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Performance Enhancement of a Serpentine Flow Field Proton Exchange Membrane Fuel Cells Through Channel Geometry and Operating Condition Optimization

Kanaparthy Satya Deepak[1], Dr. S. Somasundaram[2]
Department of Mechanical Engineering, NITTTR Chennai, India

Abstract: This type of fuel cell that has received considerable research and development interest is proton exchange membrane fuel cells that can operate at relatively low temperatures, have high energy-conversion efficiency, and emit few pollutants. The flow geometry of the reactants plays an important role in their performance along with the operating condition of temperature and relative humidity. The objective of this work is to be an experimental study of the performance of PEMFC as a function of the dimension of the serpentine channel and operating condition. The electrical response of the cell was recorded at various relative humidities, operating temperatures, channel widths and depths. The experiments were carried out in a PEMFC test station equipped with gas supply, humidification and temperature control systems, electronic loading and data acquisition system. The cell performance was evaluated for different test conditions in terms of cell voltage, current, power output, polarization characteristics and power-density behavior of the cells. The experimental results indicate that the reactant distribution, water management, pressure drop and performance of the cell can be improved by having proper geometry and operating conditions of the channel. The optimum conditions for the tested conditions were an operating temperature of 65 °C, a relative humidity of 90%, and a channel width and depth of 1 mm. The results show that the simultaneous adjustment of the flow-field dimensions and operating conditions is a practical method to enhance the PEMFC performance and operating stability for serpentine-flow-field PEMFCs.
Keywords: Proton Exchange Membrane Fuel Cell, Serpentine Flow Field, Flow Channel Optimization, Channel Width, Channel Depth, Relative Humidity, Operating Temperature, Power Density, Fuel Cell Performance.

I. INTRODUCTION

Proton exchange membrane fuel cells (PEMFCs) represent a clean technology for transportation and stationary applications which can operate at relatively low temperature, respond quickly to start-up conditions and operate with clean reactants. They are highly sensitive to operating temperature, relative humidity, flow-field geometry and reactant distribution. The channel size influences the pressure drop, mass transport, and the flow field is serpentine, which helps reactants to be transported and water to be removed. Similarly, the temperature and humidity affect the hydration level of the membrane, proton conductivity and electrochemical properties. Hence, this research experimentally examines the simultaneous influence of channel dimensions, operating temperature and relative humidity in a serpentine-flow-field PEMFC. Operating conditions are assessed in terms of voltage, current, power output, polarization and power-density characteristics to find the optimal conditions for higher efficiency, water management and stable operation.

II. PROBLEM STATEMENT AND OBJECTIVES

The flow field performance and operating conditions of a proton exchange membrane fuel cell are influenced by the flow of the reactants through the flow field. A non-uniform reactant distribution, elevated pressure losses, inadequate water removal, or flooding could occur in the channel due to unsuitable dimensions and may lower electrochemical performance and power output in a serpentine configuration. Furthermore, the reaction kinetics, proton conductivity and hydration of the membranes are affected by the operation temperature and relative humidity. Thus, it is important to maintain an appropriate temperature and humidity level to ensure that the reactants are transported effectively, water is managed properly, and the operation of the cells is stable. The geometry and operating conditions of the flow field have been investigated in great detail, but a combined experimental optimization of the two can be used to improve the performance of the serpentine-flow-field PEMFC.

This research aims experimentally identify optimum channel dimensions and operating conditions to enhance PEMFC performance. The effects of channel width, channel depth, operating temperature and relative humidity on cell behaviour are investigated. The voltage, current and power output are measured with different experimental conditions and the polarization and power-density characteristics are analysed for performance evaluation. From the above observations, suitable geometry of the flow-field and operating parameters is selected to obtain better power generation, water management, and stable operation of PEMFC.

III. LITERATURE SURVEY

Several PEMFC flow field designs such as parallel, serpentine, interdigitated and bio-inspired flow field designs are briefly described. These illustrate some of the ways in which these configurations can affect the distribution of reactants, water management and thermal behavior and demonstrate that the selection of the flow-field can enhance the efficiency, reliability and performance of fuel cells. This paper is a comparison of various flow field configuration of PEMFC, particularly the serpentine flow field [1].

