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Minimizing Corona on Power Distribution Lines Using Optimization by Graphical Method

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Abstract – *Each time Corona phenomenon occur in a transmission or distribution line, it result a high power loss, hence reducing transmission efficiency and profitability in electricity business. It may be practically impossible to eradicate these corona losses, however, efforts must be made towards minimizing its occurrences. Research has proven that increasing the spacing of the three phase in power transmission lines reduce the effect of corona. However, increasing the phase spacing increases the line inductance and hence the reactive power loss along the line which may cause low voltage (or voltage instability) at load centers. This paper will find the exact spacing between conductors of the three phases at which the corona losses will be minimal and at the same time the reactive power lost due to the inductance caused by the spacing will not exceed recognized standard. A cable/conductor sizes of 150mm^2 will be analyzed will be used in the analysis; on using a 150mm^2 size of cable for transmitting 7.5MVA, a conductor spacing of 87cm was found to be the best with corona loss of 2.80kVA/km and a corresponding reactive power loss of 5.28kVA/km. Further increase in conductor spacing will although reduce corona lost, the corresponding reactive power lost will be beyond the acceptable limit.*

Key Words: *minimizing corona power lines.*

NOMENCLATURE

L_c Corona Power Loss (kW/km/Phase)
Q_c Corona Power Loss (kVA/km/Phase)
Q_{cT} Total Corona Power Loss in all 3-ϕ (kVA/km)
Q_L Line Reactive Power Loss (kVA/km/Phase)
f Supply Frequency $(50Hz)$
r Radius of conductor (cm)
d Mean Geometrical Distance Between Conductors of Different phases (cm)
I_L Line Current (A)
X_L Total Line Reactant (Ω)
R_L Total Line Resistance (Ω)
V_{ph} r.m.s Value of the Phases Voltage (kV)
V_{cc} Corona Critical Voltage.
L_R Red Phase Inductance (H/km)
L_Y Yellow Phase Inductance (H/km)
L_B Blue Phase Inductance (H/km)
L Total Length of Line
δ Relative air density

I. INTRODUCTION

Whenever there is a potential difference (PD) between conductors of different phases spaced apart by a distance far greater than the conductor's diameter, it causes the air surrounding the conductors to be under electrostatic stress. If the PD is increased continually, at a certain voltage, a visible faint luminous glow of violet color is observed along with a hissing noise, this phenomenon is known as corona [1], [2]; this is accompanied by the production of ozone gas. This phenomenon is as a result of the insulation breakdown of the air surrounding the conductors. This corona effect or phenomenon is affected by factors that range from working voltage, whether conditions, conductor sizes and the spacing between the conductors of the different phases. Evidence has shown that corona is associated with the following

1. Electric power losses (which depend on the weather condition)
2. Formation of ozone gas which can react with bar conductors causing corrosion.
3. An irregular waveform voltage drop which may cause some interference with nearby communication lines [3].

As a result of these effects associated with this corona phenomenon, efforts must be made to reduce their rate of occurrence and the magnitude of the corona whenever it occurs. Different methods that can be employed to do this include

1. Increasing the spacing between the conductors of the different phases.
2. Using conductors with large diameters.
3. Using bundled conductors.

This paper shall concentrate on the first method of reducing corona. However, the spacing between the conductor must be done with caution; this is because a high the conductor spacing results high inductance of the phases. This high inductance can result high power losses along the line. Hence, a best spacing between the conductors shall be obtain; this spacing shall be at the point or distance where corona is minimum and at the same time the line power loss will also be minimal.

II. MODEL FORMULATION

Corona shall be minimized by minimizing the corona power loss (objective function) subject to certain constraint.

2.1 OBJECTIVE FUNCTION

Of all the effects of corona, the power loss experience after the occurrence of corona can be easily quantify; hence, we can try to minimize the power loss with its occurrence subject to certain constrains. The power loss due to corona during a fair weather is given by

$$L_c = \frac{241}{\delta}(f + 25)\left[\sqrt{\tfrac{r}{d}}\right]\left[V_{ph} - V_{cc}\right]^2 \times 10^{-5} \quad (1)$$

Where

$$V_{cc} = 21.2\delta r \log_e \tfrac{d}{r} \times m_1 m_2 \quad (2)$$

$\delta \approx 1,\quad m_1 \times m_2 = 1.$ (Source [3])

