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Distribution Voltage and Output Power Sharing Control for DC Microgrids using Fuzzy Control and Gain-Scheduling

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Abstract: A dc microgrid has gained popularity in recent years due to dc sources such as solar panels, fuel cells, and batteries. Interconnections can be made without AC to DC conversion, which improves system efficiency. Furthermore, when a utility grid is experiencing voltage sags or blackouts, A continuous supply of high-quality power is possible. Parallel operations have been proposed with several types of droop controls and microgrids, including DC and AC, were also used in some cases. Sharing the storage unit outputs via a gain scheduling scheme would result in unbalanced storage energy. Therefore, this research integrates fuzzy control with gain-scheduling techniques to create a new voltage control system that can both share energy and optimize power consumption. A microgrid consists of a variety of distributed energy sources used for the energy storage system. Fuzzy control is used to maintain power quality. Controlling fuzzy is based on different rules with the goal of maintaining constant droop.
Keywords: droop control, gain-scheduling control, energy storage unit, fuzzy control, power-sharing

I. INTRODUCTION

The adoption of DC microgrids in a smart grid environment is gaining considerable momentum. In DC microgrids, tight regulation power electronic converters provide good stability. Active damping solutions can stabilize a controlled voltage-source converter (VSC) that connects a DC microgrid to an AC power system [1]. Active damping signals are used to reshape the VSC impedance using the voltage-oriented VSC interface's outer and inner control loops. To measure the stability of the system, a small signal analysis is conducted [2]. Additionally, different compensation schemes are used to derive the reshaped source impedance and modified tracking dynamics of the VSC interface. Sensitivity and sturdiness analyses are conducted to assess interactions between active damping and voltage tracking controllers [3].

A multiterminal VSC-HVDC system experiences nonuniform variations in DC bus voltage after the DC grid flow changes. With instant balancing power, the DC voltage droop effect occurs with MTDCs using DC voltage droop control. On the dc grid, the dc voltage droop constant determines whether dc voltage drops affect balancing power allocation [4]. A logical expression is resultant to estimate the distribution of balancing power, taking into account drops in dc line voltage. There is no distortion to the grid voltage or nonlinear or unbalanced loads with this controller [5]. A great number of harmonics can be dealt with simultaneously with the repetitive control technique. Current controllers are designed by Hα control theory to combine an internal model and compensator to achieve stabilization. What appears to be the stabilizing compensator is nothing more than an inductor. As a result, the total harmonic distortion will be very low (THD) and tracking will be very accurate [6,7].

Comparing the proposed deadbeat controller with outdated proportional-integral, proportional-resonant, and predictive controllers are used to demonstrate the improved performance. Grid-connected experiments are used to evaluate control strategies for different scenarios [8]. There are no steady-state or transient responses in these cases, whereas steady-state responses do exist with disturbed resistive or nonlinear limited loads. Constant power loads (CPLs) play a role in microgrid stability problems [9]. In DC microgrids, instantaneous line-regulating converters serve as instantaneous points of load, as is typical of distributed power architectures. A constant-power load introduces a destabilizing effect that can cause oscillations or a collapse of the main bus voltage in dc microgrids [10].

The parallel connection of two single-phase inverters constitutes the system presented here. The control technique uses average instantaneous current-sharing control that entails interconnection between inverters for material sharing [11].

o improve the usage of power and current resources in a condition in which the line impedance of the inverters differs, adaptive gain scheduling is made known to the controller. They illustrate the adaptive gain-scheduling methods which introduce to enhance the routine of conventional controllers by allowing their current and power sharing among inverters under conditions of different line impedance [12].

Using a control scheme, a PV-diesel microgrid is operated in three phases without a storage element. To achieve these goals, the scheme tracks the maximum power generated by the PVA, regulates the load voltage, compensates for unbalances in load view by the diesel generator, and controls the diesel engine speed [13]. As part of the system interface, the PV array is controlled with a pulse width modulation inverter. A variant of the diesel engine's fuzzy logic controller is used for the fourth. Certain possible difficulties encountered during operation are investigated. For achieving the control scheme objectives and ensuring high-quality power under all operating scenarios, two different operation strategies are proposed.

