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RESEARCH ARTICLE

EVALUATION OF INFLUENCE OF CORONA ON LIGHTNING SURGE

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ABSTRACT

Lightning overvoltages are caused either by direct strokes to the phase conductor [back flashover] or as a result of strokes to earth very closed to the line which produce. Induced lightning surges. This paper focuses on the simulation of the effect of corona model on different conductors used in transmission line design when subjected to the lightning surge, Kudryan non-linear model corona used for this purpose. Mothematical model of Lightning Surge and analytical representation of current wave shape are evaluated.

KEYWORDS

lightning surges, corona, overvoltages.

1. INTRODUCTION

The overvoltage by which substation insulation is stressed is a function of the line construction and the system configuration. In fact, the configuration of the station itself has great influence if the traveling time of surges within the station is not negligible in relation to the front time of the surge. Overvoltage induced by indirect lightning on overhead lines can cause damage either of the power system or the electronic control and management system (Wlodek and Bajorek, 1985). Moreover, due to its more frequent occurrence, indirect lightning constitutes a more important cause of micro-interruptions than direct strike. Their estimation is therefore crucial for the correct operation coordination of overhead lines and, as a consequence, has been the object of various studies since many years. Electromagnetic compatibility contains among others also the above-mentioned problem.

A lightning flash can result in significant overvoltage on power line insulation if substantial stroke current and charge are injected into the line conductor. If first contact of lightning return stroke current is with the line, then it is modeled as a transient current generator feeding into a system of transient surge impedance representing the line conductors and the tower, and then the overvoltage's results are calculated using typical traveling wave technique. The impedance of return stroke is assumed to be larger than the surge impedance of the line or tower, because of the value of the current initiated from the lightning stroke, then may be neglected. The return stroke can then be modeled as an ideal current generator having selected magnitude and wave shape.

The wave shape parameters include the peak current amplitude (crest value), time to crest, steepness, duration, polarity, time interval and number of incident strokes within each lightning flash. In earlier analysis, the front characteristics were defined in the term of the maximum rate of rise of current. In later publications more detail studies and several additional parameters are done to define the front characteristics e.g.

(Cigre working group, 1991; Eriksson and Weck, 1988).

2. ANALYTICAL REPRESENTATION OF THE CURRENT SHAPE

To calculate the lightning performance of equipment, it is necessary to simulate the concave front in the lightning stroke current representation (Kadir et al., 2008). Three points are needed to establish such simulation: the correct amplitude of the current, the highest steepness close to the peak amplitude, For first strokes, the correct average steepness expressed as the front time passing through the 30% and the 90% values of current (Carneiro et al., 1994). This front time must be larger than the current amplitude divided by the maximum steepness, thus resulting in the concave shape.

2.1 The current front

The current front for first strokes can be expressed as

$$I = At + Bt^n \quad (1)$$

where;

A and B are constants.

It is clear that the current shape reaches the instant of maximum steepness (90% amplitude) at time t_n dependent on the exponential n .

For the subsequent strokes the current front is given by (Cigre Working Group, 1991):

$$I = S_m t_f \quad (2)$$

Where

S_m is maximum steepness,

t_f is front time.

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2.2 The current tail

The fundamental requirement for the current tail are:

- to have the maximum steepness at its beginning thus providing a steady transition from one part to the other,
- to reach correct amplitude value,
- to describe the current tail.

A suitable mathematical expression for current tail is given by, (Cigre Working Group, 1991):

$$I = I_1 e^{-(t-t_n)/t_1} - I_2 e^{-(t-t_n)/t_2} \quad (3)$$

Where

$$\begin{aligned} t_1 &= (t_h - t_n) / \ln 2, \\ t_2 &= 0.1 I / S_m, \\ t_n &= 0.6 t_f \left[3 S_N^2 / (I + S_N^2) \right], \\ S_N &= S_m t_f / I, \end{aligned}$$

$$I_1 = \frac{t_1 \cdot t_2}{t_1 - t_2} \left[S_m + 0.9 \frac{I}{t_2} \right],$$

$$I_2 = \frac{t_1 \cdot t_2}{t_1 - t_2} \left[S_m + 0.9 \frac{I}{t_1} \right],$$

t_h wavetail, time to half value,
 t_1 and t_2 are time constants.

