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Research paper

Calculation of lightning surges on the high voltage lines. Case of 220 kV line: Ngo -Brazzaville in Congo

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Abstract

The importance of line Ngo-Brazzaville (220 kV, 207 km) requires operators to avoid cuts that can increase the risk of instability. We see it is quite rare that a storm that occurs in areas crossed by this line will not cause triggering. Note that due to lightning discharges are the main causes of unscheduled outages of Congo's power lines; we ignore this during the peak values of voltage wave forms that result. In regions with high level keraunic like Congo, reducing insulation failures due to lightning is a concern in the management of overheads lines. This article clarifies the peak values of the voltages that can be achieved on the network in order to build the operators as to the precautions on the insulation coordination of protective equipment related to lightning. For these calculations surge of atmospheric origin (case of lightning), we considered the bi-exponential function and Heidler function for modeling the wave of the lightning current. This methodology led us to specially treat the effects of direct lightning strikes that constitute the worst case because they generate most destructive shock wave that indirect lightning strikes.

Keywords: *Voltage; Lightning; Power Lines; Congo.*

1. Introduction

Surges generated by lightning on power lines are among the concerns of operators, because of the adverse effects they cause on the stability of power grids and destruction of protective equipment that are accompanied. Several cases are possible: thunderbolt on the phase conductors; the ground wire (in full or reach the top of the pylon); on the floor near an overhead line, etc. In the heart of central Africa, Congo straddles the equator; it rains a lot and keraunic level is very high up to more than 100 lightning strikes per year. It is therefore easy to understand why the power lines of the Congo are often the seat of atmospheric surges (lightning).This article discusses surges due to direct lightning strike on a power line of Congo, with a computational approach based on modeling of the wave of the lightning current.

2. The line and its problems

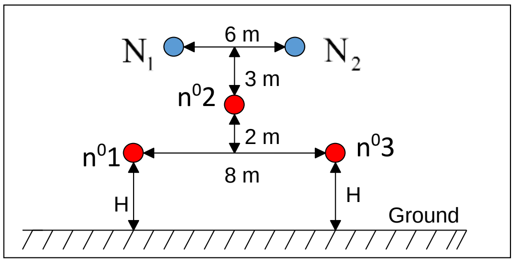

Fig. 1: Configuring of Line Ngo –Brazzaville.

n^01, n^02 and n^03 are conductors phase, N_1 is the first guard cable, N_2 is the second guard cable that incorporates optical fiber. The Phases n^01 and n^03 are located 14 m ground; other dimensions are shown in the figure above (Fig.1).
The storms that take place in the areas crossed by that line often generate, surges into the grid. Given the severity of the resulting surge lightning strikes and to protect the network adverse effects at both positions transformation subscribers City Brazzaville is often deprived of electricity occasionally heavy rains because to be in safe from power surges, the National Society of Electricity prefers meanwhile, stopping the supply of electric power.

3. Modelling of the current wave of lightning

From the physical point of view, the phenomenon of lightning is complex; research and references to this subject are numerous. The over the years, several analytical models have been developed to represent the wavelength of the lightning current and analytical models most used simple focus on the double exponential function and the of Heidler.
The figure below provides an illustration of a sudden lightning called standardized wave 1, 2/50 μs .

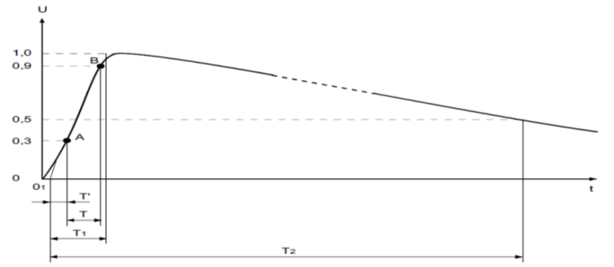

Fig. 2: Lightning Wave Example (1, 2/50 µs) Standardized To IEC 60 with $T_1 = 1{,}2\ \mu s$ And $T_2 = 50\ \mu s$

Here, the current wave of lightning considered as a varying function in time. The method used is based on the consideration of an analytical model most former proposed by Bruce and Golde in 1941 [V. Cooray 2003]. This is a bi-exponential function represented by the next relation [1]:

$$i(t) = I_0[\exp(-\alpha.t) - \exp(-\beta.t)] \tag{1}$$

I_0 is the amplitude of base current representing a peak value. α and β are time constants which are determined from the shock wave referential (wave 1,2/50 µs).Close to zero, the limited development two of order (2) of the i(t) leads to:
Right from zero, the limited development of the order n° 2 leads to the following function

$$i(t) = I_0(\beta - \alpha)\left[t - \frac{(\alpha+\beta)}{2}\right]t^2 \tag{2}$$

$$\frac{di(t)}{dt} = I_0(\beta - \alpha)[1 - (\alpha+\beta)t] \tag{3}$$

i(t) is maximum when $\frac{di(t)}{dt} = 0$,now t_m matching is:

$$t_m = \frac{1}{\alpha+\beta} \tag{4}$$

Moreover, i(t) reaches its maximum value I_0 to $t_1 = 1{,}2\,\mu s$ time. By identifying t_1 with the relationship (4), we have:

$$\alpha + \beta = \frac{1}{t_1} \tag{5}$$

At time $t_2 = 50\mu s$, the value of $i(t)$ is $I_2 = \frac{I_0}{2} = 50\,kA$ .Replacing the I_2 equation into (2), we have:

$$\beta - \alpha = \frac{1}{2\left(t_2 - \frac{t_2^2}{2t_1}\right)} \tag{6}$$

The system constituted by the equations (5) and (6) leads to:

$$\alpha = \frac{1}{2t_1} - \frac{1}{4\left(t_2 - \frac{t_2^2}{2t_1}\right)} = 0{,}4170/\mu s \tag{7}$$

$$\alpha = \frac{1}{2t_1} + \frac{1}{4\left(t_2 - \frac{t_2^2}{2t_1}\right)} = 0{,}4164/\mu s \tag{8}$$