It is shown that the proposed techniques are effective under a variety of conditions. By fuzzing the rules of hill-climbing search methodologies, the new controller improves them and eliminates their drawbacks [14]. In contrast to conventional hill climbing techniques, fuzzy-logic approaches provide profligate and precise convergence to the supreme operating point in steady-state conditions as well as those affected by varying weather conditions. A microgrid is a new concept for facilitating the installation of many distributed generation systems [15].

II. DC MICROGRID

Due to the decrease of greenhouse gases and the reduction of fossil fuels, distributed generation (DG) installation has dramatically increased in recent years. DC microgrids can provide uninterrupted power whenever utility grids experience voltage dips or blackouts aside from reducing ac/dc conversion losses. As an example, dc power supplies are frequently used in internet data centers and telecommunication buildings that need high-quality power. Droop controls are proposed in a variety of manners for parallel operations, which some have been applied to ac/dc microgrids. The experiment was therefore strengthened by the addition of another energy storage unit and the implementation of gain-scheduling control as droop controls.

Even though two energy storage units were used to share output power, the proposed system operation still required storage energy control. Due to the reduced conversion losses of inverters between dc output sources and loads, efficiency in this system increases. Reactive power and utility grid synchronization is unnecessary. A utility grid blackout or sag will not adversely affect the dc bus voltage of the dc microgrid since the dc capacitor stores energy and the ac/dc converter controls voltage. The DC system, consequently, has DGs which are difficult to trip against these disturbances. DC microgrids can ride through faults on their own.

2.1 DG Interconnected Units

A double-layer capacitor (EDLC) was used for energy storage in our experimental system. In the intentional islanding mode of the system, EDLC switches from dc to dc when each dc/dc converter is operating. The interconnected operation of DG units is shown in Fig.1.

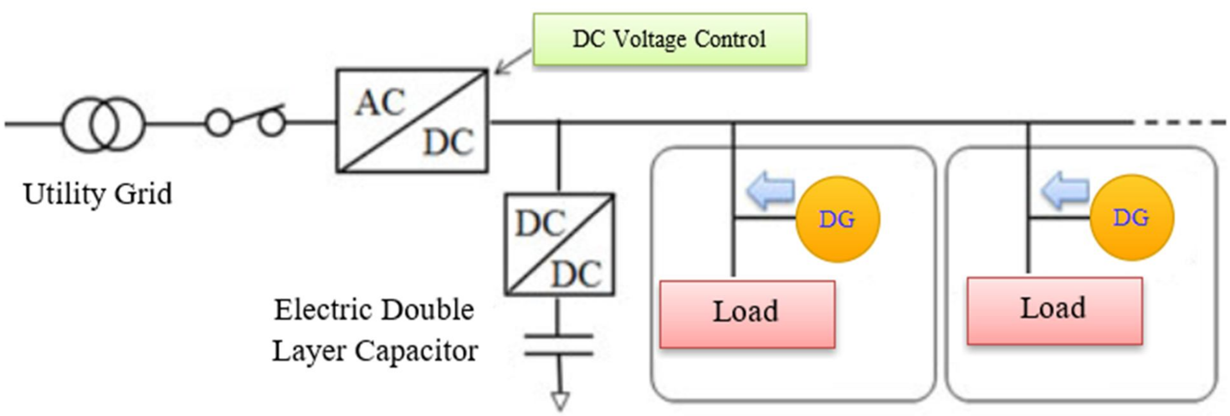

Fig. 1 Interconnected operation

In the event of a utility grid disconnect, the excess or deficient power is compensated by the EDLC. EDLC converters control the dc distribution voltage in intentional islanding operations. Despite the high load consumption, the number of operating micro-CHP units is determined by both the stored energy in the EDLCs and the load consumption. The micro-CHP units are automatically stopped when the stored energy reaches a certain limit.

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III. FUZZY LOGIC CONTROLLER

Several products, from washing machines to video cameras to automobiles, utilize fuzzy logic for controlling chemical processes, manufacturing, and other aspects of their operations. There are many types of linguistic variables; they can represent measurable quantities, such as temperature, the temperature error rate of change, distance, speed, angle weight, etc. Many concepts can be linguistic variables. A pair of crisp values belong to the same linguistic variable set, or a linguistic variable is true to a set to the same degree.

