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Lightning Overvoltage in Outer Insulator of Underground Cable in Windfarm

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***Abstract*— Wind turbine generators in a windfarm are connected by underground cables. Lightning overvoltages due to a direct lightning strike to the system cause damages in the underground cable. Many parameters should be investigated to establish a rational lightning protection design for wind power generation system. This paper discusses the influence of grounding method of metallic sheath of cable and grounding resistance on the lightning overvoltages in outer insulator of the underground cable for the direct lightning strike to the generation system.**

***Keywords*— collector cable; direct lightning strike; lightning overvoltage, wind power generation system**

I INTRODUCTION

Many windfarms have been constructed all over the world to improve the global warming. A wind generation tower is a tall structure, and lightning frequently strikes wind power generation system. Many lightning-caused troubles have occurred in wind power generation systems [1-2]. Lightning overvoltages appears in collector cable, which is frequently underground cable. Metallic sheath currents generate power loss. The sheath is sometimes opened at an end of the cable not to cause the loss. However, this grounding condition causes overvoltages in the cable [3].

This paper presents calculation results of lightning overvoltages in outer insulator of underground cable in collector system in the windfarm. The EMTP [4] based on electrical circuit theory is used to simulate the overvoltages. This paper discusses the influence of grounding of metallic sheath of the cable and grounding resistance on the lightning overvoltages in the cable caused by direct lightning strike to the wind power generation system.

II SIMULATION CIRCUIT

A. Wind Power Generation System for Simulation

Fig. 1 shows a wind power generation system to calculate the lightning overvoltages. Wind turbines are connected to a substation. The wavefront duration of lightning current in this paper is two microseconds. Considering the interval between wind towers in this paper is 100m, the total length for the eight wind towers are sufficiently long. Therefore, this paper considered eight wind towers.

Table I shows the specifications of the generator and transformer [5]. The neutral terminal of the transformer is directly connected to the tower base. Underground cable in collection system and power cable in tower are 22kV CVT 200 mm^2 and CV 200mm^2, respectively.

B. Power Cables

1)Underground Cable

Semlyen model [6], which is a frequency-dependent transmission line model in the EMTP, is adopted in this paper to represent surge phenomena in the collector cables. Cable constants are estimated using an EMTP support program "CABLE PARAMETERS" [7, 8].

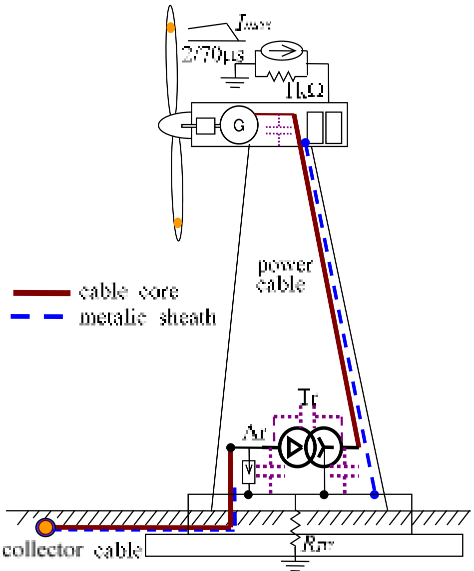


Fig. 1. Wind power generation system.

TABLE I
SPECIFICATIONS OF GENERATOR AND TRANSFORMER

Connection method	Y-Δ
Rated power of generator	1.5 MVA
Rated voltage of transformer	690/22,000 V
Power frequency	50 Hz
% impedance of transformer	6 %

The collector system cable is terminated by characteristic impedances as a matching circuit at TW8 to represent a long line [9]. Figs. 2(a) and (b) illustrate configuration of the power cable in the tower and dimension of the cable. The power cable is set to be 0.2m from the inner wall of the tower. Fig. 2 (c) illustrates the configuration of the collector cable. The of a cable closer to the S/S is called S/S side, and the opposite end is called P/S side in this paper.

The collector cable is treated by a transposed line. The coaxial mode depends on the permittivity of insulating material of the cable. The soil resistivity affects the ground-return mode. Velocities are greatly dependent on the modes [10].

