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Effects of Air Humidity on the Performance of a Polymer Insulator under Lightning Induced Voltage Conditions

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Abstract_ **Lightning induced voltage is one of the important issues pertinent to line interruptions in distribution lines.The behaviour of a polymer insulator under different weather conditions may affect the overall stability of a power flow in the line. In this paper, the lightning induced voltage due to a typical sample of return stroke current on a distribution line has been investigated, and the electrical behaviour of a polymer insulator (10 kV) under different air humidity conditions was analysed in detail. The results show that the air humidity has a direct effect on the electrical performance of a polymer insulator under lightning induced voltage conditions, which reduces the reliability of the system. Therefore, in designing new distribution lines and in modifying existing lines, various safety and protection parameters such as determining the critical distances around the distribution lines where lightning induced over voltage (LIOV) may occur, the humidity of air should be treated as an essential input parameter. Thus, the field propagation along an insulator based on recorded local information (weather conditions) can be helpful and should be taken into account in taking protection measures.**

Keywords_ Lightning electromagnetic fields, Lightning induced voltage, Polymer insulator

I. INTRODUCTION

Lighting induced voltage is one of important issues for consideration in terms of lightning protection of distribution lines whereby a lightning induced voltage will be created along line by lightning striking near a distribution line and also by coupling between the electromagnetic fields of the lightning and the distribution line. Several studies have evaluated the lightning induced voltage on a line and these studies usually consider the line parameters, the striking point and the ground conditions[1-6]. On the other hand, the behaviour of a polymer insulator on a line under different weather conditions can have a direct effect on the field profiles along an insulator and also affect the breakdown value versus the lightning induced voltage. Therefore, by considering on lightning induced voltage in parallel with the insulator performance under different weather conditions (based on local information), can be helpful to set proper protection level on the overhead power line. In this study, the value of the lightning induced voltage on a typical 10 kV distribution line will be evaluated and the electromagnetic profiles along a polymer insulator under dry and foggy weather conditions will be studied. The sum of two Heidler functions will be used for simulation of the channel base current and the electric current model selected is the Modified Transmission Line with Exponential decay model (MTLE) to consider the current behaviour at different heights along the channel. The basic assumptions in this study are listed as follows:

i. The lightning is a vertical channel without any branches.
ii. The ground conductivity is assumed to be perfect.
iii. The surface of the ground is assumed to be flat.

II. EVALUATION OF LIGHTNING INDUCED VOLTAGE

In order to evaluate the lightning induced voltage (LIV) on a distribution line as shown in Figure 1, the channel base current can be simulated using the sum of two Heidler functions as expressed by Equation (1)[7].

$$i(0,t) = \left[\frac{i_{01}}{\eta_1}\frac{\left(\frac{t}{t_1}\right)^n}{1+\left(\frac{t}{t_1}\right)^n}\exp\left(\frac{-t}{t_2}\right) + \frac{i_{02}}{\eta_2}\frac{\left(\frac{t}{t_{12}}\right)^{n_2}}{1+\left(\frac{t}{t_{12}}\right)^{n_2}}\exp\left(\frac{-t}{t_{22}}\right)\right] \quad (1)$$

Where
i_{01}, i_{02} are the amplitudes of the channel base current,
t_1, t_{12} are the front time constants,
t_2, t_{22} are the decay- time constants,
n, n_2 are the exponents (2~10),

$$\eta_1 = \exp\left[-\left(t_1/t_2\right)\left(n\frac{t_2}{t_1}\right)^{\frac{1}{n}}\right],$$

$$\eta_2 = \exp\left[-\left(t_{12}/t_{22}\right)\left(n_2\frac{t_{22}}{t_{12}}\right)^{\frac{1}{n_2}}\right].$$

