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Efficient Methods to Reduce Arc Effects in Circuit Breakers

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Abstract: This paper investigates the opening and non-opening processes of low voltage circuit breakers, the arc effects during short-circuit currents, and seeks to identify practical solutions to minimize potential damage. The reliable operation and protective capabilities of circuit breakers are crucial in power systems, especially during adverse conditions. Arc currents are a significant component of short-circuit scenarios in power systems. Additionally, arc currents typically occur between contacts during the opening of circuit breakers under normal conditions. Therefore, the components of circuit breakers play a vital role in mitigating the current flowing through the system. To diminish the destructive effects of electric arcs on circuit breaker parts, maintaining constant current values in the system is necessary, alongside conducting requisite tests and data collection. Understanding the properties and impacts of the components within the circuit breaker is also beneficial.
Keywords: Circuit Breakers, MCCB, Separator, Limiter, Arc Effects

I. INTRODUCTION

In this study, tests were conducted on three-phase systems of circuit breakers utilized in power systems. By analyzing the effects of arcs in the circuit breakers post-destruction, various features and design improvement models were developed to reduce the impact of this destruction.

The rising use of electrical energy highlights the significance of its sources. With the advent of Industry 4.0, the value of electrical energy has further increased. The seamless utilization of electrical energy is dependent on adherence to specific rules and measures. For safe production, transmission, and distribution, expertise and high-standard equipment are crucial. The human factor and quality standards of materials play a significant role in electricity usage. In electrical systems, the quality of materials is as vital as the energy itself.

The quality of materials and equipment used in the transportation and distribution of electrical energy affects their operational efficiency and lifespan. The longevity of components is linked to their appropriate use in the right time and place. There are internal and external factors that impact the lifespan of components in electrical systems. Internal factors include manufacturing defects and deformations related to the amount of electric current and heat. External factors encompass atmospheric conditions and exposure to mechanical impacts. Control and intervention of internal factors are more challenging and significant, thereby necessitating specialized methods. Electrical safety methods are not yet at an adequate level, hence researchers are working on more advanced solutions.

Deformations in circuit breakers due to internal factors are often observed in the arrangement of transmission elements. Mold Case Circuit Breakers (MCCB), which operate based on the ON/OFF principle, may encounter arcing while switching from closed to open position under voltage or during exposure to short-circuit currents. This can affect the lifespan of the breakers and lead to complete failures. Protecting the system during a short circuit is a crucial task of breakers. Technological advancements, the expansion of interconnected systems, and integrated networks, along with an increase in short-circuit currents, have made the job of circuit breakers more challenging. High voltage levels in power transmission systems have complicated the short-circuit breaking capacity. In this case, maintaining a short breaking duration is essential for stable operation [1].

MCCBs are systems used in high and medium voltage lines to interrupt electric and short-circuit currents. These devices can open and close circuits under load, no load, or during short circuits and also provide manual control. The primary purpose of breakers is to protect people, circuits, and devices. Additionally, circuit breakers stand out with their rapid opening and closing and arc extinguishing features while minimizing adverse conditions in voltage networks [2].

MCCBs can interrupt currents up to 2500A and are larger than MCB types. These devices possess thermal and/or magnetic working principles that allow setting of the interruption current.

Housed in an insulated and molded case, their bodies and covers are made using glass fiber polyester resin according to the EN 60512-20-2 standard. Bulk Moulding Compound (BMC) material, preferred for its high electrical and mechanical values, is capable of withstanding continuous temperatures of 280°C.

Bimetal in MCCBs, allowing for thermal tripping, is formed by joining metal plates with different thermal expansion coefficients and starts to bend due to the heat generated by the current. This bending triggers the opening of the breaker.

Contacts in MCCBs ensure lossless transmission continuity. Breaker contacts, especially during the interruption of short-circuit currents, are prone to wear, and these criteria are considered in their design.

Alloys used in contacts are selected based on current values and structure. Commonly used are silver, graphite, nickel, and tungsten alloy contacts. Soft silver-graphite is used in fixed contacts, while harder silver-tungsten alloys are in movable contacts. Movable contacts are designed convexly to ensure low transition resistance. It is important to maintain low contact resistance and adequate contact pressure, but excessive contact force can lead to rapid wear of the contacts.

Separators within MCCBs, crucial for their operation, are used to extinguish arcs while the breaker is under energy. The arc formed between movable and fixed contacts must be rapidly extinguished. Driven by the magnetic field created by metal plates in the separator, the arc is pulled towards the separators, elongating and thinning it (Fig 1). It breaks apart between the separator plates, and the material on the side walls of the separators emits gas at high temperatures, aiding in extinguishing the arc [3].

