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Numerical Modelling and Design Experiment of a Model Gas Turbine Petro with Combination of Natural Gas, Hydrogen

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Abstract: In this study, we are constructing an analytical model to evaluate the energy performance of a Micro Gas Turbine (MGT) utilizing H_2 NG mixes as fuel. During the experimental campaign, the model findings were verified in the real working conditions of the Micro Gas Turbine. It was during the spring and summer of this year that a model validation experiment was carried out. Fueled by H_2 NG, MGT performance has been shown to increase from zero to 10 percent hydrogen content, with a 2 percent volume step. Fuel usage has been considerably decreased, according to the data. Heat recovery and electrical reliability increase marginally even if environmental conditions have an influence on the system. A MATLAB-Simulink numerical model was built to depict the MGT's operation. As a consequence, the relative standard errors of the major output parameters have been determined.

Keywords: Numerical, Gas Turbine, Modelling, Natural Gas, Hydrogen

I. INTRODUCTION

Global warming is a serious concern, and solving it is amongst the most challenging. Decarbonizing the energy system and substituting fossil sources of renewable energy may reduce GHG emissions. It is critical that the energy utilized is safe, reliable, affordable, and long-term. Wind and solar energy are examples of renewable energy sources. Devout believers in the future of these technologies, their execution is fraught with difficulties. A Power to Gas technique uses hydrogen as an energy transporter to store power. In a pressure tank or a metal hydride tank, water electrolysis produces hydrogen.

One of the most common uses for hydrogen is as a fuel for vehicles. Constrisciani et al. defined "hydro methane" as a combination of methane and hydrogen containing 5-30% hydrogen. Hydrogen burns quicker than methane. In gas turbine applications, encouraging increased combustion of hydrocarbon fuels with hydrogen gas is now a good concept. In a combustion chamber, Rajpara et al. discovered that adding hydrogen improves flame temperature, lowers flame dimensions, and so reduces CO emissions. Also investigated was a novel integrated CHP system that incorporated solar energy, a biogas-steam reformer with methanol, and hydrogen production. On the other hand, Ouchikh et al investigated the effects of hydrogen enrichment in natural gas on dual-fuel diesel engines. Cappelletti et al. numerically redesigned a 100 kW MGT combustion chamber for 100% hydrogen, proving that although hydrogen generates more NOx than CH4, it can function lean. To test the application's pros and cons, De Santoli et al. used H2NG mixes in established technologies like internal combustion engines. Based on an experimental campaign, Lo Basso et al. reported on the impact of adding up to 15% H2 to the fuel mix on electrical and heat recovery efficiency, as well as pollution emissions of a condensing microCHP. Over a year, De Santoli et al. studied the energy and environmental characteristics of a commercial micro gas turbine using hydrogen-enriched natural gas blends. Environmental and economic advantages are claimed for CHP technology. Several research efforts are presently ongoing to develop eco-friendly fuels. A recent research found that burning H2NG emits the least CO and CO2. Because hydrogen-enhanced blends burn quicker and have a greater H/C ratio, they may minimize carbon emissions. This study's purpose is to model and examine a commercial Micro Gas Turbine that works on hydrogen and natural gas. This report summarizes key results.

II. DESCRIPTION AND USE OF TEST RIG

This study's objective is to build a compact gas turbine that works on hydrogen and natural gas. The experimental effort DIAEE of Sapienza University in Rome supplied the modeling data. MGT is rated at 30 KWel and 63 KKWth by Capstone Corporation. A series of research that gradually increased the fuel's hydrogen content. Laboratory electrolyte is made using an alkaline electrolyser. MGTs are Brayton cycle-based micro power plants (less than 500 kWel). High-performance gas turbines employ the recovery cycle and feature turbo-radial machinery. This research used the Capstone C30 microgas turbine. Table 1 lists the machine's technical specs.