There is a degree of membership ranging from zero to one. Fuzzy sets are sets that allow partial membership states. Sets with a crisp membership state have only two states; inclusion and exclusion; sets with a fuzzy membership state allow differing degrees of membership. In membership function (MBF) graphs, crisp values are represented according to the degree to which they are associated with given fuzzy sets. Members of a linguistic variable are plotted in a membership function. Crisp values are discrete physical quantities with which instruments can be used to measure inputs or outputs. Sensors and instruments are the most common sources of crisp input values.

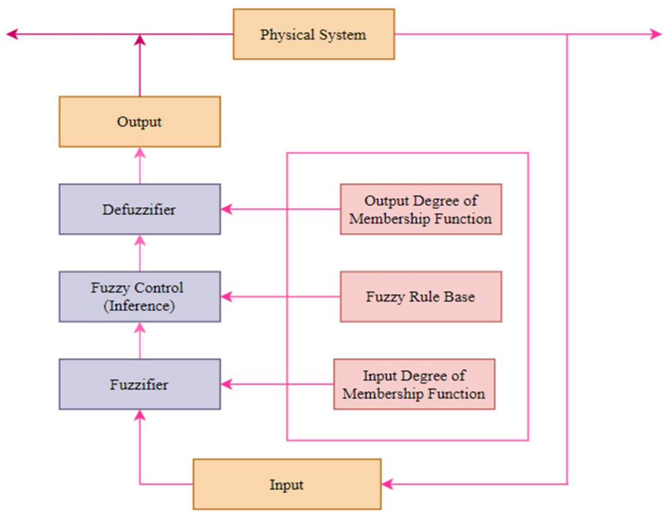

Fig. 2 Basic structure of the typical fuzzy system

Fig. 2 represents the structure of fuzzy system. Fuzzification, which involves the conversion of crisp (numerical) values into fuzzy values, is the first step of fuzzy logic. Through input membership functions, the real value of an input device can be fuzzy and analyzed. Simple geometric figures such as isosceles triangles, trapezoids, and other shapes are the membership functions. Defining their widths and overlaps between the sets is crucial to the positioning of input membership functions. Linearity may affect the overlap of membership functions.

Using a set of linguistic control rules, the rule base describes the domain's control goals and control policy. Generally, the concept of inference is based on matching facts with rules, firing the matching rule, and then deriving new facts. The process is essentially the same in fuzzy logic, but with the addition of firing matched rule pairs, everything becomes a matter of degree. Inference blocks comprise if-then statements for determining membership functions. When a condition is met, the antecedent becomes the antecedent and when a condition is met, the consequent becomes the consequent. Control applications usually start with an error or error rate based on sensor readings, then follow up with control commands. Fuzzy logic systems undergo defuzzification as the third step. Numerical values are given to fuzzy variables. The output variable may be an electrical voltage or current. The composite moment or centroid method is the most common defuzzification technique. The outcome is derived from the center mass of the composite set.

IV. GAIN-SCHEDULING CONTROL FOR OUTPUT POWER SHARING

It is difficult to achieve both good voltage regulation and voltage sharing simultaneously when a dc voltage is controlled by several converters. A higher dc gain is needed for better voltage regulation, but this will mean decreased load sharing. The control diagram to obtain the relation between the error and the gain is given in Fig.3. So, it is necessary to employ a gain-scheduling control that maximizes voltage regulation and load sharing by changing Kc according to output power.

