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Effects of Creepage distance on Leakage Current of 220kV Long Rod Insulators at Different Severity Level of Salt Contamination

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Abstract: In this paper, effects of creepage distance are examined of 220kv composite log rod insulator during different densities of salt contamination. Insulator is one of the most vital elements of Power transmission system at high voltage. The performance of high voltage insulator is strongly affected by environmental pollution in coastal regions. Long Rod insulator is widely used for good performance in pollution regions. The performance of polluted insulator mainly depends on the conductivity of the polluted surface layer or on the equivalent salt deposition density(ESDD). In this paper Leakage current is evaluated at different ESDD level of salt pollution on 220kV Long Rod insulator of different creepage length. The paper deals with three type of creeapage distance of composite long rod insulator. Model of insulator is obtained by MATLAB and results are carried out using simulink. The leakage current of all three type of composite long rod insulator with different creeapage distance is represented and discussed at different severity level.
Keywords: Creepage distance, Salt contamination, leakage current, Composite Long Rod Insulator, pollution severity, MATLAB/Simulink.

I. INTRODUCTION

In the recent years power transmission demand is abruptly increased. For satisfying the demand of power, transmission companies have had to improve the overall efficiency of transmission lines. The main problem comes arise due to environmental pollution in transmission of power. There are many types of pollution that affects the insulation property of transmission line. These are classified on basis of contaminant substance like- Salt, Cement, Fertilizers, Coal, Dust, volcanic ash, Chemical, Smoke etc. The main types of pollution can be represented as Industrial, Marine, and Desert pollution [1]. Marine pollution is commonly produced by salt particle deposition on insulation surface of insulator situated near coastal region. Near coastal areas most of insulator pollution is occurred due to airborne salt particles of ocean. Small water bubbles are raised up from sea level by ocean waves and storm. Wind is main transporter for these tiny bubbles [2]. These bubbles of sea water distributed uniformly in the air of coastal area. If the humidity is low and temperature is high then these salt carrying bubbles dry up on the surface of insulator and leave crystals of salt particles. Insulators exposed near coastal area are sprayed extremely by the strong ocean winds. The deposition density of salt is mainly depends on the wind velocity and distance from sea coast. Formation of salt particle layer on insulator provides an ideal path for leakage current from line conductor to tower through insulator surface. The presence of Fog, humidity and temperature can cause in increase of leakage current and dry band formation. Partial arcs can occurs across dry bands and further flashover of insulator may occur in bad conditions. The danger of pollution mainly depends on the conductivity of salt deposition layer. The severity of salt pollution is defined in terms of equivalent salt deposited density (ESSD) [3]. The higher ESDD value denotes higher severity as conductivity of surface increases.

A. Long Rod Insulator

In the coastal region Long Rod insulator is preferable than disc type insulator because of their superior antipollution quality. The term ‘Long Rod’ is actually used for specific design of porcelain insulator which was first introduced in Germany in the 1920s as an alternative to cap-and-pin insulator. At that time various disc (cap and pin) type insulator were dominating in electrical over head transmission line insulation [4]. They were replaced by porcelain Long Rod insulator. Insulators of Long Rod- design have been in use in central Europe for more than 60 years. More recently, the advantages of Long Rod insulators have found new places of installation as special interest of long rod design as composite Long Rod insulator [5].
Long Rod insulator is classified as

1) *Porcelain Long Rod insulator:* Porcelain Long Rod insulator is made up of single alumina porcelain structure, to be fired in automatically controlled kilns using oxidizing and reducing atmosphere. Porcelain insulator is heavier and larger in dimensions than composite Long Rod insulator. A porcelain Long Rod insulator is illustrated in fig. 1.
2) *Composite Long Rod insulator:* All composite Long Rod insulators consist of a fiber – glass rod as the mechanically bearing element. Composite or Polymer or Silicon rubber insulator has at least two insulating parts, such as a fiber glass core and a housing equipped with metal end fitting. To compare with the porcelain or glass insulator, it has many advantages and has a development trend. Construction of composite Long Rod is shown in fig.2 The fiber reinforced core, metal fitting and silicone housing can be seen.