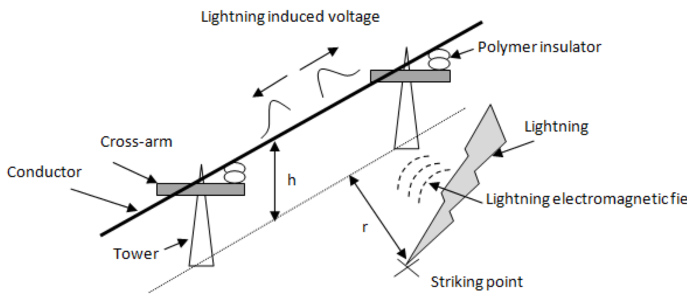

Figure.1. The geometry of problem

The current behaviour at different heights along the channel can be studied using the MTLE model as presented by Equation (2). On the other hand, the lightning generated electromagnetic fields in the x and z axis (based on Figure 2) can be estimated using the analytical field expressions as expressed by Equation (3) and Equation (4)[8,9].

$$I(z',t) = I\left(0, t - \frac{z'}{v}\right) \times P(z') \times u(t - \frac{z'}{v_f}) \tag{2}$$

Where:
z' is the temporary charge height along lightning channel,
I(z',t) is current distribution along lightning channel at any height z' and any time t,
I(0,t) is channel base current,
P(z') is the attenuation height dependent factor (for MTLE current model is exp(-z'/λ)),
v is the current-wave propagation velocity,
v_f is the upward propagating front velocity,
u is the Heaviside function as defined by

$$u\left(t - \frac{z'}{v_f}\right) = \begin{cases} 1 & \text{for } t \geq \dfrac{z'}{v_f} \\ 0 & \text{for } t < \dfrac{z'}{v_f} \end{cases}$$

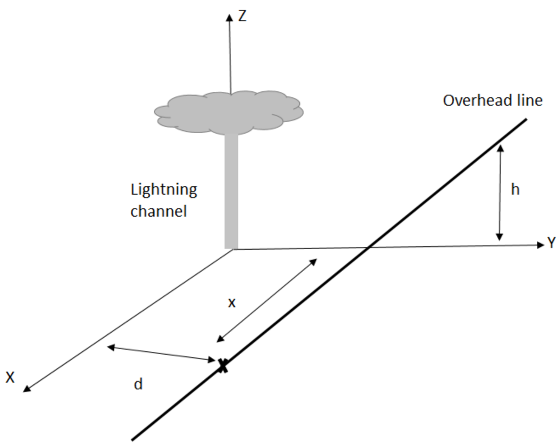

Figure 2. Coordination of line with respect to lightning channel

$$\vec{E}_x(x,y,z,t_n) = \vec{E}_x(x,y,z,t_{n-1}) + \Delta t \times \sum_{i=1}^{n_t} \sum_{m=1}^{k+1} \{a_m F_1(x,y,z,t=t_n,z'=h_{m,i}) - a'_m F_1(x,y,z,t=t_n,z'=h'_{m,i})\} U(t - \frac{\sqrt{r^2+z^2}}{c}) \tag{3}$$

$$\vec{E}_z(x,y,z,t_n) = \vec{E}_z(x,y,z,t_{n-1}) + \Delta t \times \sum_{i=1}^{n_t} \sum_{m=1}^{k+1} \{a_m F_2(x,y,z,t=t_n,z'=h_{m,i}) - a'_m F_2(x,y,z,t=t_n,z'=h'_{m,i})\} U(t - \frac{\sqrt{r^2+z^2}}{c}) \tag{4}$$

