excessive loads during normal regulation procedures.

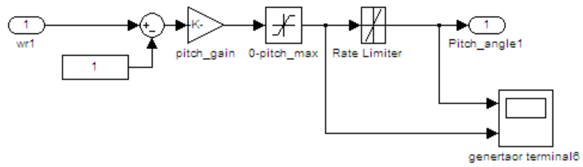

Figure 6: Simulink Model of Pitch Angle Controller

In the proposed system the pitch angle is controlled by comparing the actual generator speed with the reference speed to control it. When the generator speed exceeds due to the increase of wind speed the controller will vary the pitch angle of the wind turbine. Pitch angle variation will result in the control of aerodynamic torque of the wind turbine and the speed control will be achieved through it.

V. COMPENSATION OF LOAD VARIATION

In distribution systems, as the loads are mostly single phase in nature, the current in different phases will not be the same in magnitude and the phase difference between them may not be 120. The detrimental effects of this unbalanced current on the generating system are [1]

Electrical torque pulsation

Unbalanced voltages at PCC.

The effect and control of the above-mentioned two quantities are discussed below.

A. Effect On The Generator Torque And Its Compensation

When an inverter supplies unbalanced load current, the time variation of the dc link current (Idc) and dc link voltage (Vdc) can be expressed as a dc component superimposed with a second harmonic component. Due to the second-harmonic component present in the dc current, the electrical torque of the generator will oscillate and the life of the turbine shaft will reduce.

B. Effect On Voltage At Pcc And Its Compensation

Due to unbalanced load being connected to the inverter, the current in each phase will not be equal, leading to unequal voltage drop across each phase. This unbalanced voltage drop will cause the line voltages at PCC to become unbalanced and the voltage unbalance factor may not be within permissible limit (i.e., below 1%). Hence, it is necessary to compensate the voltage unbalance at PCC. To achieve this goal the error between the rms (or peak) value of the phase voltages at PCC and the reference phase voltage is given to a PI controller. The output of the PI controller is multiplied with a unit sine wave generator to get the reference phase voltages (Va_ref, Vb_ref, and Vc_ref)

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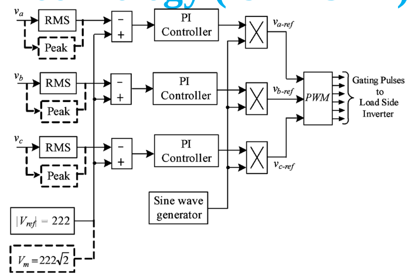

Figure 7: PWM Inverter Controller for Unbalanced Load Compensation.

PWM pulses are generated to switch ON/OFF the load side inverter. The schematic of the control scheme used for unbalanced voltage compensation is shown in Fig. 7. Through the controller shown in Fig. 7, our aim is to get different modulation indexes for three phases so as to balance out the unbalanced PCC voltages. The controller requires the information about the actual voltage. The actual voltage can be detected by different algorithms. The detection time of both the peak detection method and dq0 transformation-based approach is faster than the rms measurement approach. The dq0 values of the actual signals are acquired using abc to dq transformation blocks in the Simulink browser.

VI. SIMULATION RESULTS DISCUSSIONS

The simulation is done considering the system is always connected to the load. (i.e) The wind is always present and no backup storage devices are used.