Fig.1 Porcelain Long Rod insulator

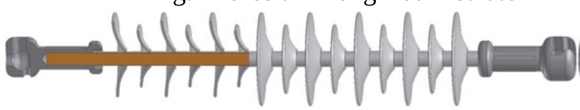

Fig.2 Construction of a composite long rod insulator

There are basic advantages of composite insulator over porcelain Long Rod insulator that is as given below-

a) Resistance to flashover in polluted atmosphere is higher.
b) High performance in contamination and polluted environment.
c) Unique hydrophobicity character & self cleaning property.
d) 10% to 35% weight of ceramic insulator.
e) High tensile strength and unbreakable in vandalism prone area.
f) Easy transport and installation.

In this paper only composite long rod insulator is discussed with three different creepage lengths 5500mm, 6500mm, 7500mm.

B. Creepage Distance

The shortest distance, or the sum of the shortest distances, along the contours of the external surfaces of the insulating parts of the insulator between those parts which normally have the operating voltage between them.

II. SALT POLLUTION MEASUREMENT

A. Determination of ESDD

Equivalent salt deposit density is determined by artificial pollution in laboratory. In order to artificially contaminate the surface of insulator, solid layer method is adopted according (IEC 60507). ESDD is measured by Periodically washing down the pollution from selected insulators with Distilled water. The conductivity of the washed water is measured and the equivalent amount of salt is determined. The composition of contaminating suspension consist of 30gm of kaolin in one liter of de-mineralized water with 0.25gm, 0.5gm, 0.75gm, 1.0gm of salts, the salinity is adopted of 10kg/m^3, 20kg/m^3, 30kg/m^3 and 40kg/m^3. The ESDD value is calculated using the formulation derived by IEC 60507.

$$\sigma_{s20} = \sigma_{V\theta}\left[1 - b(\theta - 20)\right]$$

eq. (1)

Where σ_{s20} = is the layer conductivity at temperature of 20° C (in S) $\sigma_{v\Theta}$ = is the measured volume conductivity at a solution temperature of Θ°C (in S/m)

b = is a correction factor depending on the temperature Θ.

The salinity, S_a of the solution at 20°C is calculated by the equation (2)

$S_a = (5.7\ \sigma_{s20})^{1.03}$ kg/m^3

eq. (2)

the ESDD value is obtained by dividing the measured mg value of salt, by washed area at the insulator surface.

$$ESDD = (S_a V)/A \quad (mg/cm^2)$$

It is observed that ESDD of the insulator increases with pollution accumulation period [3].

B. Relation between ESDD and conduction

Fig.2 shows that for salt pollution from 0.03 to 0.12, the variation of conductivity and ESDD is almost linear [6]. Relation between various ESDD level and surface conductivity is shown in table 1.