Where:
$\vec{E}_x$ is the electric field at x-axis,
$\vec{E}_z$ is the electric field at z-axis,
Δt is the time step,
n_t is the number of time steps,
$n = n_2$

$$t_n = (n_t - 1)\Delta t \qquad n_t = 1,2,\dots,n_{max}$$

$$a_m = \begin{cases} \dfrac{\Delta h_i}{2 \times k} & \text{for } m = 1 \text{ and } m = k+1 \\ \dfrac{\Delta h_i}{k} & \text{for others} \end{cases}$$

$$a'_m = \begin{cases} \dfrac{\Delta h'_i}{2 \times k} & \text{for } m = 1 \text{ and } m = k+1 \\ \dfrac{\Delta h'_i}{k} & \text{for others} \end{cases}$$

k is division factor(>=2) ,

$$\Delta h_i = \begin{cases} \beta\chi^2\{(ct_i - ct_{i-1}) - \sqrt{(\beta ct_i - z)^2 + (\frac{r}{\chi})^2} + \sqrt{(\beta ct_{i-1} - z)^2 + (\frac{r}{\chi})^2}\} \\ \beta\chi^2\left\{-(\beta z - ct_i) - \sqrt{(\beta ct_i - z)^2 + \left(\frac{r}{\chi}\right)^2}\right\} & \text{for } i = 1 \end{cases}$$

$$\Delta h'_i = \begin{cases} \beta\chi^2\{(ct_{i-1} - ct_i) + \sqrt{(\beta ct_i + z)^2 + (\frac{r}{\chi})^2} - \sqrt{(\beta ct_{i-1} + z)^2 + (\frac{r}{\chi})^2}\} \\ \beta\chi^2\left\{-(\beta z + ct_i) + \sqrt{(\beta ct_i + z)^2 + \left(\frac{r}{\chi}\right)^2}\right\} & \text{for } i = 1 \end{cases}$$

$$h_{m,i} = \begin{cases} \dfrac{(m-1) \times \Delta h_i}{k} + h_{m=k+1,i-1} \\ \dfrac{(m-1) \times \Delta h_i}{k} & \text{for } i = 1 \end{cases}$$

$$h'_{m,i} = \begin{cases} \dfrac{(m-1) \times \Delta h'_i}{k} + h'_{m=k+1,i-1} \\ \dfrac{(m-1) \times \Delta h'_i}{k} & \text{for } i = 1 \end{cases}$$

$R = \sqrt{x^2 + y^2 + (z - z')^2}$,

$A_1 = t - \frac{R}{c} - \frac{|z'|}{v}$,

$A_2 = \exp(\frac{\frac{R}{c} - t + \frac{|z'|}{v}}{t_2})$,

$A_{22} = \exp(\frac{\frac{R}{c} - t + \frac{|z'|}{v}}{t_{22}})$.

$$F_1 =$$

$$\frac{I_{01}P(z')x(z-z')A_2}{4\pi\varepsilon_0\eta_{01}[\left(\frac{A_1}{t_1}\right)^n+1]}\left\{\frac{\left(\frac{A_1}{t_1}\right)^n(3c^2t_2^2-3ct_2R+R^2)}{c^2t_2^2R^5}+\right.$$

$$\frac{2n^2\left(\frac{A_1}{t_1}\right)^{3n-2}+n(n-1)\left(\frac{A_1}{t_1}\right)^{n-2}\left[\left(\frac{A_1}{t_1}\right)^n+1\right]^2+(-3n^2+n)\left(\frac{A_1}{t_1}\right)^{2n-2}\left[\left(\frac{A_1}{t_1}\right)^n+1\right]}{c^2t_1^2R^3\left[\left(\frac{A_1}{t_1}\right)^n+1\right]^2}+$$

$$\left.\frac{3n(\left[\left(\frac{A_1}{t_1}\right)^n+1\right]\left(\frac{A_1}{t_1}\right)^{n-1}-\left(\frac{A_1}{t_1}\right)^{2n-1})}{ct_1R^4\left[\left(\frac{A_1}{t_1}\right)^n+1\right]}+\frac{2n(\left(\frac{A_1}{t_1}\right)^{2n-1}-\left[\left(\frac{A_1}{t_1}\right)^n+1\right]\left(\frac{A_1}{t_1}\right)^{n-1})}{c^2t_1t_2R^3\left[\left(\frac{A_1}{t_1}\right)^n+1\right]}\right\}$$