Thus, the reactive power part of the corona loss is

$$Q_c = \frac{241}{\delta} \times \tan(\cos^{-1} p.f)(f + 25)\left[\sqrt{\tfrac{r}{d}}\right]\left[V_{ph} - V_{cc}\right]^2 \times 10^{-5} \quad (3)$$

Assuming the same phase conduction for all phases, the total reactive power loss for the three phase is

$$Q_{cT} = \frac{3\times 241}{\delta} \times \tan(\cos^{-1} p.f)(f + 25)\left[\sqrt{\tfrac{r}{d}}\right]\left[V_{ph} - V_{cc}\right]^2 \times 10^{-5} \quad (4)$$

We can minimize corona from eqn (4) by finding an optimal value of ‘d’, and ‘r’ for which corona will be minimal. This paper shall concentrate on finding the optimal‘d’ while treating ‘r’ as a constant as only $150mm^2$ cable is use for transmission lines.

2.2 CONSTRAINT FUNCTION

IEE and other standard gave a maximum allowable voltage drop of 5% - 7% of working voltage along the line; but this research shall use 5%. Hence, the maximum allowable power loss is $[5\%]I_L V_{ph}$ per phase. But voltage drop along the line is $I_L(R_L + jX_L)$. Therefore,

$$Q_L = I_L^2(R_L + jX_L) \quad (5)$$

The line to neutral inductance for the red, yellow and blue phases of a 3 phase line are respectively

$$L_R = 2 \times 10^{-4}\left[\ln\frac{1}{r} + 0.3466 - j0.6\right] \quad (6)$$

$$L_Y = 2 \times 10^{-4}\ln\frac{d}{r} \quad (7)$$

and

$$L_B = 2 \times 10^{-4}\left[\ln\frac{d}{r} + \frac{1}{2}\ln 2 + j\,0.866\ln 2\right] \quad (8)$$

Considering the yellow phase alone for simplicity, $X_L = 2\pi f L$,

$$Q_L = I_L^2 X_L \quad (9)$$

Assuming the current that flow in the 3 lines are the same, total line reactive power loss incurred in the $3-\emptyset$ is

$$Q_{LT} = 2\pi f \times I_L^2[L_R + L_Y + L_B] \quad (10)$$

Minimizing corona can therefore be done by minimizing Eqn (4) subject to Eqn (10).

III. SYSTEM ANALYSIS

For this research, our analysis will consider a short line of about 24km, 33kV distribution line that feeds 7.5MVA substation at a power factor of 0.9 with an approximate current of 132A flow in each line; (a sub-circuit of Umuahia distribution circuit in Abia State, Nigeria). Information got Enugu Electricity Distribution Company (EEDC) is that the size of conductor used for that circuit is 150mm^2 ($r = 0.70cm$) but we shall also extend our analysis to using 100mm^2 ($r = 0.56mm$) cable size.
For simplicity, we take the yellow phase into consideration alone.

$$V_{ph} = \frac{33kV}{\sqrt{3}} = 19.052kV$$

For a $150mm^2$ cable

Eqn (3) can becomes

$$Q_c = 0.0735[d]^{-1/2}[19.052 - 1.1872 \times 10^{-4}\ln d]^2 \quad (11)$$

The plot of Q_c against d from 50cm to 150cm is given in fig 1.

Also, from Eqn (9), the reactive power loss in the yellow phase is

$$Q_L = 132^2 \times [6.28 \times 10^{-5}\ln d + 2.2419 \times 10^{-5}] \quad (12)$$

The plot of Q_L against d also from 50cm to 150cm is given in fig 2 below.

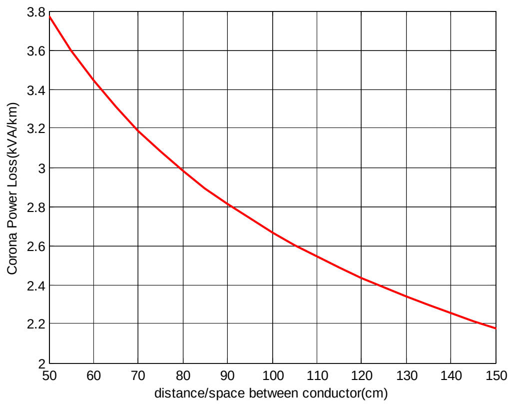

Fig 1.

