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Comparison between Fuzzy Logic Control and Predictive Torque Control, applied to a DFIG based Wind Turbine

Asit Kumar Panda[1], Swagatika Acharya[2]
[1, 2]*Instrumentation and Electronics Engineering, College of Engineering and Technology, Bhubaneswar, Odisha, India*

Abstract: In this paper, Fuzzy Logic Control (FLC) and Predictive Torque Control (PTC) methods are being introduced separately at grid side converter (GSC) of Doubly Fed Induction Generator (DFIG) based wind turbine. There are two parameters usually challenging for the power rating of a wind energy conversion system (WECS): improper control strategy for RSC, which is the primary reason behind current harmonics and for GSC, it is the reason behind voltage harmonics. In several wind turbine systems while maintaining these harmonics leads to improper electromagnetic torque. This two fold effect of controller is worst while using same controller for both GSC and RSC. Firstly, in this improved controller architecture, the general structure of conventional controller is retained and Fuzzy Logic is used to provide intelligence to the operation of controller. In several research works it has been seen different controllers for both side, resulting improved results. Secondly, a predictive methodology has been adopted which predicts torque and stator current to be used as reference signal in controlling GSC and a well-tuned PI controller for RSC. The results are being compared that shows significant reduction in harmonics at rotor side and grid side.
Keywords: Wind Energy Conversion System (WECS); Doubly Fed Induction Generator (DFIG); PI Controller; Fuzzy Logic Control (FLC); Predictive Torque Control (PTC); Total Harmonic Distortion (THD)

I. INTRODUCTION

The rapid increase in power demand, high cost, and the depleting nature of our conventional sources of energy and their disastrous impacts on our environment have made the researchers to drag their focus towards harvesting energy from renewable sources [1].There are different components of a wind energy conversion system (WECS), of which the most important is the type of generator used. There are several types of generators used such as Self-excited Induction generator (SEIG), Doubly Fed Induction generator (DFIG) and Permanent Magnet Synchronous generator (PMSG). There are immense chances of expansion of power generation of wind energy based on Doubly Fed Induction Generators (DFIGs) due to the fact that they have the ability to maximize the power extraction as well as the flexibility in control [2]. A PI control as well as Fuzzy Logic Control (FLC) which later compared with the predictive torque control (PTC) schemes are presented here, which is a new alternative to both linear and nonlinear methods that uses different control strategies and predictive algorithms.

II. WIND ENERGY CONVERSION SYSTEM WITH DOUBLY FED INDUCTION GENERATOR

Wind turbines converts the kinetic energy in the wind into rotational kinetic energy inside the turbine and then an efficient electrical energy that can be supplied through grid connections [3]. It is quite appreciable that the technological evolution form a big differences between the fixed speed wind turbines and variable speed wind turbines [4]. The major differences are:

1) Power control is by means of pitch able blades.
2) Variable speed provided DFIG and the power converters.

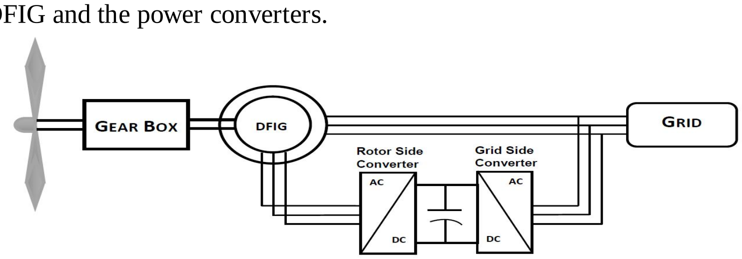

Fig.1. Block diagram of Wind Energy Conversion System.