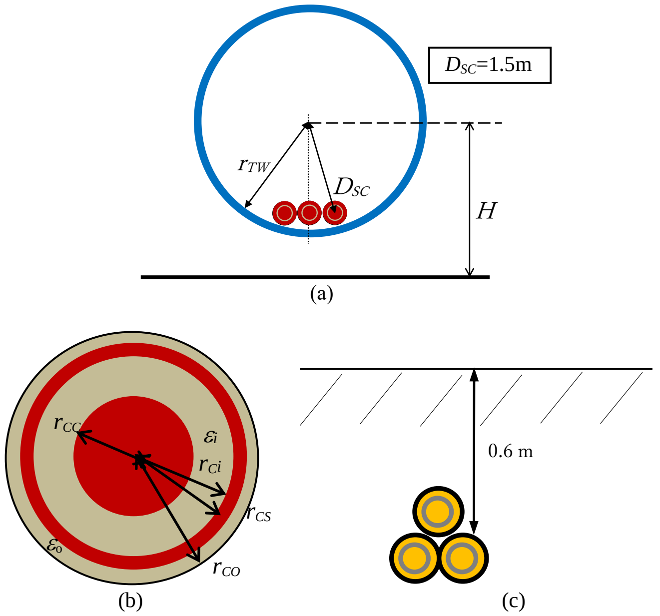


Fig. 2. Configuration of power cables in wind tower and collector system. (a) Cross section of tower and cable, (b) Cross section of cable, (c) Configuration of collector cable. (r_{CC}=8.5mm, r_{Ci}=15.5mm, r_{CS}=15.8mm, r_{CO}=19.5mm, ε_i=2.3, ε_o=6.0)

2) Power Cable in Tower

A wind tower is a tapered line, and is a kind of nonuniform lines. Based on experimental study of reinforced concrete pole, a tapered line for lightning surge analysis can be represented by a cylindrical pipe with radius which is determined from the average value of area at upper and bottom of the tapered line [11]. The tower is represented by a cylindrical pipe with radius r_{TW} of 1.7 m and height of 65 m. The values of the dimension and configuration of the cables used in this paper are shown Fig. 2(a). The wavefront duration of lightning current in this paper is sufficiently longer than the propagation time in the tower. The surge impedance can be regarded to be constant [12]. For simplicity, Dommel's line model [13] is used as a vertical conductor model with constant surge impedance.

C. Grounding System

The low-frequency grounding resistance of wind power generation systems in Japan is often less than two ohms. The low grounding resistance shows inductive variation [14]. This paper mainly uses resistor of ten ohms. The soil resistivity and relative soil permittivity are assumed to be 300Ωm and nine.

D. Power Apparatuses

Simulation models and constants of surge arrester, transformer, and generator are mentioned in [15].

E. Lightning Current

The lightning current waveform is assumed to be a triangle shape of 2/70 μs. The lightning is represented by a current source and a lightning channel impedance of 1kΩ [16]. Polarity of lightning current in the simulations is assumed to be positive. Lightning strikes the tower TW1 which is located at the end of the windfarm as shown in Fig. 3.

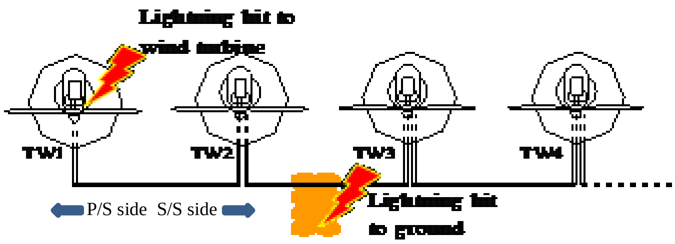


Fig. 3. Windfarm for simulation.

F. Estimation of Outer Insulation Voltage

Only node and/or branch voltages are estimated using the EMTP. Therefore, ground potential rise far from a tower base cannot be estimated in the EMTP. Now, neglecting electo-magnetic fields generated by cable currents, ground potential rise $V(x)$ at the distance x from the center of a tower base is given by [17]

$$V(x) = \frac{r_{TW}}{x} V(r_{TW}) \qquad (1)$$

where r_{TW} is the equivalent radius of the tower base.
Outer insulator voltage $V_{ins}(x)$ is given by

$$V_{ins}(x) = V_{sheath}(x) - V(x) \qquad (2)$$

where $V_{sheath}(x)$ is metallic sheath potential.

