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Impact of Transient Over-Voltages on the Skirting of Electrical Transmission Line Insulators Corona Effects

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Abstract: In this study, it is shown that the corona effect attenuates and deforms atmospheric over-voltages which are propagated on the transmission lines. This contributes in a beneficial way to minimization of skirting of the insulators and makes it possible to avoid the short circuits from where a good continuity of service. This has been observed for over-voltages under different distances from its point of impact. The line was represented by its equivalent diagram, divided into N identical cells. The corona effect was simulated by a power source placed in parallel with the capacitor line. The load is simulated by 3 elements in parallel, a resistance, an inductance and a capacitor. The point of impact of over-voltage is taken as voltage source. Over-voltage is simulated by a shock wave 1.2/50 µs represented by an Bi-exponential function. Line of 220 Kv, a 60 km long was used. Equations of the propagation and the current leading to 2n+1 differential equations. The solutions of these equations enabled us to plot the representative curves of over-voltage with: 0; 1000;3000; and 7000 m. the method of Runge-Kutta-Verner was used for the resolution of the differential equations.

Key words: Skirting, over-voltages, corona effect, pollution, short-circuit, insulation

INTRODUCTION

The skirting of the insulators of the electrical transmission lines of transport is one of the major problems which the owners of the electrical supply networks encounter and represent 80 % of the defects in the electrical transmission line. The origin of the phenomenon of skirting is with two factors: the covering of the surface of the insulators of a layer of conducting pollution which associated moisture will lead to the setting in short-circuit of these insulators and in addition with overpressures of various origin which can cause perforations and damage with the insulation involving of the cuts of the electric power in the grid systems. In this article we will devote our work to the attenuation of transitory overpressures to minimize the phenomenon of skirting.

The perfection of an electrical networks system is characterized by its continuity of service, this constraint being able to be ensured by the reinforcement of the insulation obeying a rational dimensioning and this requires to have all knowledge on the constraints to which the material will be subjected. It is then necessary to know the forms and the amplitudes of overpressures which can reach the lines networks and to calculate their propagation to the stations of interconnection and distribution.

Transient over-voltage have a great importance in the coordination of insulations and the choice of the types of protection and the place of their site[1]. Thus any attenuation of over-voltage must adequately be evaluated. The corona effects which can accompany transient over-voltage when they are propagated along the lines, has a beneficial effect in reductions of insulation constraints on the material compared to the values usually calculated and used[2]. Indeed by causing losses of powers, the corona effects subjects the waves of over-voltages of the deformations and attenuations, which is superimposed to that caused by the skin effect, occur dissipation by injection of the space charges in the environment of the drivers. This process takes place as soon as the instantaneous voltage exceeds the threshold voltage of the corona effects wires. Studies were published on the corona effects since 1920[3]. It is the phenomenon of appearance of emanations around a wire with a high potential. This effect appears when the electric field creates by the wire reached the disruptive field of the surrounding air. The corona effects appears by the appearance of undesirable phenomena: luminous emanations around the wire, an audible crackling; losses of power, radio-electric disturbances[4,5]. In this study, one showed that the corona effect can have a beneficial effect by attenuating transient over-voltages which will be reflected in a positive way on skirting of the insulators

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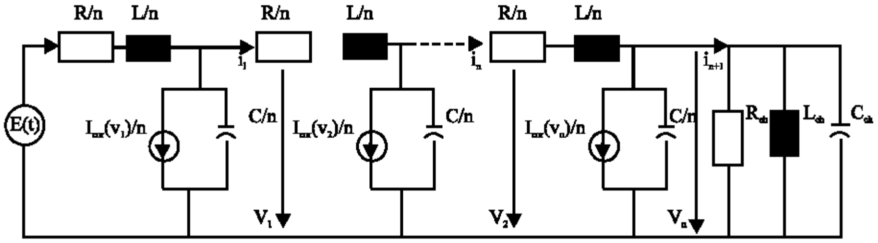

Fig. 1: Simplfied equivalant transmission line

and will avoid the probable short-circuits in the electrical networks systems, for that, an over-voltage was injected in a three-phase line horizontal configuration 220 Kv, 60 km of length.