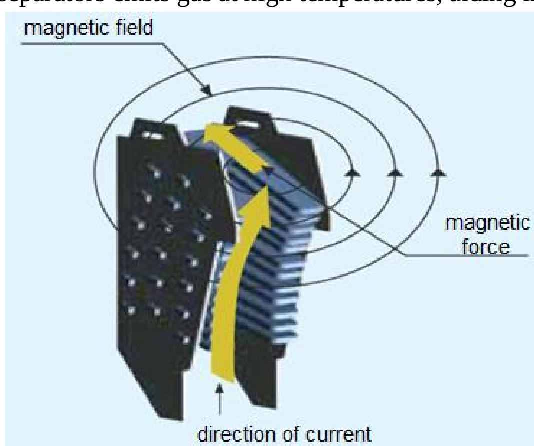

Fig. 1. Seperator

II. INTERRUPTION TECHNOLOGIES IN LOW VOLTAGE CIRCUIT BREAKERS

Circuit breakers play a critical role in the safety of power systems and the restructuring of networks. These devices enhance system and human safety by providing rapid and robust current interruption in the event of faults or undesirable conditions. Low Voltage Circuit Breakers (LVCB) are used in multiple applications, and modeling these devices for improvement is important in terms of analyzing current interruption processes. This enables performance optimization while reducing the costs of prototyping and testing, but it requires in-depth knowledge about the devices and their components [4].

The interruption technologies in LVCBs are based on the formation and extinguishing of electric arcs. These devices consist of main components such as fixed and movable conductors, fixed and movable contacts, arc chambers, and terminals. Separators are designed to divide the arc into smaller paths and extinguish it. Although all circuit breakers have these features, significant differences may exist depending on nominal voltage or current.

Conventional LVCBs include Miniature Circuit Breakers (MCB), Molded Case Circuit Breakers (MCCB), and Air Circuit Breakers (ACB). The general structure of these devices is similar, with some open-type circuit breakers using air to facilitate current interruption. During operation, the geometry of current-carrying parts generates a magnetic force that moves the arc into the chamber. Some designs use coils to enhance this force, while others assist the arc with air blasts.

The arc formation process in a typical Air Circuit Breaker starts with the opening of the main contacts, followed by the opening of the arc contacts and the beginning of the arc movement. The arc is transported to the arc chamber by magnetic forces or blowing coils, where it is divided into several smaller parts by separators. The arc chamber helps cool the arc, extending and narrowing its cross-section, and restores the dielectric strength in the air gap between contacts, thus extinguishing the arc.

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Low voltage circuit breakers primarily use air as the interrupting medium, maintaining it until the next natural zero current in AC situations, or until the arc voltage drop exceeds the circuit voltage in DC situations. Then, the arc is extinguished, which is one of the main functions of the device.

A. The Effect of Limiter Feature on Arc Extinguishing in Circuit Breakers

In short-circuit conditions, alongside magnetic protection, the limiter feature is a vital protection system. This feature, with the U-shaped fixed contact, causes the current to flow in the opposite direction through the fixed and movable contacts. Due to the limiter's feature, a counterforce is created by the magnetic field effect during a short circuit, causing the fixed and movable contacts to separate more rapidly. Without a limiter, this separation takes longer, and the high current passing during this time can damage the circuit breaker and the circuit it protects. Figure 2 shows models of circuit breakers with and without limiters [5].

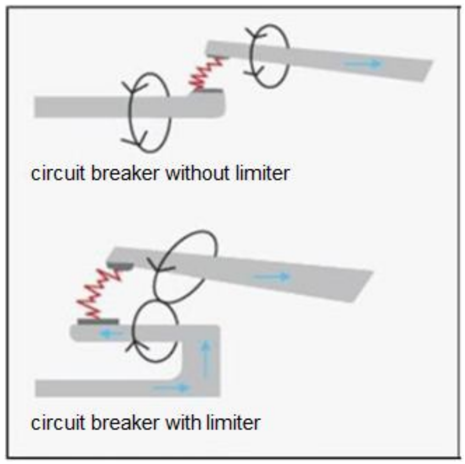

Fig. 2. Circuit Breakers with and without limiters

When electric charges move, they create a magnetic field around them. Magnetic field lines are always closed, but in some cases, they can be thought of as lines moving from an N pole to an S pole. When a charge q moves at velocity v into a magnetic field B in a current-carrying wire, a magnetic force acts on the charge (Figure 3). The velocity of the charged particle is V, and the magnetic flux density is B.