We obtain the following curve:

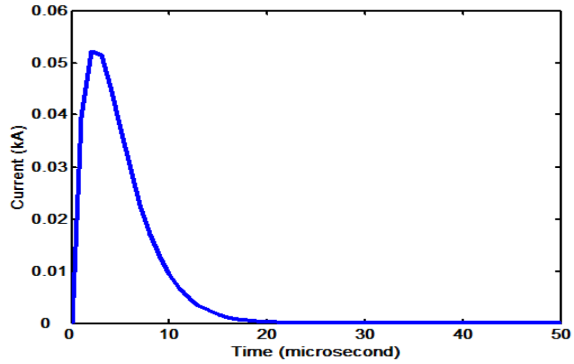

Fig. 3: Waves of Lightning Current According to Bi-Exponential Function.

3.2. The function of Heidler

The usually adopted analytical model one proposed by Heidler, commonly known as "according to Heidler" where the wave of is represented by the lightning current channel basis by the following expression [Heidler F.1985] [1]:

$$i(t) = \frac{I_0}{\eta}\frac{(t/\tau_1)^n}{1+(t/\tau_1)^n}\exp\left(-\frac{t}{\tau_2}\right) \tag{9}$$

$$\eta = \exp\left[-\left(\frac{\tau_1}{\tau_2}\right)\left(n\frac{\tau_2}{\tau_1}\right)\right]^{\frac{1}{n}}$$

η: the correction factor of the amplitude of wave;
I_0: the current amplitude of the basis channel;
τ_1 : the constant rise time;
τ_2 : constant decay time;
n: an exponent varying between 2 and 10.

The figure below shows the curve of the wave the lightning current outcome parameters shown in the following table:

Table 1: The Parameters of the IEC 62305-01 [2006] for I_0= 100 kA [2]

$\tau_1\,(\mu s)$	$\tau_2\,(\mu s)$	n	η
19	485	10	0.93

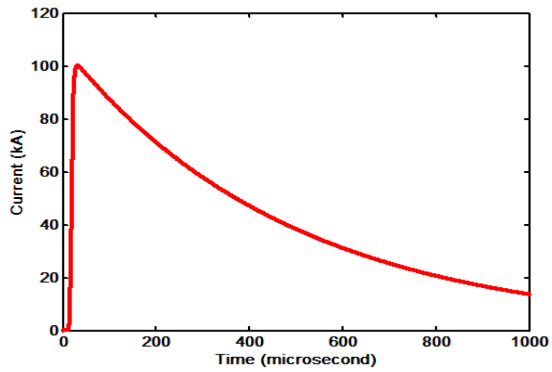

Fig. 4: Wave Current of Lightning According to the Function of Heidler.

After several measures of real lightning bolt [3], recommended values in literature and documentations are estimated of 100 kA. The Peak values of lightning currents in the Congolese tropics can reach value of 100 kA and lowest turn the order of 3 to 4 kA.

4. Characteristic impedance of the line power lines are systems

Distributed constants, that is to say the physical parameters (R, L, C) are spread over the entire length of the line and are therefore not located. And a length L of line can be regarded as the sum of the elements length (dx) distributed along the latter.
A length of element (dx) is characterized by a resistor (rdx), a inductance (ldx), capacity (cdx) and conductance (gdx).
Let r, l: the resistance and inductance longitudinal per unit length; c, g: the capacity and conductance transverse per unit length.
For this Ngo-Brazzaville line, the easy model to use is that by pi. Indeed, the pi model to model lines lower than or equal to 240 km. Here, the diagram of a high voltage line [4]:

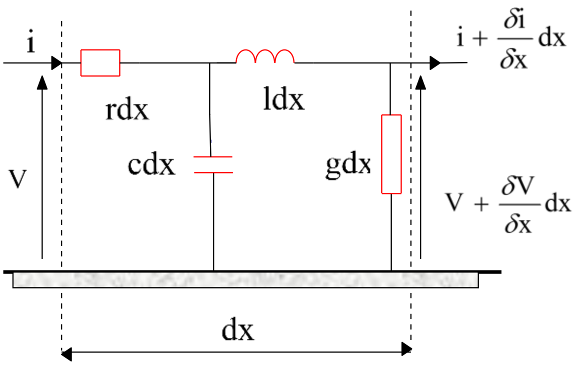

Fig. 5: Diagram of a High Voltage Line.

According to the laws of KIRCHOFF:

$$v(x) = v_r + v_l + v(x+dx)$$

$$v(x) - v(x+dx) = v_r + v_l$$

$$-\frac{\delta v}{\delta x}.dx = v_r + v_l \quad (10)$$

$$i(x) = i_C + i_g + i(x+dx)$$

$$i(x) - i(x+dx) = i_C + i_g$$

$$-\frac{\delta i}{\delta x}.dx = i_C + i_g \quad (11)$$

As i and v are sinusoidal we have:

$$v_r = ri.dx\,;\; v = (jl\omega).idx\,;\; v = \left(\frac{1}{g.dx}\right).i_g$$

$$i_g = v.g.dx\,;\; i_C = v.(jl\omega).dx$$

By replacing the voltages and currents above in the relations (10) and (11) we obtain the following:

$$\begin{cases} \frac{dv(x)}{dx} = -Z_1.i(x) \\ \frac{di(x)}{dx} = -Y_t.v(x) \end{cases} \quad (12)$$