It acknowledges the need to distribute the reactants uniformly, minimize the pressure loss and make the best use of water for cell performance improvement. The research also reveals that for the optimization of the flow field there are a number of geometric and operating factors to be considered [2].

The conventional and emerging flow-field designs are discussed which include parallel, serpentine, interdigitated, 3-D, metal, and bio-inspired flow-field designs. The results reported herein show that the appropriate design changes can enhance the movement of reactant and removal of the liquid-water from the reaction system while not sacrificing the pressure drop [3].

This project aims at investigating the feasibility of the application of serpentine flow fields for thermal management in PEMFC. The results indicate improved coolant distribution, improved heat transfer, improved uniformity of the coolant temperature and improved operation stability compared to the other flow-field configurations. Advanced serpentine configurations are also demonstrated to provide increases in performance [4].

Serpentine flow fields are analyzed with the perspective of thermal management of a PEMFC. Improved delivery, transfer, temp control and stability during operation. The results suggest that more complicated and/or hybrid serpentine designs would allow for the development of more efficient sustainable PEMFC systems [5].

This review deals with the correlation of the flow-field design parameters with the performance of the PEMFC. It takes into account conventional, modified and bio-inspired configurations in terms of reactant distribution, water management and mass transport. The results suggest that optimization of the flow field in a fuel cell can increase fuel-cell efficiency, and that various flow field configurations might be appropriate for various applications[6].

Three-dimensional numerical studies are carried out to compare the performance of parallel serpentine and parallel serpentine-baffled flow field for different operating and geometric condition. Results indicate that, under certain circumstances, the baffled configuration could lead to better gas transport and to lower concentration related losses. The synergy between the operating conditions and flow field geometry on the PEMFC performance is another aspect of the study [7].

This review outlines the possible configurations of the flow channels in PEMFCs for automotive and industrial applications. Evaluation is done on properties of reactant distribution, water management and thermal behavior of parallel, serpentine, interdigitated and bio-inspired designs. The indicates that optimized flow-channel structures can enhance the efficiency, reliability and appropriate application in sustainable transportation applications[8].

The study succinctly outlines several flow field designs of PEMFC including parallel, serpentine, interdigitated and bio-inspired flow fields. These demonstrate how such arrangements can impact the distribution of reactant gases, the thermal characteristics and water management, and that an intelligent selection of the flow-field may lead to better fuel cell performance, reliability and efficiency. In this paper, this is a comparison of different flow field configurations for PEMFC focusing on serpentine flow field[9].

A new flow structure where parallel baffled wide and serpentine flows are present in a combination is studied for enhancing the power density and gas transport. This suggested configuration will improve the distribution of reactants, perform better fuel-cell operations and at the same time minimize the pumping losses. The study demonstrates that by changing the flow field the performance of future PEMFC systems can be improved[10].

IV. PROPOSED SYSTEM

The proposed system experimentally explores the influence of flow-channel geometry and operating conditions on the performance of a proton exchange membrane fuel cell with a serpentine flow field. The experimental setup is comprised of controlled hydrogen and oxygen supply units, humidifier, temperature control unit, electronic load and data acquisition unit. A serpentine flow-field configuration is chosen to ensure more uniform distribution of the reactants and to ensure good water removal from the cell.

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The experiments are conducted by varying the width, depth, operating temperature and relative humidity of the channel and maintaining the flow rates of hydrogen and oxygen in constant value. The cell voltage, current, power output and polarization characteristics are recorded and analyzed for each cell operating condition. Experimental results are compared to establish the optimum operating parameters and flow-channel geometry to increase the power output, water utilization and membrane hydration. The optimization of the experimental results offers a practical way for the evaluation and enhancement of a serpentine-flow-field PEMFC system in terms of performance, efficiency, and operating stability.

V. SYSTEM ARCHITECTURE

The system consists of PEMFC test station, hydrogen supply, oxygen supply, gas humidification, temperature control and electronic loading and data-acquisition modules. The following conditions are assumed for the experimental evaluation: The reactant gases are injected into the serpentine flow field under controlled conditions, the width/height of the channels, the flow rate of the gases, the relative humidity of the gases. The temperature is controlled--and the voltage, current, temperature and power output are constantly measured--in the cell. The recorded data are used to generate polarization and power density curves; the influence of channel geometry and operating parameters on the PEMFC performance, water management and pressure loss is discussed.

