

Modeling of Corona at Ultra High Voltage Transmission Lines

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Abstract. The paper makes use of the calculation results of ANSYS software, and establishes a model of corona at ultra high voltage transmission lines with Electromagnetic Transient Program (EMTP). The proposed model is applied to lightning calculation of the conductors. The simulation results indicate that the wave attenuation caused by corona takes an important place and it is significant to reduce the insulation level. Therefore this factor should be considered when determine the insulation coordination for the transmission lines so not as to increase the cost of the project.

Introduction

Surge corona occurs when the electric field intensity around the transmission line is greater than breakdown field strength of the air. However, surge corona produces radio interference, television interference and audible noise at the same time, which are the crucial factors of the choice of transmission lines and width of corridor for the design of EHV and UHV transmission lines[1]. Although there are a variety of detriment of surge corona, the amplitude and steepness of wave edge for overvoltage wave spread on transmission lines will be reduced because of surge corona, which has the positive significance for determining the insulation level. However, it is difficult to confirm its features due to the nonlinearity and uncertainty. Domestic and foreign scholars have done a lot of experiments in order to fully understand the characteristics of corona[2-5], many models are also established for simulation study, including the simple circuit model established by foreign scholars Wagner etc., and the nonlinear model established by kudyan and shih[6]. The model combining surge corona with frequency-dependent characters of lines was established by Shu Hongchun, and the corona model of bundled conductor was established by Yuan Haiyan[7].

Equivalent radius of the wire increases when the surge corona occurs, so that the coupling coefficient between lines increases too. The models established by Wagner, kudyan, and Shu Hongchun haven't consider the coupling between lines, references [8] has considered the coupling between different phase line, however it hasn't considered the coupling between paralleled double lines. It is inevitable choice for the development of backbone network with the increase of voltage grade and the lack of land. Therefore it is requisite taking the coupling between the paralleled double line into account when established the surge corona model.

In the paper, the corona model established on the basis of predecessors' research which considers both interphase coupling and the coupling between paralleled double lines is used to calculate lightning overvoltage of transmission line to make the results more accurate, and provide the reference in determining insulation level of lines.

The Start Electric Field Intensity of Surge Corona

The Start Electric Field Intensity of Surge Corona

Surge corona occurs when the electric field intensity around the transmission line is greater than breakdown field strength of the air. The experience formula of the corona inception field E_c is obtained by derived, and Peek formula is well known in numerous empirical formula, and the

approximate formula of E_c is as following[7]:

$$E_c = E_0 m \delta f (1 + 0.308 / \sqrt{\delta r_0}) \quad (1)$$

Where E_0 is the breakdown field strength of the air, which is equal to 30kV/cm; m is roughness coefficient of line surface, $m \approx 1$ for smooth line, $m \approx 0.8 \sim 0.9$ for sterepsinema, and it is taken as 0.82 generally ; δ is the relative density of the air, which is equal to 1.0; f is the coefficient of voltage polarity, which is taken as 0.5 when the voltage is positive, or it is taken as 1.0; r_0 is the radius of the line, cm.

In the paper, the voltage of calculation is positive, so f is taken as 0.5, and the radius of the line is 52.2cm, so the corona inception field is approximated to 12.8kV/cm.

Electric field intensity analysis results of ANSYS software

In the paper, the electric field strength around the transmission line suffering the lightning is calculated by ANSYS software, and the calculation results are shown in Fig.1. It can be seen from the figure that the electric field strength around the transmission line occurring corona is the largest, and the maximum value is 3.77×10^6 V/m. The field intensity weakens gradually with the increase of distance from line. The minimum value of field intensity is 2.15×10^5 V/m with the increase of distance, which is less than the corona inception field, and the air ionization will not occur.