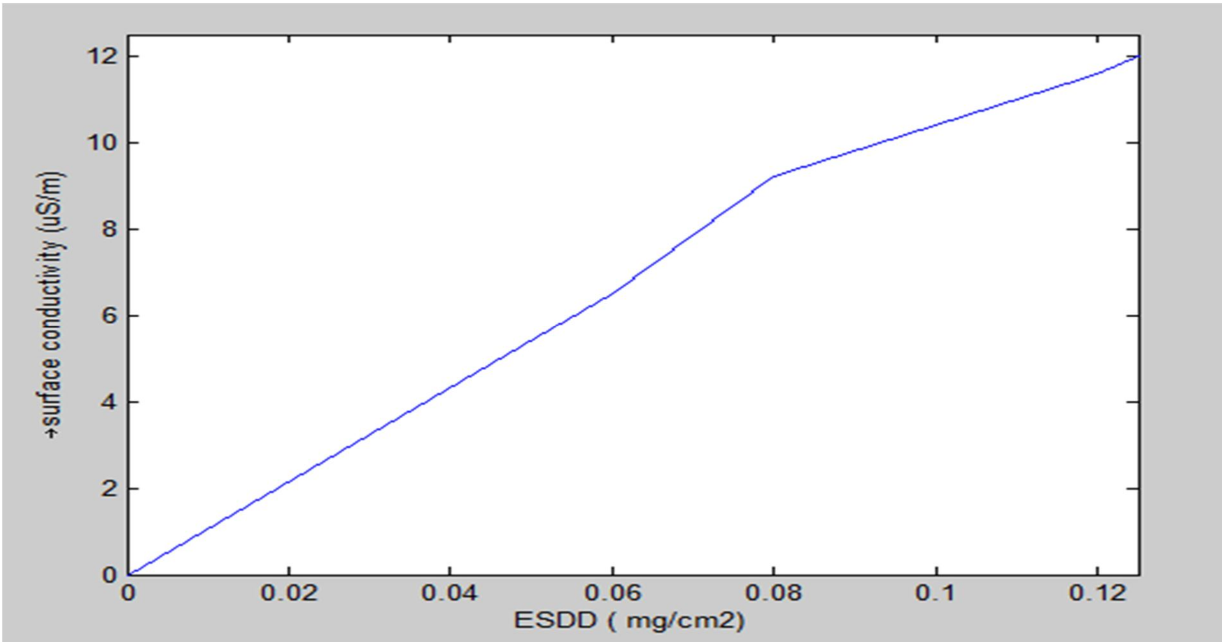

Fig. 2 graph between ESDD & surface conductivity

Table 1 . Conductivity and ESDD of Insulator

NaCl (gm)	ESDD (mg/cm^2)	S_a (Kg/m^3)	σ_{s20} (μS/m)
5	0.03	3.4	3.2
10	0.06	13.5	6.5
30	0.08	59.05	9.2
50	0.12	74.84	11.6
100	0.25	146.67	22.3

It can easily understand that the value of surface conductivity is directly proportion to the salt contamination level. With the help of this table, surface conductivity is known at different ESDD level. So Pollution leakage resistance value for insulator can be calculated for Long Rod insulators at different contamination level.

III. POLLUTION LEAKAGE RESISTANCE FOR LONG ROD INSULATOR

Specifications of parameters of composite long rod insulator are taken from Gem production site catalogue:

Model name	Rated voltage (kv)	Insulation height H (mm)	Creepage distance (mm)	Tensile strength (kN)
FXBW 2 220/160	220	1900	5500	160

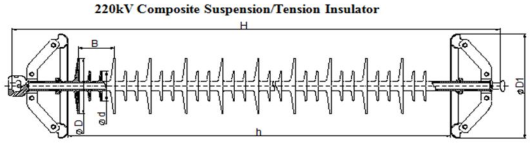

Fig.3 FXBW 220/160 Long rod suspension insulator

This type of insulator has specific creepage distance of 30.6 mm/kV. Specific creepage distance is obtained by dividing the overall creepage distance of an insulator by the highest operating voltage across the insulator. It is generally expressed in mm/kV.

For analysis of leakage current three specific creepage distances are taken of that insulator.

Model	Creepage distance (mm)	Specific creepage distance (mm/kV)
Model 1	5500	30.6
Model 2	6500	36.1
Model 3	7500	41.7

Leakage resistance due to salt pollution can be calculated with the help of conductivity given in table 1. Formula used for pollution leakage resistance is given as-

$$R_p = \frac{1}{\sigma s20} * L/A$$

Where L is the leakage distance of insulator in meter, A is cross sectional area of insulator in m^2. In this paper creepage distance 5500mm, 6500mm, and 7500mm are taken for different specific creepage distance of insulator FXBW 220/160, while diameter of shed is 256mm. By taking surface conductivity from Table.1 and values of L and A of given insulator model, leakage resistance value is calculated for all ESDD level given in Table.1. Accordingly different surface conductivity at different contamination level the pollution leakage resistance is tabulated as below in table 2. for all three insulator model of different specific creepage distance. It is observed that leakage resistance value is decreasing as salt pollution level is increased from low severity to high severity

Table 2. Pollution leakage resistance of Long Rod insulators with different creepage length

ESDD (mg/cm^2)	σ_{s20} (µS/m)	Pollution resistance R_P (MΩ)			Severity (IEC 60815)
		For L_1=5500mm	For L_2=6500mm	For L_3=7500mm	
0.03	3.2	16.696	19.731	22.767	Very light
0.06	6.5	8.219	9.714	11.208	Light
0.08	9.2	5.807	6.863	7.919	Moderate
0.12	11.6	4.605	5.443	6.280	High
0.25	22.3	2.395	2.831	3.267	Very high

IV. SIMULATION MODEL

Long Rod insulator is a single unit insulator; it has no disc connected structure like string insulator. So there is one capacitance representing the whole unit rather than several disc capacitances in a string. In healthy condition there is no pollution and hence no leakage resistance. But in polluted condition a leakage resistance exists across insulator. An equivalent circuit of polluted Long Rod insulator is shown in fig.4