Theoretically the loss is 41%. More and more researches are going on to match the theoretical limits. Hence in this paper different control strategies have been proposed to control the generator parameters to get at least 40% power extraction. The core of any WECS as shown in Fig.1. uses the principle to convert the mechanical rotational energy into electrical energy. All the device parameters are being affected by controlling this machine (here the machine operates as DFIG) [5]. The devices are fixed-speed or, variable-speed turbine, power electronic converter with parameters like torque and power. For Experimental point of view in MATLAB Simulink an Asynchronous Machine was taken, which has the construction principle similar to the traditional squirrel-cage machine consisting two three phase winding sets: stator and rotor.

III. PROPOSED CONTROL STRATEGIES

The control of DFIG is mostly based on its rotor, where the attached power electronic converter plays a vital role for controlling rotor parameters. Here the converter is back-to-back type (AC-DC-AC) [6]. The rotor side converter (RSC) controls the rotor currents, whereas the grid side converter (GSC) controls the DC-link voltage and reactive power flow between the converter and power system [7]. It is possible to control the power as well as the torque generated from the DFIG by using different control strategies. In this paper PI, Fuzzy Logic Control (FLC), and Predictive torque control strategies have been used at RSC and GSC respectively shown in Fig.2.

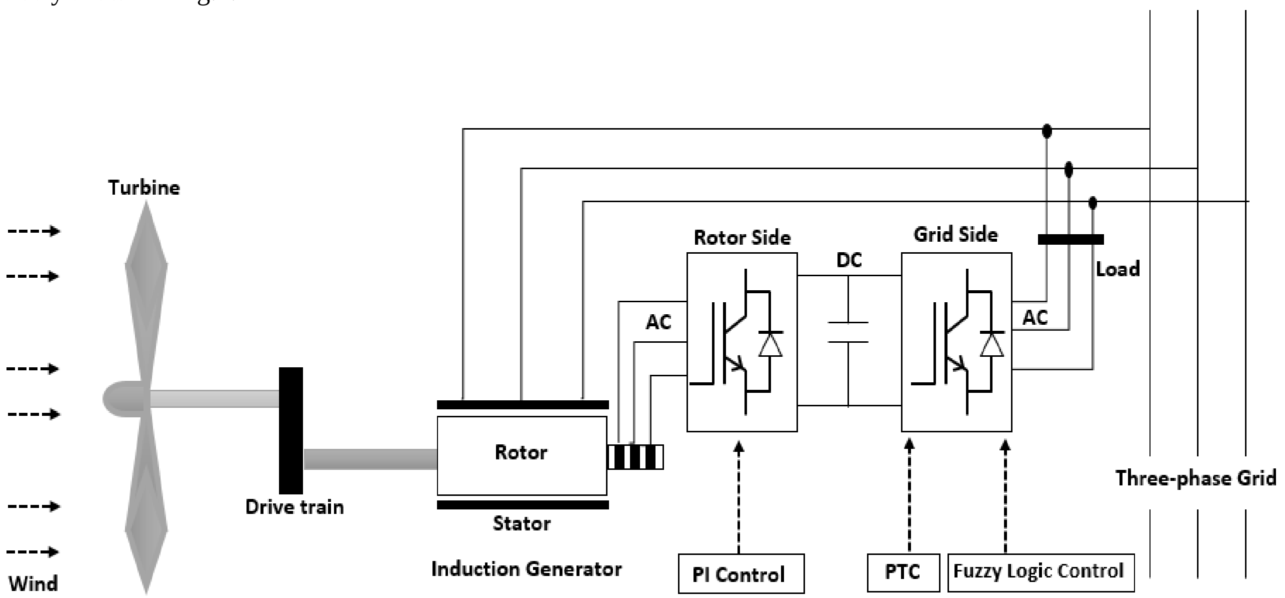

Fig.2. DFIG with proposed control strategies showing grid connection and internal architecture i.e. rotor side converter and stator side converter.

A. PI Control

The proposed control scheme has the province to extract maximum power from the wind as well as minimize the harmonic distortion from produced currents and voltages. It also enables variable speed control operation. The Simulink model for PI-Controller is shown in Fig.3.