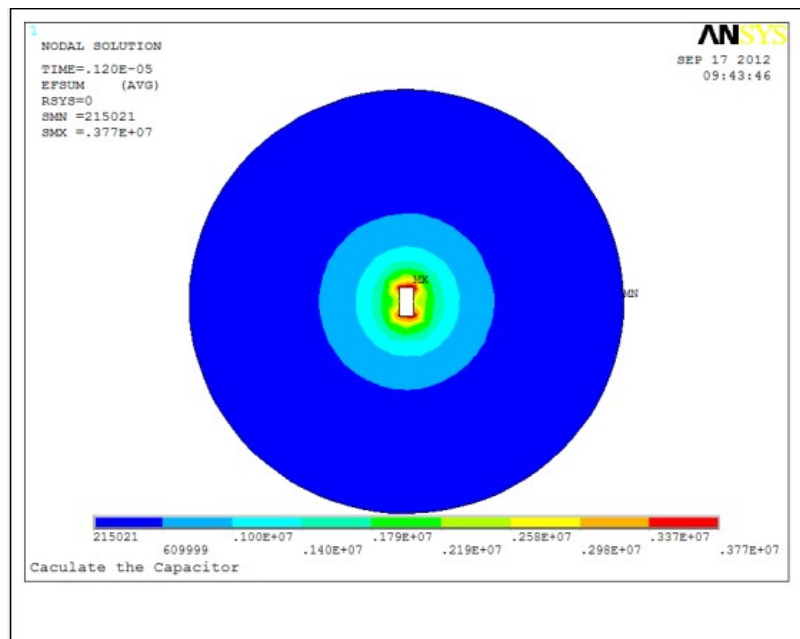


Fig.1 The distribution of electrical field of transmission line occurring surge corona

The Calculation of Equivalent Capacitance for Transmission Line Considering the Ground

The Calculation of Equivalent Capacitance for Transmission Line

The ground will affect the electric field around the lines for the distance between them, so the effect of the ground should be taken into account. In the calculation of electrostatic field, the influence of ground to electric field of its parallel energized conductor can be replaced with a mirror image of the conductor, which is shown in Fig. 2(a) and the equivalent circuit is shown in Fig. 2 (b).

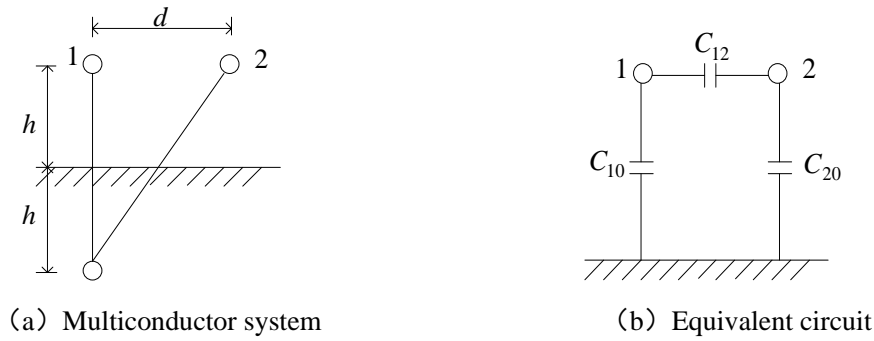


Fig.2 Multiconductor system and its equivalent circuit

Per unit length capacitor of transmission lines is available by simplified calculation:

$$C_{10} = C_{20} = \frac{2\pi\epsilon_0}{\ln \frac{2h\sqrt{4h^2 + d^2}}{ad}} \quad (2)$$

$$C_{eq} = \frac{\pi\epsilon_0}{\ln\left(\frac{2hd}{a\sqrt{4h^2 + d^2}}\right)} \quad (3)$$

Among them a is the radius of the line. The other parameters are as shown in Fig. 2(a).

The Comparison of Calculation Results Between ANSYS Software and Numerical Calculation

In this paper, ANSYS software is used to calculate the equivalent capacitance of the transmission line considering the effect of the ground, the calculation results of ANSYS software and the numerical calculation results are shown in table 1.

Table1 The Comparison of Calculation Results

Type of calculation	$C_1/10^{-12}F/m$	$C_{12}/10^{-12}F/m$	$C_{20}/10^{-12}F/m$
numerical calculation	7.964	2.723	7.964
ANSYS software	8.856	2.759	8.853

It can be seen from table 1 that the maximum error of results for capacitance calculated by ANSYS software and numerical calculation is 1.04%, which are close to each other, so that the calculation results are accurate relatively using ANSYS software to calculate.

The Calculation of Equivalent Capacitance for Three-phase Double-circuit Line

According to the concept of corona radius, the capacitance of lines increase significantly when surge corona occur, and its numerical is obtained by calculated the capacitance of coaxial cylinder surrounded the lines. The radius of the cylinder is equal to the radius of corona, and the radius of corona will be obtained by the following equation :

$$U_n = E_0 r_0 \ln \frac{2h_n}{r_0} \quad (4)$$

Where h_n and U_n is the height of the conductor n and its voltage.

According to equation (4), the calculation results of ANSYS software are shown in table 2.

It can be seen from Table 2 that not only the self-capacitance of lines but operating capacitance between lines increase after the corona compared with the static (the corona don't occur), this is because that the air around the conductor is ionized after the corona, which develop into corona shell on the surface of the conductor. Corona shell has a better radial conductive performance, which is equivalent to increase the radius of the line to increase the capacitance parameter of the conductor.