Table 1. datasheet of Capstone C30

Parameters	Values
Engine type	Natural gas Micro Turbine
Rotational speed	96,000 rpm
Compression ratio	4:1
Gross Active power	30 kW
Width	0.76 m
Depth	1.5 m
Height	1.8 m
Weight	Grid Connect - 405 kg
Net Active Power	28 kW
Voltage	400 -480 V, AC, PPPN
Frequency	50-60 Hz (Grid Connected)
CHP electric efficiency (based on LHV)	0.26
CHP heat recovery efficiency (based on LHV)	0.58
Max. thermal output power	60 kW
Hot water flow	2.9 m^3/h
Exhaust Temperature	275ºC (530ºF)
Exhaust Gas Flow	0.31 kg/s
Max. operating pressure	6 bar
Average fuel consumption	11 Nm3/h
Fuel	Natural gas, Liquid Fuels

MGTs have a compressor, combustor, turbines, heat reboiler, and generator. They may be powered by natural gas, biogas, and biodiesel. In the commercial Capstone C30 package, process air is compressed by a radial compressor (from stage 1 to state 2) and pre-heated by an annular regenerator utilizing hot turbine exhaust gas (from state 2 to state 2'). (see Figure 1). Micro gas turbines may dramatically boost electrical efficiency at low pressure ratios. In the combustion chamber, the process air is mixed with the fuel (state 3). The expander (4) depressurizes combustion by-products, which are subsequently cooled by the heat regenerator (4 to 4') and transferred via the liquid to gas heat exchanger (5 to 6) to create hot water for the HVAC system. Some MGT energy efficiency features have been measured directly using sensors and probes, while others, especially those linked to intermediate states, have been reverse-engineered. Onboard PLC records power output, rotation speed, input temperature T1, and combustion temperature T3 (Programmable Logic Controller). The gas analyzer temperature probe measured T6 and the thermal counter recorded hot water temperature and flow rate.

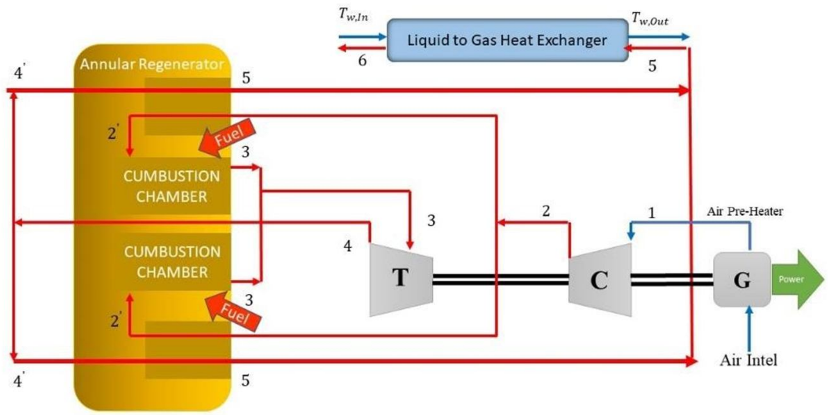

Fig. 1. Process layout of Capstone C30.

III. MATLAB-SIMULINK Model

In the simulation model, MATLAB-Simulink was used to implement the compressor, recuperator, combustor, and turbine. To begin, the miniature gas turbine's components were modeled and the equations regulating their functioning were put into action. In the second step, the process system was examined and characterized. Using the model, we can see how the MGT responds to H2NG mixes. Experimentation and calculated outcomes are then compared.

A. Air Compressor

As a centrifugal compressor is attached to the turbo-shaft, alternator's it is referred to as the compressor block. inputs are the intake temperature (TT_1, polytropic efficiency (pt), the air constant (RR), inlet pressure (pp1, the notional compression ratio (cc), and air specific heat (CCpp), which is derived using the equation:

$$T_2 = \beta_c T_1^{\frac{k-1}{\eta_{pt} * k}} = \beta_c T_1^{\frac{R}{\eta_{pt} * Cp}} \quad (1)$$