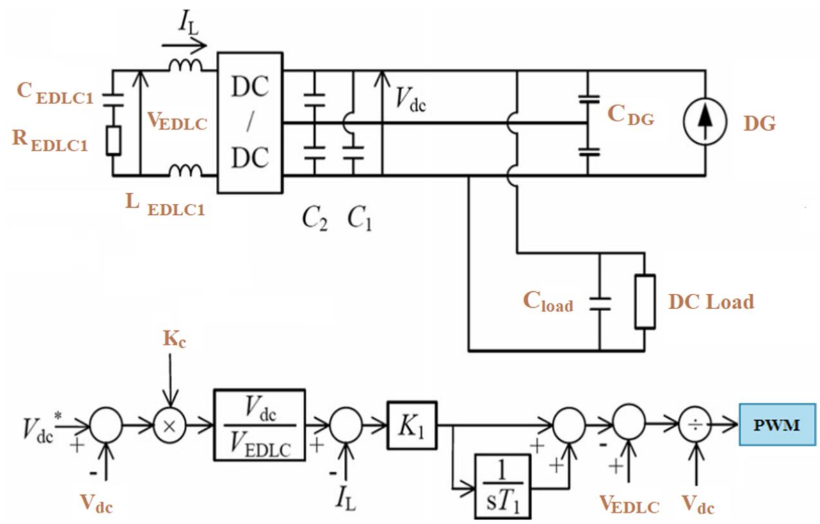

Fig. 3 Circuit and control diagrams to obtain the relation between the steady state error and the gain Kc

340 V and 3 kW were the voltage and capacity rated outputs, respectively. When the load is heavier or the gain Kc is smaller, the steady-state error of the dc voltage increases. Within 2%, dc voltage variation can be used to determine the gain Kc and the output power (p.u.). Gain Kc represents a linear relationship between the output power and the gain Kc. The same equation can be obtained when the voltage is allowed to vary within 2% of the input power. Through gain scheduling, it is possible to better distribute load and control voltage at the same time. However, the converter energy storage unit also requires a control system to prevent the excess or deficiency of stored energy.

V. RESULTS AND DISCUSSIONS

DC distribution made use of the intentional isolation mode to operate the voltage. The proposed control can serve both the purpose of regulating dc voltage and balancing stored energy simultaneously. Electrical double-layer capacitors (EDLCs) are necessary for microgrids with a large energy capacity. A fuzzy control method is employed in the proposed system to balance the stored energy in the Microgrid using dc-voltage control. Fig. 4 illustrates the simulation of the fuzzy logic controller and gain scheduling circuit combined. The output of voltage in an Electrical double-layer capacitor is given in Fig. 5.