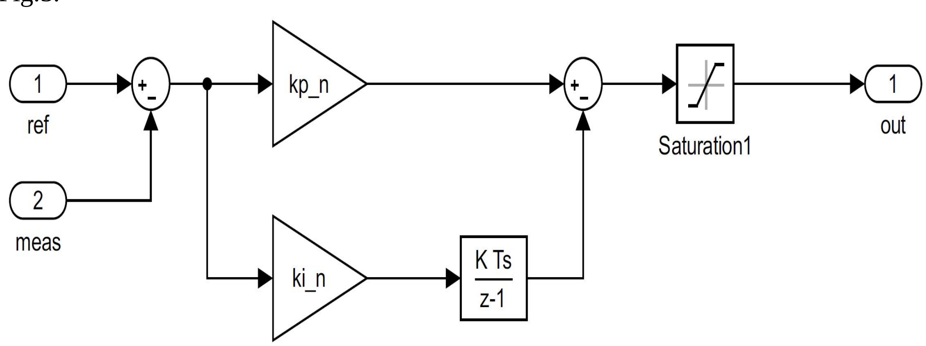

Fig.3. Basic PI-controller used in this control strategy with gain and discrete integrator.

B. Fuzzy Logic Controller

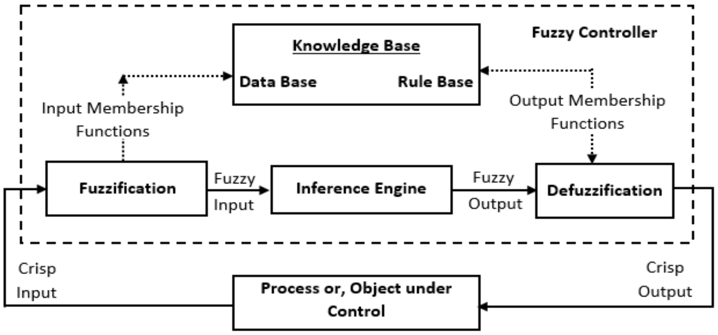

Fig.4. Structure of Fuzzy Logic Controller

Objective of the proposed work is to control power generation. The output power (*Po*) and reference power (*Pr*) are the inputs of fuzzy logic controller as shown in Fig.5. A pulsated output signal (*u*) is generated as the output variable of the FLC (Sugeno Fuzzy Inference System) [8]. As two power inputs are provided to the fuzzifier block the output before defuzzification process is a power signal whereas, we are getting a pulse signal in the form of 0 or, 1 after this defuzzification process. The controlled signal we get which is used as a reference signal for PWM generator [9].

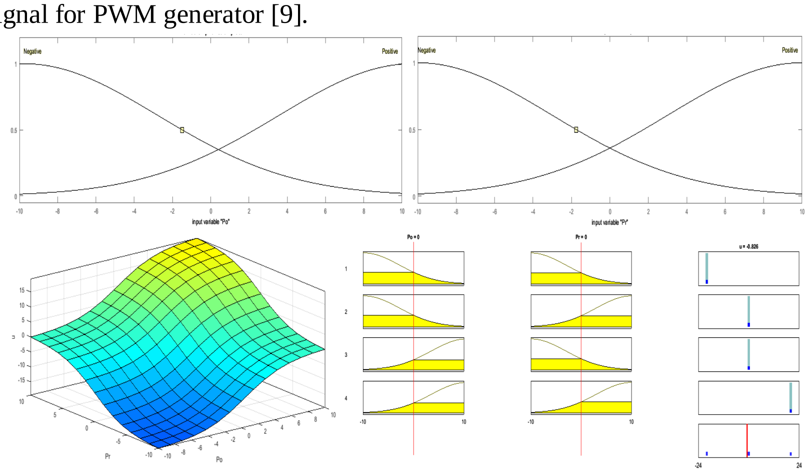

Fig.5. Membership function for input; Control Surface, Rule view Of Fuzzy Logic Controller