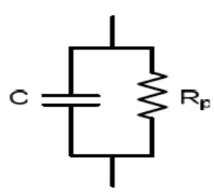

Fig.4 simplified equivalent circuit of polluted Long Rod insulator

The capacitance exist between two end metal fittings of Long Rod insulator is known as self capacitance and denoted as C_1 in model. Beside the self capacitance, air behaves as dielectric between conductor end side of insulator and the tower. This forms earth capacitance or shunt capacitance and denoted by C_2 . Usually shunt capacitance value is taken as 2 pF to 3 pF. In this model value of C_2 is taken as 3 pF , while shunt capacitance value is calculated for composite and porcelain Long Rod insulator separately by taking relative permittivity of composite and porcelain material ε_r=3.5 and ε_r = 6.5 respectively. C_1 = 3.11 pF is taken for porcelain Long Rod insulator and C_1 = 1.67 pF is taken for composite Long Rod insulator.

MATLAB / SIMULINK software is being used for modeling of that model. SIMULINK is one of the powerful modeling tools for modeling and simulation of electrical system. The complete model for measuring the leakage current of polluted long rod insulator is shown in fig.5

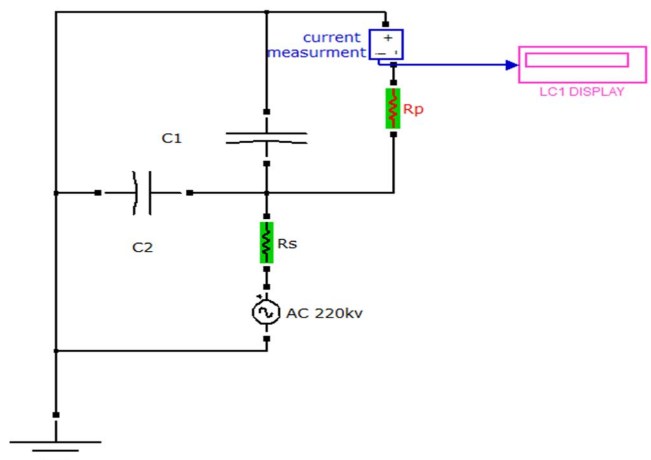

Fig.5 simulation model of polluted long rod insulator

In that model 220kv supply is given with a source resistance R_s = 400 Ω. Leakage current is the current that flows over the surface of insulator that is intended for making rest part of tower non-conducting comparing from the line conductor. So the leakage pollution resistance is connected across the long rod insulator in series of a current measuring element. A display is connected from that current measuring element for taking the readings of leakage current.

V. RESULTS AND DISCUSSION

For all the three composite long rod insulator models of different creepage length, leakage current is obtained during salt contamination of different severity level. Results are tabulated in Table.3 The values of leakage current shown in table.3 are obtained from simulation model of 220kv composite Long Rod insulators of specific creepage distance of 30.6 mm/kv, 36.1mm/kv and 41.7 mm/kv at different level of salt contamination.

Table.3 Leakage current value at different severity level of Long insulator

ESDD (mg/cm^2)	Severity as per (IEC 60815)	For creepage distance L_1 = 5500 mm		For creepage distance L_2 = 6500 mm		For creepage distance L_3 = 7500 mm	
		R_P (MΩ)	LC_1 (mA)	R_P (MΩ)	LC_2 (mA)	R_P (MΩ)	LC_3 (mA)
0.03	Very low	16.696	6.629	19.731	6.172	22.767	5.896
0.06	Low	8.219	15.7	9.714	14.47	11.208	13.69
0.08	Moderate	5.807	17.63	6.863	16.0	7.919	14.02
0.12	High	4.605	32.47	5.443	20.53	6.280	17.83
0.25	Very high	2.395	44.91	2.831	31.72	3.267	27.32

Form the table it is clear that pollution resistance is increased as the specific creepage distance is increased of insulator. But for observing the exact impact of increasing the specific creepage distance on leakage current a comparable graph is needed. A graph is plotted to compare the results of leakage current of composite insulators of different specific creepage distance.

From the graph plotted in Fig.6 it is clearly observed that for low to moderate severity (up to ESDD 0.08 mg/cm^2) , there is no special variation in leakage current of all three type of insulators. Further at higher severity (from ESDD 0.08 mg/cm^2 to 0.12 mg/cm^2) leakage current of long rod insulator having specific creeapage distance 30.6 mm/kV (L_1= 5500 mm) is increased much compare to rest of two insulator having specific creapage distance 36.1 mm/kV and 41.7 mm/kV. At very high severity of salt contamination there is no much relative increment in leakage current of insulators but low creepage length insulator has very high value of leakage current compare to other two insulators. And at higher severity insulator having higher creepage length has minimum value of leakage current but it is not much lower than the insulator of 36.1 mm/kV creepage length.