$$+\frac{I_{02}P(z')x(z-z')A_{22}}{4\pi\varepsilon_0\eta_{02}[\left(\frac{A_1}{t_{12}}\right)^n+1]}\left\{\frac{\left(\frac{A_1}{t_{12}}\right)^n(3c^2t_{22}^2-3ct_{22}R+R^2)}{c^2t_{22}^2R^5}+\right.$$

$$\frac{2n^2\left(\frac{A_1}{t_{12}}\right)^{3n-2}+n(n-1)\left(\frac{A_1}{t_{12}}\right)^{n-2}\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]^2+(-3n^2+n)\left(\frac{A_1}{t_{12}}\right)^{2n-2}\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]}{c^2t_{12}^2R^3\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]^2}+$$

$$\left.\frac{3n(\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]\left(\frac{A_1}{t_{12}}\right)^{n-1}-\left(\frac{A_1}{t_{12}}\right)^{2n-1})}{ct_{12}R^4\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]}+\frac{2n(\left(\frac{A_1}{t_{12}}\right)^{2n-1}-\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]\left(\frac{A_1}{t_{12}}\right)^{n-1})}{c^2t_{12}t_{22}R^3\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]}\right\}$$

$$F_2=\frac{I_{01}P(z')A_2}{4\pi\varepsilon_0\eta_{01}[\left(\frac{A_1}{t_1}\right)^n+1]}\left\{\frac{(x^2+y^2)\left[\left(\frac{A_1}{t_1}\right)^n(-3c^2t_1t_2^2+3ct_1t_2R-t_1R^2)+n\left(\frac{A_1}{t_1}\right)^{n-1}(-3ct_2^2R+2t_2R^2)\right]}{c^2t_1t_2^2R^5}+\right.$$

$$\frac{2\left(\frac{A_1}{t_1}\right)^n(ct_1t_2-t_1R)+2n\left(\frac{A_1}{t_1}\right)^{n-1}t_2R}{ct_1t_2R^3}-\frac{n(n-1)(x^2+y^2)\left(\frac{A_1}{t_1}\right)^{n-2}}{c^2t_1^2R^3}+$$

$$\frac{(x^2+y^2)\left[2n^2t_2R\left(\frac{A_1}{t_1}\right)^{2n-2}+3nct_1t_2\left(\frac{A_1}{t_1}\right)^{2n-1}+n(n-1)t_2R\left(\frac{A_1}{t_1}\right)^{2n-2}-2nt_1R\left(\frac{A_1}{t_1}\right)^{2n-1}\right]-2nct_1t_2R^2\left(\frac{A_1}{t_1}\right)^{2n-1}}{c^2t_1^2t_2R^4\left[\left(\frac{A_1}{t_1}\right)^n+1\right]}-$$

$$\left.\frac{2n^2(x^2+y^2)\left(\frac{A_1}{t_1}\right)^{3n-2}}{c^2t_1^2R^3\left[\left(\frac{A_1}{t_1}\right)^n+1\right]^2}\right\}$$

$$+\frac{I_{02}P(z')A_{22}}{4\pi\varepsilon_0\eta_{02}[\left(\frac{A_1}{t_{12}}\right)^n+1]}\left\{\frac{(x^2+y^2)\left[\left(\frac{A_1}{t_{12}}\right)^n(-3c^2t_{12}t_{22}^2+3ct_{12}t_{22}R-t_{12}R^2)+n\left(\frac{A_1}{t_{12}}\right)^{n-1}(-3ct_{22}^2R+2t_{22}R^2)\right]}{c^2t_{12}t_{22}^2R^5}+\right.$$

$$\frac{2\left(\frac{A_1}{t_{12}}\right)^n(ct_{12}t_{22}-t_{12}R)+2n\left(\frac{A_1}{t_{12}}\right)^{n-1}t_{22}R}{ct_{12}t_{22}R^3}-\frac{n(n-1)(x^2+y^2)\left(\frac{A_1}{t_{12}}\right)^{n-2}}{c^2t_{12}^2R^3}+$$