III Simulation Results

A. Simulation Cases

The metallic sheath of collector cable should be grounded from the viewpoint of lightning protection. Grounding of both the terminals of a metallic sheath causes power loss, and an end of the sheath is sometimes opened. Thus, the sheath grounding condition is a parameter. Table II shows simulation parameters in this paper. The parameter with underline in Table II means a basic case. 26kA is 50% value of cumulative frequency distributions of peak lightning current [18].

TABLE II
SIMULATION PARAMETERS

Item	Values
Cable length	100 m
Cable sheath grounding	Both ends, P/S side, S/S side
Grounding resistance	2, 5, 10, 20 Ω
Lightning current	10, 26, 50, 10 kA
Striking tower	TW1 (see Fig. 3)

B. Influence of Grounding Resistance on Lightning Over-voltages in Outer Insulator

The grounding resistance is an important factor to determine lightning overvoltages in the cable. The lightning overvoltages only for the metallic sheath grounding at P/S side are discussed. Figs. 4 and 5 show peak value and waveform of the outer insulator voltage as a parameter of the grounding resist-ance of the tower base, respectively. Lines in the figures mean as follows:

: 0m (TW1), : 10m, : 20m
: 30m, : 50m, : 70m
: 90m, : 100m (TW2).

From Fig. 4, the outer insulator voltages become higher as the grounding resistance is higher. This increase of the voltages slightly become saturated for high grounding resistance. Considering the arrester voltage at one ampere is about 70kV, the sheath voltage to the tower base is suppressed by the surge arrester for high grounding resistance [15]. Therefore, the outer insulator voltage becomes higher as the grounding resistance is higher.

The propagation time of the voltages between towers in Fig. 5 is approximately 8μs. This propagation time on the collector cable of 100m corresponds to ground return velocity. Surge propagation characteristics on the metallic sheath are mainly determined by the ground return component. The velocity of the ground potential rise is $v_0/3$ where v_0 is the velocity of light in free space, and that of the ground return mode is approximately $v_0/24$, Thus, the difference of the propagation velocities is observed. The ground potential rise firstly appears, and then the sheath voltage reaches. As a result, the outer insulator voltage having negative polarity occurs considering eq. (2).

C. Influence of Crest Lightning Current on Lightning Over-voltages in Outor Insulator

Figs. 6 and 7 show peak value and waveform of the outer insulator voltage as a parameter of the peak value of lightning current, respectively. Fig. 6 suggests that the outer insulator voltage is approximately proportional to the crest value of lightning current.

D. Influence of Grounding of Cable Sheath on Lightning Overvoltages in Outer Insulator

Grounding condition of metallic sheath greatly affects the voltage in the collector cable [15]. Simulations for various grounding conditions of a cable sheath as in Table II are carried out. Figs. 8 and 9 show peak values and waveforms of the outer insulator voltage, respectively.

Tower base potential rise is higher than the core potential at the lightning strike to tower. As a result, the metallic sheath voltage to the tower base at the lightning strike to tower shows the opposite polarity against the lightning current in case that the sheath is opened at the lightning striking tower. Fig. 8 indicates the sheath grounding condition greatly affects the outer insulator voltages. The core voltage to the tower base in case that both the ends of the sheath are connected to the tower is much low. Thus, both the ends of the cable sheath should be grounded from the view point of lightning protection.

