# INFLUENCE OF CORONA AND SKIN EFFECT ON THE NIGERIAN 330KV INTERCONNECTED POWER SYSTEM

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## ABSTRACT

The geographical location of Nigeria has made the country prone to natural and environmental hazards, which drastically affect the transmission network in the country. The Northern part of the country is hilly and mountainous, while the Southern part has equatorial climate with high humidity and rainfall. The consequence is ionization of air surrounding the conductor and the generation of skin effect. This paper reviews the adverse actions of corona loss and skin effect on the Nigerian 330KV transmission lines and proffers dependable solution to these problems.

**Keywords:** *Technical loss, Corona loss, Skin effect, Bundled conductors.*

## 1.  INTRODUCTION

The Nigerian power system is largely affected by climatic condition.  The Southern part starts with mangrove forests which is interspersed by a network of rivers and creeks. It transits to tropical rain forest further inland and progresses into savannah region in the North. The climate in the Southern area is equatorial with high humidity and rain fall [1].   Large proportion of the transmission network located in the Southern region of the country experience fog and humidity weather. The Northern areas are  semi-equatorial with low humidity and rainfall. The air in the North is not perfect insulator and contains electrons and ions as a result of  various effects like ultra violet rays of the sun, cosmic rays, radio activity of the soil, etc [2].  These culminated to trigger ionization of air surrounding the conductors. The humidity and the fog weather cause the air surrounding the power conductors to be subjected to electro-static stresses and become conductive [3].

## 2.  CORONA LOSS

Corona phenomenon is the ionization of air surrounding the power conductor   [4] .  It is a phenomena of violent glow, production of ozone gas and hissing noise in an overhead power conductor [5]. Free air surrounding the power conductor is not perfect insulator and contains some ionized particles (i.e. free electrons and positive ions and neutral molecules due to cosmic rays, radioactivity, ultraviolent radiation, sun, etc  [6] when ac p.d is applied across two conductors whose spacing is large compared to the diameters [7], potential gradient is set up in the air between the two parallel conductors, and increase the conducting surface and the velocity of the free electrons, thereby increasing the electrostatic stress in the air.  When the potential gradients reaches or exceeds a critical disruptive value of 30kv cm or 21.1kv (rms)/cm [3, 6, 7] the ions attain a sufficiently high velocity and on striking another neutral molecule, disintegrates one or more electrons from the neutral molecule. This produces a new electrons and positive ion which are in turn accelerated until a complete electric breakdown occurs and an arc is established between the electrodes.  Thus, the ionization process is cumulative to form corona [4, 5, 6].  Corona is noted by a faint luminous bluish discharge along the length of the conductors and at the same time a hissing sound is heard. Corona discharge is always accompanied by production of ozone, which is dictated by its odour.  Increase in the p.d increases the intensity of the glow and hissing and consequently cause spark-over between the conductors.  The corona will be uniform along the length of the conductor if they are smooth and polished. If the conductors are rough the glow will be relatively brighter.  When dc is applied instead of ac there will be a difference in the appearance of the two conductors. The positive conductor will have a smooth glow while the negative conductor will be spotty.  If the spacing is shorter as to compared with the diameters, the sparking will start without visible glow [8].

## 3.  CORONA LOSS EQUATION

The formation of corona is always accompanied by energy losses which is dissipated inform of sound, light, chemical, heat and radio interference. The corona loss affect the efficiency of the transmission line in [4, 6, 9] Peek noted that power loss under fair weather condition due to corona is

$$P_c = 2435 \left[\frac{f + 25}{\delta}\right] \sqrt{\frac{r}{D}} (V - Vd)^2 \text{ X } 10^{-5} \text{ kw/km/phase}\ldots\ldots\ldots\ldots\ldots(1)$$

Where;
  f  =  Supply frequency in Hz
  V  = Phase-neutral voltage (rms) in kv
  Vd = disruptive voltage (rms) per phase in kv
  r  = Radius of conductors in meters
  D  = Spacing between conductors in meters.
The corona losses under bad weather condition may be many times more than that under fair weather conditions.