A. Hardware Implementation

The experimental set-up is a PEMFC testing station which is being used to test the effect of PEMFC geometry and working parameters on the PEMFC performance. The hardware comprises hydrogen supply cylinder, oxygen/air supply cylinder, pressure regulators, humidification unit, temperature control unit, PEMFC stack, electronic load, voltage and current sensors, data acquisition system and computer to analyze the performance. The anode and cathode are continuously supplied with a stream of hydrogen and oxygen, respectively, under pressure, using pressure regulators. To keep the membrane hydrated, the RH and hydration of the gases are high before entering the fuel cell stack, through the humidification unit. A temperature control unit ensures the required operating temperature and the electrochemical reaction rate and proton conductivity are improved. The serpentine flow field PEMFC is designed to provide uniform distribution of the gas in the channel width and depth, and is aimed to improve the water management. Current is controlled by a electronic load and voltage and current is monitored continuously. The DAQ system collects experimental data and the computer monitors and analyses the performance during the experiment. The performance of PEMFCs with various channel dimensions and operating conditions was evaluated and compared to optimize the operating conditions for high efficiency and stable operations, using polarization curves and power density characteristics.

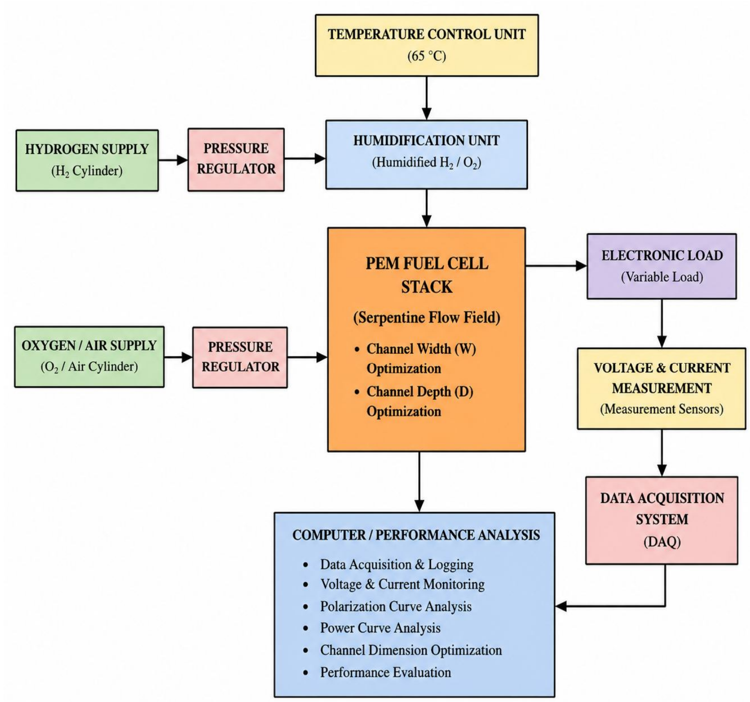

Fig. 1.The proposed system architecture of the experimental optimization of channel geometry and operating parameters.

Fig.1 The system design comprises of the pressure regulators and humidification unit which are used to feed PEMFC stack with hydrogen and oxygen, respectively, into the serpentine flow field PEMFC stack. The cell is kept at the constant temperature of 65°C in the temperature control to promote the electrochemical reactions that take place in the cell. unit. The channel width and depth of the channel is optimized for promoting the distribution of reactants and water management in the fuel cell. The voltage sensors and current sensors sense the electrical data which is recorded by the Data Acquisition system.

B. Software Design and Methodology

The proposed system is an experimental technique using software to monitor, collect and analyses the Performance of Proton Exchange Membrane Fuel Cell under different operating conditions. The experimental setup is interfaced to a Data Acquisition system for the real-time processing and recording of important fuel cell parameters such as voltage, current, fuel cell temperature, relative humidity and power Output.