C. Predictive Torque Control

From the DFIG model described in the previous section we can estimate the rotor flux vector $\vec{\psi}_r[k]$ from the stator current measurements. This model can also predict the next sampling instant of stator current and rotor flux, as shown in Fig.6, $\vec{i}_s^{\,p}[k+1]$ and $\vec{\psi}_r^{\,p}[k+1]$ (superscript p for predicted variables) at current sampling instant based on three parameters i.e. stator voltage $\vec{v}_s[k]$, measured current $\vec{i}_s[k]$, and the estimated rotor flux $\vec{\psi}_r[k]$. Adding to this voltage vector $\vec{v}_s[k]$ it is also possible to predict the electric torque developed by the machine $T_e[k+1]$ and stator flux $\vec{\psi}_r^{\,p}[k+1]$.

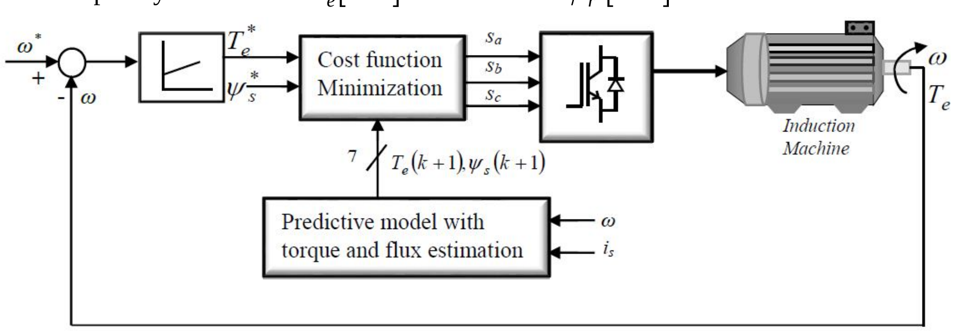

Fig.6. Schematic of predictive torque control

When the stator voltage vector $\vec{v}_s$ is applied to the DFIG terminals by a two-level voltage source inverter, the power drive provides seven number of different voltage vectors $\vec{v}_0 \rightarrow \vec{v}_6$ that can be applied on DFIG terminals [10]. This action allows one to predict the effect that each voltage vector would have on electric torque and stator flux, if it was applied for the next sampling period.

With the predicted values of torque and stator flux, electric torque and stator flux magnitude control is obtained by the minimization of a cost function *g* (for each stator voltage vector available, this cost function *g* is evaluated, and the stator voltage producing the minimum cost is selected to be applied on DFIG terminals) for which the inputs are: torque reference T_e^*, predicted torque $T_{ei}^{pred}[k+1]$, reference stator flux $|\vec{\psi}_s|^*$, predicted stator flux. Here the sub index *i*, means it is produced by the stator voltage $\vec{v}_s$ with *i=0…7.0.* The cost function will try to minimize the deviation between reference torque and predicted torque and between reference flux and predicted flux. From the measurements of rotor speed and stator current the prediction of torque and stator flux for all seven different voltage vectors are estimated.