The above empirical formula derived by Peek has certain limitations and gives correct results if the ratio V/Vd > 1.8, the supply frequency has between 25 – 125 Hz, and the conductor radius is greater than 0.25cm. However, Peterson's formula gives better result when the value of the ratio  V/Vd is less than 1.8 [3,4,6]

i.e.

$$P_c = \frac{21 \text{ x } 10^{-6} \text{ } fV^2}{(\log 10 \text{ } D/r)^2} \text{ x F} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where
  f  =  a factor which varies the ration V/Vd
  V  =  Phase voltage in kv
It has been found out that both equations give different results.
From the Peek's formula, it is clear that corona loss is a function of air density correction factor  δ which appears directly in the denominator of the expression and indirectly in the value of the disruptive critical voltage.

$$Vd = 21.1M_0 \text{ } \delta r \text{ In } \frac{d}{r} \quad KV$$

High value of  δ gives higher losses
∴ Loss is equal to  δ (V – Vd) $^2$. Lower value of  δ gives lower value of Vd. Thus bad atmospheric conditions like rains, hailstorm and snow reduces the disruption critical voltage and hence increases the corona effects.
The Peek's formula also indicate that the conductor size appears at two places;

$$Loss \quad \delta \quad \sqrt{\frac{r}{d}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..2(a)$$

$$Loss \quad \delta \text{ } (V - Vd)2\ldots\ldots\ldots\ldots\ldots\ldots\ldots...2(b)$$

Equation 2(a) shows that loss is proportional to the square root of size of conductor. This implies that increase in the conductor diameter also increases the corona loss. Also, the equation 2(b) implies that Vd is directly proportional to the size of the conductor. Large conductor decreases the factor (V – Vd)$^2$.

## 4.  FACTORS AFFECTING CORONA AND CORONA LOSS
The various factors affecting corona and corona loss include:

### 1.  Surface conditions
Corona also depends on the surface conditions. Rough and uneven surfaces will give rise to more corona loss because unevenness of the surface decreases the value of breakdown voltage.  The value of disruptive voltage is less

and corona effect is dominant. Stranded conductor has an uneven surface and hence attract more corona effect than the smoothened conductor.

## 2.   Line voltage
The line voltage directly affects corona and the corona loss. For lower line voltage corona loss may be absent. But for voltages higher than critical disruptive voltage, corona starts. Higher the line voltage, higher is the corona loss.

## 3.   Atmospheric conditions
The atmospheric pleasure and temperature adversely control the presence of corona. The expression of corona loss implies that it is a function of the air density correction factor value of  δ.  The lower the value of δ the higher the loss. The pressure and temperature together decide the value of air density which affects critical disruptive voltage and the corona loss. The lower the value of critical disruptive voltage the higher the corona loss. For lower pressure and higher temperatures, the value of critical disruptive voltage will be small and corona effect and loss is dominant [9]. Hence in mountain areas the corona loss is high. Corona is affected by the physical state of the atmosphere. In stormy weather conditions, dusty and rainy conditions, number of free electrons and ions are more hence disruptive voltage is lower. This increases the corona loss considerably.

## 4.   Size of conductor
Increase in the conductor size also increases the conductor surface field intensity.  Also from Peek's equation, the corona loss is directly proportional to square root of radius conductor i.e. is $\alpha = \sqrt{r/d}$ the factor $(V-Vd)^2$  is proportional to the size of the conductor. So the loss is more if the size of the conductor is more. But for large size conductors, Vd is more and hence the term (V – Vd) is less. Thus loss is less. The effect of Vd is more dominating than the factor squared hence higher the size of the conductor, lower is the corona loss [3, 4].

## 5.   High Supply Frequency
From the Peek's equation of corona loss, it can be observed that corona loss is affected by the supply frequency. Higher the supply frequency, higher the corona loss. The d.c. corona loss is less compared to a.c. corona loss. Due to corona effect in ac line, the third harmonic components are generated hence actual corona loss is higher [9].

## 6.  Bundled conductors
For higher voltages a single conductor per phase produces large corona loss and consequently large radio interference which affect communication lines.  This can be overcome by using two or more than two conductors per phase. This increases the geometric mean distance (GMD) of the conductors, which increases the disruptive voltage and reduces corona loss [4].

## 7.  Spacing between conductors
Spacing the conductors is an effective method of ameliorating the corona. If the spacing is made very large, corona can be absent. Practically the spacing is selected so that corona is tolerable.

## 8.  Profile of conductors
The shape of the conductors whether flat, oval, cylindrical etc. affects the corona loss. The cylindrical shaped conductors have field uniformity which reduces corona loss when compared to any other shape.

## 9.  Mean sea level
The height of the conductors from the sea level also affects the corona loss. At a very high level above the mean sea level, the number of ion per c.c of air is quiet high. The smaller the clearance of the conductors from the sea level, higher is the corona loss.

## 10.  Load current
As the load current increases, the temperature of the conductors increases and does not allow snow and, dew to deposit on the surface. Thereby minimizing the conductivity of the surrounding the conductor and limiting the formation of corona.  Sequel to the above factors, for the long transmission lines the corona loss per km at various points is obtained.  The net corona loss is taking average of all the values.

## 11. Conductivity of the atmosphere
The conductivity of the air is determined by the number of ions per unit volume of air, the size and charge per ion. At higher air density, the conductivity of air increases and corona loss also increases. Thus, corona loss is higher in hilly areas than in plain areas.