3. MODELLING OF LIGHTNING CURRENT IMPULSE

In general the shape of the lightning current impulse can be modeled by double exponential time function as:

$$f(t) = c \cdot I_{max} [exp(-\alpha t) - exp(-\beta t)] \quad (4)$$

This double exponential approximation, in fact gives the sufficient accuracy approximating after 30% point of the current value. In the initial part of lightning current impulse is its real slope of the smaller value than that of the double exponential function (De Jesus and Correia de Barros, 1994). The authors, present another approximating function of lightning current surge, their procedure for verifying this approximation is coming as follows (Wlodek and Bajorek, 1985). When the lightning current stroke contact the line, the voltage wave starts to be formed as shown in figure 1.

Figure 1: The voltage wave

This scheme can be represented by electrical equivalent circuit, considering the lumped parameters, as shown in figure 2:

Figure 2: The electrical equivalent circuit of formed voltage wave

Where, the line conductor is represented by two impedance Z_p , the transmission line tower is represented by L_t , and earth resistance by R_e . If the lightning current is approximated by double exponential function, the transient voltage $u(t)$ can be written as:

$$u(t) = \frac{c \cdot I_{max} \cdot Z_p}{2} \left[\frac{\alpha - a}{\alpha - b} \cdot exp(-\alpha t) - \frac{\beta - a}{\beta - b} \cdot exp(-\beta t) + \frac{(b-a)(\alpha - \beta)}{(\alpha - b) - (\beta - a)} exp(-\beta t) \right] \quad (5)$$

Where

$$a = \frac{R_e}{L_t}, \quad \text{and} \quad b = \frac{(R_e + Z_p/2)}{L_t}$$

A good application examples to calculate the transient voltage according to eq. (5) were done for double exponential approximation of lightning current surge, 1.2/50 μs , and 8/80 μs (Wlodek and Bajorek, 1985). From these examples it was approved that the almost whole front of the voltage impulse is formed during the time interval from 0 to 30%, and that is leads to another approximation which should be used.

The approximation presented in is based on following assumptions (Wlodek and Bajorek, 1985):

- The impulse front is formed mildly during the time interval (0, $t_{30\%}$)

where:

$$i(t)|_{t=0} = 0 \quad (6)$$

$$\left. \frac{di(t)}{dt} \right|_{t=0} = 0 \quad (7)$$

- The impulse front transients smoothly at $t = t_{30\%}$ for double exponential function where:

$$i(t)|_{t_{30\%}} = i(t)|_{t_{30\%}} \quad (8)$$

$$\left. \frac{di(t)}{dt} \right|_{t_{30\%}} = \left. \frac{di(t)}{dt} \right|_{t_{30\%}} \quad (9)$$

Then the approximation which can verify the conditions in eq. (6) and (7) may be written as;

$$i(t) = A \cdot I_{max} \cdot t^B \quad (10)$$

The parameters A and B should be chosen to verify the conditions in eq. (8) and (9).

So, as the conclusion, the approximation of lightning current impulse can be presented in two parts (Wlodek and Bajorek, 1985).

- The approximation of the lightning current impulse in the time interval from 0 to 30% of the front time can be written as:

$$i(t) = A \cdot I_{max} \cdot t^B \quad (11)$$

- For the time interval $t > 30\%$ the approximation can be written as:

$$i(t) = c \cdot I_{max} [exp(-\alpha t) - exp(-\beta t)] \quad (12)$$

The non-linear corona model is presented by Kudyan, the equivalent circuit of which is shown in figure 3. The model circuit, which changes its state depending on the present and previous applied voltage, consists of series inductance, capacitance, resistor, DC batteries and ideal diodes (Kudyan and Shih, 1981).