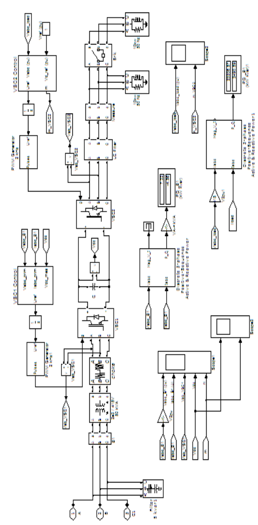

Figure 8: Simulation of AC to AC Converter

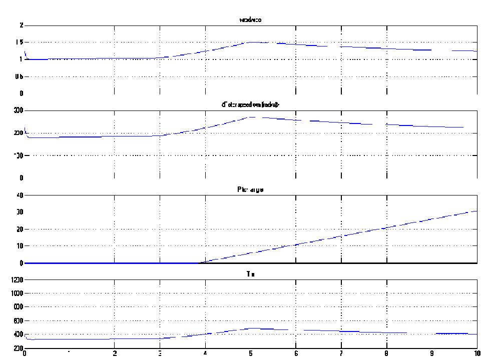

Fig 9: Without Pitch Control

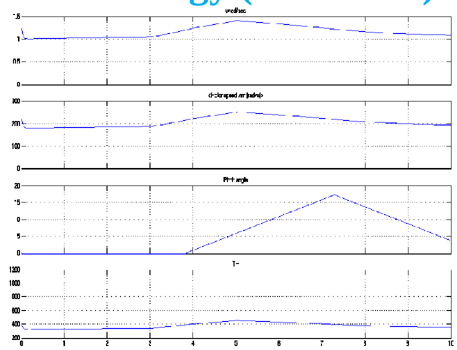

Figure 10: With Pitch Control

The wind speed is set to 12 m/s for first 3s and it is set to 25 m/s up to 7s the again 12 m/s up to 10s. In this the base speed is set to 12m/s. From Fig (9) the generator speed crosses more than 1.5 p.u which is 2550 rpm. In Fig (10) it is shown that the generator speed is controlled to 1.2p.u at the excess wind speed (25 m/s). And parameters like generator torque and output voltage are also controlled. Fig (11) shows the control of DC link voltage is shown. The disturbance occurs at .25s of the simulation period. But the system is providing a constant voltage over the entire simulation period because of the control of the rectifier as explained in section [V].

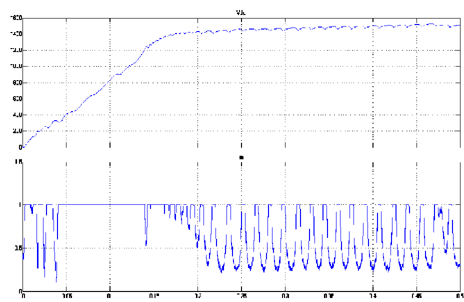

Figure 11: Dc Link Voltage and Magnitude of Reference Signal for PWM Generation of Rectifier

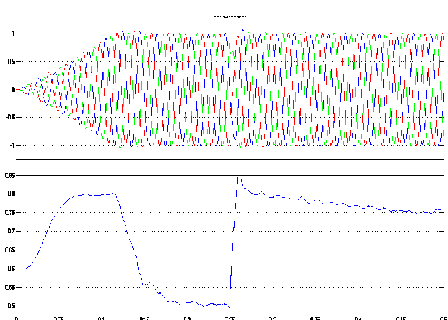

Figure 12: Output Voltage of Inverter and Magnitude of Reference Signal for PWM Generation of Inverter

The load is varied at 0.25s by using breaker in the Simulink model. In the above figure (12) it is shown that the output voltage of the inverter is maintained constant. The disturbance is tolerated by the pulse generation. The magnitude of the modulating signal is shown in below plot.

VII. CONCLUSION

It is more important to concentrate on renewable energy resources now a day. The concept dealt in this paper is very much useful in rural power supply areas where grid connection in cost effective. It can be used with diesel generator as a hybrid DG system since wind in nature is not constant always. From the simulation results, it is seen that the controller can maintain the load voltage quite well in spite of variations in wind speed and load. PWM inverter control is incorporated to make the line voltage at PCC balanced under an unbalanced load scenario. The simulation results demonstrate that the performance of the controllers is satisfactory under steady state as well as dynamic conditions and under balanced as well as unbalanced load

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conditions.

