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Design and Implementation of the Propeller for Marine Propulsion Using Pi Controller

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Abstract-- Marine vehicles propulsion control is a challenging task in water transport system. Marine vehicle propulsion system uses a propeller power, shaft, and motor, sensors, guidance and navigation system in which thrusters are generally propellers driven by electrical motors. Motor model, propeller design, and hydrodynamic effects, which makes mathematical modelling procedure of thrust to resolve these difficulties these are affected for thrust force. To eliminate these difficulties, a thruster controller modelled in this project. The knowledge of the thrust and torque is essential to achieve high marine vehicle control performance. The thrust control is done by developing a mathematical model of the propeller speed controller. The controller used is a conventional PID controller which gives an effective method of controlling the torque and thrust of the propeller. Despite the environmental changes in the wave current, temperature, drift forces due to waves, the thrust is controlled and maintained to be constant, thus guiding the vehicle in desired direction.
Keywords:- Mathematical modelling, hydrodynamic effect, PID controller

I. INTRODUCTION

The field of power electronics has contributed immensely in the form of voltage-frequency converters which has made it possible to vary the speed over the specified range. However, the highly non-linear nature of the induction motor control dynamics demands strenuous control algorithms for the control of speed. Conventional controllers are used for the aforementioned purpose The controller types that are used are: Proportional Integral (PI), Proportional Derivative (PD), Proportional Integral Derivative (PID), Fuzzy Logic Controller (FLC). PID controller is very efficient solution to numerous control problems in the real world. If PID controllers are tuned properly, they can provide a robust and reliable control. This very feature has made PID controllers exceedingly popular in industrial applications. conventional PI, PD and PID controllers in speed control of induction motors is the complexity in design arising due to the non-linearity of Induction Motor dynamics. By using calculate the parameters, the conventional controllers have to linearize the non-linear systems. To obtain a perfect non-linear model is almost impossible and hence the values of the parameters that are obtained from it are thereby approximate. Again, Variable Speed Drives (VSD) for Induction Motor (IM) require wide operating speed range along with variations in load, torque response thereby advanced methods of control so as to meet the real demand. A thruster is an electromechanical device equipped with a motor and propeller that generates thrust to push an Underwater Vehicle. Underwater vehicle control controlled by thruster control and modelling these are the important parts . It is the lowest control loop of the system; accurate and practical modelling of the thrusters are used for these system. In underwater vehicle thrusters are generally propellers driven by DC motors. Therefore motor model, propeller design, and hydrodynamic effects are affected the thruster force.

II. INDUCTION MOTOR DESIGN

Short circuited of the machine rotor, and the stator is fed by a pulse width modulation inverter, PWM inverter built with interfaced to the Asynchronous Machine block through the Controlled Voltage Source block and Simulink blocks. Sinusoidal pulse-width modulation used for the inverter, sinusoidal reference base frequency of wave is set at 60 Hz and set at 1980 Hz for triangular carrier wave frequency. This frequency corresponds to a frequency modulation factor mf of 33 (60 Hz x 33 = 1980).The 3 HP machine is connected to a constant load of nominal value (11.9 N.m). It is started and reaches the set point speed of 1.0 pu at t = 0.9 second. The parameters of the machine are those found in the preceding except for the stator leakage inductance, its set as twice its normal value to simulate smoothing inductor placed between the inverter and the machine The stator of both types of motors consists of a three phase balanced distributed winding with each phase mechanically separated in space by 120 degrees from the other two phase windings. This gives rise to a rotating magnetic field when current flows through the stator. In squirrel cage IM, the rotor consists of longitudinal conductor bars which are shorted at ends by circular conducting rings. Whereas, the wound rotor IM has a 3-phase balanced distributed winding even on the rotor side with as many number of poles as in the stator winding.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Considering the three phases to be balanced, the analysis of a 3-phase induction motor can be done by analysing only one of the phases. The per phase equivalent circuit of an induction motor is shown below:

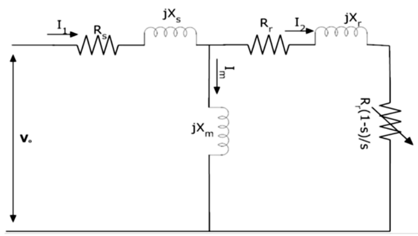

Fig. 1: Per phase equivalent circuit of a 3-phase induction motor

R2 and X2 are the stator referred values of rotor resistance R1 and rotor reactance X1.Slip is defined by

$$s = (\omega s - \omega m)/ \omega s \qquad (1)$$

where, ωm – rotor speed

ωs synchronous speeds, respectively.