Each phase is constituted by a wire 2,62 cm of diameter and inter-phase distance D = 7 m. the line is represented on the Fig. 1 with a resistance R, an inductance L and a capacitor C, was divided into N identical sections. The load was simulated by an impedance Z_c was composed with a resistance R_{ch}, an inductance L_{ch} and a capacitor C_{ch} in parallel. The point of impact of over-voltage is assumed as a source of this line. Several work was completed in the field[6,7]. Nevertheless the non linearity of the corona effects phenomenon make sum problems in the simulation. The various models published in the literature, suggest the uniform distribution along the line, of nonlinear resistances or, as equivalent power sources controlled by the voltage[8]. Other models consider that the corona effect is taken perfectly into account in a dynamic capacitor of the line[2]. In this study, it is the first representation which was used. The corona effects are simulated on the level of each section, by a power source in parallel with the capacitor of the line. Thus it was possible to determine over-voltage at various distances from its point of injection, to represent it graphically and to evaluate its distortion and its attenuation. The practical consequences of such study, lead us to a good coordi-nation of insulation and the implementation of the means of protection[9].

MATERIALS AND METHODS

E(t) is the over-voltage which will be propagated on the line represented by Fig. 1. The line is divided into N identical sections of which the length depends mainly on the duration of rising ramp of over-voltage. More the amplitude and the stiffness of overpressure are higher, more this length must be small. For the amplitude E_0 used in this work, with a E(t) function simulating a wave of the lightning 1,2/50 μs, we used n = 120. This corresponds to lengths of section of 500 m. Each section is a cell of R/n resistance, L/n inductance and C/n capacitor. The critical voltage of appearance of the corona effects V_{cr} was calculated, by using the data line, on the basis of Peek law[10]. The corona effect cannot take place, on the level of an unspecified cell K, that if the instantaneous voltage V_K exceeds the critical voltage. It is simulated by a power source which precisely depends, on the voltage V_K.

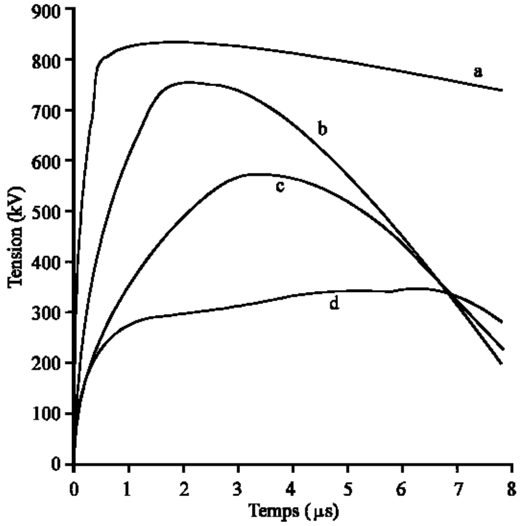

Fig. 2: Representative curves of over-voltages : With the source(a); 1000 m (b); 3000 m © and 7000 m (d)

For $V_K = V_{cr}$ $\quad I_{hom}(V_K) = 0$
And if $V_K > V_{cr}$ $\quad I_{hom}(V_K) = V_K / R_{hom}$

- V_K is the amplitude of the instantaneous voltage V_K of the line on the level of kth cell
- V_{Cr} is the critical simple voltage, of appearance of the corona effects in the line (maximum value)
- $I_{hom}(V_{Cr})$ is corona current on the level of the kth cell
- R_{hom} is corona resistances equivalent to current $I_{hom}(V_K)$ and to the voltage V_K.