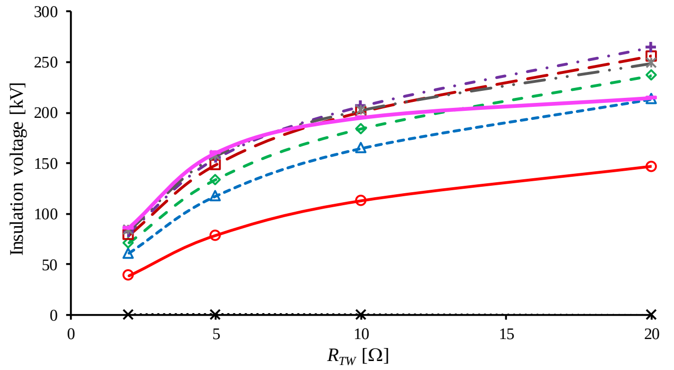
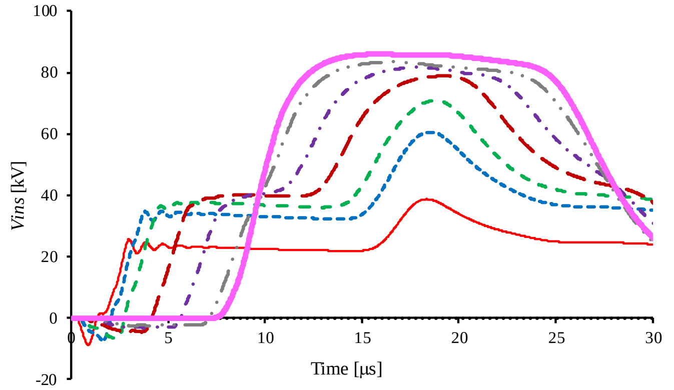
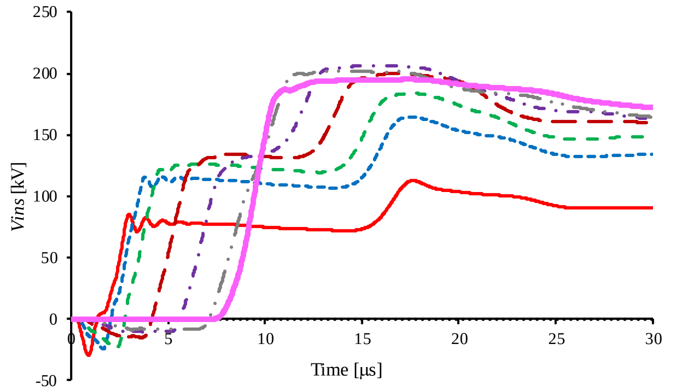


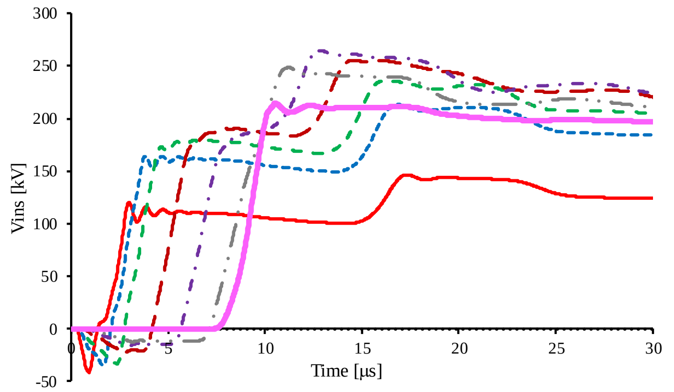
Fig. 4. Peak values of outer insulator voltage as a parameter of grounding resistance.



(a)



(b)



(c)

Fig. 5. Waveforms of outer insulator voltage for various grounding resistance. (a) 2Ω, (b) 10Ω, (c) 20Ω

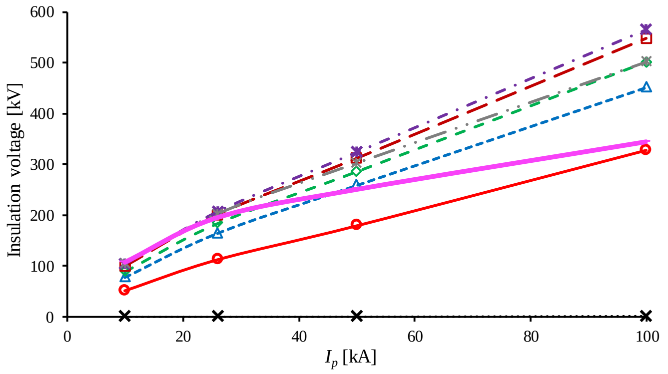


Fig. 6. Peak values of outer insulator voltage as a parameter of crest lightning current.