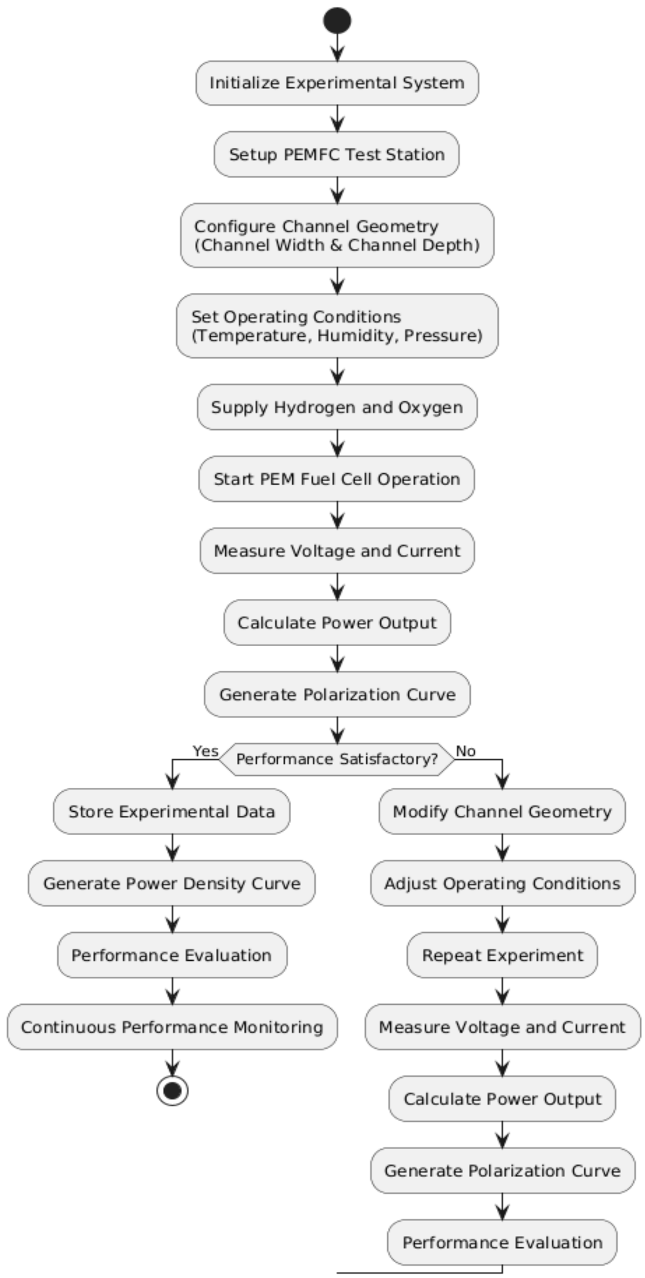

Fig. 2.The experimental optimisation of geometry and operating condition of the channel.

Fig.2 The preparation of the PEMFC experimental system with selected dimensions of the channel and working conditions is the first step of the proposed methodology.Other test conditions are used for electrical performance and a controlled flow rate used for both hydrogen and oxygen. Operating temperature and relative humidity and the channel width are systematically varied, keeping all the flow rates of the reactants constant. Experimental data is collected and then manipulated on the computer to be displayed and compared with performances. Data is collected and performance curves created with software and the electronic load is controlled. The results are then compared to see which combination will optimize the performance of the PEMFC for higher efficiency, stable operation under no fluctuation and good overall performance.

VI. RESULTS

Fig. 3.Hydrogen Gas Generator Used for the PEM Fuel Cell Experimental Setup

Fig.3 The figure shows the hydrogen gas generator, which is used to supply the high purity hydrogen to the Proton Exchange Membrane Fuel Cell for the experimental investigation. The generator provides a steady, continuous and controlled supply of hydrogen gas, allowing for a consistent fuel supply to the anode side of the fuel cell. Efficient electrochemical reactions, stability of cells and better reduction of performance variations requires a constant hydrogen flow.
The hydrogen gas generator also enhances the reliability and accuracy of the experimental measurements by generating the uniform operating condition during the test process.

Fig. 4.PEM Fuel Cell Stacks Used for Experimental Performance Evaluation

Fig.4 The stacks of 3W/10W PEMFCs for experimental study are presented in Fig.4. A series of tests were performed on fuel cell stacks that involves their voltage, current and power characteristics based on different operating conditions.

Fig. 5.Electronic Load Used for PEM Fuel Cell Performance Testing

Fig.5 The programmable electronic load for applying the variable load conditions to the PEMFC during the experiments It has the ability to measure and display voltage, current and power production with various operating conditions. The recorded results are analyzed to understand the polarization properties of PEMFC and overall performance.