$$p_2 = \beta_c p_1 \quad (2)$$

B. Recuperator

Compressed air flow is warmed in the recuperator, a counter-flow heat exchanger in which exhaust expanded gases are recirculated back to pre-heat compressed air entering the turbine. The subsystem outputs the temperature of the air before it enters the combustion chamber (TT2′). the approach temperature, represented as (TT4 - TT2′), which is set to 50°C under nominal circumstances and assessed iteratively on the exchanger exhaust gas temperature, as stated on the technical data sheet for each power output air temperature, and the exhaust flow rate are the system's inputs. The efficiency of a heat exchanger may be calculated if the fluctuation of the approach temperature with the load (that is, with temperatures and flow rates) is known.

The following equation may be used to compute TT2′:

$$\left(\frac{1+\alpha}{\alpha}\right) Cp_{\text{exhaust},4-5}(T4 - T5) = Cp_{\text{air},2-2'}(T2' - T2) \quad (3)$$

C. Combustor

According to an energy density modeling of the combustor, the atmosphere proportion and fuel energy may be determined using the following equation:

$$(1 + \alpha\alpha)CC_{pp\ eeeehaaaaaaaa,2'-3}(TT_3 - TT_2') = LLLLLL\eta\eta_{cccccccc} \quad (4)$$

Where $\eta\eta_{cccccccc}$ is the Combustion efficiency and is calculated by multiplying a particular quantity of fuel by its lower heating value (LHV), which is defined as the amount of heat generated by combusting at 25°C and restoring the temperature of combustion products to 150°C, with water in the reaction products not recovered. Depending on the kind of gasoline used, this amount may range from a few percent to a few percentage points higher or lower.

Turbine

This equation may be used to compute T4 given the nominal expansion ratio (e), the reference (T3), and the polytropic efficiency (pt) in the turbine block.

$$T_4 = \frac{T_3}{\beta_e^{\frac{\eta_{pt}(k-1)}{k}}} = \frac{T_3}{\beta_e^{\frac{\eta_{pt}R}{Cp}}} \qquad (5)$$

Where $= \eta_{pp}\beta\beta$, with η_{pp} pneumatic efficiency, which is a measure of total pressure, is expressed as a percentage.

D. Heat Transfer of Water Gas

The MGT might employ a water-gas heat exchanger to finish the heat rehabilitation process. The energy balance models this element.

𝑇𝑇6 = 𝑇𝑇5 − 𝛼𝛼 𝑚𝑚______ ̇ 𝐻𝐻2(·𝑐𝑐1+𝑝𝑝,𝐻𝐻2𝑂𝑂𝛼𝛼) 𝑚𝑚(
𝑎𝑎𝑖𝑖𝑎𝑎𝑇𝑇𝑤𝑤,𝑜𝑜𝑜𝑜𝑜𝑜·𝑐𝑐𝑝𝑝5,6−𝑇𝑇𝑤𝑤,𝑖𝑖𝑖𝑖) (6)

The thermal user selects the flow rate of the water, inlet, and outflow temperatures. The energy balance needs the air flowrate, computed from specific useable power:

$$\dot{m}_{air} = \frac{P_{el}}{\left[\frac{(T_3-T_4)c_{p3,4}(1+\alpha)}{\alpha} - c_{p1,2}(T_2-T_1)\right]\cdot\eta_{el}} \qquad (7)$$

IV. RESULTS AND DISCUSSION

This research models and analyzes the MGT mathematical model when utilized to power a machine on Hydrogen and Natural Gas Blends.

A. Model Validation

During testing, the hydrogen fraction in the blended fuels was raised by 2%. A moderate load (15 kW) and the maximum supplied electrical energy (22 kW) were tested on the MGT. The model is fed experimentally measured electrical power, and simulated operating principles are compared to experimental ones.