$$\frac{(x^2+y^2)\left[2n^2t_{22}R\left(\frac{A_1}{t_{12}}\right)^{2n-2}+3nct_{12}t_{22}\left(\frac{A_1}{t_{12}}\right)^{2n-1}+n(n-1)t_{22}R\left(\frac{A_1}{t_{12}}\right)^{2n-2}-2nt_{12}R\left(\frac{A_1}{t_{12}}\right)^{2n-1}\right]-2nct_{12}t_{22}R^2\left(\frac{A_1}{t_{12}}\right)^{2n-1}}{c^2t_{12}^2t_{22}R^4\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]}-$$

$$\left.\frac{2n^2(x^2+y^2)\left(\frac{A_1}{t_{12}}\right)^{3n-2}}{c^2t_{12}^2R^3\left[\left(\frac{A_1}{t_{12}}\right)^n+1\right]^2}\right\}$$

The values of the LIV on the power line can be estimated using different coupling models such as Agrawal, Taylor and Rachidi models which use different field components as current and voltage sources along the line for generation of the LIV. The Taylor coupling function can be expressed by Equation (5) [1,2].

$$v(x,t)=\left[\begin{array}{c}-\int_0^h E_z(x,z,d,t)dz-\frac{1}{2}\int_x^{\frac{(ct+x)^2-h^2-d^2}{2(ct+x)}}E_x\left(\eta,h,d,t-\frac{\eta-x}{c}\right)d\eta \\ +\frac{1}{2}\int_{-\frac{(ct-x)^2-h^2-d^2}{2(ct-x)}}^{x}E_x\left(\eta,h,d,t+\frac{\eta-x}{c}\right)d\eta\end{array}\right]U(t-\frac{\sqrt{x^2+d^2+h^2}}{c}) \quad (5)$$

Where:

$\vec{E}_x$ is the electric field at x-axis,
$\vec{E}_z$ is the electric field at z-axis,
h is height of line,
c is light speed in free space,
d is radial distance between striking point and line,
x is observation point along power line,
t is time

In this study, the analytical lightning induced voltage expression (based on sum of two Heidler functions) was used to evaluate the LIV along the line using Equation (6) which is based on the Taylor coupling model [10].

$$V(x,t=t_n)=[A_{RS}^1+A_{RS}^2+A_{RS}^3]U(t_n-\frac{\sqrt{x^2+d^2+h^2}}{c}) \quad (6)$$

Where:

$\Delta x=\frac{\frac{(ct_n+x)^2-h^2-d^2}{2(ct_n+x)}-x}{q}$,
$x_{m'}=x+(m'-1)\times\Delta x$,
q is division factor (>=2) ,
$c_m=\begin{cases}2 & \text{for } m'=1 \text{ and } m'=q+1\\ 1 & \text{for others}\end{cases}$
$\Delta h=\frac{h}{k'}$,
k′ is division factor (>=2)

$$A_{RS}^1=-\int_0^h E_z(x,z,d,t=t_n)dz$$
$$=\frac{-1}{2\Delta h}\sum_{m'=1}^{k'+1}b_m\times[\vec{E}_z(x,y,z=(m'-1)\times\Delta h,t_{n-1})+\Delta t\times\sum_{i=1}^{n}\sum_{m=1}^{k+1}\{a_m F_2(x,y,z=(m'-1)\times\Delta h,t=t_n,z'=h_{m,i})-a'_m F_2(x,y,z=(m'-1)\times\Delta h,t=t_n,z'=h'_{m,i})\}U(t-\frac{\sqrt{r^2+z^2}}{c})]$$