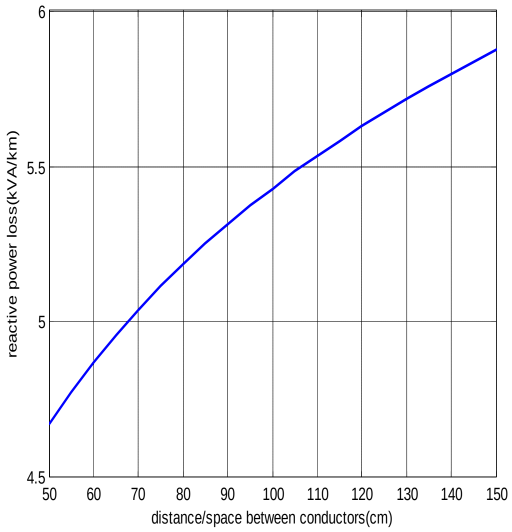

Fig 2

IEEE standard says a maximum of 5% voltage drop can be tolerated. Hence, a voltage drop of 0.21% can be tolerated for the line under analysis.

Form IEEE standard, in each phase the receiving end voltage must not drop below $[V_{ph} - IX_{LR} \leq 0.21\% V_{ph}]$; multiplying both sides of the inequality by the line current I_L, it means that the reactive power loss must not exceed $0.21\% V_{ph} \times I_L = 0.21\% \times \frac{33}{\sqrt{3}} \times 132$ this will represent extreme condition.

Combing the two plots on one plane and taking into account the extreme condition. The plot is given below.

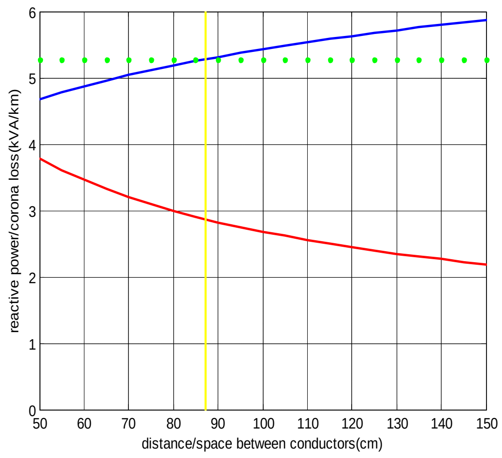

Fig 3.

KEY ON PLOTS

RED: Corona Reactive Power Loss

BLUE: Reactive Power Loss Due to $I_L^2 \times X_{LN}$

GREEN: Boundary or Extreme Point

For a $100mm^2$ cable

The objective function is

$$Q_c = 0.0657[d]^{-1/2}[19.0519 - 9.4976 \times 10^{-5} \ln d]^2 \quad (13)$$

The constraint is given below

$$Q_L = I^2[6.28 \times 10^{-5} \ln d + 3.6424 \times 10^{-5}] \quad (14)$$

The plot of corona loss 'Q_c' and reactive power loss due to $I_L^2 \times X_L$ against 'd' for d between 50cm to 150cm are shown in figures 4 and 5 respectively.

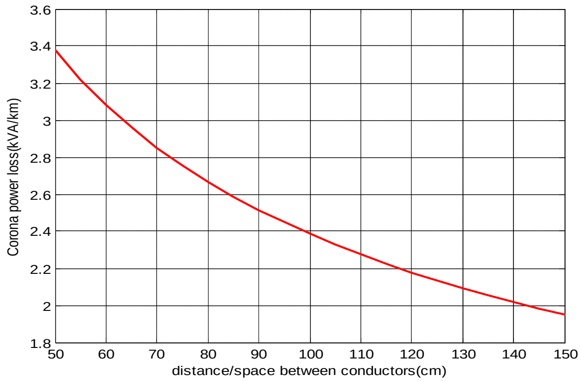

Fig 4

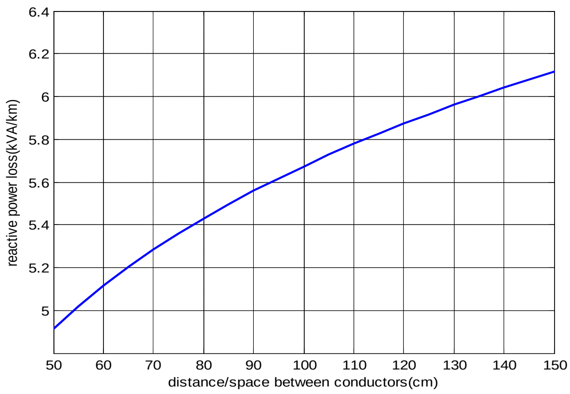

Fig 5

Again, combing the 2 graphs on the same plane and taking into account the extreme condition. The plot is given below

