Calculation of Electric and Magnetic Field under AC Transmission and Distribution Lines in Guwahati City

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Abstract*: With the increasing population rate and industrial growth rate, the demand for power has escalated significantly. High Voltage AC transmission can be termed as one of the measures to quench this increasing energy demands. This paper evaluates the safety limits for electric and magnetic fields generated around the AC transmission and distribution lines at various voltage levels and configuration. Surface current density for an average height human being has also been calculated for safety precautions.*

Keywords: Safety limits, electric field, magnetic field, surface current density

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1. Introduction

Owing to the rapidly increasing and varied uses of electric power in modern society, the likelihood and level of exposure of biological systems to electromagnetic fields has eractions between the man made electromagnetic environment with human and whether such interaction will be beneficial or detrimental.

According to ICNIRP (International Commission for Non-Ionizing Radiation Protection), the safety limits are 5 kV/m (rms) for the electric field and 100 μT (rms) for the magnetic field [1]. Electric Field around the transmission lines needs to be analysed for different configurations and at various heights. Of particular concern is the ground level electric field in the right of way. An efficient method to reduce the field consists of using grounded shield wires under transmission lines [2]. Shield wires of single, double and triple configuration have been used for the analysis [3],[4].To check the safety limit of magnetic fields for various transmission line configurations, at various Surge Impedance Loading (SIL) levels is necessary as it provides wide range of possibilities to set the safety level for different conditions. So in this work the calculations have been carried out for 30% SIL, 50% SIL, 100% SIL and 110% SIL. Considering the human body to be a cylindrical structure with cylinders of different radii representing the different body parts, the surface current density calculated on a cylindrical structure, representing a body part of radius 'r' and electrical conductivity 'σ' is related to the flux density at a frequency 'f' as follows:[5]

$$J_{rms} = \pi f r B_{rms} \sigma \ \ A/m^2 \qquad (1)$$

where,

increased by several orders of magnitude over the past century. It is appropriate and important to evaluate possible int.

J_{rms} = rms value of current density,
B_{rms}= rms value of flux density in Tesla,
σ = electrical conductivity of the tissue
= 0.2 S/m [6]

Surface current density safety limit: A human being is in danger if the surface current density over his body exceeds 1 mA/m^2 [6]. Though minor biological effects are reported in the range of 1-10 mA/m^2, but experts predict that long term exposure even at this level may prove fatal. Beyond 10 mA/m^2**,** it leads to more complex health hazards [6]. The computations have been carried out on existing lines within and near about Guwahati city.

2. Geometries Used For Computations

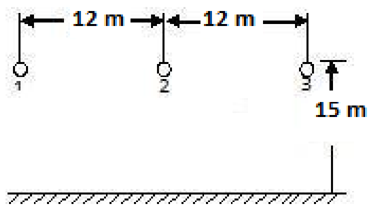

Figure 1: 400 kV single circuit line

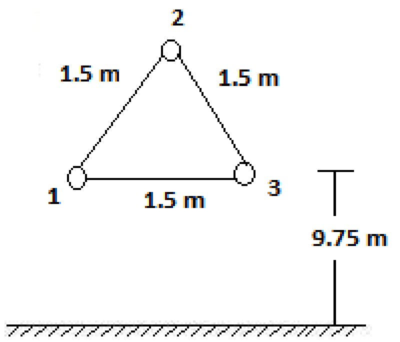

Figure 2: 33 kV single circuit triangular line

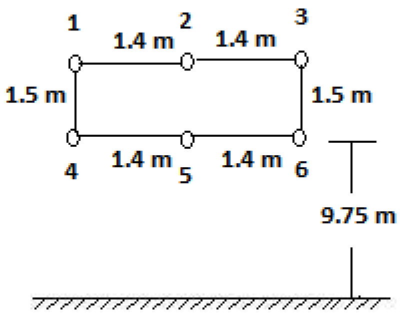

Figure 3: 33 kV double circuit horizontal line

3. Calculations

3.1 Electric field calculations

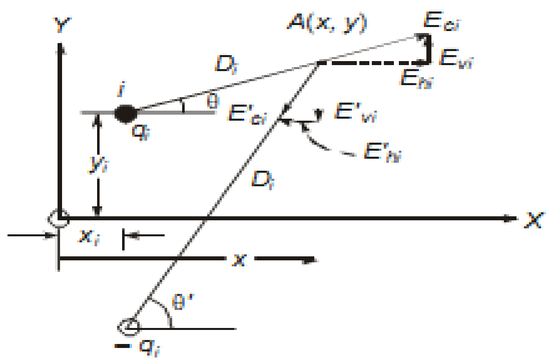

Figure 4: Calculation of electrostatic field components near a transmission line [6]