$$A_{RS}^2=-\frac{1}{2}\int_x^{\frac{(ct_n+x)^2-h^2-d^2}{2(ct_n+x)}}E_x\left(\eta,h,d,t_n-\frac{\eta-x}{c}\right)d\eta$$
$$=-\frac{1}{4\Delta x}\times\sum_{m'=1}^{q+1}c_m\times\left[\vec{E}_x\left(x=x_{m'},y=d,z=h,t_{n-1}-\frac{x_{m'}-x}{c}\right)+\Delta t\times\sum_{i=1}^{n}\sum_{m=1}^{k+1}\{a_mF_1\left(x=x_{m'},y=d,z=h,t=t_n-\frac{x_{m'}-x}{c},z'=h_{m,i}\right)-a'_mF_1\left(x=x_{m'},y=d,z=h,t=t_n-\frac{x_{m'}-x}{c},z'=h'_{m,i}\right)\}\ U(t_n-\frac{x_{m'}-x}{c}-\frac{\sqrt{{x_{m'}}^2+d^2+h^2}}{c})\right]$$

$$A_{RS}^{3} = \frac{1}{2}\int_{-\frac{(ct_n-x)^2-h^2-d^2}{2(ct_n-x)}}^{x} E_x\left(\eta, h, d, t_n + \frac{\eta - x}{c}\right) d\eta$$

$$= \frac{1}{4\Delta x'}$$

$$\times \sum_{m'=1}^{q+1} c_m \times [\vec{E}_x\left(x = x'_{m'}, y = d, z\right.$$

$$\left. = h, t_{n-1} + \frac{x'_{m'} - x}{c}\right) + \Delta t$$

$$\times \sum_{i=1}^{n} \sum_{m=1}^{k+1} \{a_m F_1\left(x = x'_{m'}, y = d, z\right.$$

$$\left. = h, t = t_n + \frac{x'_{m'} - x}{c}, z' = h_{m,i}\right)$$

$$- a'_m F_1\left(x = x'_{m'}, y = d, z = h, t\right.$$

$$\left. = t_n + \frac{x'_{m'} - x}{c}, z' = h'_{m,i}\right)\} \; U(t_n$$

$$+ \frac{x'_{m'} - x}{c} - \frac{\sqrt{{x'_{m'}}^2 + d^2 + h^2}}{c})]$$

$$b_m = \begin{cases} 2 & \text{for } m' = 1 \text{ and } m' = k' + 1 \\ 1 & \text{for others} \end{cases}$$

$$\Delta x' = \frac{x + \frac{(ct-x)^2-h^2-d^2}{2(ct-x)}}{q},$$

$$x'_{m'} = -\frac{(ct_n-x)^2-h^2-d^2}{2(ct_n-x)} + (m' - 1) \times \Delta x'.$$

Table 1 shows the channel base current parameters that were used in this study based on Equation (1). The lightning induced voltage on the distribution line based on Figure 1 is illustrated in Figure 3 assuming a radial distance of r=50 m and a conductor height of 10 m.

Table.1.The channel base current parameters based on sum of two Heidlerfunctions[7]

i_{01} (kA)	i_{02} (kA)	τ_{11} (μs)	τ_{12} (μs)	τ_{21} (μs)
19.5	12.3	1	2	8
τ_{22} (μs)	n_1	n_2	λ (m)	V (m/s)
30	2	2	1500	$1 * 10^8$

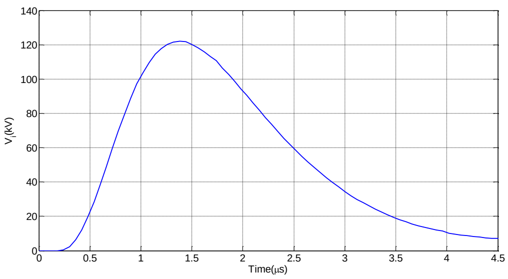

Figure 3. Evaluated induced voltage at r=50m and h=10m

III. ELECTROMAGNETIC PROFILES ALONG A POLYMER INSULATOR UNDER DIFFERENT WEATHER CONDITIONS

In this paper, the values of the electromagnetic fields along a polymer insulator under an induced voltage in dry and foggy conditions will be studied. A 10 kV polymer insulator was selected as shown in Figure 4. The parameters of the insulator are tabulated in Table 2 as follows [11-13]:

