ZIBELINE INTERNATIONAL PUBLISHING
ISSN: 2590-4043
CODEN: AEMCDV

Acta Electronica Malaysia (AEM)

DOI : http://doi.org/10.26480/aem.01.2019.06.09

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REVIEW ARTICLE

EFFECT OF CORONA ON THE WAVE PROPAGATION ALONG OVERHEAD TRANSMISSION LINES

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ARTICLE DETAILS

Article History:

Received 23 November 2018
Accepted 24 December 2018
Available online 7 January 2019

ABSTRACT

By means of a previously used and developed model, which contains non-linear shunt conductance in parallel with non-linear shunt capacitance, the effects of corona on travailing waves along h. v. transmission line are presented. A mathematical formula is used to evaluate its parameters. Simulink method of mat lab software is used to simulate the problem and solve the line differential equations including corona which is a part of it. A summary of pervious literature with different models is discussed. The result of the resented model compared with previous one.

KEYWORDS

Component, corona, conductance, protection, transmission lines.

1.INTRODUCTION

Overvoltage protection and insulation coordination are based to the knowledge of the magnitudes and waveforms of overvoltage. The corona attenuation and distortion of overvoltage wave is an important factor in determination of the overvoltage level in the electrical system due atmospheric lightning discharge.

Two kinds of significant phenomena affect the attenuation and distortion of overvoltage which is propagating along overhead transmission lines:

1) variation of transversal parameters due to corona.
2) frequency dependence of longitudinal parameters caused by skin effect of conductors.
3) frequency dependent of ground parameters.

Simulation of overvoltage wave propagation in electrical network by digital procedure is often used for solving the problem of the effect of corona on the wave propagation process.

The aims of this paper are:

To discuss of some methods of corona modeling which already have been presented by some authors concerning either linear or non-linear approach to the problem.
To show and discuss the effect of corona which is represented by non-linear shunt capacitance in parallel with non-linear shunt conductance together with numerical example.
Using the Simulink method on the Mat lab software to solve the differential equations of the transmission line with corona "which is considered a part of it". A mathematical formula was used to evaluate the value of these parameters.

2.METHODS OF CORONA MODELING

There is a lot of technique proposed in many literatures to include corona effect in transmission line transient calculation. Some authors develop a number of mathematical or physical models on the basic of the physical mechanism of corona to obtain charge versus voltage characteristic in the line transient computation, taking both space and surface charge into account [1-4]. Then several numerical models have been developed, most of them cover the case of a single conductor and are based on the principle of a variable capacitance between the conductor and the ground, and this capacitance is estimated from experimental or computed (q-v) curves.

Other authors include non-linear branches of resistance and capacitance in the transmission line to represent the non-linear effect of corona [5, 6]. The value of the element in the branches are voltage dependent and determined in most cases according to the energy relationship of corona losses, or experimental (q-v) curve and the parameter of transmission line is calculated according to the configuration of it.

The short discussion of some of these methods is given here. The multilayer three-phase corona model presented in a study [1]. This model is developed going out from microscopically physical laws and reflected relations between charge and electrical field intensity or voltage. Space charges, their development and their displacement are taken into account. The parameters of the model are determined so that the simulated (q-v) curves closely fit those available from measurement. Then the corona model is used as an element of the discretized transmission line model. This consists either of longitudinal inductance or of travel delay modules. The line equations are integrated using the trapezoidal rule, so that Norton equivalents are obtained for the two line ends to interfacing with the external system.

The researcher develops practical model using the image method to calculate the dynamic capacitance of the line in corona [2]. This model has advantage that its parameters can be determined before and according to the condition of the line. Also, a concept of time delay in the formation of corona space charges is introduced to make the model more logic and accurate both in simulation results and in understanding of many important characteristics of (q-v) curves. This model can be used to calculate corona effect on traveling wave.

In other hand, the researchers present the non-linearity model of corona, the consideration of non-linear characteristic of the corona discharge as a shunt variable conductance GC to represent the discharge resistance and a shunt variable capacitance to represent the capacitive effect [5]. The value of shunt admittance of the non-linear corona model is dependent on the value of the operating voltage at the buses. Mathematically the dynamic variation of the shunt discharge resistance R_C , where

$R_C = 1/G_C$ can be represented by;

$$R_C = \frac{2.142\times10^3 m}{n}\left[\log_{10}\frac{D}{r}\right]^2 \exp[-4.772]\frac{V_e}{V_c} \qquad (1)$$

where, V_e / V_c is the ratio between the operating voltage and critical corona voltage respectively, n is the length of the transmission line in km, D is the distance between the conductors, r is the conductor radius, and m is the weather factor equal about 1 to 0.7.