Table 2. Experiment vs. 15 kW simulation

15kW	H_2%					
	0 %	2 %	4 %	6 %	8 %	10 %
T_3 Simulated	1052.36	1051.66	1050.34	1050.09	1050.24	1049.52
T_3 Measurements	1052	1051	1051	1050	1050	1049
Error %	0.0339	0.0627	0.0628	0.0083	0.0231	0.0500
T_4 Simulated	868.164	868.164	868.164	868.164	868.164	868.164
T_4 Measurements	865.044	865.156	864.737	864.4	864.462	864.362
Error %	0.3594	0.3464	0.3947	0.4336	0.4264	0.4379
T_2 Simulated	449.92	449.94	449.92	449.96	449.92	449.91
T_2 Measurements	450.133	449.484	449.918	450.446	450.996	450.235
Error %	0.0925	0.0041	0.0518	0.2435	0.0518	0.0744

Table 3. Experiment vs. 22 kW simulation

22 kW	H_2%					
	0 %	2 %	4 %	6 %	8 %	10 %
T3 Simulated	1074	1074	1075	1075	1075	1073
T_3 Measurements	1073.62	1074.57	1074.18	1074.69	1075.91	1073.57
Error %	0.0539	0.0758	0.0289	0.0849	0.0849	0.0534
T_4 Simulated	868.164	846.961	868.164	868.164	868.164	868.164
T_4 Measurements	865.04	846.30	846.43	846.46	846.22	846.23
Error %	0.0574	0.0781	0.0626	0.0582	0.0899	0.0855
T_2 Simulated	488.51	488.52	488.51	488.52	488.51	488.52
T_2 Measurements	487.13	489.35	488.30	488.82	489.30	488.85
Error %	0.278	0.176	0.039	0.066	0.164	0.073

Both simulations (minimum and maximum feasible loads) have a smaller error than the measurement uncertainty, according to results of the study.

B. *Modeling of the MGT's H2NG-fuelled functioning*

Turbine Inlet Temperature (TIT) values are almost constant since T4 and the expansion ratio are set for each speed and power, with only fluctuations in the heat capacity and the gas steady effecting TIT.

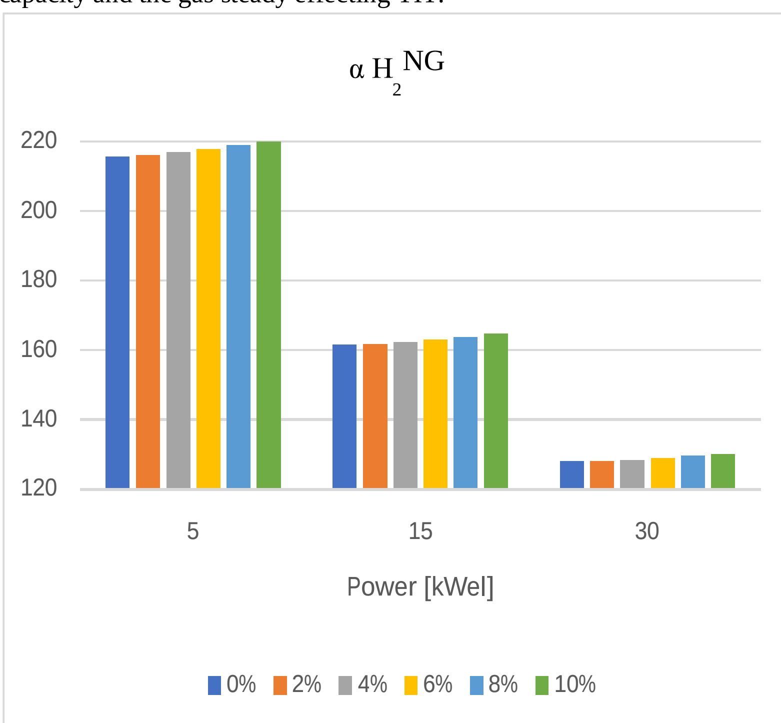

Fig. 2. Change of air to fuel volume ratio at 5,15 and 30 kWel with H2 percent

According to Figures 3 and 4, an improvement in air flow rate may be noted as fuel consumption decreases.