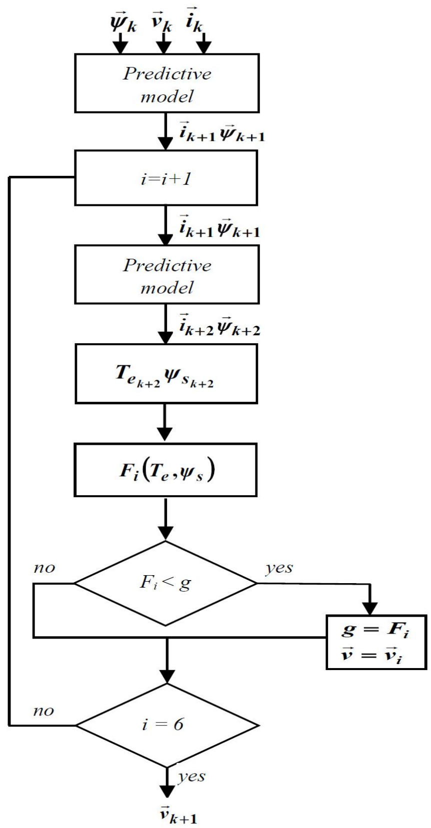

Fig.7. Control algorithm flow chart of PTC

The control algorithm considering all the time intervals is shown in Fig.7. In real time the calculations of optimal voltage needs almost all sampling periods. In the flow chart of the control algorithm the inputs are the measured current at instant *k*, estimated value $\vec{\psi}_r[k]$, and the selected voltage vector $\vec{v}_s^*[k]$ both calculated in the previous sampling interval.

The following steps explains the basic operation of the predictive controller:

1) Stator currents and rotor speed are measured.
2) These measurements are used for prediction of torque and stator flux for all seven different voltage vectors (Predictive model block).
3) The seven predictions are evaluated using the cost function block.
4) The voltage vector that minimizes the cost function is selected and applied in the machine terminals.

Taking into account new measurements and references for each sampling time, these steps are repeated. For experimental purposes a MATLAB simulation was performed and results were analysed. Experimental results are shown in the next section.

IV. EXPERIMENTAL RESULTS

The modelling of all the machine and control (simulation and coding), was performed using MATLAB r2016a Here in this section the overall results are shown below:

The FLC is applied to the grid side converter and PI controller at the Rotor side Converter. The above shows the speed response with high over shoot and high rate of error when compared with the reference speed signal taken.

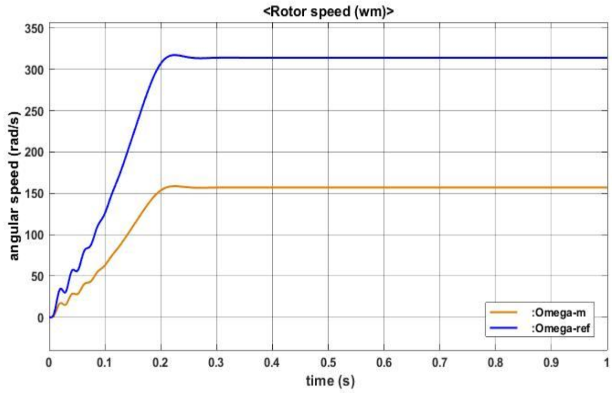

Fig.8.Rotor speed curve between measured speed and Reference Speed under varying wind speed

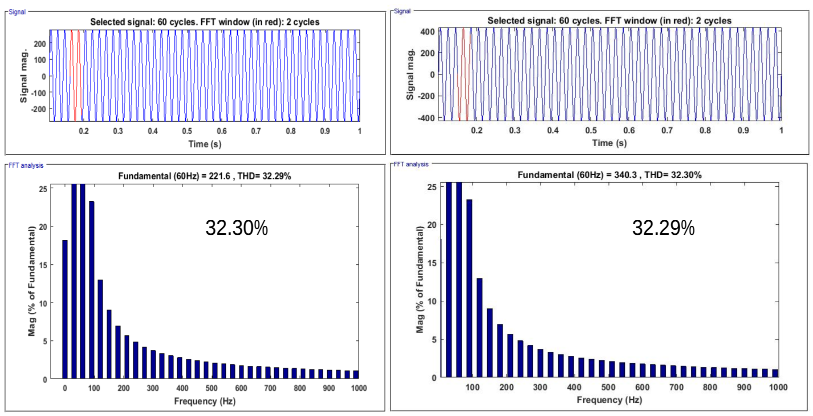

Fig.9.The Total Harmonic distortion of renewable side and Grid side voltage are calculated and found to be 32.29% and 32.30% respectively.

The PTC is applied to the grid side converter and PI controller at the Rotor side Converter. The above shows the speed response with low over shoot and a low rate of error when compared with the reference speed signal taken as compared to FLC.