TABLE 1. ~3kW Fuel Cell

Voltage (V)	Current (I)	Power (P)
3.67	0	0
S2.56	0.1	0.2 W
1.42	0.2	0.3 W
0.78	0.30	0.2 W

Table.1 the fuel cell performance decreases from 3.67 V at 0 A to 0.78 V at 0.30 A of the current when the cell voltage decreases. But the power output rises to its maximum power of 0.20 A with the current, above which the voltage will drop to 0.2 W at 0.30 A, resulting in reduced fuel cell efficiency.

Fig. 6.Complete Experimental Setup of the Proposed PEM Fuel Cell System

Fig.6 The schematic diagram of the experimental setup for the performance evaluation of the proposed PEMFC system is shown. It comprises of a hydrogen gas generator, the PEMFC stack and a programmable electronic load connected to each other for conducting experimental tests. This set up was used to study the electric performance of PEMFC under various operating conditions.

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TABLE 2. 10W Fuel Cell (10W FC)

Voltage (V)	Current (I)	Power (P)
7.25		0
6.35	0.1	0.6 W
6.82	0.2	1.4 W
6.37	0.3	1.9 W
5.93	0.4	2.4 W
5.60	0.5	2.7 W
5.30	0.6	3.2 W
4.90	0.7	3.5 W
4.86	0.8	3.9 W
4.71	0.9	4.2 W
4.90	1.0	4.9 W

Table.2 Finally, the fuel cell is found to be continuously decreasing in voltage with the increase of current, and power output increases continuously from 0W to a maximum of 4.9W when the current is at its highest point of 1.0A. During the experimental process, the voltage value of the fuel cell decreases gradually, so the voltage value of the fuel cell is relatively constant; the power output increases, the voltage value decreases as the current value increases.

TABLE 3. COMPARISON WITH EXISTING SCHEDULING SYSTEMS

Parameter	Existing System	Proposed System
Flow Field Design	Conventional flow field designs with limited optimization.	Optimized serpentine flow field with improved channel geometry.
Channel Geometry	Fixed channel dimensions without systematic optimization.	Optimized channel width and channel depth for improved performance.
Operating Conditions	Temperature and humidity are maintained at standard values.	Operating temperature and relative humidity are experimentally optimized.
Reactant Distribution	Non-uniform gas distribution may occur, reducing efficiency.	Uniform hydrogen and oxygen distribution through optimized serpentine channels.
Water Management	Possibility of flooding or membrane dehydration.	Improved water removal and membrane hydration for stable operation.
Pressure Loss	Higher pressure drops due to non-optimized channel configuration.	Reduced pressure loss through optimized channel dimensions.
Performance Evaluation	Limited experimental analysis.	Comprehensive evaluation using polarization and power density curves.
Optimization Technique	Individual parameter optimization.	Simultaneous optimization of channel geometry and operating conditions.
Overall Efficiency	Lower fuel utilization and efficiency.	Improved fuel utilization, higher efficiency, and better operational stability.

Table.3 The steady decrease in voltage with increasing current is observed as shown in Table.3 and the steady increase in power output is from 0W to maximum of 4.9W at 1.0A. the larger the current output, the smaller the output voltage, the higher the output power.

VII. APPLICATIONS

Proton Exchange Membrane Fuel Cell is optimized Serpentine Flow Field Proton Exchange Membrane Fuel Cell which is utilized in clean and sustainable energy applications due to its high efficiency, low emissions and enhanced electrochemical performance. It is applied to Fuel Cell Electric Vehicles, stationary power generation and renewable, mobile power. It is used in Fuel Cell Electric Vehicles, stationary power generation, and renewable energy, mobile power. telecommunication back-up power, aerospace and marine. Optimized channel dimensions allow for more even distribution of reactants, water control, increased fuel efficiency/power generation, and decrease in pressure drop. The proposed PEMFC could be a more reliable, durable, and efficient hydrogen-powered transportation system, as well as a smart grid and next generation sustainable energy system.