Figure 3: Equivalent circuit for element of line in coron

In this circuit, C_1 represents the normal line capacitance, while C_2 and C_3 represent the effective capacitances corresponding to the abnormal increase in space charge when the corona threshold voltage is exceeded (Nucci et al., 2000). The parameters of line model circuit with corona can be determined from the experimental q-v characteristics and D. C. corona leakage current of a sample conductor.

3.1 Numerical Example

This example is done to evaluate the influence of Kudyan non-linear model of corona phenomenon on current wave propagation along a segment of transmission line (Podporkin & Siyaev, 1997). The observation points are taken at last two towers before substation, as shown in figure 4.

Figure 4: Lightning stroke on last two towers before substation

This scheme can be represented by the equivalent circuit according to the Dommel model for inductance as in figure 5.

Figure 5: Equivalent circuit of scheme (4) with Dommel model

The voltage impulse can be calculated digitally by chose of the time moment,

$t = h, 2h, \dots, kh$ where:

$$G_L = \frac{h}{2l} \quad (13)$$

$$i_L(k) = i_o(k-1) + G_L u_L(k-1) \quad (14)$$

Then the voltage $u(t)$ at time moment $t = kh$ can be calculated as (Bajorek et al., 1992):

$$u(k) = \frac{Z_p(I + R_e G_L) i(k) - Z_p i_L(k)}{2 + G_L(Z_p + 2R_e)} \quad (15)$$

The current wave is modeled with two parts and according to the equations, (11) and (12), as:

$$U_o(t) = 1.0534 U_m \left[\exp(-1.478 \times 10^4 t) - \exp(-1.635 \times 10^6 t) \right] \quad (16)$$

For the parameters data used to simulate the problem see appendix of the paper. Results of transient simulation are presented in figure 6 and 7.

Figure 6: Voltage observed at 1st tower with and without influence of corona

Figure 7: Voltage observed at 2ed tower with and without influence of corona

4. CONCLUSION AND DISCUSSION

Distortion and attenuation from corona on high voltage transmission line can be modeled by a non-linear circuit. Therefore, a numerical model based on Kudyan model have been developed to illustrate the effect of non-linear corona phenomena on the overvoltage wave propagation on overhead transmission line.

From the results obtained from this model the following points can be written:

1. The model simulates the corona characteristics of a line under impulse voltages and currents and represents the increase of line capacitance and conductance induced by corona.
2. The constants of circuit model are normally determined by a experimental test, as this was not available in our case, the chosen of these data depends upon the ref.
3. Although the computed results obtained are satisfied and have a good match point with all physical influence of the corona phenomena and factors affecting of it, but it should underlined that the present is not sufficient for evaluate all and specific corona data. Hence, corona experimental test should be done systematically to be more useful and logic and cover all atmospheric conditions and other influences.
4. As a general conclusion, the results under these selected case and conditions seem to satisfy the efficient modeling of the effect of non-linear corona phenomena and verify the purpose of study.

Therefore, according to these investigations it can be stated that this developed model seems to be accurate and good model to represent the non-linear corona effect in sufficient measure for technical purpose.

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APPENDIX

The following data are used to simulate the problem:

I_m	wave amplitude	100 kA,
a	wave parameter a	0.13,
b	wave parameter b	2.06,
c	wave parameter c	1.1,
t_0	wave parameter t_0	$0.887e^{-6}$ s,
t_{30}	wave parameter t_{30}	$1.5e^{-6}$ s,
α	Wave parameter α	$0.995e^4$ s,
β	Wave parameter β	$0.534e^6$ s,
L_t	Tower inductance	$0.2 e^{-4}$ H,
R_e	Tower earthing resistance	5.0 Ω ,
Z_c	Surge impedance of line	487 Ω ,
u_c	Critical corona voltage	386 kV,
C_p	Positive capacitance of corona	5.13 pF/m,
C_n	Negative capacitance of corona	3.68 pF/m,
G_{pn}	Positive and negative conductance of corona	$1.69e^{-9}$ S/m.