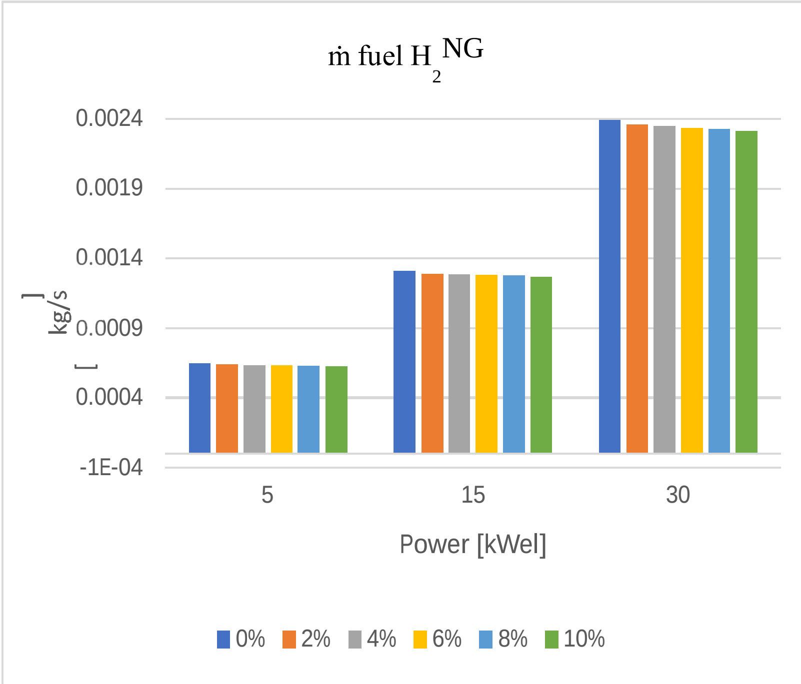

Fig. 3. Change of air to fuel mass flow rate at 5,15 and 30 kWel with H2 percent

The lower heating value of the mixes means that less fuel is needed to produce the same quantity of heat during combustion.

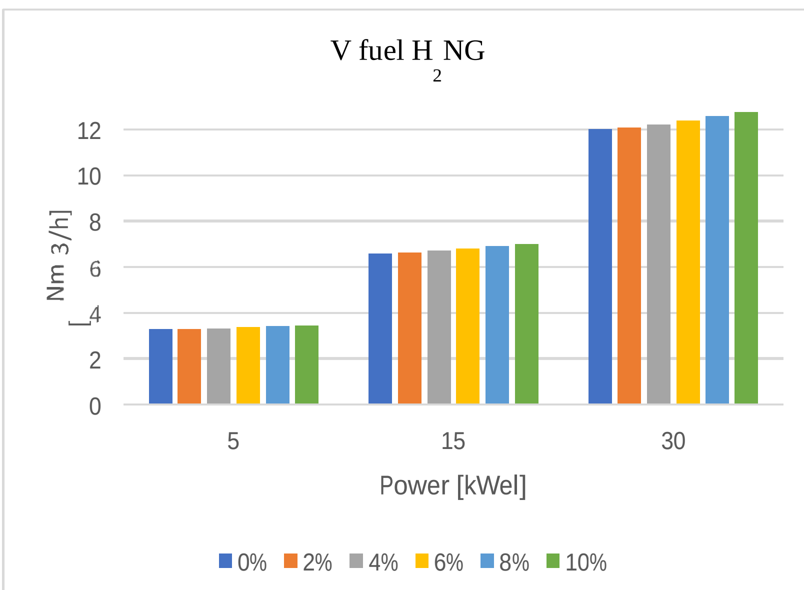

Fig.4. Change of air to fuel Volumetric flow rate at 5,15 and 30 kWel with H2 percent

T2, T3, and T5 are unchanged. The experimental campaign observed the same pattern. When the lower heating value is higher, less fuel is needed to accomplish the same T3-T4 enthalpy difference. Due to combustion energy, the expansion ratio may rise with TIT. Maximum TIT and compress ratio will be reached at a lower RPM, leading in no nominal power. Figure 5 shows that reduced fuel usage increases electrical efficiency marginally, offsetting the increased heating value.