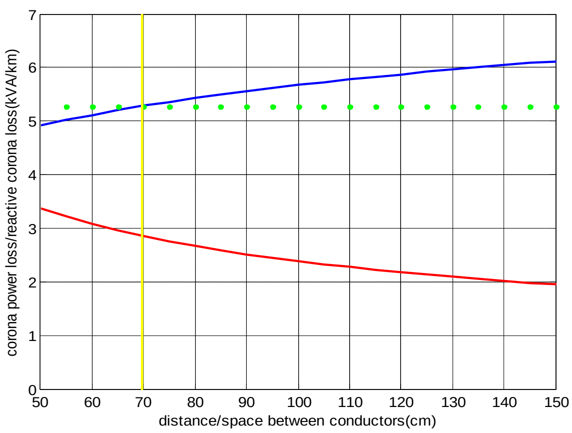

Fig 6

The tabulation of the results got from the graphs of different sizes of conductors is shown on table 1.

TABLE 1

Conductor sizes (mm^2)	*Optimal Distance between conductors (cm)*	*Corona Loss Q_c (kVA/km)*	*IEEE maximum allowable reactive power loss (kVA/km)=0.21%$V_{ph}I$*
150	87.20	2.80	5.28
100	69.90	2.78	5.28

IV. DISCUSSION OF RESULT

When using $150mm^2$ cable, as seen from figure 3, a reactive power of $4.7kVA/km$ will be lost in the line when a spacing of 50.0cm between the conductor (phases) is used. This reactive power loss increases as the spacing between conductors is increased as seen from the graph (the blue curve). However, with that 50cm spacing between the conductors, $3.75kVA/km$ will be lost due to corona and this decreases as the spacing is increased (the red curve). This means that the minimal corona loss can be obtain by using a spacing of 150cm. But note that a spacing of 150cm will give raise to a reactive power lost of $5.8 \times kVA/km$ in the line. Here corona power loss is less but with a higher reactive power loss compared to using a smaller value of spacing of conductor. Using the recommended allowable voltage drop per kilo meter and considering the line current flowing, the maximum reactive power that can be lost in the line is $5.28kVA/km$ (this is shown in the green dotted line). This means that the spacing used should not give rise to more than the recommended reactive power lost per kilometer in the line (from the recommended voltage drop per kilo meter). This is shown on the graph at $d = 87.20cm$.

When using $100mm^2$ cable, figure 6 shows that a reactive power of $4.9kVA/km$ will be lost in the line when a spacing of 50.0cm between the conductor (phases) is used. However, with that 50cm spacing between the conductors, $2.80kVA/km$ will be lost due to corona and this decreases as the spacing is increased (the red curve). This means that the minimal corona loss can be obtained by using a spacing of 150cm. But note that a spacing of 150cm will give raise to a reactive power lost of $6.15kVA/km$ in the line. Here corona power loss is less but with a higher reactive power loss compared to using a smaller value of spacing of conductor. Using the recommended allowable voltage drop per kilometer and considering the line current flowing, the maximum reactive power that can be lost in the line is $5.28kVA/km$ (this is shown in the green dotted line). This means that the spacing used should not give rise to more than the recommended reactive power loss per kilometer in the line (from the recommended voltage drop per kilometer). This is shown on the graph at $d = 69.90cm$.

V. CONCLUSION

It has been observed that the spacing between conductors of a three phase transmission or distribution line can be used to control the corona loss of the line. This research has shown that the higher the spacing of the conductors, the reduced corona loss in the power line, but the higher the line inductance and consequently, the higher the reactive power lost. To find the best spacing between the conductors of the phases means finding a balance between the corona lost and reactive power lost. This reactive power lost also depends on the line current which is a function of the power being transmitted or distributed. Using the guide (IEEE Regulation) that the lost in voltage along the line should not exceed 0.21% of phase voltage per kilometer for a short line, and with a certain line current I_L flowing, this means that the lost in power for a short line should not exceed $0.21\% V_{ph} \times I_L\ (VA)$. It is on this basis that we find the best distance between conductor phases for any system. The size of conductor or cable used in the power line also affects the best spacing of the phases of the conductor.

VI. RECOMMEDATION

On designing any transmission or distribution line, the method used in the analysis of this research should be adopted to minimize corona losses that may result.

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