$$F = q(VxB)$$

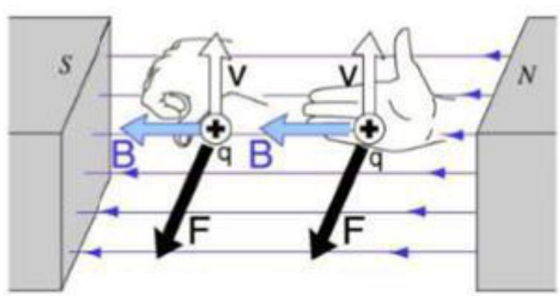

Fig. 3. Magnetic force implementation

B. Factors Influencing Arc Formation in Circuit Breakers

Various design studies and material reinforcement solutions should be developed to minimize the destructive effects of circuit breakers in short-circuit conditions.

In low voltage circuit breakers, it is believed that modifying the designs of the fixed busbars with the limiter feature will change the opening times during short circuits. Improvements in opening times will undoubtedly result in less arc energy. Therefore, comparing circuit breakers with and without limiter features will be beneficial.

The contact pressure distances in movable and fixed busbars play a significant role in the short-circuit performance of circuit breakers. Adjustments made to the busbars or contacts will affect arc formation. Analyzing experimental data related to these components by comparison is necessary.

Regarding the extinguishing of arcs during short circuits, the structure and ideal position of separators are crucial. The geometric design of the sheets in the separator plate changes depending on the ampere values. It is thought that conducting experiments to observe the effect of changes in separators on arc extinguishing, while keeping the amperage constant, will be beneficial.

Conducting or comparing relevant experiments in the IHP test laboratory, examining and interpreting arc effects, and obtaining results for studies aimed at reducing arcing are of great importance for these topics.

III. EXPERIMENTS AND RESULTS

A. Arc Effect in Circuit Breakers with and without Limiters

This experiment compares situations with and without the limiter feature's components, specifically the spring and spring holder, in the circuit breaker. The first experiment was conducted without a limiter.

According to the EN 60947-2 standard, the circuit breaker must successfully complete three maneuvers in the short-circuit test. These maneuvers are, in order, opening and closing twice without interrupting the test current, followed by opening by the breaker. In this test, the circuit breaker was subjected to a 36 kA short-circuit test. The maximum interrupted current value indicates the maximum current value passing through the phases of the circuit breaker. The maximum breaking time is the value that shows the time taken for the circuit breaker to open in milliseconds. The Joule integral value represents the energy values in the phases of the circuit breaker.

There is no structural change in the fixed and movable contacts of the circuit breaker. The dimensions of the fixed busbar contact are 7.5x10x2.25 mm. The dimensions of the movable busbar contact are 9x5x2.5 mm. A 250-ampere non-limiter product was used as the circuit breaker.

In the first sample (non-limiter 250A) experiment, the circuit breaker failed to complete the 3rd Maneuver (under 36 kA). Hence, the experiment concluded negatively (Fig 4 and 5).

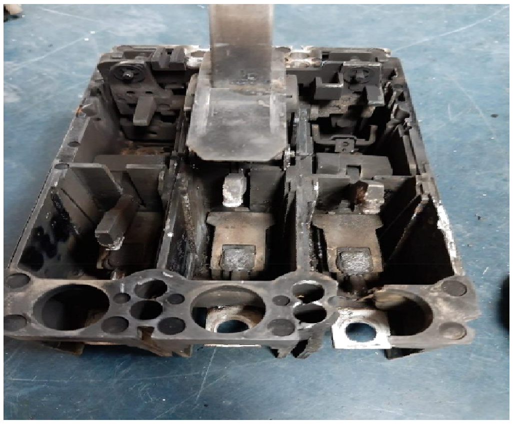

Fig. 4. Damage in Non-Limiter Circuit Breakers

Fig. 5. Damage in Separators of Non-Limiter Circuit Breakers

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In the experiment with the second sample (250A with a limiter), the circuit breaker successfully completed all three maneuvers (under 36 kA). Therefore, the experiment resulted positively (Fig 6 and 7).

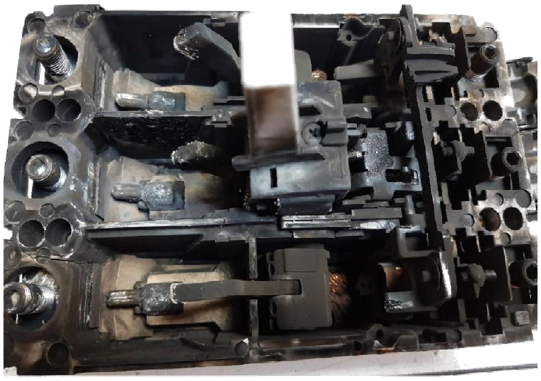

Fig. 6. Damage in Limiter-Equipped Circuit Breakers

Fig. 7. Damage in Separators of Limiter-Equipped Circuit Breakers

The circuit breaker smoothly completed all three maneuvers (under 36 kA) in the test, confirming the experiment's success.