As shown in figure.6, it is clear from the graph that all values of leakage current during low to high salt contamination are in range of 1-100 mA for all three composite long rod insulator. In other investigations it is found that for disc type insulator the leakage current varies from 100 mA to 1.2A for all contamination level from low to high [7][8].

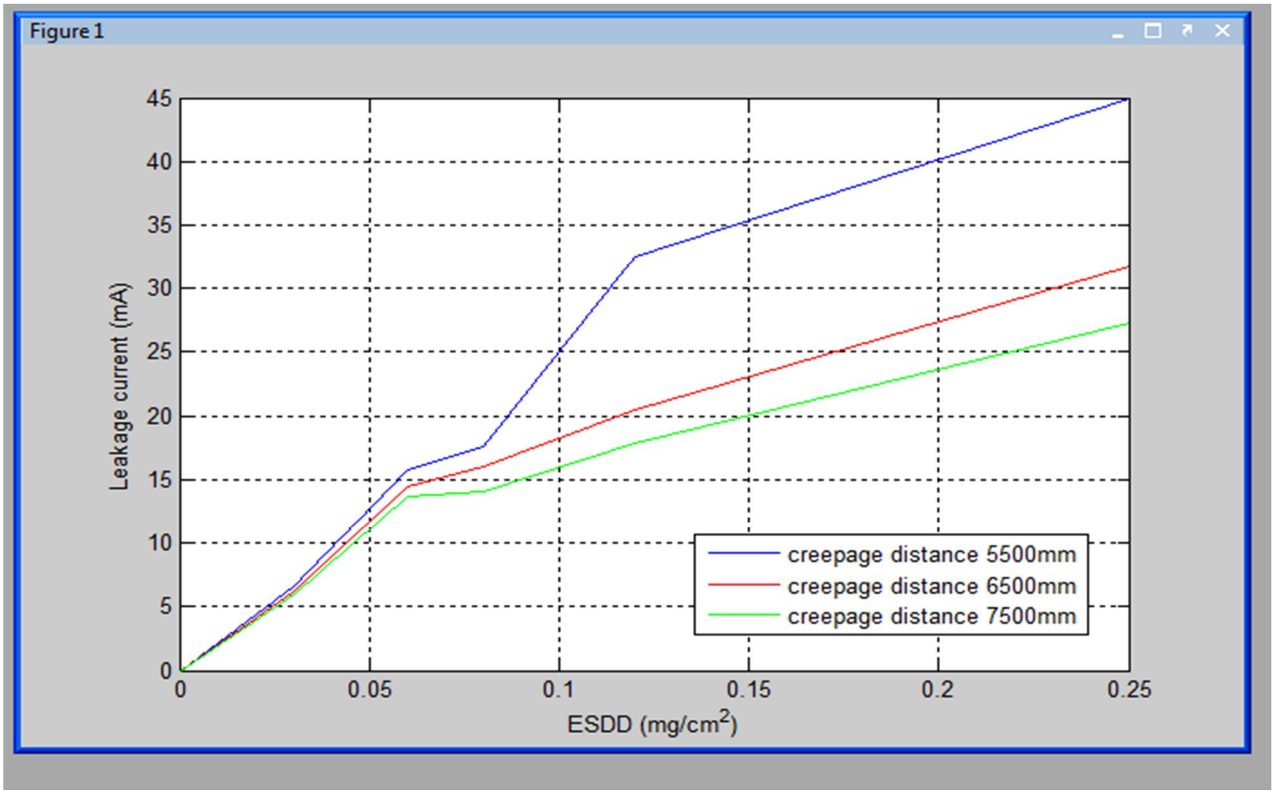

Fig.6: Graph between leakage current of composite long rod insulator having different creepage length and severity of salt contamination

VI. CONCLUSION

In this study , leakage current of insulator having different specific creepage distance is evaluated at different salt contamination level. By observing results It can be concluded that increasing specific creeapage length of long rod insulator is vast advantageous in heavily polluted areas. By increasing specific creepage distance leakage current is reduced to a safe value at higher severity of pollution. Although an economical way should be approached to find out the suitable creepage length of insulator as there is no much difference in leakage current by increasing the specific creepage distance to very high value of 41.7 mm/kV.