Table 2 The capacitance calculated by ANSYS

State of lines	Static /pF	Corona occur/pF
Numbers of lines		
self-capacitance of line1	195.67	302.08
self-capacitance of line2	199.27	300.81
self-capacitance of line3	270.39	378.32
self-capacitance of line4	264.94	375.77
self-capacitance of line5	260.96	372.27
self-capacitance of line6	259.62	373.07
Operating capacitance between line1and2	57.204	163.313
Operating capacitance between line1and3	47.545	152.055
Operating capacitance between line1and4	117.48	234.040
Operating capacitance between line1and5	130.13	249.810
Operating capacitance between line1and6	47.662	153.053
Operating capacitance between line2and3	121.62	234.910
Operating capacitance between line2and4	47.365	151.333
Operating capacitance between line2and5	48.636	152.766
Operating capacitance between line2and6	132.13	249.580
Operating capacitance between line3and4	83.768	192.691
Operating capacitance between line3and5	24.488	125.617
Operating capacitance between line3and6	32.500	134.765
Operating capacitance between line4and5	32.224	134.048
Operating capacitance between line4and6	23.921	125.422
Operating capacitance between line5and6	80.342	181.325

The Established of Surge Corona Model

The established of single-phase surge corona model

The transmission line occurring surge corona is shown in Fig.3. It is shown that when the corona occurs, the air surrounding the transmission line ionizes (from the surface of lines to the border of the corona sheath), so that the electric field between transmission lines and the ground is divided into two parts: one is from r to r_{cor} , another is from r_{cor} to the ground.

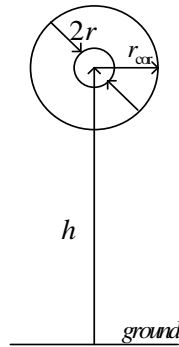


Fig.3. Line under surge corona

$$\int_r^h E dl = \int_r^{r_{cor}} E dl + \int_{r_{cor}}^h E dl = U_{cor} + U_{air} = U \quad (5)$$

Where E is the electric field between transmission lines and the ground; r is the radius of the conductor; r_{cor} is the radius of the corona sheath; h is the height between the border of the corona sheath and the ground; U_{cor} is the voltage of ionized air; U_{air} is the voltage of unionized air.

It can be seen from the above equation that the capacitance C_{cor} and capacitance C_{air} connected in series between the line and the ground. An improved surge corona model can be proposed according to (2), as shown in Fig.4.

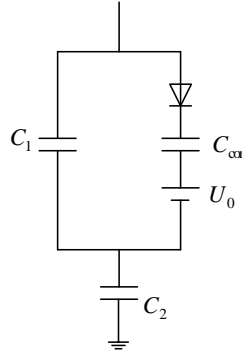


Fig.4. The single-phase surge corona model

The lines geometric capacitance C_1 (from the surface of line to the border of the corona sheath) and C_2 (from the border of the corona sheath to the ground) connected in series in the improved model, the series value is equal to the total geometric capacitance C_0 of the transmission line. The diode doesn't conduct when the voltage is less than the inception voltage of the surge corona, at this time, the total capacitance in the circuit is equal to the geometric capacitance of transmission line. While the diode conducts and the C_{cor} is added to the circuit paralleling to the C_1 when the voltage exceeds the corona inception voltage.

The model established in the paper has divided the region between the transmission line occurring surge corona and the ground into the zone occurring surge corona and the zone without surge corona, and use two capacitance to represent respectively, which lives up to the development of surge corona.

The surge corona model considering coupling between lines

According to the calculation results of ANSYS software(table 2), the model considering both interphase coupling and the coupling between paralleled double lines is established on the base of the single-phase model, as is shown in Fig.5. Where C_{ij} ($1 \leq i \leq 5, 2 \leq j \leq 6$ and $i \neq j$) is operating capacitance between lines, C_{55} and C_{66} are self-capacitance of line 5 and line 6 respectively, that is the single-phase surge corona model described earlier. Self-capacitance of line 1 to line 5 didn't show in the figure. The corona model which considers both interphase coupling and the coupling between paralleled double lines makes the result of calculation more tally with the actual.