B. The Effect of Increasing Contact Pressure Forces and Distances on Arc in Circuit Breakers

This experiment investigated the effect on arc formation when increasing the contact pressure distances and forces between the movable busbar and fixed contacts in circuit breakers. To increase pressure distances and forces in circuit breakers, the pulley path (the round joint used in the mechanism) must be reduced. The pulley path is related to the triple pressure block mechanism to which the movable busbar is connected.

In the experiment with the first sample, an 800-ampere circuit breaker was used and subjected to a 70 kA short-circuit test. There were no deformations in the contacts and busbars used in the experiment. The existing pulley path diameter of 18 mm was increased to 19 mm in the first sample and reduced to 17 mm in the second sample. These changes will alter the pressure distances and forces, resulting in different arc intensities in the two circuit breakers.

According to the experiment results, the circuit breaker with the reduced pulley path diameter passed the test, while the one with the increased diameter failed (Fig 8 and 9).

Fig. 8. Circuit Breaker with Pulley Path Diameter Reduced to 17 mm

Fig. 9. Sample Separator Damage

C. The Effect of Separator Changes on Arc in Circuit Breakers

Separators play a significant role in extinguishing arc effects in circuit breakers; hence, their structural forms are designed for this purpose. A short-circuit test was conducted to observe the effect of changes in the separator assembly on arc extinguishing.

The existing separator in the experiment contained arc-extinguishing sheets. The sheets are attached to right and left side plates made of a composite, an insulating material. In the first sample, the separator structure and side plate materials were kept constant.

In the second sample, glass fiber-reinforced polyester was used as the raw material for the side plates, and the thickness of the plates was reduced from 1 mm to 0.8 mm.

The experiment results showed that changing the separator side plate material and reducing the thickness negatively affected the circuit breaker (under 50 kA). The separators in the samples experienced significant deformation after the test (Fig 10 and 11).

Fig. 10. Effect of Separator Changes on Arc in the Sample

Fig. 11. Sample Separator Deformation

In the short-circuit test with altered pulley path diameters in circuit breakers, the first sample showed cracking from the top alignment of the R phase on the cover. Upon opening, it was observed that the R phase movable busbar remained in the limiter, while the S and T phase movable busbars did not reach the fully open position and stayed lower.

In the short-circuit test of the second sample, the circuit breaker completed all three maneuvers smoothly. The movable busbars of the R, S, and T phases reached the fully open position. At the end of the test, the breaker was mechanically operational, transmission was present, and there was no damage to the body.

In the short-circuit tests related to the separators of circuit breakers, the sample with 0.8 mm thick separator side plates failed to properly interrupt the current during the second maneuver. The cutting time was around 40 ms. The separator pressboards burned, and the separators disintegrated while trying to be removed. Contacts were melted, and there was no transmission in the R phase.

The breaker with existing separators completed all three maneuvers. After three maneuvers, the separators and fixed contacts were intact. There was transmission in the circuit breaker. Therefore, the separators' side cover raw material provided thermal insulation and was made of heat-resistant composite, effectively extinguishing the arc.

IV. CONCLUSION

Research and comparisons of short-circuit test results have led to effective solutions in reducing the arc effect in circuit breakers. Circuit breakers with limiter features have been observed to perform better and offer higher protection than those without limiters. The reverse magnetic field generated in circuit breakers with limiters more forcefully pushes the movable busbars, preventing arc formation and deformation. This effect enables the circuit breaker to interrupt the current earlier. Early interruption of current in a short-circuit situation not only prevents arc effects but also reduces environmental deformation.

It has been observed that the fixed busbar form with the limiter feature shows a lower energy level compared to the non-limiter. The lower the energy carried by the busbar during a short circuit in circuit breakers, the sooner the breaker interrupts the current. Furthermore, according to observations in short-circuit tests with and without limiters, the limiter-equipped circuit breaker underwent less deformation internally, while the non-limiter circuit breaker experienced more deformation.

Changes in pressure distances and forces in circuit breakers affect arc formation. Increasing pressure distances and forces positively contributes to reducing arc effects in circuit breakers.