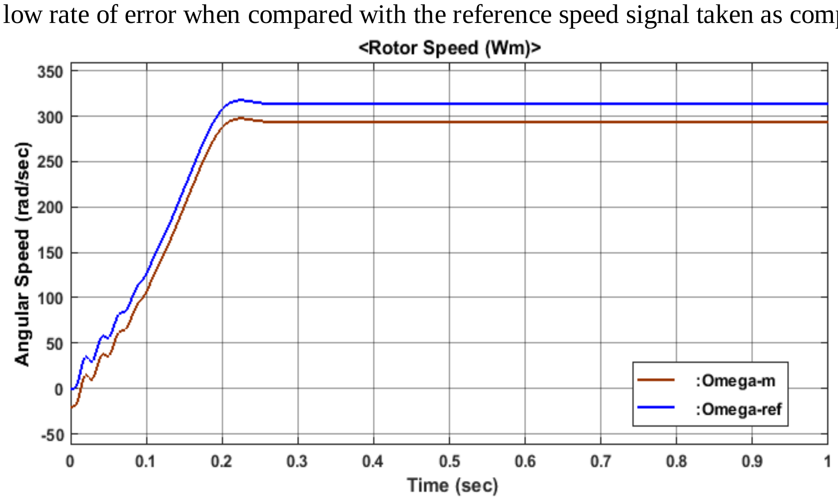

Fig.10. Rotor speed curve between measured speed and Reference Speed under varying wind speed

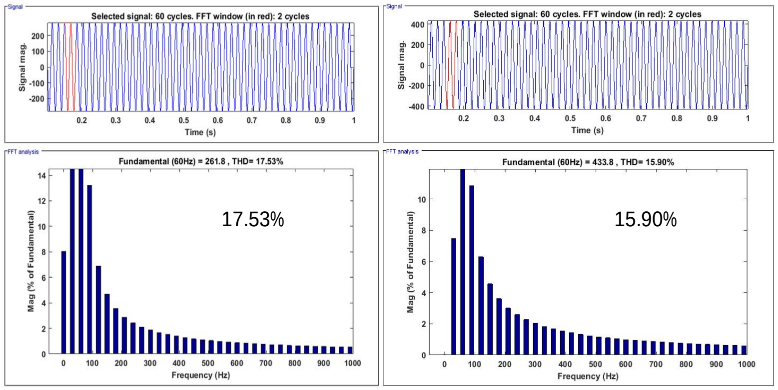

Fig.11.The Total Harmonic distortion of renewable side and Grid side voltage are calculated and found to be 17.53% and 15.90% respectively.

As compared to THD calculations of Renewable side the THD calculations of PTC at grid side has Lower harmonics because of its proper sector selection based on minimized cost function value.

Table.1.The THD Comparison between FLC and PTC for rotor and grid side Voltages.

Controller Type	THD of Rotor Side Voltage (in %)	THD of grid Side Voltage (in %)
Fuzzy Logic	32.29	32.30
PTC	17.53	15.90

Using Fuzzy Logic Controller reduces THD but as its prediction of reference signal comes in a range. The obtained THD is high as compared to PTC.

V. CONCLUSION

The DFIG based Wind Energy Conversion System has modeled and simulated using MATLAB & SIMULINK**.** The dynamic model of Wind Energy Conversion System has developed.

A predictive control strategy has been developed for DFIG that gives better performance as compare to the Fuzzy Logic controller. The model includes the time-varying effect of rotor speed ω_m in order to achieve a more accurate prediction of state variables such as stator flux, rotor flux, and electric torque where an enhanced prediction is achieved and the disturbances effect is included in the model by using the grid side measurements.

A well-tuned PI controller has been proposed and a torque controlled system with fast dynamic response is obtained, which shows the feasibility of the proposed control strategies. The THD has been calculated and minimized using FFT analysis in MATLAB simulations, which shows a significant reduction in harmonics at rotor and grid side.