$$\text{Further, } \omega\mathbf{s} = 120f/p \text{ rpm} \qquad (2)$$

Where f,p are supply frequency and number of poles, respectively. Since, stator impedance drop is generally negligible compared to equivalent circuit and terminal voltage can be simplified to that shown below:

Rotor current

$$I_{2=} V0 / [\left(Rs + \frac{Rr}{s}\right) + j(Xs + Xr) \qquad (3)$$

Power transferred to rotor (or air-gap power)

$$P_g = 3I_2 \frac{Rr}{s} \qquad (4)$$

Rotor copper loss is

$$P_{cu} = 3I_2 R_r \qquad (5)$$

Mechanical power is given by,

$$P_m = P_g - P_{cu} = 3I^2 R_r \left(\frac{1-s}{s}\right) \qquad (6)$$

Torque developed by motor

$$T = P_m/\omega_m \qquad (7)$$

Thus,

$$T = \frac{3I_2^2 R_r}{s\omega_s} \qquad (8)$$

Substituting the value of I2 into the equation,

$$T = \frac{\frac{3V_0^2 R_r}{s}}{\omega_s\left[(R_s + \frac{R_r}{s})^2 + (X_s + X_r)^2\right]} \qquad (9)$$

Differentiating T wrt s and equating to zero gives the slip for maximum torque

$$s_m = \pm \frac{R_r}{\sqrt{[R_s^2 + (X_s + X_r)^2]}} \qquad (10)$$

Substituting Sm in T gives maximum torque,

$$T_{max} = \frac{3V_0^2}{2\omega_s\left[R_r \pm \sqrt{R_r^2 + (X_s + X_r)^2}\right]} \qquad (11)$$

III. PROPELLER LOAD MODELLING

Modelling of propellers is complicated by the fact that it is impossible to develop a finite-dimensional plant model from first principles. A combination of simplified analytical and empirical models is therefore the commonly used solution. This section treats modelling of propellers from a control. Models are required to be accurate enough to capture the main physical effects, and such facilitate control system design and testing. The actual propeller thrust Ta and torque Qa are influenced by many parameters, the most important being propeller geometry, submergence, and propeller loading—which depends on the propeller pitch ratio and shaft speed. Ta and Qa can in general be formulated as functions of fixed thruster parameters θp (i.e. propeller diameter, geometry, position, etc.),the shaft speed n, and variables xp (i.e. pitch ratio)

$$Ta = f_T(n, xp, \theta p), \qquad (12)$$

$$Qa = f_Q(n, xp, \theta p) \qquad (13)$$

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In the following, only speed controlled FPP at low advance speed will be considered. The models are, however, easily extendable to both controllable pitch propellers (CPP) and higher inflow velocities, as experienced on vessels in transit. The pitch ratio will in this case be a fixed parameter. The functions $f_Q(.)$ and $f_T(.)$ may include loss effects due to e.g. in-line and transverse velocity fluctuations, ventilation ,in-and-out-of water effects, and thruster–thruster interaction, as well as dynamic flow effects. In addition, the dynamics of the motor and shaft must be considered. The basic propeller characteristics, some quasi-static loss effects, and dynamic effects due to the water inflow, motor, and shaft are considered.

A. Propeller Characteristics

The relationships between the propeller thrust Ta, torque Qa, shaft speed n (in revolutions-per-second—rps), diameter D, and density of water ρ are commonly given by

$$Ta= fT (.)=sign(n)\ KT\ \rho\ D^4 n^2 \quad (14)$$

$$Qa= fQ (.)=sign(n)\ KQ\ \rho\ D^5 n^2 \quad (15)$$

KT and KQ are strictly positive thrust and torque coefficients. The propeller power consumption Pa is written as

$$Pa= 2\pi nQa = sign\ (n)\ 2\pi\ KQ\ \rho\ D^5 n^3 \quad (16)$$

For a specific propeller geometry, KT and KQ are commonly given as functions of the advance number

$$Ja= \frac{Va}{nD}, \quad (17)$$

Where Va is the propeller advance (inflow) velocity. This relationship is commonly referred to as an open-water propeller characteristic. The corresponding open- water efficiency η_0 is defined as the ratio of produced to consumed power for the propeller:

$$\eta_0= \frac{VaTa}{2\pi n\ Qa} = \frac{VaKT}{2\pi n\ KQD} = \frac{JaKT}{2\pi n\ KQ} \quad (18)$$