Figure 4 shows the geometry for the calculation of the electric field at a point near a transmission line .The coordinates of the line conductors are (x_i,y_i) where i=1 to n , n is the number of phases of transmission. The conductor is represented by charge q_i and its image directly below is represented by q'_i . The coordinate of the point at which the horizontal, vertical and total electric field is found is A(x,y). For a 3-phase line, constants J and K are defined and calculated as follows:

$$J_i=(x-x_i)[1/D_i^2-1/D'^2_i] \quad (2)$$
$$K_i=(y-y_i)/D_i^2-(y+y_i)/D'^2_i \quad (3)$$
where , i = 1,2,3

To check the variation of the electric field from the centre phase upto 60 m on both sides x coordinate is varied from -60 m to 60 m as it is believed over this distance electric field will be well below safe limits.
[P]=nxn matrix of Maxwell's potential coefficients ;

$$M=[P]^{-1} \quad (4)$$

Using the values of matrix M, constants Kv_1, Kv_2 and Kv_3 are calculated as follows:

$$Kv_1=K_1M_{11}+K_2M_{21}+K_3M_{31}; \quad (5)$$
$$Kv_2=K_1M_{12}+K_2M_{22}+K_3M_{32} \quad (6)$$
$$Kv_3=K_1M_{13}+K_2M_{23}+K_3M_{33} \quad (7)$$

The rms value of the total vertical component of the electric field at point A(x,y) due to all three phases is:

$$Ev_n = ((Kv_1^2+Kv_2^2+Kv_3^2-Kv_1Kv_2-Kv_2Kv_3 -Kv_3Kv_1)^{1/2})1000/(\sqrt{3})) \quad (8)$$

Using the values of matrix M, constants Jh_1, Jh_2 and Jh_3 are calculated as follows:

$$Jh_1=J_1M_{11}+J_2M_{21}+J_3M_{31} \quad (9)$$
$$Jh_2=J_1M_{12}+J_2M_{22}+J_3M_{32} \quad (10)$$
$$Jh_3=J_1M_{13}+J_2M_{23}+J_3M_{33} \quad (11)$$

The rms value of the total horizontal component of the electric field at point A(x,y) due to all three phases is:

$$Eh_n= ((Jh_1^2+Jh_2^2+Jh_3^2-Jh_1Jh_2-Jh_2Jh_3 - Jh_3Jh_1)^{1/2})1000/(\sqrt{3}) \quad (12)$$

Total rms value of the electric field at point A is :

$$E = (Eh_n^2+Ev_n^2)^{0.5} \quad (13)$$

3.2 Magnetic field calculations

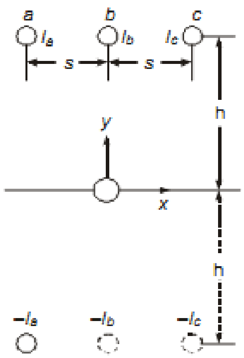

Figure 5: Three phase overhead conductors and their images [6]

Figure 5 represents the geometry of the three phase overhead conductors and their image conductors below the ground level. The origin of the co-ordinate system is placed on the ground underneath the centre phase. Considering the arrangement shown in the above figure the horizontal components of the magnetic field is calculated as detailed below:

Constants for horizontal components k_a, k_b and k_c of the magnetic field are defined and calculated as

$$k_a=((y+h)/((x+s)^2+(y+h)^2))-((y-h)/((x+s)^2+(y-h)^2) \quad (14)$$

$$k_b=((y+h)/(x^2+(y+h)^2))-((y-h)/((x)^2+(y-h)^2)) \quad (15)$$

$$k_c=((y+h)/((x-s)^2+(y+h)^2))-((y-h)/((x-s)^2+(y-h)^2)) \quad (16)$$

$$H_{ht}=(I/2\pi)(k_a^2+k_b^2+k_c^2-k_a x k_b-k_b k_c-k_c k_a)^{0.5} \quad (17)$$