The shunt capacitance can be calculated for the phase conductor from the following equation:

$$C_c = 2\delta_c\left[\frac{r}{2h}\right]^{1/2}\left[1-\frac{V_c}{V_e}\right]10^{-11} \qquad (2)$$

Where C_c the corona capacitance, r and h are radius and height of the conductor respectively, δ_c is the corona loss constant normally in the range of (15 to 30).

Besides that, the researcher presents similar model for non-linear corona, describing the corona phenomena by the modified transmission differential equations [6]. The phenomena can be studied accurately by solving the equations describing the electromagnetic wave propagation, taking into account corona i.e. adding two parts to transmission line differential equations: one of them represent the non-linear corona capacitance and other represent the non-linear corona resistance.

Next, the researcher presents the first case by a switching capacitor C_0, which is included in the circuit only during the corona period [7]. The value of this capacitance may be obtained as constant using a straight-line approximation of the computed q-v curve for the conductor geometry. In most theories describing corona it is assumed that the corona effects are a function of voltage only, in fact this assumption is not correct, and the other researcher discusses this point [8]. So, in order to calculate the part played by corona in causing distortion and attenuation, the corona current must be first defined and then calculated, as his conclusion, the influence of corona on overvoltage occurring on lines can be predicted only by observing the voltage "and its previous history" at some points along the line and by calculating the corona current at these points.

3.CORONA MODELING AND TRANSMISSION LINE EQUATIONS

Corona effect is modeled with two branches in parallel, one of them is non-linear shunt capacitance to present the corona capacitance, and the other is non-linear shunt conductance to present the corona discharge resistance, and they are considered as a part of transmission line differential equations.

From figure (1) The transmission line differential equations can be written as:

$$u_2 = iR + L\frac{\partial i}{\partial t} + i_1$$
$$\frac{\partial i}{\partial t} = -\frac{R}{L}i - \frac{1}{L}u_2 + \frac{1}{L}u_1 \qquad (3)$$

$$i = C\frac{\partial u}{\partial t} + i_{Corona} \qquad (4)$$

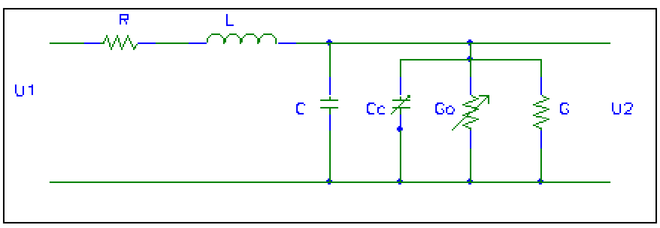

Figure 1: Transmission line model with corona

$$i_{Corona} = i_{C_{corona}} + i_G$$
$$i_g = i_G + i_{Go}$$
$$= (G + G_0)u_2 \qquad (5)$$

According to attenuation of the wave front caused by corona can be explained by an increase in shunt capacitance. Then, the increase in shunt capacitance is proportional to the voltage above critical voltage V_{CO} [6], i.e.

$$C_{corona} = 2K_C\left(1-\frac{u_O}{u}\right) \qquad (6)$$

Where

$$K_C = \sigma_C\sqrt{\frac{r}{2h}}\times10^{-11} \quad \text{F/m}$$

σ_C is corona loss constant.

R, h is radius and height above the ground of conductor.
So, this increase in capacitance can be modeled as capacitance branch to ground with capacitive current loss i_c where;

$$i_{C_{corona}} = 2K_C.\left(1-\frac{u_O}{u}\right)\frac{\partial u}{\partial t} \qquad (7)$$

By adding this part to transmission line differential equations, the capacitive corona will be presented.

According to (v-i) characteristic for non-linear conductance,

$$\mathrm{i_g} = \left[G + G_o.1(\mathrm{u}-\mathrm{u}_0).\mathrm{u}\ \ .(\mathrm{u}-\mathrm{u}_o)\right]\mathrm{u}_2 \qquad (8)$$

Where G is constant value we take it as 3e-5.

The initial conditions for current in this model are,

$$i = \begin{cases} 1 & \text{for } u_2 \geq u_o \\ 0 & \text{for } u_2 \leq u_0 \end{cases}$$

Where u_2 is the output voltage and u_0 is critical corona voltage.
From equations (2, 3, and 5) we have,

$$i = C\frac{\partial u_2}{\partial t} + 2K_C\left(1-\frac{u_O}{u}\right)\frac{\partial u_2}{\partial t} + \left[G + G_O.1(u-u_O)\right]u_2 \qquad (9)$$

$$\frac{\partial u_2}{\partial t} = \frac{1}{2K_C\left(1-\frac{u_O}{u}\right)+C}.i + \frac{G+G_O(u-u_O)}{2K_C\left(1-\frac{u_O}{u}\right)+C}.u_2 \qquad (10)$$