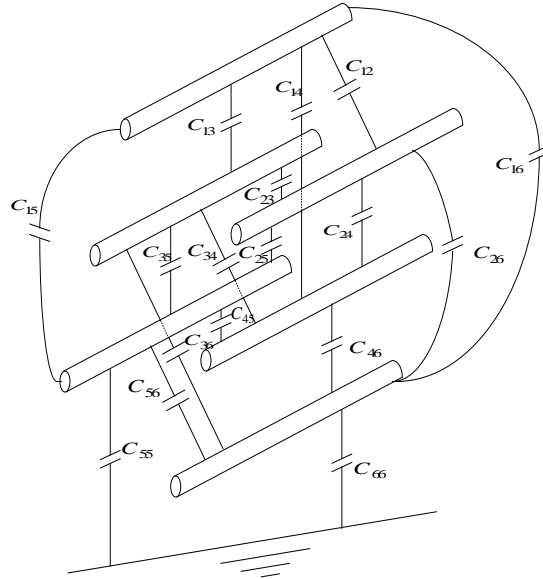


Fig.5 Three-phase double-circuit line surge corona model

The results of simulation

1) The simulation results of single-phase model

Lightning overvoltage is simulated based on single-phase model established in the paper, and the results are shown in Fig. 6.

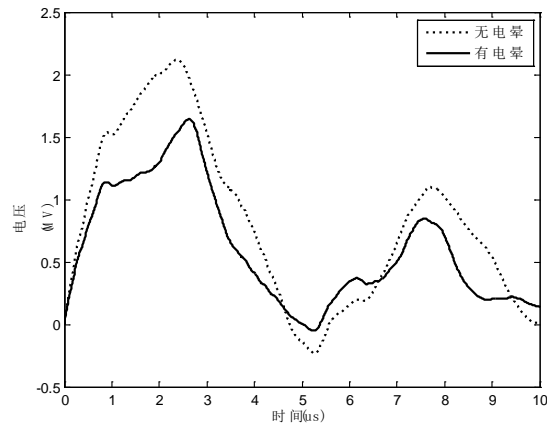


Fig. 6 The influence of surge corona

It can be seen from figure 6 that there is obvious attenuation and distortion of overvoltage waveform taking surge corona into account compared with without considering the corona, and there is some delay in peak time, which is important to determine insulation level of transmission line appropriately. If ignore the influence of this aspect is ignored, the insulation of the transmission line level and project cost will be improved. So the influence of surge corona can't be neglected.

2) The voltage of capacitor C_1 and C_2 after corona

The diode closed when surge corona disappeared to cut off C_{cor} from the circuit, at this point the total capacitance in the circuit is the geometric capacitance of transmission line. The voltage of capacitor C_1 and C_2 after corona when the diode closed are shown in figure 5. It can be seen from the figure that the voltage of capacitor C_1 and C_2 has achieve a balance when the surge process is completed, and the difference of voltage between the two capacitance reduce to 117.3 kV. Besides, the difference between the two voltage has a tendency to further reduce.

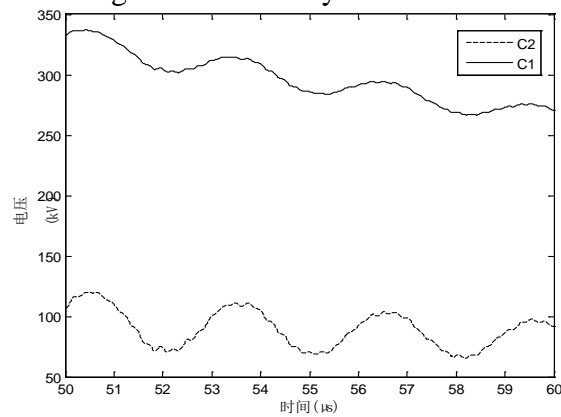


Fig.7 The voltage of capacitor C_1 and C_2 after corona

3) The Simulation Results of Three-phase Double-circuit Line Surge Corona Model

Lightning overvoltage is simulated based on three-phases double-circuit model established in the paper, and the results are shown in Fig.8.

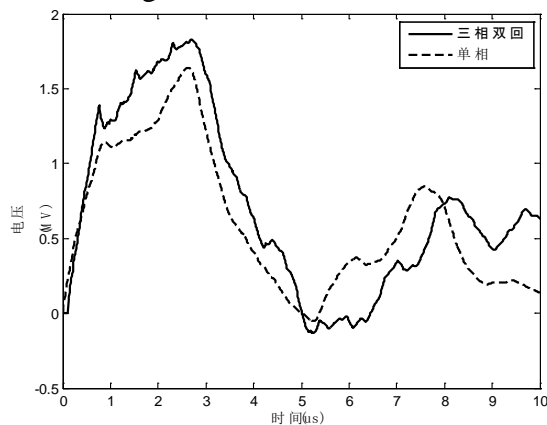


Fig 8

Conclusions

(1) Surge corona has obvious attenuation effect on the lightning overvoltage, which should be considered when determining the insulation level of transmission line.

(2) Three-phase Double-circuit Line Surge Corona Model not only considers the coupling of phases but also the coupling of Paralleled double circuit lines, which makes the calculation more accurate.

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