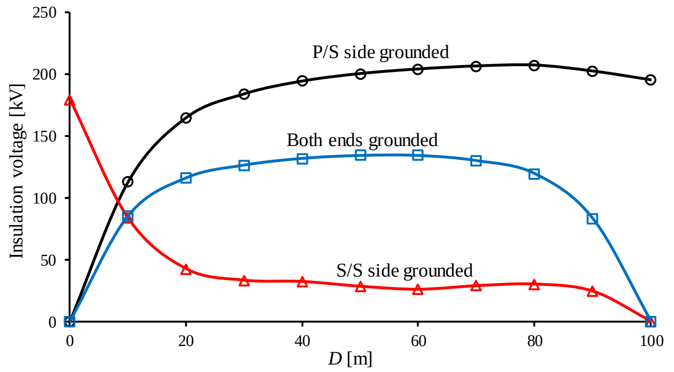


Fig. 8. Peak values of outer insulator voltage as a parameter of sheath grounding condition.

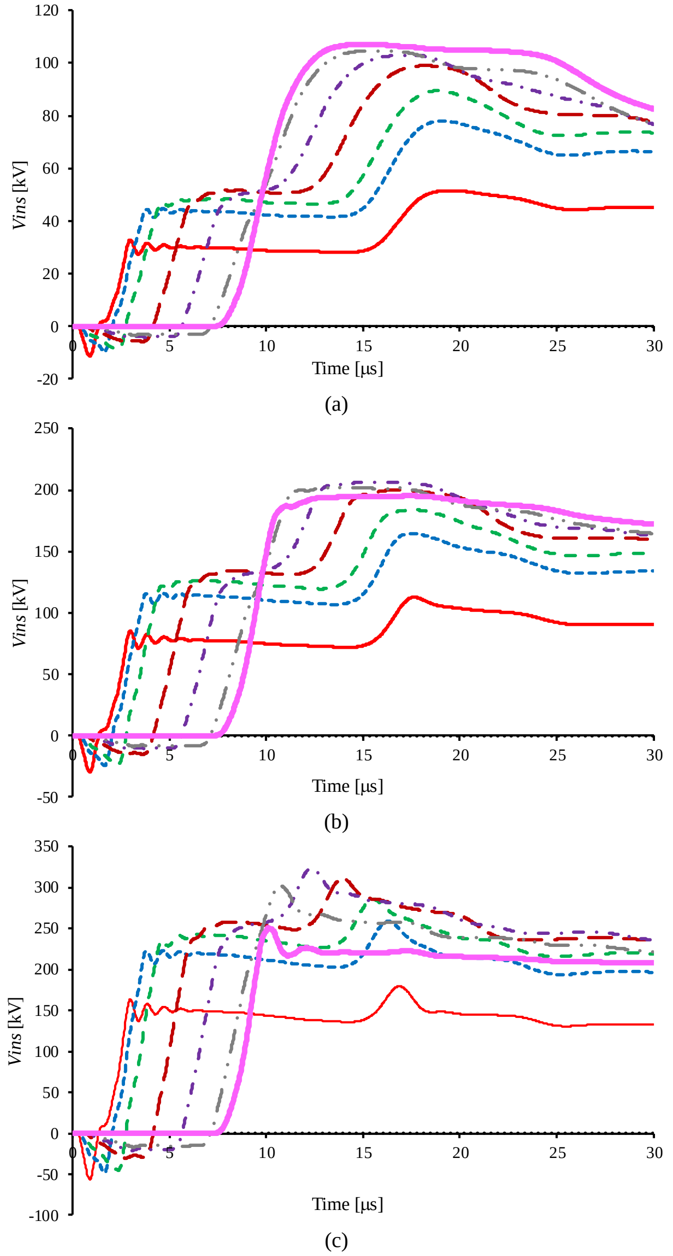


Fig. 7. Waveforms of outer insulator voltage as a parameter of grounding resistance. (a) 10kA (b) 26kA (c)50kA.