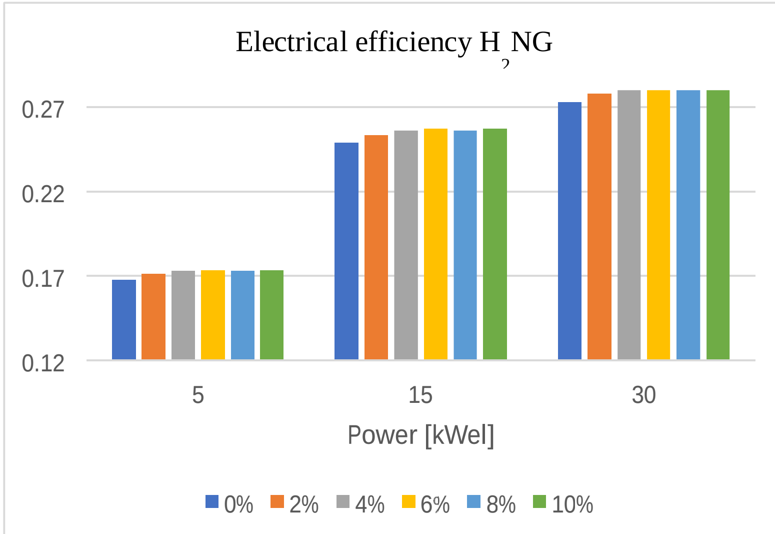

Fig.5. Electric utilization at 5,15, and 30 kWel with H2 percent change

Up to 10% H2 in the combination has no obvious influence on the little gas turbine, although it may boost performance (maximum of nearly 0.01). As thermal power is heavily reliant on waterside parameters and fluctuates little with exhaust flow rate, heat recovery efficiency follows the same pattern. Figure 6 shows heat recovery efficiency at 5, 15, and 30 kW hydrogen concentration.

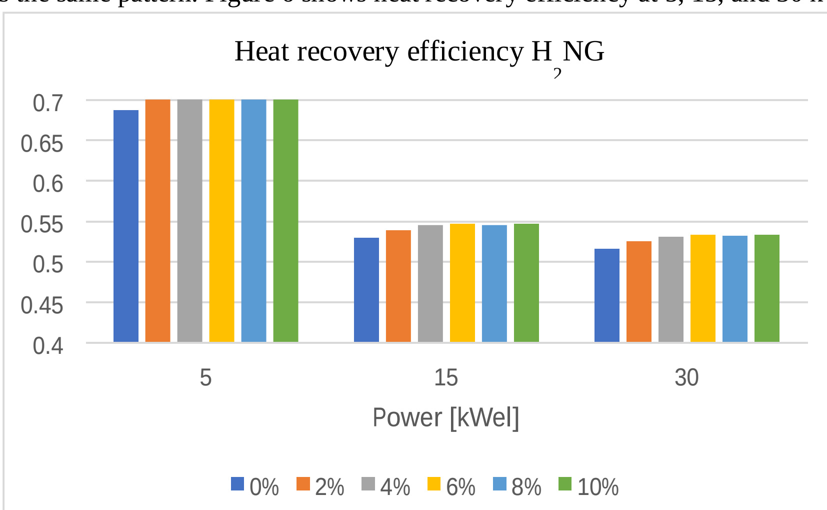

Fig. 6. Change of heat recovery rate with H2 percent at 5,15 and 30 kWel

V. CONCLUSIONS

The present work models and analyzes a 30 kWel micro gas turbine fed with Hydrogen and Natural Gas mixtures with increasing hydrogen percentages. This research uses MATLAB-Simulink to simulate MGT functioning. Simulations are compared to technical datasheets and experimental campaign data to assure real-world validity. The simulation-reference error is 1.4%. Hydrogen doesn't modify the cycle parameters, yet it reduces fuel usage, showing the model's accuracy. Up to 10% H2 in the mixture has no influence on the small gas turbine's behavior and significantly boosts its performance.