With $Z_1 = r + jl\omega$ (longitudinal impedance)

$Y_t = g + jc\omega$ (Transverse admittance)

Differentiating members of both equations system (12) above are:

$$\begin{cases} \frac{d^2v(x)}{dx^2} = -Z_1.\frac{di(x)}{dx} \\ \frac{d^2i(x)}{dx^2} = -Y_t.\frac{dv(x)}{dx} \end{cases}$$

$$\begin{cases} \frac{d^2v(x)}{dx^2} = -Z_1.Y_t.v(x) \\ \frac{d^2i(x)}{dx^2} = -Y_t.Z_1.i(x) \end{cases}$$

We suppose that: $\gamma_\omega^2 = Z_1.Y_t$ and therefore:

$$\gamma_\omega = \sqrt{(r + jl\omega)(g + jc\omega)}$$

γ_ω is the propagation constant of the wave on the line. We find the following equations:

$$\begin{cases} \frac{d^2v(x)}{dx^2} = \gamma_\omega^2.v(x) \\ \text{et} \\ \frac{d^2i(x)}{dx^2} = \gamma_\omega^2.i(x) \end{cases} \quad (13)$$

Considering as impedance Z_0 characteristic of the high-voltage line:
Firstly,

$$v(x) = Z_0.i(x)\,;\; Z_0 = \frac{v(x)}{i(x)} \quad (14)$$

On the other hand, deriving v(x) with respect to x, we obtain:

$$\frac{dv(x)}{dx} = Z_0\frac{di(x)}{dx}\,;\; Z_0 = \frac{dv(x)}{dx} \quad (15)$$

By dividing the two equations of the relationship (12), we find:

$$\frac{dv(x)}{di(x)} = \frac{Z_1}{Y_t}\frac{i(x)}{v(x)} \quad (16)$$

Relating the relations (14) and (15) in (16) we find:

$$Z_0 = \frac{Z_1}{Y_t}\frac{1}{Z_0}\,;\; Z_0^2 = \frac{Z_1}{Y_t}$$

$$Z_0 = \sqrt{\frac{r + jl\omega}{g + jc\omega}} \quad (17)$$

Let us write the complex number $z = a + jb$ under the exponential form:

$Z = |Z|\exp(j\theta)$ With $Z = \sqrt{a^2 + b^2}$ the module of (Z) and θ the argument.

$$Z_0 = Z_1^{\frac{1}{2}} \text{ with } Z_1 = \frac{r + jl\omega}{g + jc\omega} = |Z_1|\exp(j\arg(Z_1))$$

$$|Z_1| = \left|\frac{r + jl\omega}{g + jc\omega}\right| = \sqrt{\frac{r^2 + (l\omega)^2}{g^2 + (c\omega)^2}}\,;\; \theta = \arg(Z_1) = \arg\left(\frac{r + jl\omega}{g + jc\omega}\right)$$

$$\theta = \arg(r + jl\omega) - \arg(g + jc\omega)$$

$$\theta = \arctan\left(\frac{l\omega}{r}\right) - \arctan\left(\frac{c\omega}{g}\right)$$

The impedance Z0 will be written:

$$Z_0 = \sqrt{\frac{r + jl\omega}{g + jc\omega}} = |Z_1|^{\frac{1}{2}} \exp\left(j\frac{\theta}{2}\right)$$

$$Z_0 = \left(\frac{r^2 + (l\omega)^2}{g^2 + (c\omega)^2}\right)^{\frac{1}{4}} \exp\left(j\frac{\theta}{2}\right) \quad (18)$$

The complex impedance of the module is:

$$Z_0 = \left(\frac{r^2 + (l\omega)^2}{g^2 + (c\omega)^2}\right)^{\frac{1}{4}} = \sqrt{\frac{l}{c}}\left[\frac{1 + \left(\frac{r}{l\omega}\right)^2}{1 + \left(\frac{g}{c\omega}\right)^2}\right]^{\frac{1}{4}}$$

$$\left(\frac{r}{l\omega}\right)^2 \approx 0 \text{ and } \left(\frac{g}{c\omega}\right)^2 \approx 0$$

r and g are negligible, the parameters inductive and capacitive become so predominant, the characteristic impedance is:

$$Z_0 = \sqrt{\frac{l}{c}} \quad (19)$$

The characteristics of the Ngo –Brazzaville line:
Length: 207 km;
Linear capacitance: $C = 9{,}033 nF/km$;
Resistance per unit length: $r = 0{,}057 \Omega/km$; Reactance linear : $x = l\omega = 0{,}404 \Omega/km$.
We then find the characteristic impedance $Z_0 = 377{,}41\,\Omega$

5. Calculation of surges due to strokes direct lightning

A direct lightning strike is one that touches directly, at least one of the conductors assets. In most cases, strokes direct lightning are the most severe on electrical equipment. Indeed, the overvoltage from them can reach thousands volts with strong currents on the lines. In this type of lightning, are distinguished if lightning strikes a single conductor, two, three or simultaneously phases conductors like us the plan below. Network designers have planned an insulation coordination to surge Lightning 1050 kV line pylon, the highest level provided by the standards a network to 220 kV.

5.1. Direct thunderbolt on one phase conductor

When lightning strikes a single conductor phase, for example here, the $n^0$1 conductor, there are a current wave which is injected on this conductor. This current wave which spreads on either side of the point of impact is the half wave of the lightning current is fell on the conductor.