It can be generally concluded that long rod insulators having specific creepage distance higher than 36.1 mm/kV for 220kV can be operated more efficiently at heavily polluted coastal area with minimum leakage current. Further work is required to investigate the optimal value of specific creepage distance for minimal loss by leakage current.

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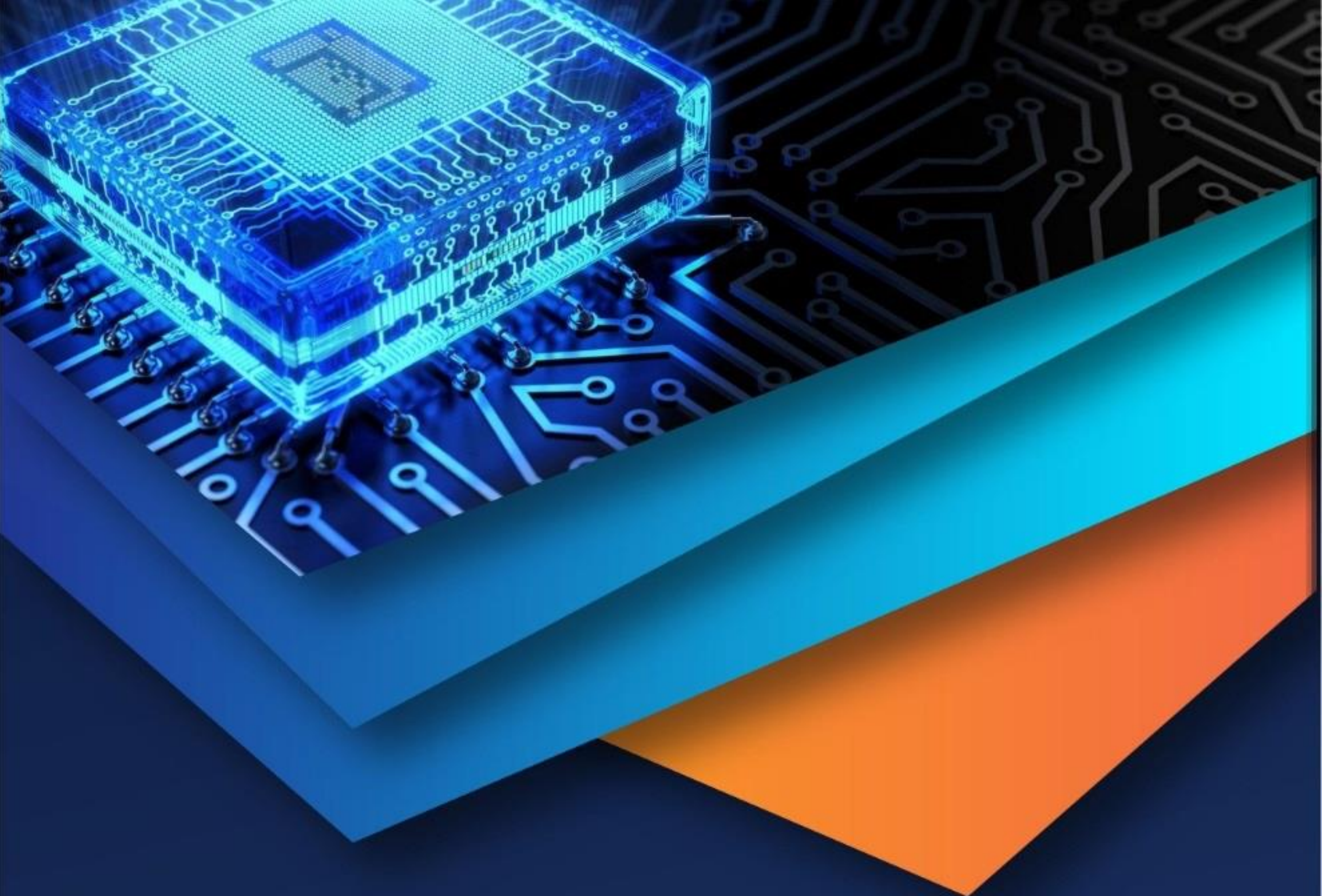

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