Total flux density due to the horizontal components is:

$$B_{ht}=(4x3.14x10^{-7})H_{ht} \text{ Tesla} \quad (18)$$

Constants for Vertical components j_a, j_b and j_c of the magnetic field are defined and calculated as

$$j_a=((x+s)/((x+s)^2+(y-h)^2))-((x+s)/((x+s)^2+(y+h)^2)) \quad (19)$$

$$j_b=((x)/((x)^2+(y-h)^2))-((x)/((x)^2+(y+h)^2)) \quad (20)$$

$$j_c=((x-s)/((x-s)^2+(y-h)^2))-((x-s)/((x-s)^2+(y+h)^2)) \quad (21)$$

$$H_{vt}=(I/2\pi)(ja^2+jb^2+jc^2-j_a x j_b-j_b x j_c-j_c x j_a)^{0.5} \quad (22)$$

Total flux density due to the vertical components is:

$$B_{vt}=(4x3.14x10^{-7})H_{vt} \text{ Tesla} \quad (23)$$

Total magnetic field density is :

$$B=(B_{ht}^2+B_{vt}^2)^{0.5} \quad (24)$$

4. Results and Discussions

4.1 Electric Field comparison at different heights for 400 kV line.

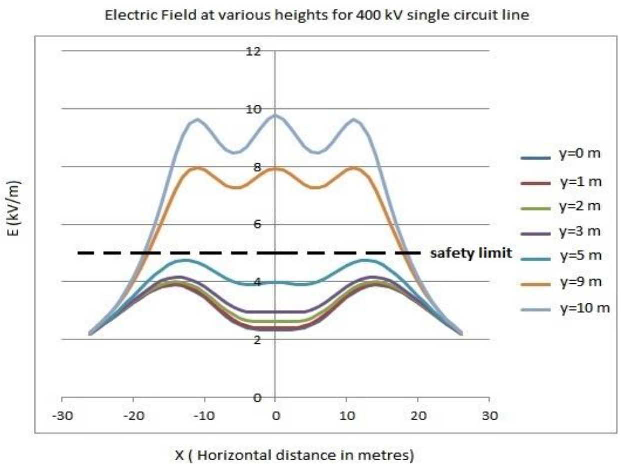

Figure 6: Electric Field comparison at different heights for the single circuit 400 kV line

Figure 6 shows the electric field comparison at different heights for the 400 kV single line configuration shown in Figure 1. This graph is computed to observe the electric field at different heights from the ground level .From the figure, it can be observed that the electric field level is more as the height increases from the ground level. The electric field safety limit of 5kV/m is violated at a height of 9 m from the ground level. The electric field is higher directly below the conductors.

4.2 Electric Field comparison at different heights for the 33 kV triangular configuration line

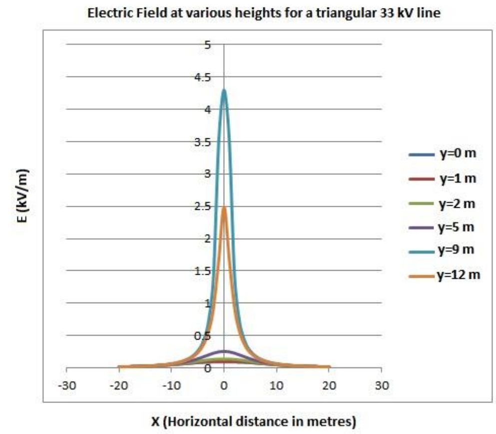

Figure 7: Electric Field at different heights for the 33 kV triangular configuration line

Figure 7 shows the electric field at different heights from the ground level for the 33 kV single circuit triangular configuration line. From the graph it is observed that the electric field increases as the height increases from the ground level. The electric field safety limit of 5 kV/m is not violated under this configuration.