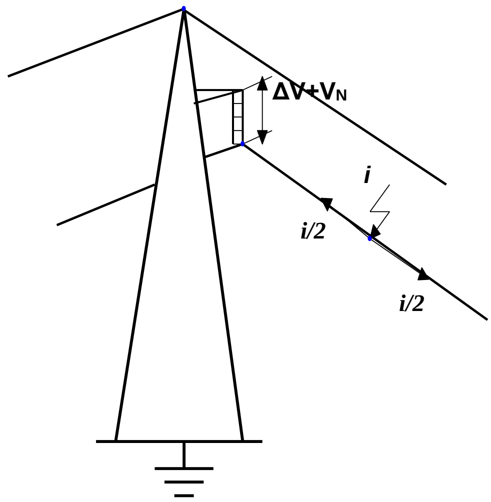

Fig. 6: Direct Lightning Bolt On A Conductor of Phase.

According to the laws of KIRCHOFF:
This current wave $\frac{i(t)}{2}$ causes overvoltage on the $n^0$1 conductor $\Delta V_1(t)$ given by the classic formula [5]:

$$\Delta V_1(t) = Z_0 \frac{i(t)}{2}$$

With Z_0 the characteristic impedance of the line. Hence the voltage on conductor $n^0$1struck down:

- From the dual function exponential:

$$\Delta V_1 = Z_0 \frac{I_0}{2}\left[\exp(-\alpha.t) - \exp(-\beta.t)\right] \quad (20)$$

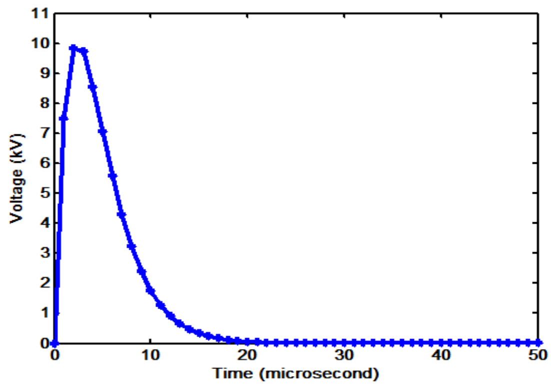

Fig. 7: Curve Overvoltage According to Bi- Exponential Function.

The maximum voltage on conductor by no1 in relation to the modeling of lightning wave with the bi-exponential function is:

$$\Delta V_1 = 9{,}8406 \quad kV$$

- From the function of Heidler

$$\Delta V_1 = Z_0 \frac{I_0}{2\eta} \frac{(t/\tau_1)^n}{1 + (t/\tau_1)^n} \exp\left(-\frac{t}{\tau_2}\right) \quad (21)$$

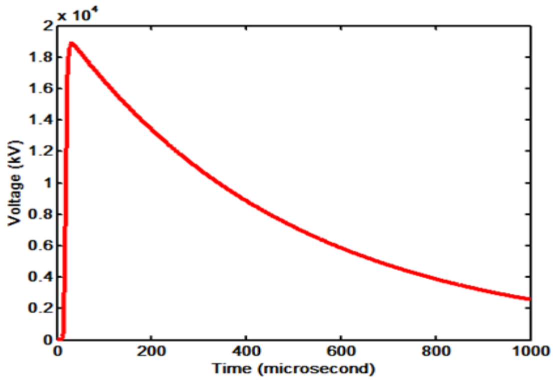

Fig. 8: Curve Surge on the N^{0}1 Conductor Struck by Heidler Function.

The maximum surge on conductor n^{0}1 in comparison with the modeling of lightning wave with the function of Heidler is:

$\Delta V_1 = 18\,893$ kV

The surge voltage is similar to that of the lightning current, however it may be changed after the spread, corona or by reflections at the ends. At a given point of the line, for example the first pylon encountered by the wave, the voltage may possibly grow until the occurrence of the initiation of the insulator string (circumvention of the insulator), if the following is true:

$\Delta V_1 + V_N \geq V_{CR}$

V_N is the peak voltage between the phase and the fitting of the pylon of the line at the natural frequency, V_{CR} is the critical starting voltage of the insulator chain. The surge above is that due to the fall of lightning conductor on one of the line (it was considered such as the n^{0}1 conductor). At the same time, the current injected into the n01 conductor will generate surges through magnetic induction on the other two n^{0}2 and n^{0}3 conductors as represented here.

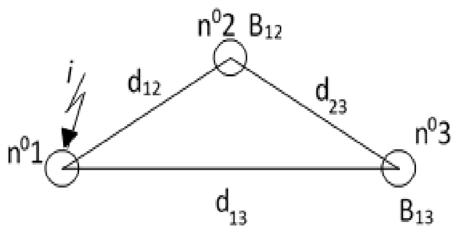

Fig. 9: Direct Thunderbolt on the Stage N^{0}1.

$d_{12}= d_{23}=$ 4,47 m; d_{13}=8 m

The inductions created by this current on the n^{0}2 and n^{0}3 conductors have the values:

$$B_{1k} = \frac{\mu_0}{4\pi d_{1k}} \frac{i}{2} \quad \text{with k=2 and h=3}$$

- From the exponential double function:

$$B_{1k} = \frac{\mu_0}{4\pi \pi_{1k}} \left[\exp(-\alpha.t) - \exp(-\beta.t)\right] \qquad (22)$$