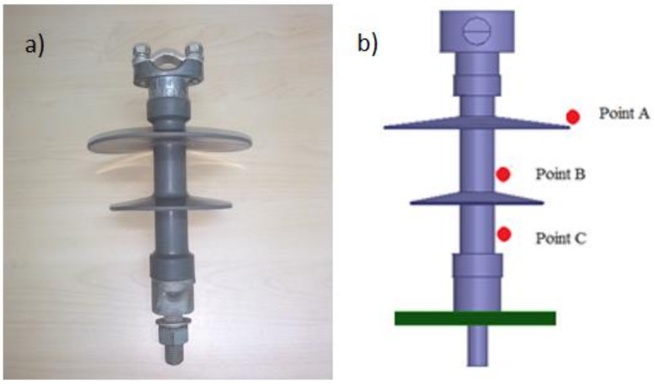

Figure.4. Polymer insulator (a. considered insulator and b. the observation points)

Table.2. Parameters of polymer insulator a) dimensions b) electrical parameters

a)

Parts of Insulator	Dimension
Shed diameter (mm)	148/118
Shed-to-shed spacing (mm)	50
Structure Height (mm)	250
Min Nominal CreepageCreepage distance (mm)	420

b)

Parts	Material	Relative permittivity (ε_r)	Relative Permeability (μ_r)	Volume Conductivity (σ) S/m
Fittings	Aluminium	1	1.000021	3.8×10^{7}
Sheds	Silicone rubber	3	1	1×10^{-17}
Core	Fiberglass	5	1	1×10^{-12}

The electric field distribution of the insulator under dry condition can be obtained from Figure 5. Moreover, the electric fields at different points along the insulator for dry and foggy conditions are demonstrated in Figure 6 and Figure 7, respectively with the weather parameters obtained from Table 3 [11-13].

Table.3. The electrical parameters of air

Material	Relative permittivity (ε_r)	Relative Permeability (μ_r)	Volume Conductivity (σ) S/m
Dry	1.0006	1.0000004	0.295 x 10^{-14}
Foggy	1.0008	1.0000004	5 x 10^{-14}