Propellers are, with the exception of tunnel thrusters, usually asymmetric and optimized for producing thrust in one direction. The propeller characteristics will therefore depend on both the rotational direction of the propeller and the inflow direction. The four quadrants of operation of a propeller are defined in Table 3.1.

	1st	**2nd**	**3rd**	**4th**
N	>=0	<0	<0	>=0
v_a	>=0	>=0	<0	<0

Table. 1

Four Quadrants Operation Of Propeller, With Advance Velocity v_a

The typical open-water characteristic is a 1-quadrant model, covering positive shaft speeds and positive advance velocities. The open-water characteristic is extended into the 2nd quadrant, i.e. negative Va. If reversing the propeller operating direction, this can be modelled by a similar open-water characteristic for negative shaft speeds and negative advance velocities. In a complete 4-quadrant model both positive and negative shaft speeds and positive and negative advance velocities are covered. This is typically done by modelling the propeller lift and drag coefficients as a function of propeller blade angle of attack. In the 4-quadrant characteristics of some of the Wageningen B-series propellers are given by a Fourier series representation. It is also possible to tabulate the lift and drag coefficients as functions of propeller blade angle of attack. A simplification of the first-quadrant propeller characteristics often seen in control literature is to approximate the KT and KQ curves to be linear. This approximation is in reality only valid in the1st quadrant. The nominal thrust Tn, torque Qn, and power Pn are expressed by

$$Ta= fT (.)=sign(n)\ KT_0\ \rho\ D^4 n^2 , \quad (19)$$

$$Qa= fQ (.)=sign(n)\ KQ_0\ \rho\ D^5 n^2 , \quad (21)$$

$$Pa= 2\pi nQa = sign(n)\ 2\pi\ KQ_0\ \rho\ D^5 n^3 \quad (22)$$

KT0 and KQ0 are the nominal thrust and torque coefficients for a deeply submerged propeller with Va=0 and no thrust losses.

IV. PROPOSED SYSTEM

The block diagram propeller speed control by using induction motor shown in Fig. 2.

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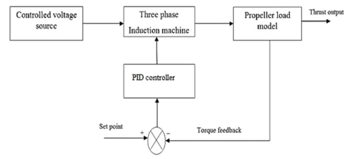

Fig. 2: Block diagram of speed control electrically driven propeller

In this system, electric motor is used to drive the marine propeller to yield the ship propulsion. The ship propeller can be directly coupled with the electric motor. The squirrel cage induction motor is the most popular electric motors because it has simple in construction, inexpensive, high efficiency and maintenance easy. Induction motor to control a constant speed is difficult whenever the load is changed. Many methods have been proposed by many researchers to solve such kind of problem. The controlled voltage source is directly connected to the induction motor, where thus source gives supply to the stator of induction motor. The supply is fed to induction motor by using control the time sequence of voltage. PI controller controls the speed of induction motor by keeping motor torque constant or desired value.

A. PI Controller

PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively. Integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the response of the speed. Since PI controller does not have means to predict what will happen with the error in near future. This problem solved by derivative mode which has ability to predict what will happen with the error, thus to decrease a reaction time of the controller.

PI controllers are very often used in industry. Speed control without D mode is used when:

Does not required fast response of the system.

large disturbances &noise are present during operation of the process

In process there is only one energy storage (capacitive or inductive)

B. Low-Level Thruster Control

A block diagram of the propulsion system, including the low-level thruster control, is depicted in Figure.2.2. The primary objective of the low-level thruster controller is to obtain the desired thrust from the propeller regardless of the environmental state and vessel motion. The thrust tracking capability is one of the performance criteria considered in a thruster controller. It is also very important to take into account the power consumption as well as the power fluctuations and the mechanical wear-and-tear of the propulsion system. When performs an operation of marine vehicles, propellers are often affected by thrust losses due to the influence of the environment, vehicle motion, and the interaction between the vehicle and propellers between propellers.