The following measures are recommended to reduce arc effects in circuit breakers:

1) Circuit breakers should have movable and fixed busbars with limiter features.
2) Any structural design that increases pressure distances and forces in circuit breakers reduces the arc effect. Hence, this aspect should be emphasized in circuit breaker development.
3) High energy levels in busbars of circuit breakers increase the potential for arc damage. When energy levels are high, the circuit breaker cannot interrupt the current quickly, and the peak current value tends to be higher. Therefore, keeping bar energies low will be beneficial in reducing arc effects.
4) The separator structure among the arc chamber elements of circuit breakers should be examined, and high thermal insulation composite materials should be used in relevant improvements.
5) The bodies of circuit breakers should be designed to withstand arc damage. To prevent any arc jumping between phases, wall thicknesses should be maintained at appropriate values, and sealing should be ensured.

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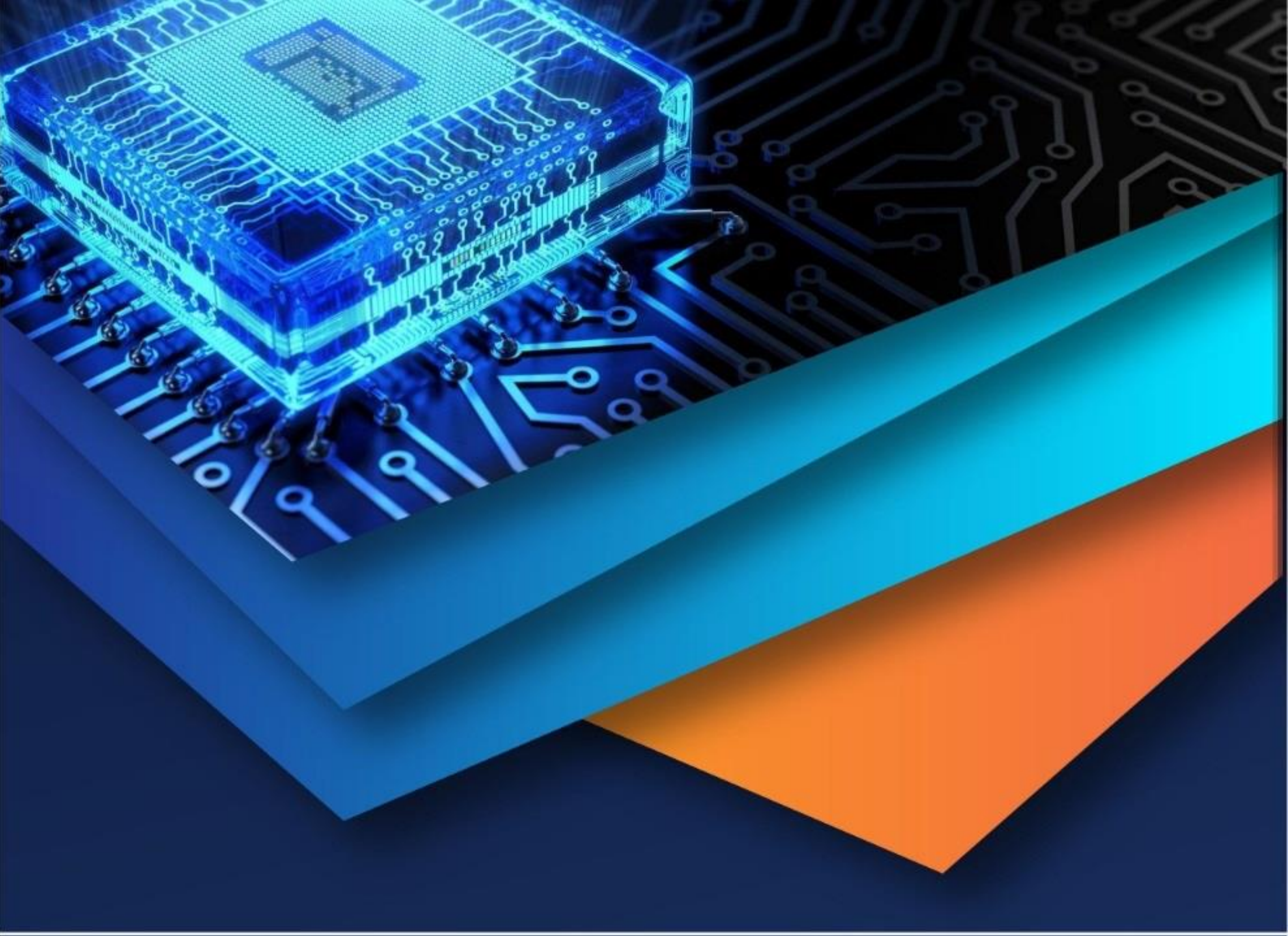

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