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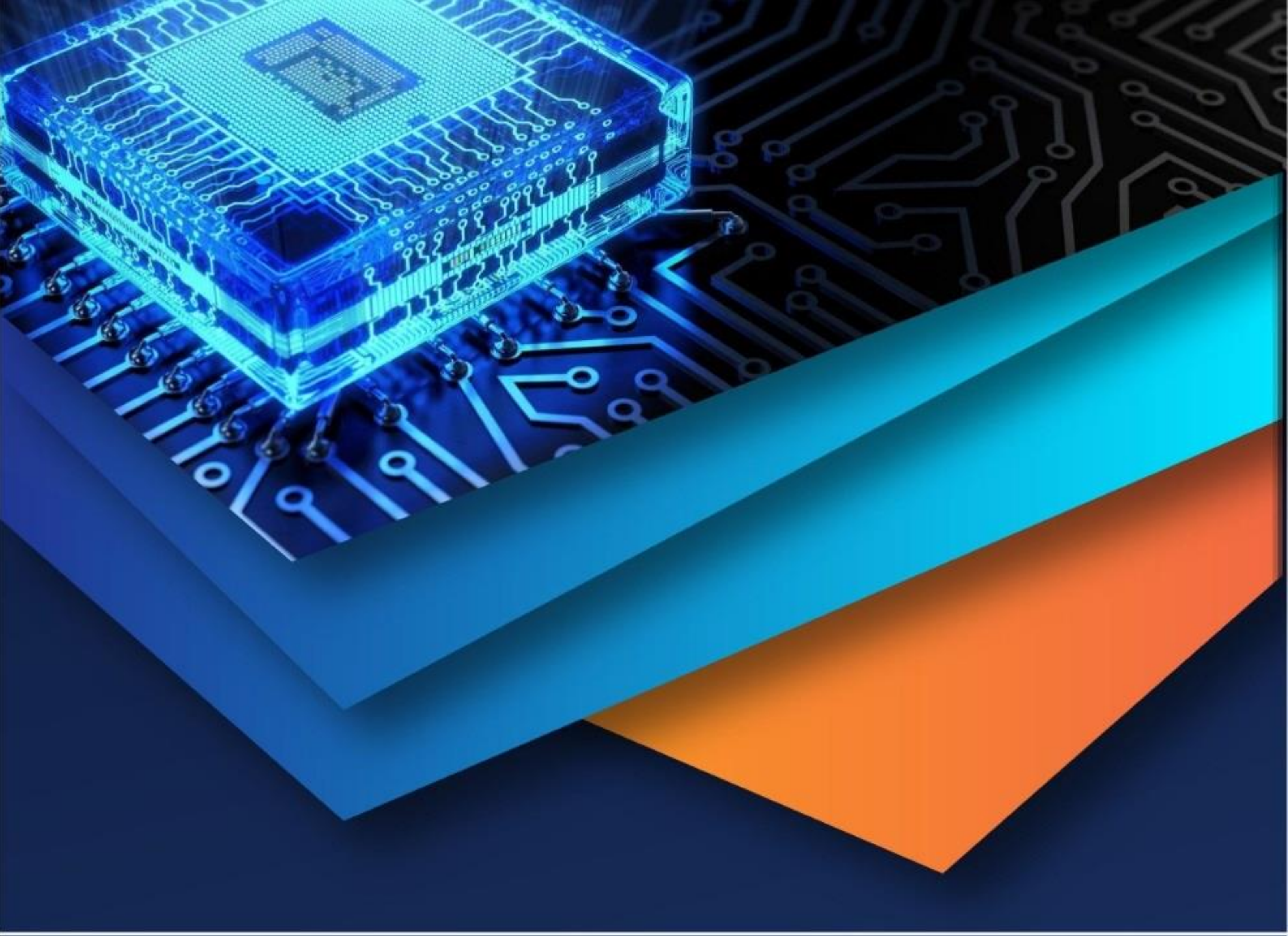

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