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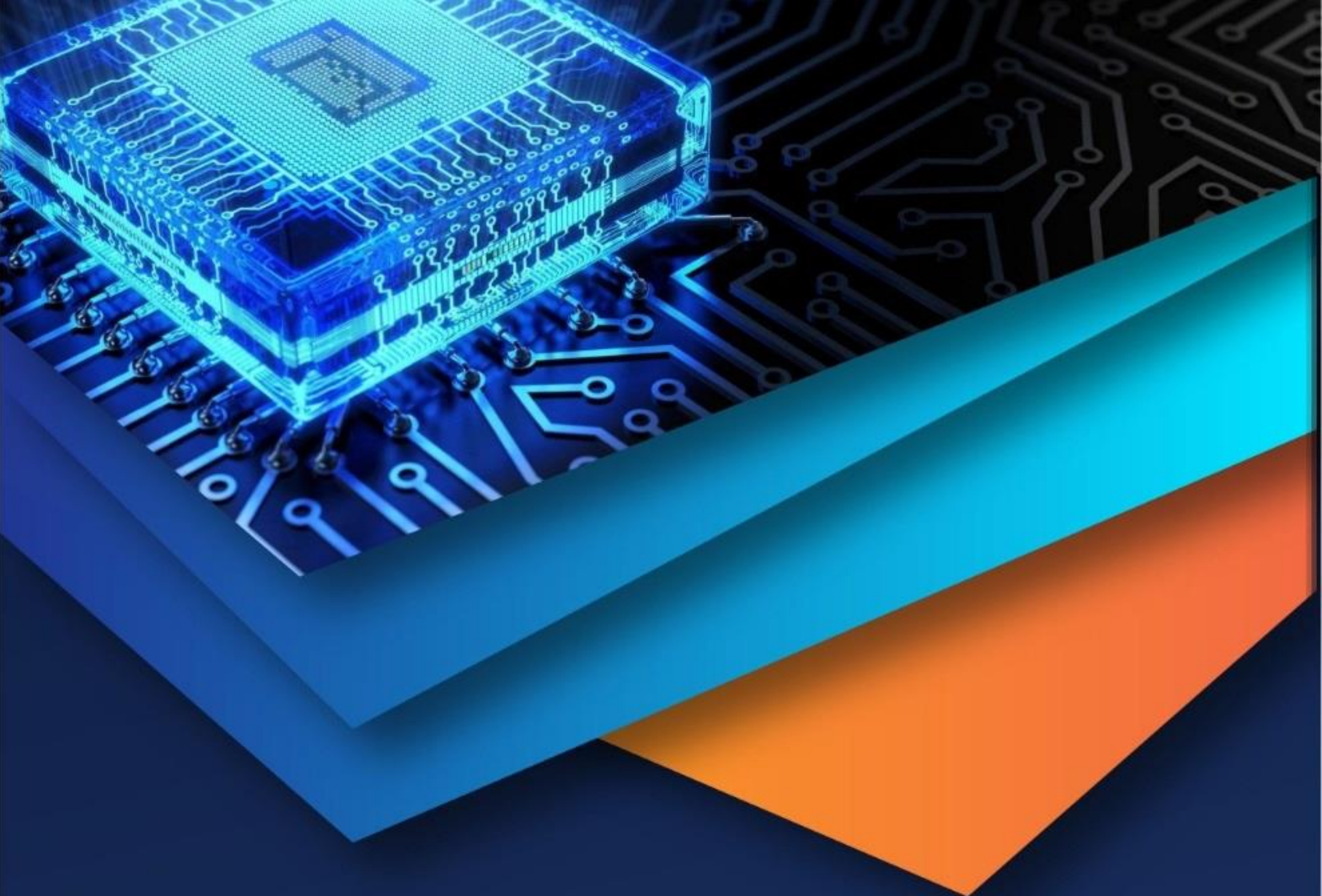

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