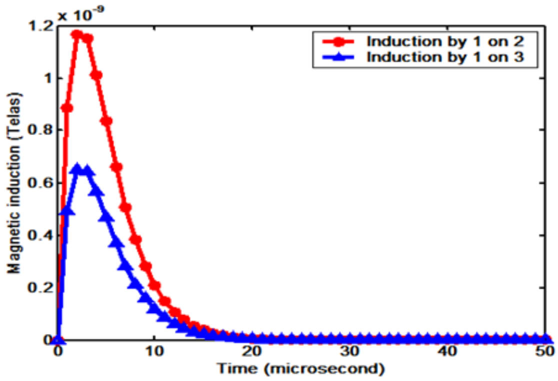

Fig. 10: Curves of Magnetic Induction According to the Bi-Exponential Function

- From the function of Heidler

$$B_{1k} = \frac{\mu_0}{4\pi d_{1k}} \frac{I_0}{\eta} \frac{(t/\tau_1)^n}{1+(t/\tau_1)^n} \exp\left(-\frac{t}{\tau_2}\right) \qquad (23)$$

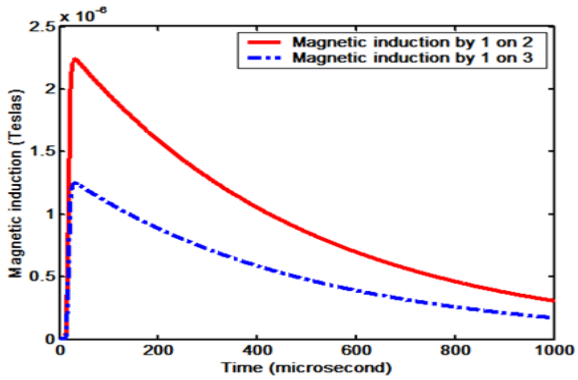

Fig. 11: Curves of Magnetic Induction According Heidler.

The values of maximum magnetic inductions on the conductors n^{0}2 and n^{0}3 with respect to two-exponential functions and Heidler are indicated in the following table:

Table.2: Values of Magnetic Induction

	function	
magnetic induction	Bi-exponential	Heidler
B_{12}(Teslas)	1,1666.10^{-9}	2,2398.10^{-6}
B_{13}(Teslas)	0,6519.10^{-9}	1,2515.10^{-6}

It shows that these inductions are very low.
Overvoltage induced on the n^{0}2 and n^{0}3 conductors
Considering that the conductors are great lengths to their diameter, we have:

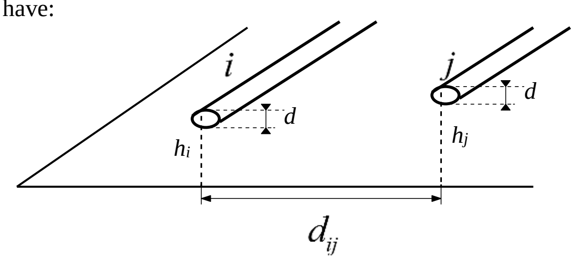

Fig. 12: Provision of Two Conductors.

The mutual inductance between the two conductors i and j of the line and in the presence of soil is the real part m_{ij} of the complex inductor $\underline{L}_{ij}$ [6].

$$\underline{L}_{ij} = \frac{\mu_0}{4\pi}\left[\frac{(h_i + h_j + 2\underline{\delta})^2 + d_{ij}^2}{(h_i - h_j)^2 + d_{ij}^2}\right][\text{H/m}] \quad (24)$$

d_{ij} : Horizontal distance of the two conductors (distance between their projections on the ground);
h_i : Average height of the conductor i above the ground;
h_j : Average height of the conductor j above the ground;
$\underline{\delta}$: Penetration depth of the current wave in the ground [7], [8];

$$\underline{\delta} = \frac{1}{\sqrt{j\mu_0\sigma\omega}}$$

μ_0: Permeability of vacuum;
σ (S/m): Soil electrical conductivity.
The mutual inductance per unit length m_{ij} will be written:

$$m_{ij} = \frac{\mu_0}{4\pi}\frac{\sqrt{\alpha_{ij}^2 + \beta_{ij}^2}}{(h_i - h_j)^2 + d_{ij}^2} \quad (25)$$

With $\alpha_{ij} = (h_i - h_j)^2 + \sqrt{8}(h_i + h_j)|\underline{\delta}| + d_{ij}^2$

$\beta_{ij} = 4|\underline{\delta}|^2 + \sqrt{8}(h_i + h_j)|\underline{\delta}|$

$|\delta| = \frac{1}{\sqrt{\mu_0\sigma\omega}}$

Penetration depth $\delta = |\underline{\delta}|$

In the case of Ngo and Brazzaville, the resistivity's measuring of the soil revealed values similar 1000 Ω.m, far beyond the traditional results of 200 Ω.m. Thus for a frequency of 50 Hz, the depth of current penetration into the ground takes the following value: $\delta = 1592,4$ m.

The coefficients m_{ij} have the values:

$$m_{12} = \frac{\mu_0}{4\pi}\frac{\sqrt{\alpha_{12}^2 + \beta_{12}^2}}{(h_1 - h_2)^2 + d_{12}^2} = 0{,}0514\text{H/m}$$

$$m_{13} = \frac{\mu_0}{4\pi}\frac{\sqrt{\alpha_{13}^2 + \beta_{13}^2}}{(h_1 - h_3)^2 + d_{13}^2} = 0{,}0160\text{H/m}$$

With h_1=h_3 =14 m; h_2=16 m ; d_{12}=4 m; d_{13}=8 m;

α_{12}=1,3604.10^5 m^2 ; β_{12}=1,0278.10^7 m^2 ; α_{13}=1,2696.10^5 m^2;

β_{13}=1,0269.10^7 m^2 ; μ_0=4π.10^{-7} ; δ=1592,4 m.