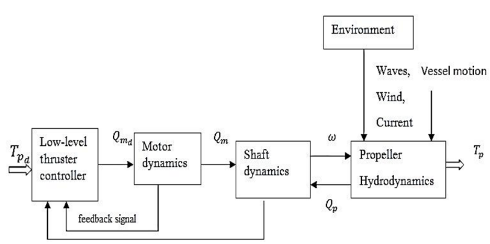

Fig. 4: Block diagram of the propulsion system.

Propellers may thus work far from ideal conditions therefore, knowledge of the propeller thrust and torque is fundamental to achieve high vehicle control performance. Today's industrial standard for fixed pitch propellers is shaft speed control where the desired shaft speed is computed from the desired thrust through a static mapping. Conventionally, also torque and power control are employed for propellers. In general, these controller schemes do not employ the actual value of the propeller thrust since it is not usually measured. Therefore, when large thrust losses occur, the performance of the low-level thruster control reduced.

C. Propeller Dynamics

The propeller characteristics and loss effects presented so far are all quasi-static. Propeller dynamics is introduced via the

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propeller motor and shaft, and also by flow dynamics.

D. Shaft Dynamics

Let Qm denote the torque generated by the propeller motor. A torque balance for the propeller shaft is written as

$$I_s\dot{\omega} = Q_m - Q_a - Q_f(\omega) \qquad (23)$$

Where I_s is the moment of inertia for the shaft, propeller, and motor, $\omega = 2\pi n$ is the angular shaft speed, and $Q_f(\omega)$ is the shaft friction. The friction may for most applications be viewed as a sum of a static friction(or starting torque) Qs and a linear component:

$$Q_f(\omega) = sign(\omega)\ Qs + K_\omega \omega \qquad (24)$$

Where Kω is a linear friction coefficient. If desired, more sophisticated friction models may be used, including e.g. Nonlinear elements, Steinbeck friction, and hysteresis effects. This has not been considered in the current work; even though the experimental facility exhibited some nonlinear friction characteristics, the model in above equation proved sufficient for control and control design purposes.

E. Motor Dynamics

The torque control loop is inherent in the design of most applied control schemes for variable speed drive systems. Torque is controlled by motor currents and motor fluxes with high accuracy and bandwidth. The closed loop of motor and torque loop controller may for practical reasons be assumed to be equivalent with a first-order system

$$\dot{Q}_m = \frac{1}{T_m}(Q_c - Q_m) \qquad (25)$$

Where Qm is the motor torque, Tm is the time constant in the range of 20–200ms, and Qc is the commanded torque from the thruster controller. Normally, the electric time constant is small compared to the mechanical time constant. The motor dynamics is therefore dominated by the rotational dynamics of the shaft.

F. Flow Dynamics

For a deeply submerged propeller, additional dynamics may be introduced by including the flow rate through the propeller disc as a state in the system .This flow rate is in steady state connected with the inflow velocity and the propeller thrust through momentum theory.

V. SIMULATION RESULTS

In the MATLAB/simulink environment the simulation model can be build based on mathematical model; the corresponding simulation model contains many a functional simulink block in simulink. An easy copy from module library module to the model window and a connect of each module make a simulation model in place. As the model structure is complicated, a subsystem module is used to make the whole model simpler and more readable. In this project work propeller load model is control as shown below fig. 5