4.3 Electric Field comparison for 33 kV line at ground level with different configurations

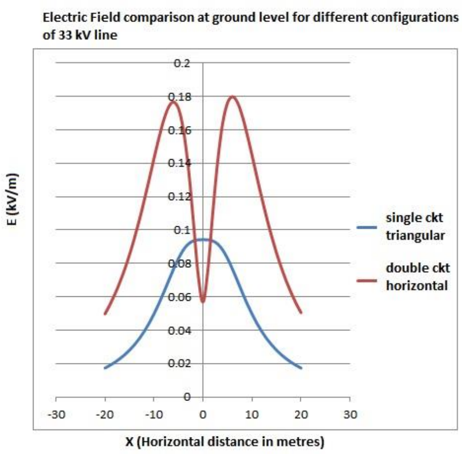

Figure 8: Electric Field comparison at ground level for 33 kV line with single circuit triangular and double

circuit horizontal configuration

Figure 8 shows the electric field comparison for the 33 kV line at ground level with the single circuit triangular configuration and double circuit horizontal configuration. From the graph, it is observed that the electric field generated by the double circuit horizontal configuration is higher than the electric field generated by the single circuit triangular configuration. Electric field generated by the triangular configuration is much lower compared to the field generated by the horizontal configuration. But the electric field safety limit of 5 kV/m is not violated at the ground level under both the configurations.

4.4 Magnetic Field Calculations at different heights for 400 kV line

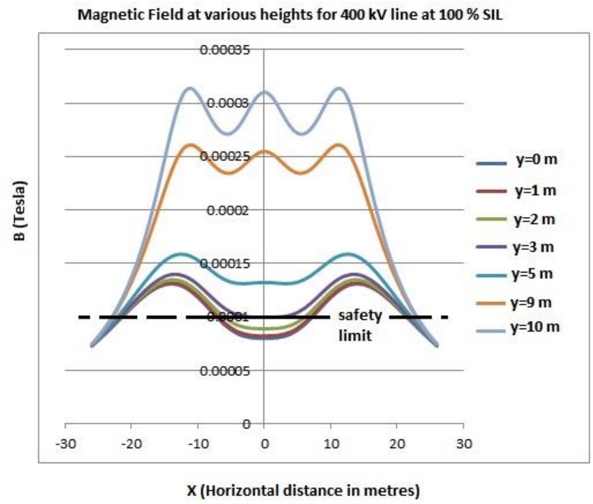

Figure 9: Magnetic field at different heights for the 400 kV line at 100% SIL

Figure 9 shows the magnetic field calculations at various heights for the 400 kV single circuit line under 100% SIL condition.
From the graph, it can be seen that the magnetic field increases as the height increases from the ground level. From the graph, it can also be observed that the magnetic field safety limit of 100 µT is violated at a height of 3 m from the ground level. The safety limit is violated beyond 24 m on both sides of the central conductor assuming the central conductor is at the origin. The magnetic field is higher directly under the overhead conductors.

4.5 Magnetic Field calculations at ground level for the 400 kV line at various levels of SIL

Figure 10 shows the magnetic field calculations at the ground le vel for the 400 kV line under different SIL conditions. The calculations were carried out under 30%, 50% and 110% SIL conditions. From the graph, it can be observed that the magnetic field increases as the SIL level increases. The highest magnetic field is experienced under 110 % SIL level. The magnetic field safety limit of 100 µT is also violated under 110% SIL level and it is violated beyond 8 m on both sides of the central conductor assuming the central conductor is at the origin.

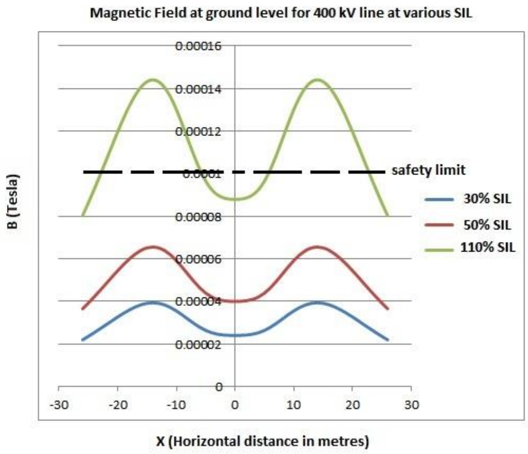

Figure 10: Magnetic Field calculations at ground level for the 400 kV line at various levels of SIL