## 12. Heat from load current
Heat dissipated when the conductor is carrying load also contribute to the minimization of corona loss. During the fog and humid weather, tiny dew drops accumulate on the surface of the conductor when the temperature is low, thereby causing large corona loss. At rated load, the conductor become warm and heat from the conductor prevents such condensation and reduces corona losses along the lines [8, 12].

## 5.   EFFECT OF CORONA LOSSES ON THE NIGERIAN 330KV TRANSMISSION NETWORK VIZ
### a.   Increase flow of charging currents
When corona occurs, it increases the effective diameter of the conductor and effective capacitance of the conductor. This action increases the flow of changing current. If the system is grounded, the frequency of currents flowing through the ground and the voltage are tripled.

### b.   Interference
Another effect of corona is its interference with the communication circuits due to electromagnetic and electrostatic induction effects, which tends to introduce third harmonic components. The current pulses generated by corona discharge propagate along the conductor and cause interference with the communication signals. The amplitude modulated broadcasting, aviation, marine, power line carrier, ship to shore SOS, calls, etc, are affected by this interference.  The rate of interference depends on the conductor surface and diameter. Rough conductor surface causes accumulation of airborne particles which become a layer of semi-carboniferous materials on the conductor.

### c.   Power Loss
Among other effects, corona loss reduces the energy delivered and the transmission efficiency of the line. During corona action, non-sinusoidal current is drawn, causing non-sinusoidal voltage drop along the line. Power is also lost through the flash-over in insulator or between phases, resulting considerable damage to the equipment.  Power is also wasted in form of violet glow which is also harmful to the human beings.

### d.   Chemical Action
Production of ozone during corona generates the corrosion of the conductors.

### e.   Bus-bar flashover
Poor design transmission network is prone to corona on bus-bars of substations rated for 35kv and above during normal operation. Corona discharge around bus-bar is extremely bad due to the fact that intensive ionization of the air reduces its dielectric strength, result flashover in the insulators and between phases especially when the surfaces are dirty. The production of ozone due to corona discharge aggressively corrode the metallic components in the substations and the switch gears covering them with oxides.

## 6.   SKIN EFFECT LOSS
Skin effect entails high resistance to alternating current which results in non-uniformity of linkage flux [3,7]. Basically, when direct current flows in the conductor, the current is uniformly distributed across the section of the conductor. But the flow of alternating current in a conductor is non-uniform, with the outer filaments of the conductor carrying more current than the filaments closer to the centre.  Hence, there is higher resistance to ac than dc. This effect increases the frequency and size of conductor is increased. The inner filaments carrying current produces flux that links the outer filaments. The inductance/impedance of the inner strands is greater than outer strands which results in more currents in the outer strands than the inner strands. The energy dissipated in the non-uniformity of flux linkage constitutes skin effect loss.

The skin depth of a copper conductor transmitting a 60Hz signal is approximately 0.75cm [10].  As a result, not much of the current flows in the center of the conductor. This fact is a fortunate one because it allows the aluminum conductor, whose skin depth is root two times that of copper used in transmission lines to be reinforced with a braided steel core without lowering the current carrying capacity.

The internal flux of a conductor produces phenomena known as skin effect. The flux consists of flux lines which are circular and concentric with the conductor surface. This results in flux lines which only link a portion of the conductor's cross section. Therefore the central cross sections of the conductor have larger total flux linkages than the portions closer to the outside of the conductor. This means that a higher voltage will be induced, longitudinally,

in the inside of, the conductor than on the outside. The total voltage gradient, however, must be the same in the conductor whether it is measured along the axis on the inside or along the outer surface.

Consequently, the current will not be uniformly distributed over the cross sectional area of the conductor. Instead the current density will be greater and closer to the surface of the conductor. The ohmic voltage drop is directly proportional to the current density and is larger at the surface. This compensates for the opposite variation of induced voltage and maintains the uniformity of the total voltage change per unit length. Since the ohmic and induced voltages are not in phase, not only will the magnitude of the current vary along the cross section of the conductor, but so will the phase angle of the current. To account for this effect the line resistance value is multiplied by a constant based on the cross sectional area and the current rating of the conductor [10].

## CONCLUSION

The Nigerian Power System installations located in the southern region of the country are vulnerable to incessant ionization of air surrounding the conductors and bus bars due to fog and humidity. Whereas the Northern part is affect by corona due to high level of the conductors and unbundled conductors. Therefore, it becomes comparative to modify the Nigerian 330kv with due considerations on the conductor spacing, bundling of conductors, profile of the conductors, mean sea level and solidify the interconnectivity of the stations via construction of new transmission lines.

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