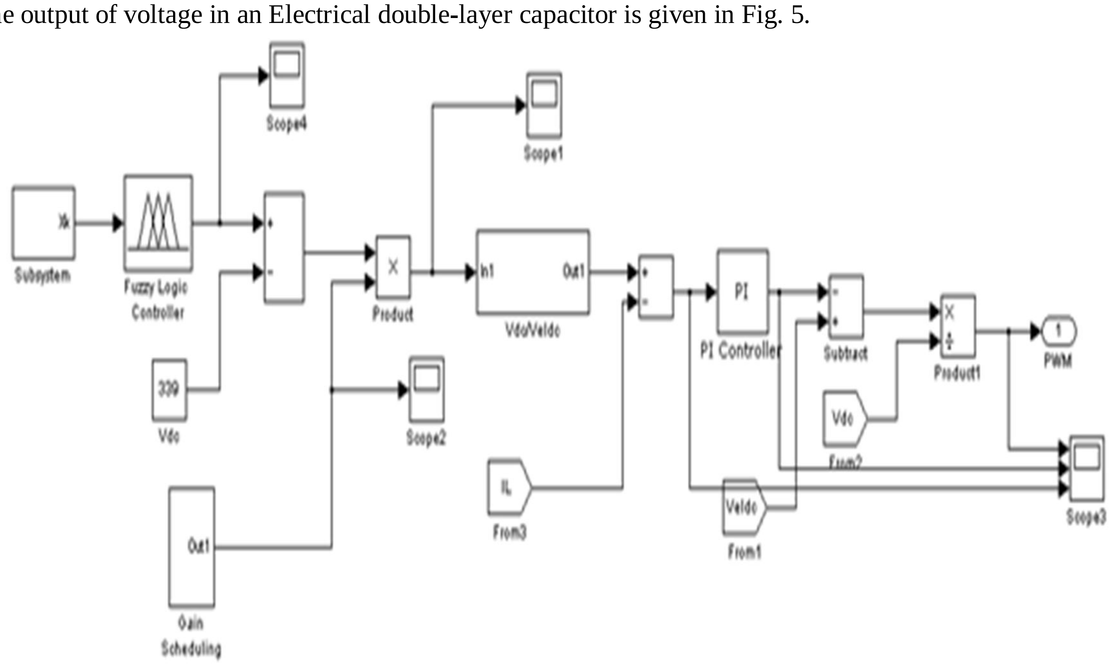

Fig. 4 Control Circuit that combines both fuzzy and gain scheduling

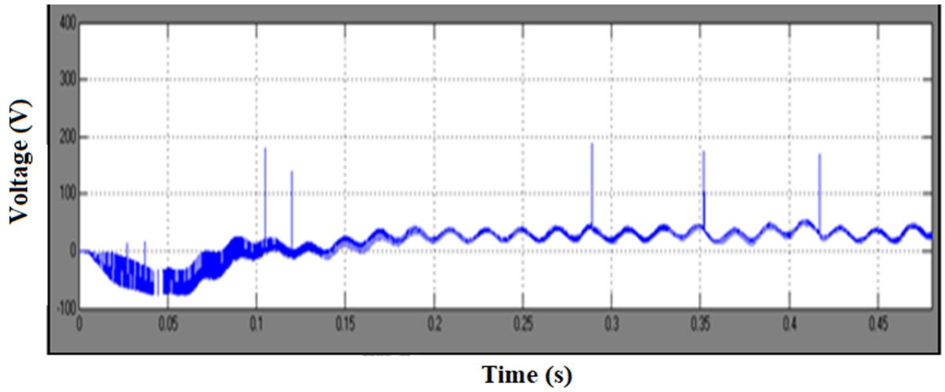

Fig. 5 Output of voltage in Electrical double layer capacitor

The solar characteristics and their output are given in Fig. 6 and Fig. 7. In Fig. 8 the grid output is shown.

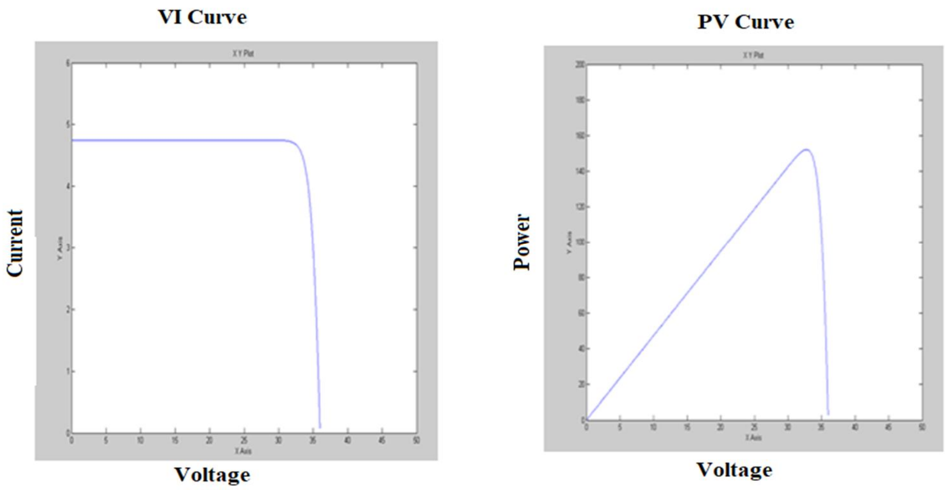

Fig. 6 Solar Characteristics

With the different distributed generation options, the energy demand is well satisfied. Using fuzzy logic control, control of the flow of energy is easily decentralized. With the combination of the energy control circuit, the large value of dc link capacitance is reduced.