4.6 Magnetic Field calculations at ground level for the 400 kV line at various levels of SIL

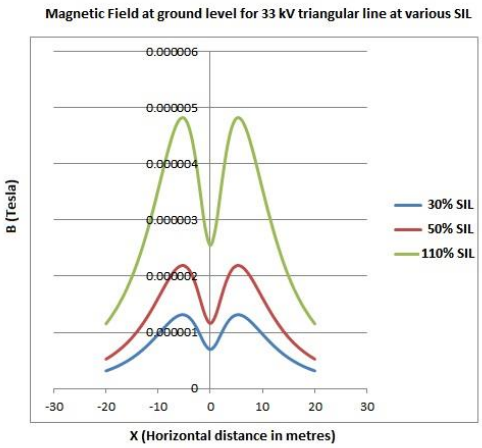

Figure 11: Magnetic Field calculations at ground level for the 33 kV line at various levels of SIL

Figure 11 shows the magnetic field calculations at the ground level for the 33 kV triangular configuration line under different SIL conditions. The calculations were carried out under 30%, 50% and 110% SIL conditions. From the graph, it can be observed that the magnetic field increases as the SIL level increases. The highest magnetic field is experienced under 110 % SIL level. The magnetic field safety limit of 100 µT is not violated under all the conditions.

4.7 Surface Current Density calculations for an average height human being under the 400 kV line at the central line at various levels of SIL

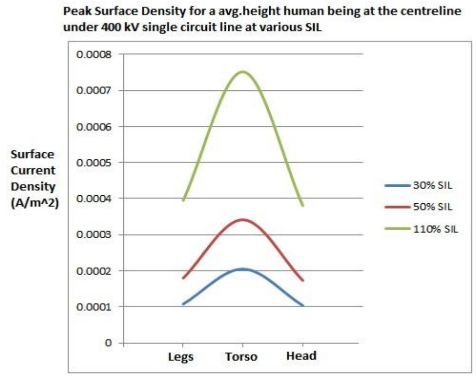

Figure 12: Peak Surface Current Density calculation for an average height human being at x=0m under 400 kV line

Figure 12 shows the peak surface current density for an average height human being (1.75 m tall) at the central line (x=0 m) directly below the 400 kV line. The surface current density increases with the increase in SIL level. The peak surface current density is experienced at the torso part of the human body. The safety limit of $1mA/m^2$ is not violated at all under the 400 kV single circuit line at the central line

4.8 Surface Current Density calculations for an average height human being under the 33 kV line triangular line at the central line at various levels of SIL

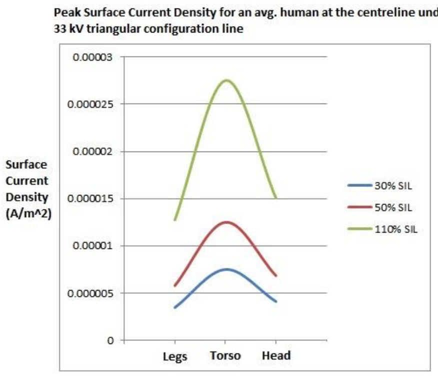

Figure 13: Peak Surface Current Density calculation for average height human being at x=0m under 33 kV line

Figure 13 shows the peak surface current density for an average height human being (1.75 m tall) at the central line below the 33 kV line. The surface current density increases with the increase in SIL level. The peak surface current density is experienced at the torso part of the human body. The safety limit of $1mA/m^2$ is not violated.

5. Conclusion

For human beings, standing under transmission and distribution lines, the horizontal span over which the safety limit for electric and magnetic field is violated depends on the height and spacing of the overhead conductors.

The horizontal range over which safety limit violations occur is larger for horizontal conductor configuration than triangular conductor configuration. For the AC lines, magnetic field at ground level at various levels of SIL was compared. It was observed that the horizontal span within which the magnetic field exposure safety limit for human beings is violated for the same conductor configuration increases with the increase in Surge Impedance Loading level. At 30 % SIL, the safety limit is minimum and at 110 % SIL, the safety limit is maximum.
Considering the calculations carried out for the different SIL levels in this work, it can be observed that the Right of Way calculated considering the electric field safety levels will also take care of the magnetic field safety limits. For the surface current density calculation for an average height human being, at various levels of SIL, it was seen that the surface current density for the human being increases with the increase in SIL. And the peak surface current density was experienced at the torso part of the human body. Surface Current Density also increases with the increase in voltage level.

6. Acknowledgment

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