Now the equations (1&8) are put in matrix form to prepare it in computer program, then,

$$\begin{vmatrix} \frac{\partial i}{\partial t} \\ \frac{\partial u_2}{\partial t} \end{vmatrix} = \begin{vmatrix} -\frac{R}{L} & -\frac{1}{L} \\ \frac{1}{2K_C\left(1-\frac{u_O}{u}\right)+C} & -\frac{G+G_O(u-u_O)}{2K_C\left(1-\frac{u_O}{u}\right)} \end{vmatrix} \quad (11)$$

$$\cdot\begin{vmatrix} i \\ u_2 \end{vmatrix} + \frac{u}{L}\cdot\begin{vmatrix} 1 \\ 0 \end{vmatrix}$$

And we have,

$$u_2 = \begin{vmatrix} i \\ u_2 \end{vmatrix} \cdot \begin{vmatrix} 0 & 1 \end{vmatrix} \quad (12)$$

4.METHOD OF SOLUTION AND DATA APPROXIMATION

The Matlab software program is used to simulate the problem.

First the double exponential wave is applied on the sending end of the line (eq. 13), and then by solving the transmission line differential equations with corona using mat lab simulation software the output voltage is obtained. The output results represent the effect of corona as voltage-time characteristic.

$$U(t) = 10.38U_m\left[(\exp - 0.048t) - (\exp - 0.97t)\right] \quad (13)$$

The data are carried out on a single phase two wire 220 kv line, with 9 km long divided to three sections each one 3Km. The cross-section of conductor was 411 mm, with diameter of 26.4 mm [9]. The space between the bundle conductors was 0.457 m and the height above the earth is 12m [10].

The effect of corona phenomenon can be presented by solving the transmission line partial differential equations describing the electromagnetic wave propagation adding extra terms represent the capacitive corona and discharge resistance due corona.

The value of parameter K_C can be evaluated from the equation at σ=20.

$$K_C = \sigma_C \sqrt{\frac{r}{2h}} \times 10^{-11} \quad \text{F / m}$$

The value of shunt admittance Go is according to assumption, taking in account three values of Ve/Vc ratio is 0.8, and weather factor as 0.9, it found approximately 3.36×10^{-8} 1/Ω.

The values line parameter is determined according the transmission line parameters equations as:

$$R_{dc} = \frac{\rho l}{A} \quad \Omega/\text{m}$$

At fixed frequency (60 Hz), the value of ac resistance is a few percentage higher than the dc value, so we assume its value as 0.25Ω[11-14].

For a single phase two wire the conductance can be calculated from the equation[8]:

$$L = 4 \times 10^{-7} \ln\frac{D}{r'} \quad \text{H/m}$$

Where $r' = 0.7788\ r$.

For the same line the capacitance can be calculated as [11]:

$$C = \frac{2\pi\varepsilon}{ln(2h/r)} \quad \text{F/m}$$

Table 1: gives the values of this parameter according the sections of line length.

Parameters/Length	At 3Km	At 6Km	At 9Km
R Ω	0.3	0.5	0.7
L mH	4.551	9.107	13.66
C µF	0.222	0.444	0.666
K_C µF	0.141	0.282	0.424

4.1. Results

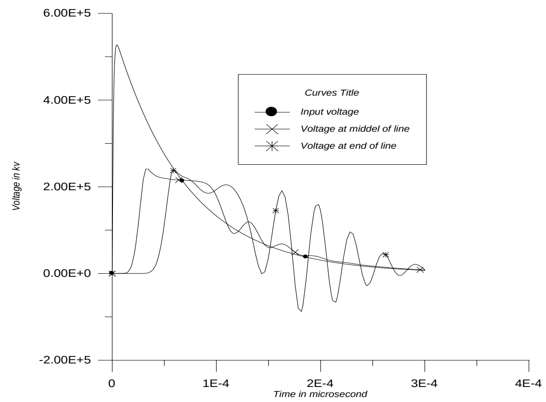

Figure 2: Show voltage-time curve and the attenuation of applied wave caused by corona

5.CONCLUSION AND DISCUSSION

The corona has a very high effect on the propagation of overvoltage wave: increased attenuation, distortion, and reduction in the crest value of the wave took place. So according to this we can write:

-The effect of corona reduces and retards the crest value of the surge as it travels along the line.
A simulation method to solve the deferential equations of the transmission line with corona "which is consider a part of it" was done using the Simulink method on the Mat lab software, to show the effect of corona on traveling surge.
-The corona was modeled by non-linear shunt capacitance in parallel with non-linear shunt conductance. A mathematical formula used to evaluate the values of these parameters.
-Double exponential wave was applied on sending end of the line; the output was taken in two sections, at the middle and at the end of it.
-Figure 2: Show voltage-time curve and the attenuation of applied wave caused by corona.

It clears from the previous graph, that the overvoltage's wave which propagate along transmission line, are subjected to attenuation and distortion, the main source of it here, is corona which is a very non-linear phenomenon.

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