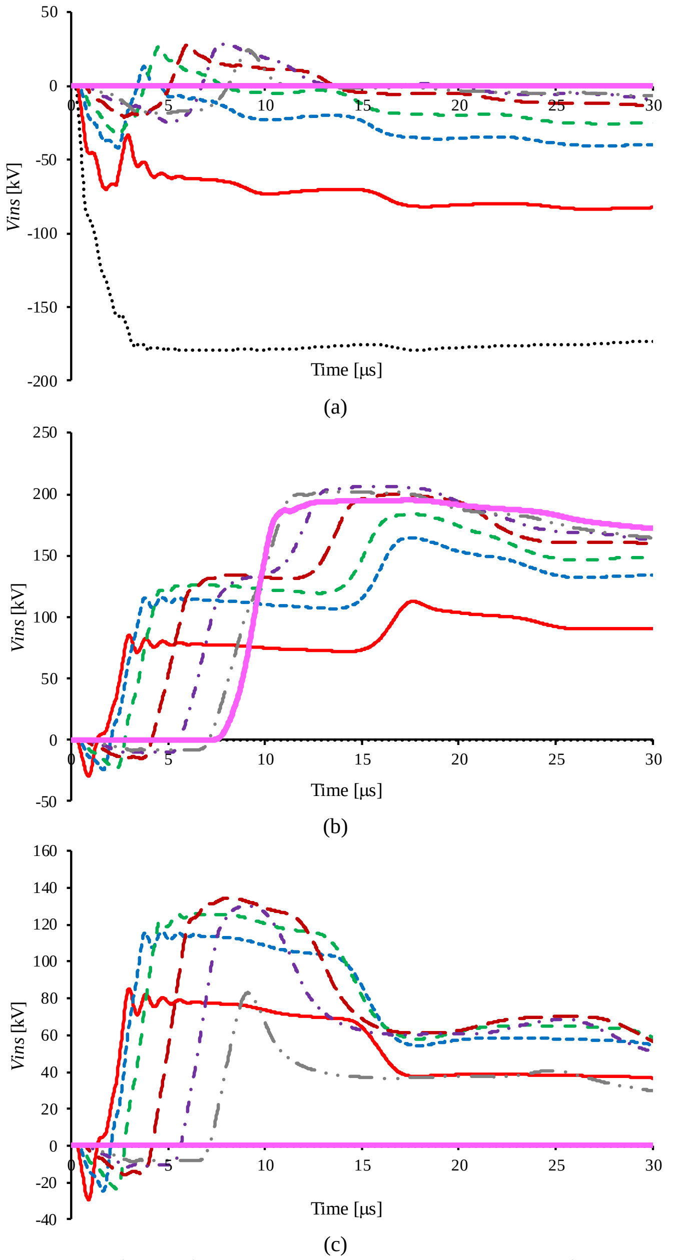


Fig. 9. Waveforms of outer insulator voltage as a parameter of grounding condition. (a) Open-grounded (b) Grounded-open (c) Grounded-grounded.

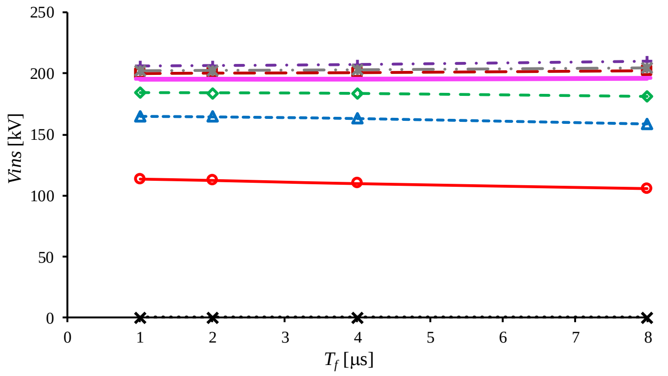


Fig. 10. Peak values of outer insulator voltage as a parameter of wavefront duration of lightning current.