Appendix Generator Ratings

Stator phase resistance	0.085 ohm
Rotor speed	1700 rpm
Line Voltage	2500v
Torque constant	16.54n-m
No of pole pairs	4

Wind Turbine Ratings

Nominal mechanical output	100kw
Base power of the electrical generator	100/.9 KVA
Base wind speed	12 m/s
maximum power at base wind speed	0.8 p.u

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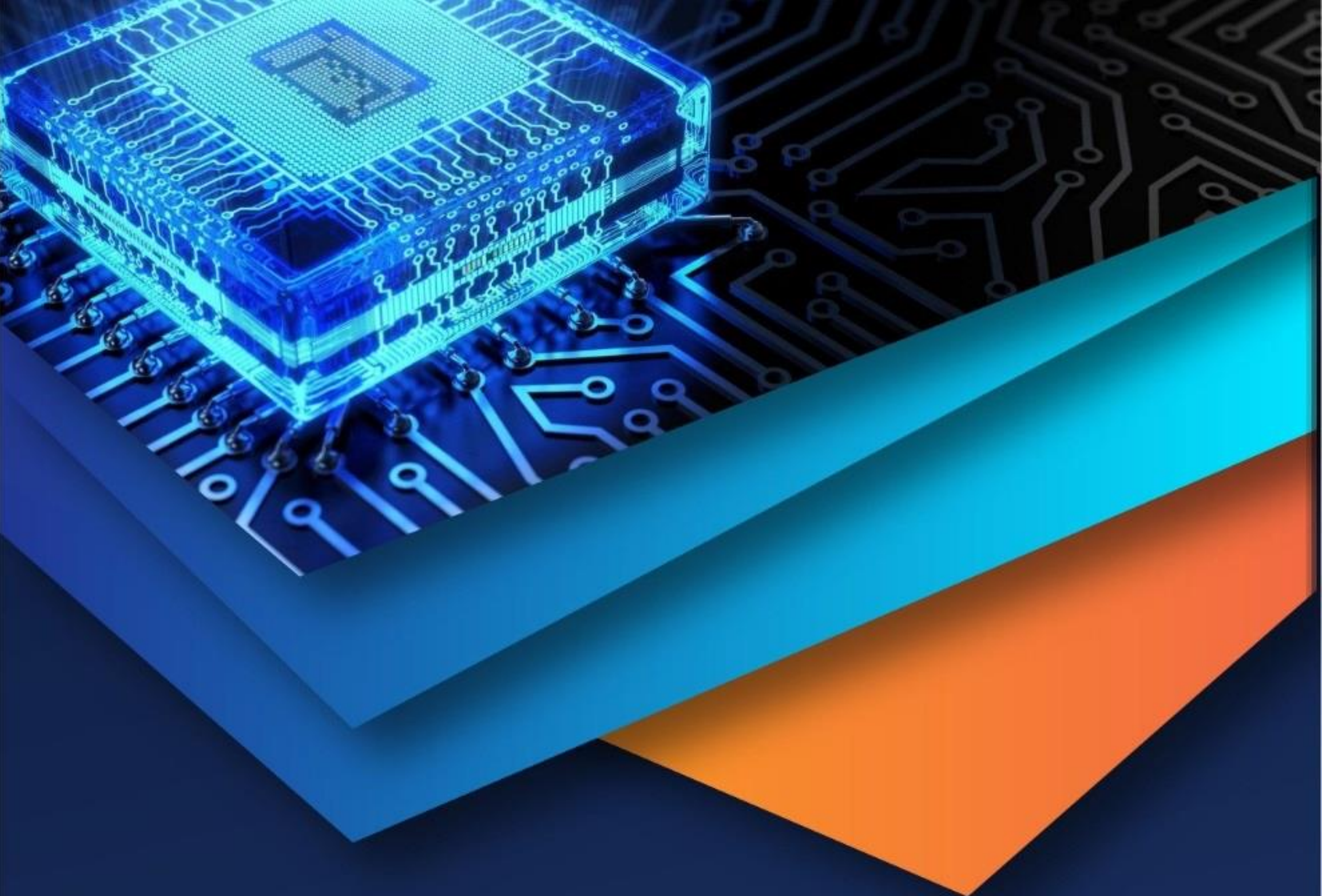

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