Literature information that beyond a distance of L=1500 meters of the impact point of lightning on the line, lightning surge is virtually no danger because of the potential flashover, spark gaps, and made the land at the pylons [9].

$$M_{ij} = m_{ij} \times L \quad (26)$$

That is :

M_{12}=0,0514×1500= 77,1 Henry

M_{12}=0,0160×1500= 24 Henry

The flow induced through the n^{0}2 and n^{0}3 conductors are:

$$\begin{cases} \varphi_2 = M_{12}.\frac{i(t)}{2} \\ \text{and} \\ \varphi_3 = M_{13}.\frac{i(t)}{2} \end{cases}$$

Overvoltage ΔV_2 and ΔV_3 corresponding:

$$\begin{cases} \Delta V_2 = -\frac{d\varphi_2}{dt} = -\frac{1}{2}M_{12}\frac{di(t)}{dt} \\ \text{and} \\ \Delta V_3 = -\frac{d\varphi_3}{dt} = -\frac{1}{2}M_{13}\frac{di(t)}{dt} \end{cases}$$

Either in absolute terms:

$$\begin{cases} \Delta V_2 = \frac{1}{2}M_{12}\frac{di(t)}{dt} \\ \text{and} \\ \Delta V_3 = \frac{1}{2}M_{13}\frac{di(t)}{dt} \end{cases} \quad (27)$$

- For the bi-exponential function:

$$\Delta V_k = \frac{M_{ik}I_0}{2}[-\alpha.\exp(\alpha.t) + \beta.\exp(\beta.t)] \quad (28)$$

With k=2 and k=3

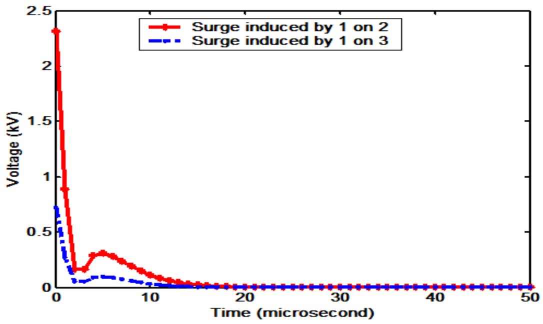

Fig. 13: Curves Surges Induced on the N^{0}2 and N^{0}3 Conductors Following the Bi-Exponential Function

Max surge on the conductor n^{0}2 = 2, 3130 kV and on the conductor n^{0}3 = 0, 7200 kV

- For the Heidler function:

$$i(t) = \frac{I_0}{\eta}\frac{(t/\tau_1)^n}{1 + (t/\tau_1)^n}\exp\left(-\frac{t}{\tau_2}\right)$$

By the method of the logarithmic derivative with respect to time on the basis of Heidler, one obtains:

$$\log(i(t)) = \log\left(\frac{I_0}{\eta}\frac{(t/\tau_1)^n}{1 + (t/\tau_1)^n}\exp\left(-\frac{t}{\tau_2}\right)\right)$$

$$\log(i(t)) = \log\left(\frac{I_0}{\eta}\right) + n\log(t/\tau_1) - \frac{t}{\tau_2} - \log(1 + (t/\tau_1)^n)$$

$$\frac{di(t)}{dt} = \left[\frac{n}{t} - \frac{1}{\tau_2} - \frac{n}{\tau_1}\frac{(t/\tau_1)^{n-1}}{1 + (t/\tau_1)^n}\right]i(t)$$

$$\frac{di(t)}{dt}=\left[\frac{n}{t}\frac{1}{1+(t/\tau_1)^n}-\frac{1}{\tau_2}\right]i(t) \quad (29)$$

Substituting (29) into equation (27), we find:

$$\Delta V_k=\frac{M_{ik}}{2}\left[\frac{n}{t}\frac{1}{1+(t/\tau_1)^n}-\frac{1}{\tau_2}\right]i(t) \quad (30)$$

With k=2 et k=3

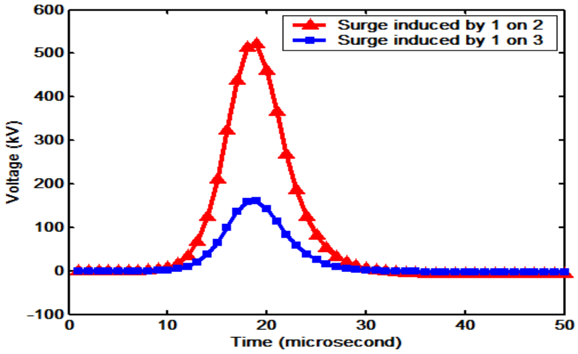

Fig. 14: Curve Surges Induced on the $N^0$2 and $N^0$3 Conductors According Heidler

Induced surge peak on n°2 and n°3 conductors are low:

$$\Delta V_2=520{,}35\text{kV}\ ,\ \Delta V_3=161{,}97\text{kV}$$

The following table gives the values of lightning surges on the three conductors of the Ngo-Brazzaville line taking into account the bi-exponential and Heidler functions.