To calculate R_{hom} we use the work of Illiceto[6] which proposes a model of calculation of R_{hom} starting from the slope of the linear part of characteristic $I_{hom}(V)$ such as:

$$R_{cor} = \frac{V_m}{\pi.p}\left[V_m.\cos^{-1}\left(\frac{V_{cr}}{V_m}\right) - V_{cr}.\sqrt{1-\left(\frac{V_{cr}}{V_m}\right)^2}\right] \qquad (1)$$

$V_m$is the maximum value, of the simple voltage of the line; p is the total corona losses power line. (In practice a value of 100 W/m is an order of loss for corona effects rather intense)

It is supposed that $I_{hom}(V_K)$ is the same in all the cells.

The load is was represented by three elements in parallel: a resistance R_{ch}= 566 Ω, an inductance; L_{ch} = 3.12 H and a capacity. C_{ch} = 8.79µF These values were selected to obtain a load impedance equal to the characteristic impedance of the line Z_{car}, to avoid the effect of reflection.

The transient over-voltage of the lightning is simulated by a shock wave 1.2/50 µs of 850 Kv ;amplitude. This wave is represented by the following exponential Bi time function[4]

$$E(t) = E_0.(e^{-\frac{t}{62.27}} - e^{-\frac{t}{0.357}}) \qquad (2)$$

$E_{\underline{0}}(\underline{T})$ is the amplitude of overpressure; and T time in µs.

The equations of Kirchhoff applied to the n+ 1 mesh and N nodes Fig.1, give us respectively:
n+1 differential equations for the currents:

$$\begin{aligned}
\frac{di_1(t)}{dt} &= \frac{n}{L}.\left[E(t) - v_1(t) - \frac{R}{n}.i_1(t)\right] \\
\frac{di_2(t)}{dt} &= \frac{n}{L}.\left[v_1(t) - v_2(t) - \frac{R}{n}.i_2(t)\right]. \\
\frac{di_n(t)}{dt} &= \frac{n}{L}.\left[v_{n-1}(t) - v_n(t) - \frac{R}{n}.i_n(t)\right] \\
\frac{di_{n+1}(t)}{dt} &= \frac{v_n}{L_{ch}}
\end{aligned} \qquad (3)$$

And N differential equations for the voltages:

$$\begin{aligned}
\frac{dv_1(t)}{dt} &= \frac{n}{C}.\left[i_1(t) - i_2(t) - \frac{v_1(t)}{n.R_{cor}}\right] \\
\frac{dv_2(t)}{dt} &= \frac{n}{C}.\left[i_2(t) - i_3(t) - \frac{v_2(t)}{n.R_{cor}}\right]. \\
\frac{dv_n(t)}{dt} &= \frac{1}{\frac{C}{n} + ch}.\left[i_n(t) - i_{n+1}(t) - (\frac{1}{n.R_{cor}} + \frac{1}{R_{ch}}).v_n(t)\right]
\end{aligned} \qquad (4)$$

The Runge Kutta Verner method is used to solve these equations.

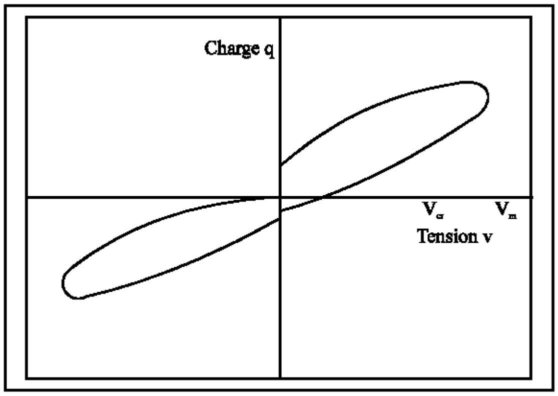

Fig. 3: Diagram cycle qu

The determination of voltage and current which is associated to it, can be made on the level of each cell.

For a good analysis of deformation and attenuation of overpressure, we represent our results in the same Figure, overpressure: at the point of impact; 1000 m; 3000 m; and 7000 m.

In this Figure, one observes that the waves of overpressure strongly diminish, during their propagation.