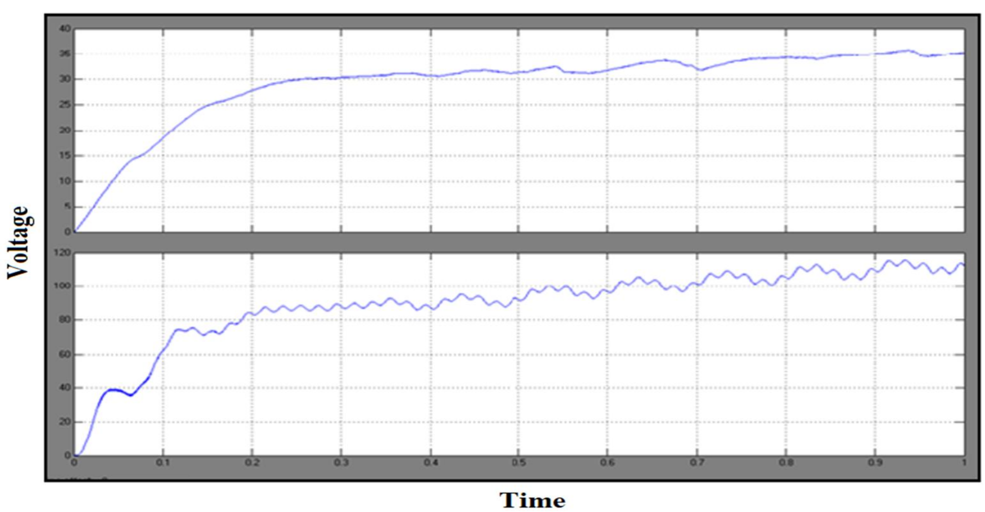

Fig. 7 Output voltage of solar and wind

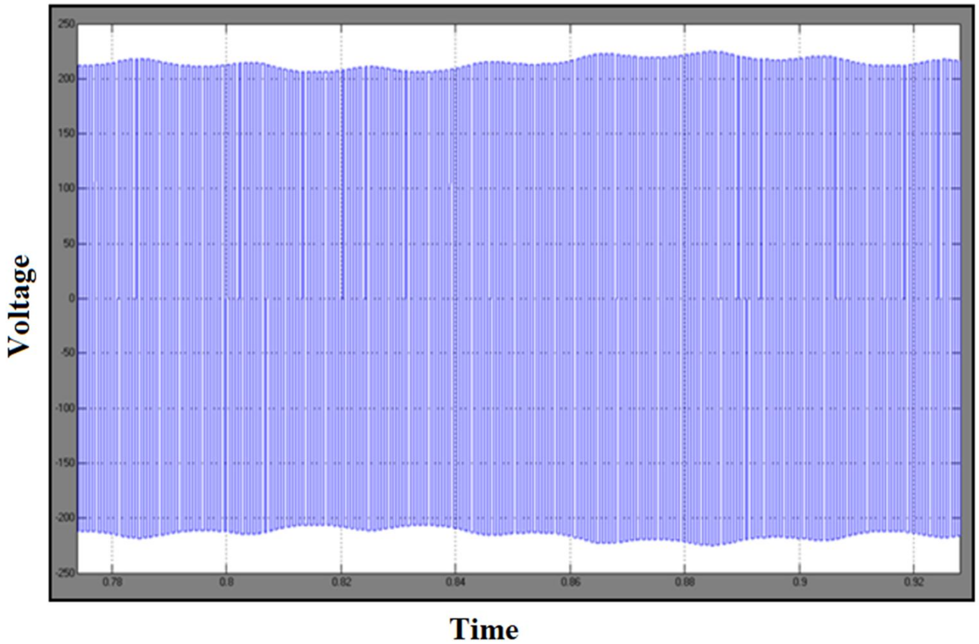

Fig. 8 Grid Output

A droop control strategy will be implemented without an inner control loop and an outer control strategy by using this method instead of EDLC. By reducing inverter conversion losses between DC output sources and loads, system efficiency increases. The dc capacitors and ac/dc converters in dc microgrids store energy when there is a blackout or voltage sag on the utility grid and prevent it from negatively affecting the dc bus voltage directly. DC microgrids are already equipped with fault-ride-through capabilities.

VI. CONCLUSION

In this project, an energy storage unit for dc/dc converters was used to control the distribution voltage of dc power supplies. Gain-scheduling and fuzzy control are combined in the proposed control. As a result of the simulation, dc voltage regulation and stored energy balancing are both achieved simultaneously. In cases where the model is unknown or mathematically complex, the proposed control has a significant advantage. Compared to modern control theories that utilize the time-domain state space representation, the proposed control is relatively simple to implement in real-life applications. The membership functions can be adjusted in practice, however, by using trial and error methods, which is time-consuming.