VIII.CONCLUSION

In experimental research, the geometry and operating parameters of a PEMFC with serpentine flow field were optimized to accomplish highest electrochemical cell performance. The controlled experimental setup was designed and the effect of channel width, channel depth, operating temperature relative humidity was studied in a systematic way. The optimized serpentine flow fields had greater voltage, current and power output figures than the traditional flow field, better water usage than the traditional flow field, less pressure loss than the traditional flow field and better reactant distribution than traditional flow field. PEMFC performance was analyzed by polarization and power density curves, demonstrating an increase in performance and stability of the optimized parameters. Therefore, the proposed optimization method is a promising and economical approach for designing high-performance PEMFCs for the future clean hydrogen energy, stationary power generation and transportation applications.

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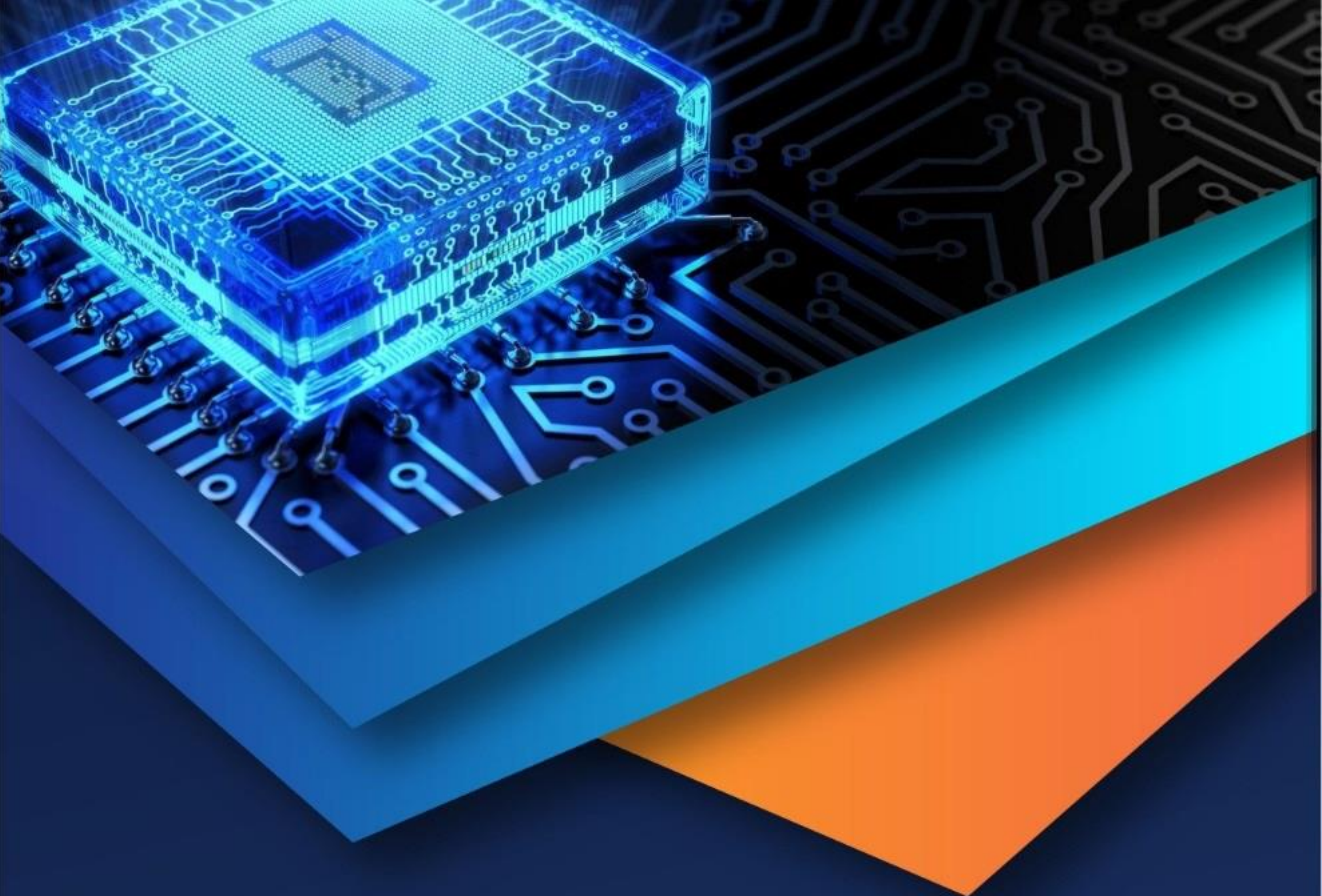

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