The amplitudes decrease and clearly tend to be flattened, with the increase of propagation distance . With a positive polarity and at 1000 m of the impact point the attenuation is 19,6 %; to 3000 m it reaches 44 % and at 7000 it exceeds 68 %. The authors also notices that the maximum amplitudes are reached with less speeds of, which makes over-voltages less dangerous for the material and the probability of crowning insulators.

The explanation of this phenomenon can be given by cycle q = f(u) Fig. 3 which show the radial charges Q of a wire and its voltage.

Before the tension U does not reach the breaking value of appearance of the corona effects , the relation between Q and U is linear, such as:

$$q = C_{geo}.u \qquad (5)$$

Where q_{deo} is the geometrical capacitor of the wire which depends only on the geometrical magnitudes of the line.

Above this critical voltage a space charge around the wire appears which induced a charge named of additional corona q_{cor} The wire charge becomes

$$q = C_{geo}.u + q_{cor} \qquad (6)$$

The charge q_{cor} qvaries with the voltage U
Consider then, the relation:

$$q = C_{dyn}.u \quad (7)$$

Where, C_{dyn} would be the dynamic capacitor, variable with the voltage. This capacitor taken accounts the increase in the wire charge by the corona effects, and must consequently be higher than. C_{geo} The propagation velocity of the waves on the lines, almost equal to that of the light, is given by:

$$v = \frac{1}{\sqrt{L.C}} \quad (8)$$

Where L and C are respectively, the inductance and the capacitor of the line. With the increase in the charge, while passing from C_{geo} to C_{dyn}, the speed decreases. However this reduction is so fast that it should be considered that over-voltage cannot be propagated completely with the same speed and we must divide it into parts. These parts, of the same duration, must be each one as short, as we can consider being propagated with same speed. Thus each section of over-voltage will be propagated with a delay compared to that which precedes it and a distortion appears, increasingly accentuated with the increase of the distance from propagation. This increase is equivalent, moreover, with larger of corona power source.

On another side, the dissipation of energy per corona effects, during the propagation of an unspecified voltage, being calculated such as:

$$\Delta W = \frac{1}{Z}\int\left[u_1^2(t) - u_2^2(t)\right].dt \quad (9)$$

Where Z is the line impedance; u_1 and u_2 voltages in two points of propagation, respectively: 1 and 2

If there are corona effects, the existence of the dissipation of energy requires a voltage u_2 lower than. u_1 from where the explanation of the attenuation of over-voltages by the corona effects .

In addition, it is known that the cycles (q,c) depend only on the amplitude of the voltage and the geometry of the line[10]. Knowing that the energy dissipated by the corona effect is represented by the surface of these cycles[2], it follows that more these cycles "are inflated" and more the corona losses are significant. What is equivalent to a greater corona resistances and with more significant damping of over-voltages[7].

A significant disparity exists between the positive (q,u) cycles and negative. In positive polarity these cycles are inflated much than in negative polarity. It is concluded that the attenuation of over-voltages are definitely more significant in positive polarity.

In addition, it is observed Fig. 2 that before dispersing, the four curves representing over-voltages remain grouped, from origin of the voltage up to the critical value of the beginning of the corona effects. we can draw from this remark that without the corona losses, it would not have there great differences, between the various representations of over-voltage during the propagation. For the same reason, as the attenuation of transient over-voltages due to the corona effect is much more significant than that which would be due to the only skin effect.

CONCLUSION

The atmospheric over-voltage waves become deformed while attenuating very quickly during their propagation along the transmission line. As we move away from the impact point (7 km), these over-voltages can be characterized by a flattened ramp and attenuated amplitude (more than 60 %) which becomes practically lower, to shock behaviors of the material station.

After the propagation, this over-voltages present very different form from the starting wave 1.2/50 μs and a smaller speed of increase. All those are accentuated more when the polarity of over-voltage is positive and contributes in a positive way to the insulation and reduces the skirting of the insulators of the electrical transmission lines.

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