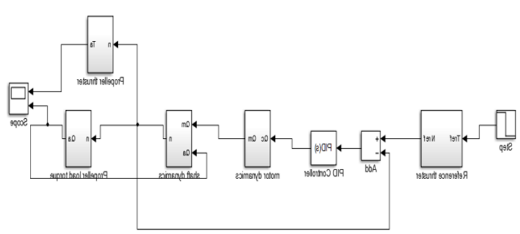

Fig. 5: Simulation of speed controller for propeller dynamics

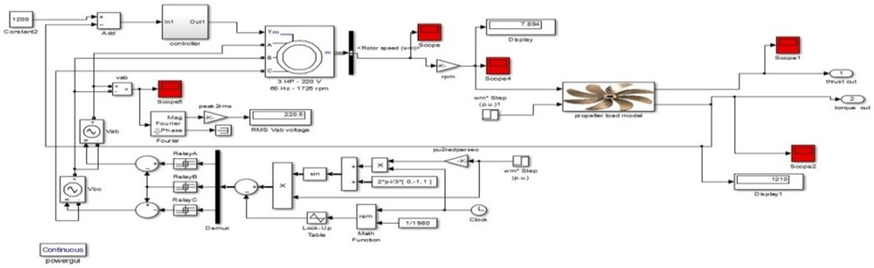

Fig 6. Simulation of speed controller with propeller load

The simulation model is built based on mathematical model In the MATLAB/simulink environment. In simulink tool box there are many packaged blocks, which can be copied to model window and then be connected together. As this model is complex. Here choose a subsystem, making the model simple and easy to read.The output of propeller thrust as shown in below,

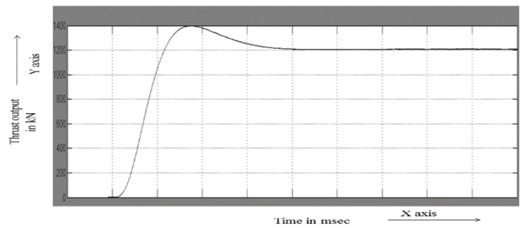

Fig. 7: Output Of Thrust Control For Setting 1200

The output of thruster varies with respect to time. Here thrust output shown in Y-axis and time in X-axis. The maximum thrust value obtained is 1400 for set point 1200 in input

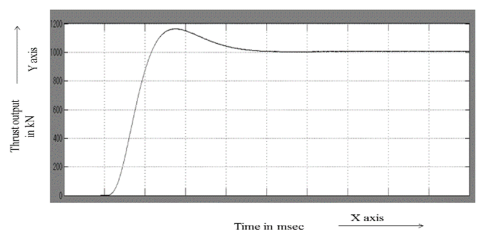

Fig. 8: Output of thrust control for setting 1000

The output of thruster varies with respect to time. Here thrust output shown in Y-axis and time in X-axis. The maximum thrust value obtained is 1400 for set point 1200 in input.

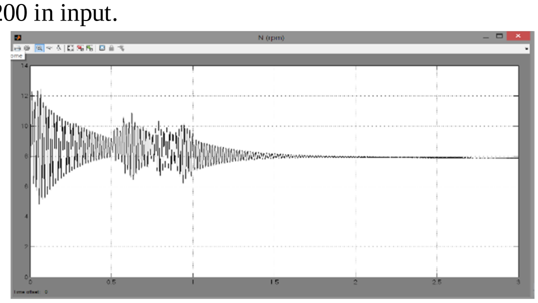

Fig. 9: output of motor speed for propeller load model

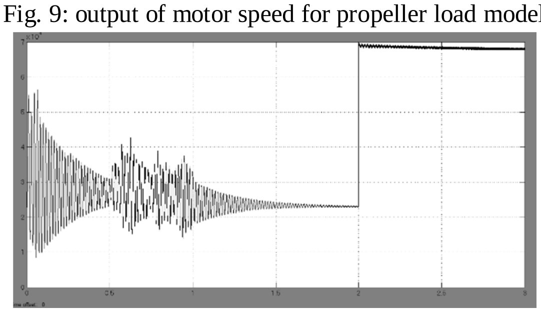

Fig. 10: output of thrust output for propeller load model

Parameters	Values
Diameter	4m
Density of water	1025 Kg/m^2
Nominal thrust coefficient	0.445
Nominal torque coefficient	0.0666
Rated motor speed	7.9 rps
Maximum motor torque	1200,1000
Gear ratio motor : propeller	4

Table. 2
Parameters for propeller model

VI. CONCLUSION

In this project the propeller is the drive of the ship movement and the load of the propulsion motor. It is concluded that the propeller torque is proportional to its square of the speed approximately. it can meet the requirement of the Constant output of torque in real time for propulsion motor. Simulations offer beneficial references for analysis and design of the ship propulsion system. With a proper choice of transition speed, the proposed configuration can enable full speed range for the drive with minimal power electronics. The results show that the proposed controller works equivalently under the tested operating conditions. The conventional PID control technique used, benefits the users in terms of cost, thus providing an economical design. The conventional monotonous time consuming manual calculations are avoided since, the use of efficient time saving mathematical model is developed which allows flexibility when dealing with complex control system. The mathematical model is developed taking into consideration various test conditions and it is simulated and validated in MATLAB with results. In future soft computing techniques will be used to control propeller load at transient condition. Thus the control techniques are a) Artificial Neural Network b) Fuzzy-Neural Network .Thus, to overcome the complexities of conventional controllers, fuzzy control has been implemented in many motor control applications.