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Conflict of Interest
The authors declare no conflict of interest.

VII. ACKNOWLEDGMENT

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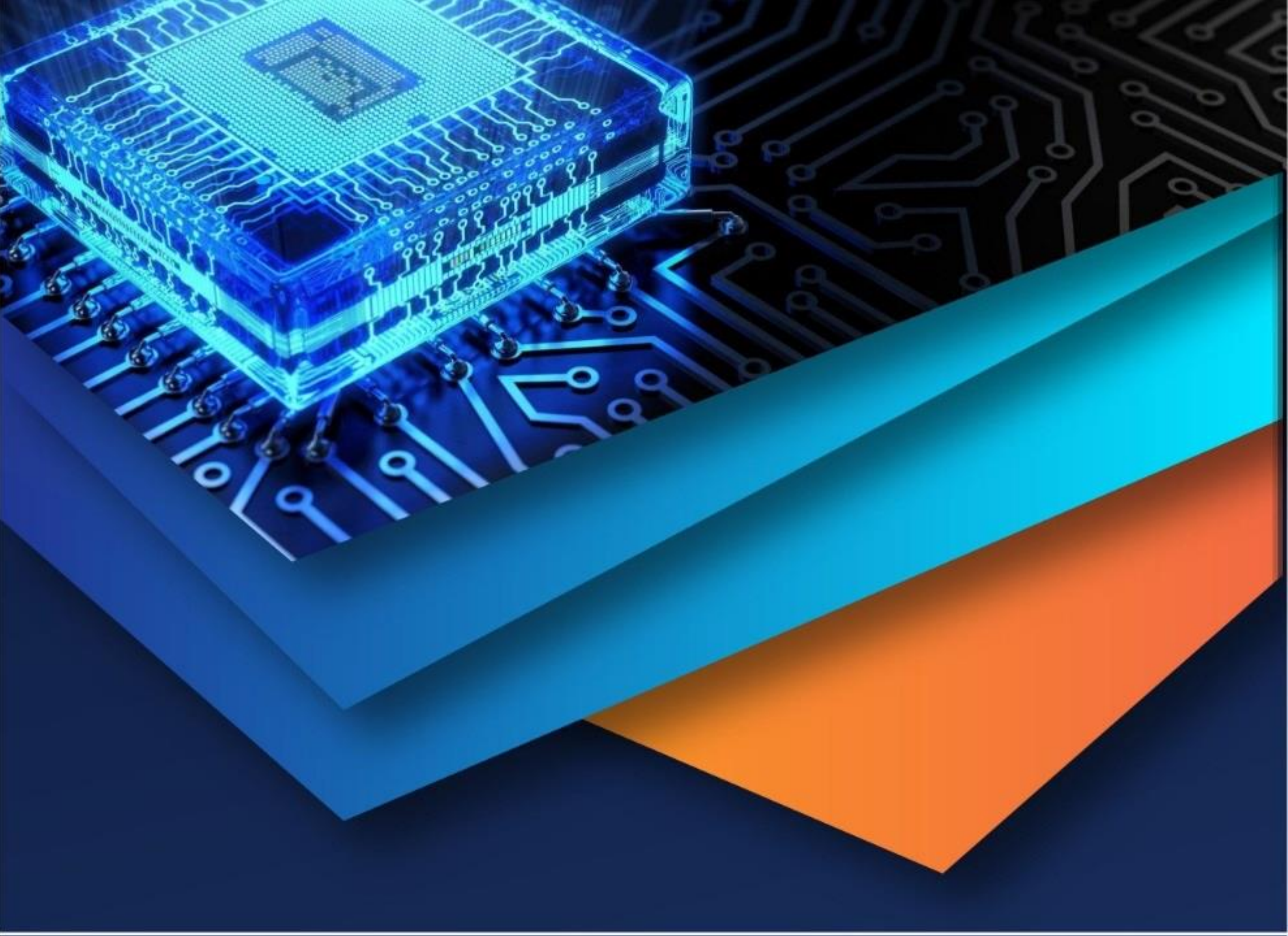

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