Table 3: Surge in First Case

Thunderbolt on one phase conductor for example $n^0$1 conductor			
	Maximum Voltage Conductor		
Conductors	Notation	Value kV Bi-exponential Function	Heidler Function
$n^0$1	ΔV_1	9,8406	18 893
$n^0$2	ΔV_2	2,3130	520,3531
$n^0$3	ΔV_3	0,7200	161,9977

5.2. Direct thunderbolt on two phases conductors simultaneously

When lightning intensity $i(t)$ falls simultaneously on two phases conductors (eg $n^0$1et conductor the conductor $n^0$2), the intensity of lightning splits in half on both live conductors. The respective voltages on each of the two conductors are:

$$\Delta V_1=\Delta V_2=Z_0\frac{i}{4}$$

The corresponding curve is:

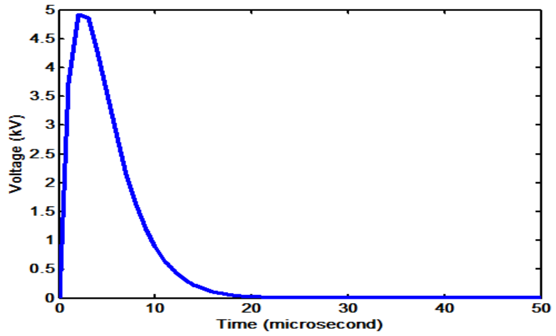

Fig. 15: Curve of the Overvoltage on the $N^0$1 and $N^0$2 Conductors According to the Bi-Exponential Function.

The maximum voltage on the $n^0$1 and $n^0$2 conductors is:

$$\Delta V_1=\Delta V_2=4{,}92\,\text{kV}$$

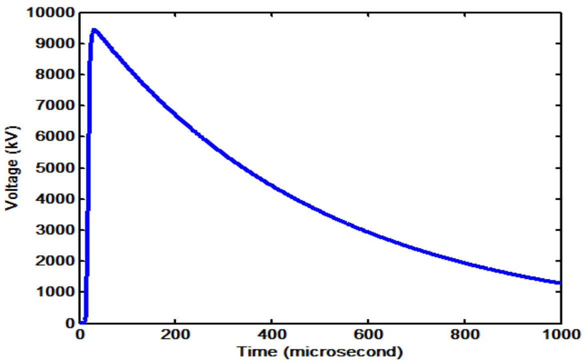

Fig. 16: Curve of the Overvoltage on the $N^0$1 and $N^0$2 Conductors According to Heidler Function.

The surge on the $n^0$3 conductor is the sum of the voltage and induced $n^0$1 and $n^0$2 respectively conductors on $n^0$3 conductor:
Referring to relations (28) and (30) is deduced and so that:

- According to the bi-exponential function:

$$\begin{cases}\Delta V_{13}=\dfrac{M_{13}I_0}{4}\left[-\alpha.\exp(-\alpha.t)+\beta.\exp(-\beta.t)\right]\\[2ex]\Delta V_{23}=\dfrac{M_{23}I_0}{4}\left[-\alpha.\exp(-\alpha.t)+\beta.\exp(-\beta.t)\right]\end{cases}$$

Taking into account the relation (25) and (26), mutual inductors M_{13} and M_{23} are found.

M_{13}=24 Henry and M_{23}=77,1 Henry

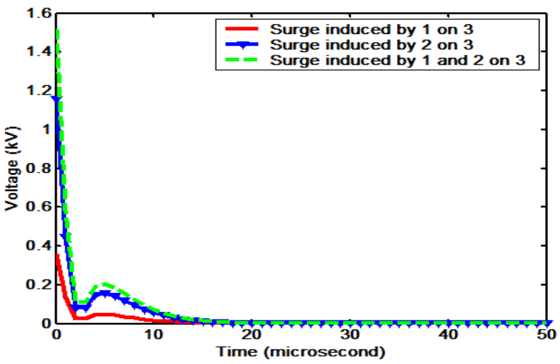

Fig. 17: Curves of Lightning Induced Simultaneously by $n^0$1 and $n^0$2 Conductors According to Bi-Exponential Function.

The maximum voltage induced $n^0 1$ conductor on the $n^0 3$ conductor: $\Delta V_{13\max} = 0{,}36\,kV$

Similarly, the maximum voltage induced by the $n^0 2$ conductor on $n^0 3$ conductor is:

$\Delta V_{23\max} = 1{,}1565\text{ kV}$. It was therefore the maximum total voltage on the $n^0 3$ conductor: $\Delta V_{3\max} = 1{,}5165\text{ kV}$

- Depending on the function of Heidler:

$$\begin{cases} \Delta V_{13} = \dfrac{M_{13} I_0}{4}\left[\dfrac{n}{t}\dfrac{1}{1+(t/\tau_1)^n} - \dfrac{1}{\tau_2}\right]\dfrac{I_0}{\eta}\dfrac{(t/\tau_1)^n}{1+(t/\tau_1)^n}\exp\left(-\dfrac{t}{\tau_2}\right) \\ \Delta V_{23} = \dfrac{M_{23} I_0}{4}\left[\dfrac{n}{t}\dfrac{1}{1+(t/\tau_1)^n} - \dfrac{1}{\tau_2}\right]\dfrac{I_0}{\eta}\dfrac{(t/\tau_1)^n}{1+(t/\tau_1)^n}\exp\left(-\dfrac{t}{\tau_2}\right) \end{cases}$$

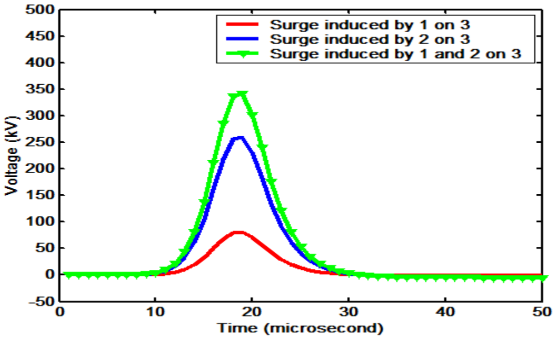

Fig. 18: Curves of Lightning Induced Simultaneously by $N^0 1$ and $N^0 2$ Conductors According Heidler Function.