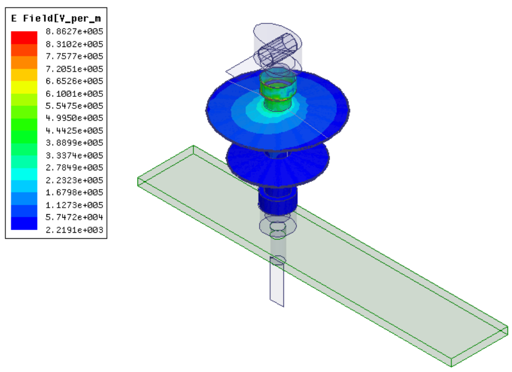

Figure.5. The electric fields along insulator under dry condition

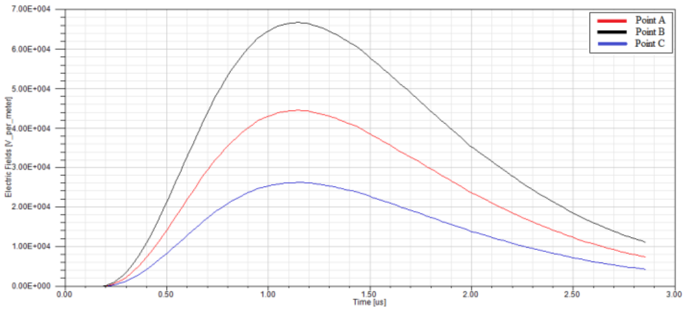

Figure.6. The electric field profile along insulator under dry condition

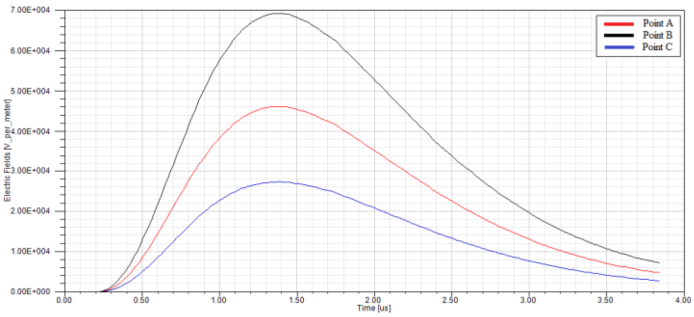

Figure.7. The electric field profile along insulator under foggy condition

Similarly, the magnetic fields at different points along insulator for dry and foggy conditions are demonstrated in Figure 8 and Figure 9, respectively.

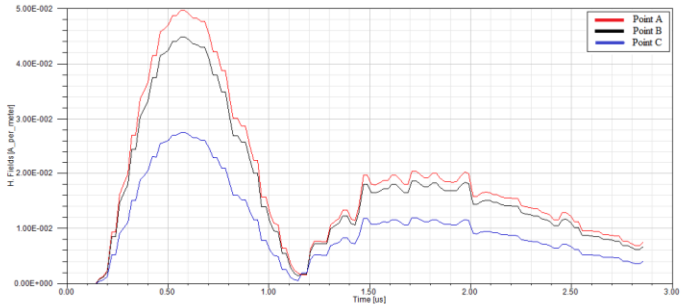

Figure.8. The magnetic field profile along insulator under dry condition

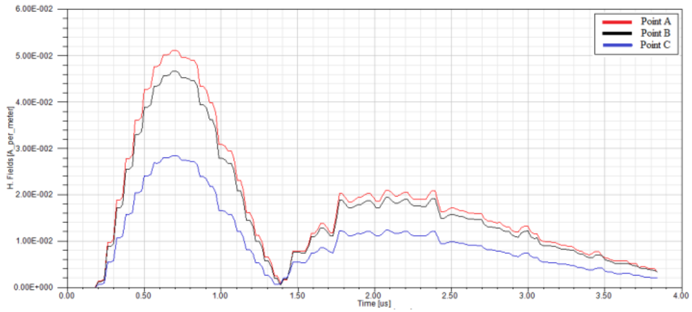

Figure.9. The magnetic field profile along insulator under foggy condition

A comparison between Figure 6 and Figure 7 and also Figure 8 and Figure 9 shows that the air humidity has a direct effect on the field values at different parts of the insulator and this can reduce the electrical performance of the insulator when subjected to a lightning induced voltage. The results show that the air humidity can have an effect in terms of increasing the electric field in the range 3.5-6.5 % at different points along the insulator. Moreover, the values of the magnetic fields increased under foggy conditions compared to dry conditions in the range of 2-5.5 % at different points along the insulator. Therefore, when the humidity of the air increases, the chance of electrical breakdown will also be increased. In addition, in order to set the proper level of lightning protection on a distribution line, consideration should be given to the evaluation of the lightning induced voltage on the line and also an estimation of the critical distance for the induced overvoltage is important [14,15]. Therefore, appropriate consideration of the effect of air humidity on the electromagnetic profiles of polymer insulators should be given, and taking the due reduction factor into account can be helpful for designing new lines or improving existing distribution lines.

IV. CONCLUSION

In this paper, the values of the lightning induced voltage on a typical distribution line were evaluated and the behaviour of the electromagnetic fields along a polymer insulator under dry and foggy conditions was evaluated by applying the lightning induced voltage as an excitation source of the insulator. The results show that the humidity of the air has a direct effect on the field values at different points along an insulator and also it can increase the chance of an electrical breakdown. Therefore, in order to protect the distribution line and to evaluate the insulation level of the line versus the indirect effect of lightning, consideration of the local information including local weather conditions is very important and taking an appropriate reduction factor into account can be helpful for designing of new lines or improving existing distribution lines.

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