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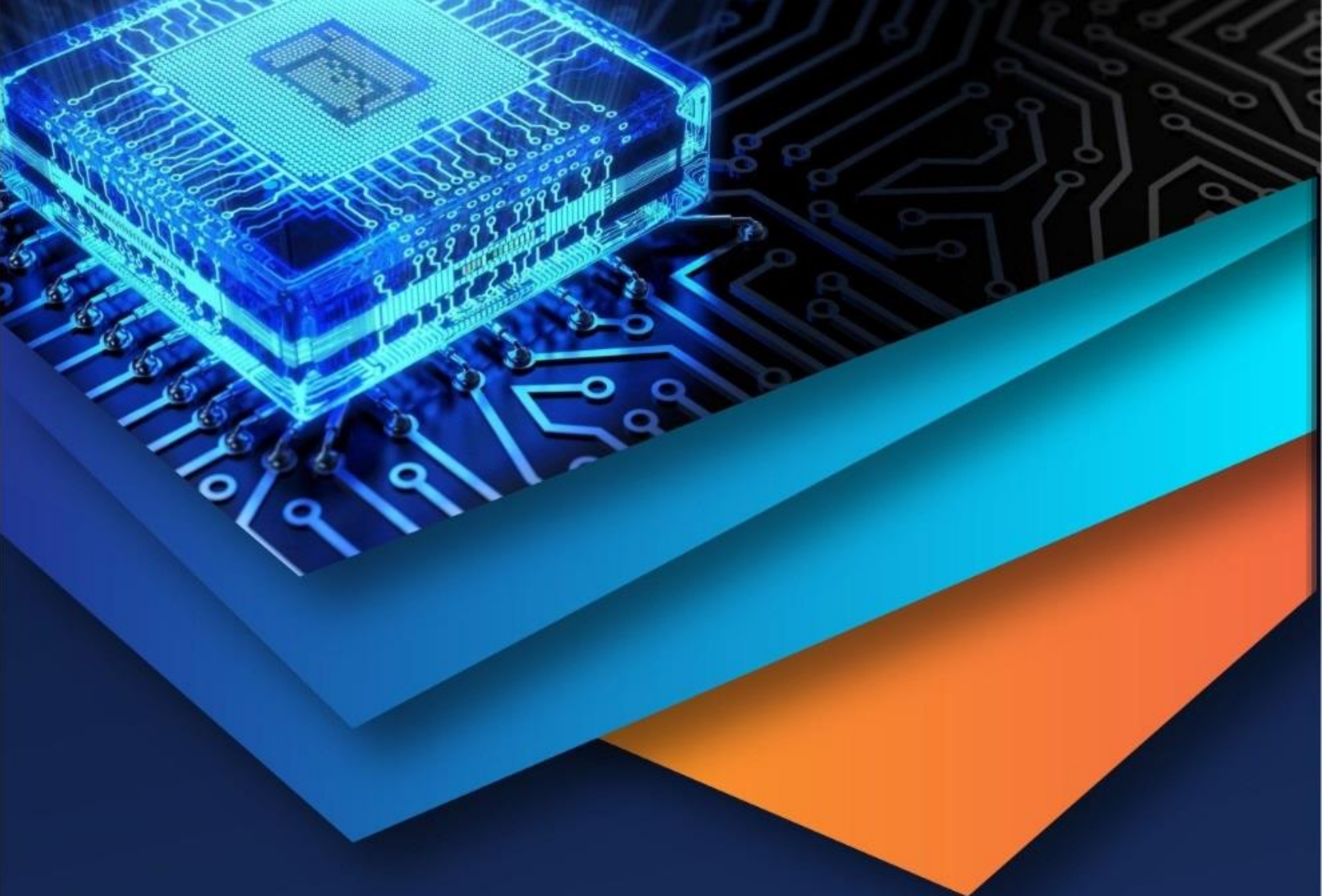

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