The maximum voltage induced by $n^0 1$ conductor on the $n^0 3$ conductor is:

$$\Delta V_{13\max} = 80{,}98\text{ kV}$$

Similarly, the maximum voltage induced by the $n^0 2$ conductor on $n^0 3$ conductor is:

$$\Delta V_{23\max} = 260{,}17\text{kV}$$

It was therefore the maximum total voltage on the $n^0 3$ conductor:

$$\Delta V_{3\max} = 341{,}16\text{ kV}$$

Table 4: Surge in Second Case

Thunderbolt on two phases conductors for example the $n^0 1$ and $n^0 2$ conductors			
Conductors	Maximum Voltage Conductor Notation	Value kV Bi-exponential Function	Heidler Function
$n^0 1$	ΔV_1	4,92	9446,6
$n^0 2$	ΔV_2	4,92	9446,6
$n^0 3$	ΔV_3	1,51	341,16

5.3. Direct thunderbolt on three phases conductors simultaneously

When lightning strikes the three conductors, the intensity of lightning split into three on three active conductors, overvoltage on each conductor is:

$$\Delta V = Z_0 \frac{i}{6} = \Delta V_1 = \Delta V_2 = \Delta V_3$$

The corresponding curves surge are:

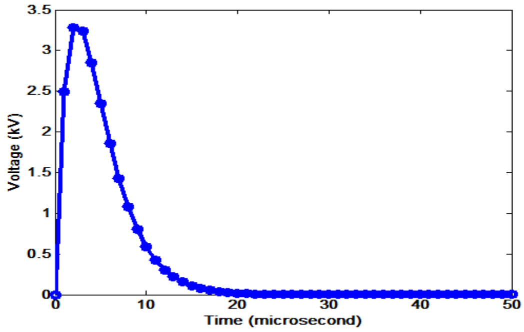

Fig. 19: Surge Curve Simultaneously on the Three Phases Conductors According to the Bi-Exponential Function.

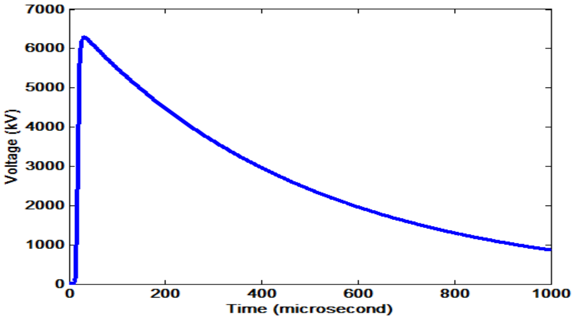

Fig. 20: Curves Surges Simultaneously on the Three Phases Conductors According to Heidler Function

The maximum values of over voltages in the following table:

Table 5: Surge in Third Case

Thunderbolt simultaneously on the three phases conductors ($n^0 1$, $n^0 2$ et $n^0 3$)			
Conductors	Maximum Voltage Conductor Notation	Value kV Bi-exponential Function	Heidler Function
$n^0 1$	ΔV_1	3,2802	6297,7
$n^0 2$	ΔV_2	3,2802	6297,7
$n^0 3$	ΔV_3	3,2802	6297,7

6. Study analysis

It is possible to reduce the number of trips of the power lines and insulation breaks due to lightning by proper installation of guard cables and made the appropriate ground at the pylons. These earthing should be checked regularly. Indeed, the literature information that beyond 1.5 kilometers from the point of impact of lightning on the line, lightning surge is virtually no danger. It is desirable that excessive voltage can not spread to the position. In this case, the use of arresters near the transformers stations with grounding of low impedance is capital. It is important to realize grounding of low impedance for all the pylons at a distance of about 2 km from the stations. Generally, when there is priming the insulator chain (at the spark gaps), after a given time, the switching devices are set to automatically reset. In tropical regions (case of Congo), this reclosing often causes a further opening of the fact that the ionization of the air still leaves the conductor. The reset time must, therefore, be more important to expect the complete deionization of the air occurred. It is best to use long insulators benefit longer possible leakage paths. In the area of Brazzaville where the risk of lightning is huge, maintenance of insulators becomes imperative. It is recommended that periodical washing with distilled water.

7. Results

In all cases enumerated here, one can end up with surges reaching 18.850 kV value extremely above 1050 kV is the highest level of stage-pylon surge provided by the requirements for a network to

220 kV. The situation is more catastrophic when lightning strikes a single phase conductor if it struck simultaneously, three. Electricity of France provides for a 225 kV line, the phase-pylon starting voltage of about 1000 kV and the critical current around 5 kA [10].

Here, to put the network safe from power surges related to lightning, the obvious and safest solution is to realize during storms, the power cut from the plant. By prioritizing the requirements of the continuity of service, we have to rely on updates to the appropriate ground at the pylons.

8. Conclusion

This study is to reveal the results, the figure is now known: 18 893 kV is the value of the voltage can be attained in a phase when lightning strikes on the 220 kV NGO – Brazzaville line. To limit the damage, it is important to realize grounding very low resistances RT <1 Ω on pylons and equip the types of insulators to several channels phase to drain very high currents in case boot or circumvention by the arcing. It is best to use long insulators benefit longer possible leakage paths. In the area of Brazzaville, where the risk of lightning is huge, maintenance of insulators becomes imperative. It is recommended that periodical washing with distilled water. This article reveals the gravity of the situation thunderbolts on the electricity network in the Congo with the values of the surge could exceed the limits of the standards. It is up to the designers of the networks and the manufacturers of electrical equipment, study provisions that can adapt to such situations for the uninterruptible power supply, even during thunderstorms and lightning strikes as a magnitude.

In order to protect the network, the importance of surges due to lightning strikes still leaves avail the solution of the general power failure during major storms.

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