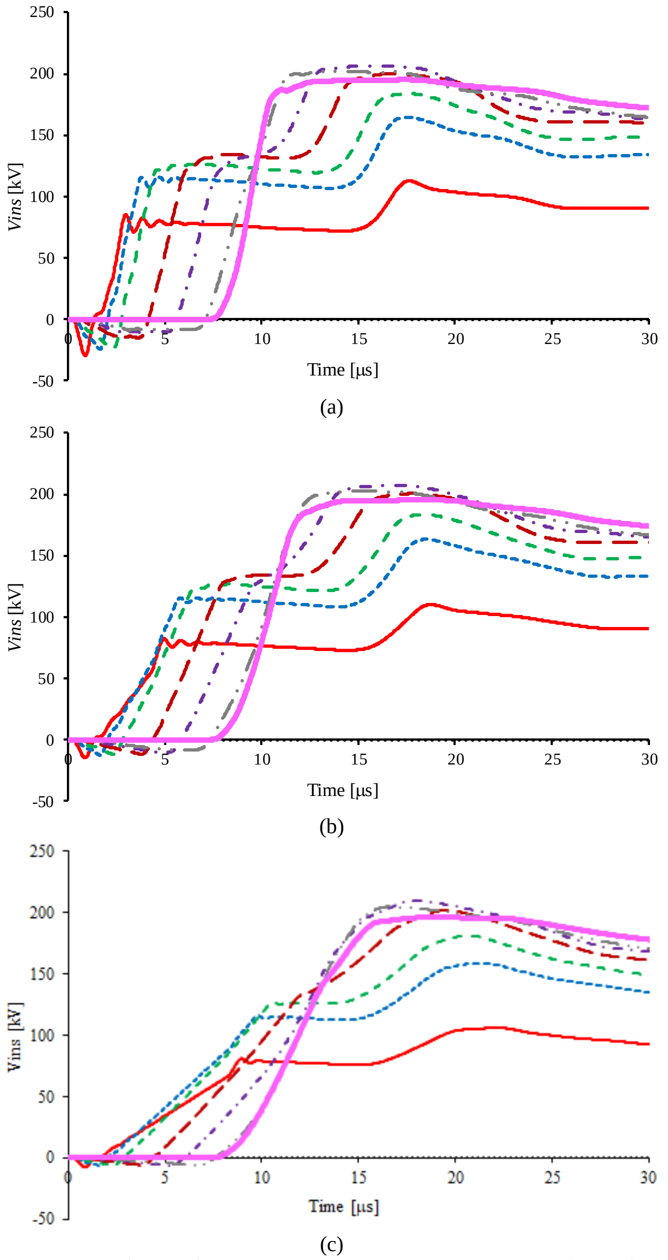


Fig. 11. Waveforms of outer insulator voltage as a parameter of wavefront duration of lightning current. (a) 2µs (b) 4µs (c) 8µs.

However, the voltage is not significantly reduced by grounding both the ends of the sheath. The peak voltage takes at approximately center of the cable except for the case that the sheath is opened at the lightning striking tower.

E. Influence of Wavefront Duration Lightning Current on Overvoltages in Outer Insulator

Figs. 10 and 11 show peak values and waveforms of the outer insulator voltage as a parameter of wavefront duration of lightning current, respectively. Fig. 10 suggests that the influence of the wavefront duration of lightning current on the outer insulator voltage is small. The surge velocity of the ground return mode is very slow. Therefore, the influence of the outer insulator voltage in wave front

IV Discussion

The simulation results suggest that the outer insulator voltage shows about 200kV in fundamental case. The breakdown voltage of the outer insulator of 22kV CVT cable is also about 200kV in case that the sheath is grounded at only the lightning striking tower. Thus, the outer insulator might be damaged due to lightning overvoltage. Even if both the ends of the metallic sheath are grounded, the outer insulator voltage is not significantly reduced. Considering peak voltage appears approximately at the center of the cable, it is difficult to find breakdown points.

V Conclusion

This paper has described simulation results of outer insulator voltage in an underground collector cable in wind farm. Lightning overvoltage to cause breakdown in outer insulator voltage might appear. Further discussions will be done.

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