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Experiments of Lightning Induced Overvoltages on a Real-size Overhead Power Distribution Line

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Abstract—**The authors produced induced voltages on a real –size distribution line, the height of which is 10meters. A balloon filled with helium gas lifted a 150 meter-long copper conductor near the overhead distribution line. A pulse current was applied to the above conductor. Induced voltages on the overhead distribution line were observed at three points. As the distance between the grounding point of a copper wire and an overhead distribution line becomes large, the induced voltages on an overhead distribution line become small. The induced voltage is the largest at the nearest point to the balloon. As the distance from the nearest point to the balloon on the distribution line becomes large, the peak value of the induced voltage becomes small. Experimental results agree roughly well with calculated results obtained by a numerical analysis.**

Keywords- **lightning, lightning protection, distribution line, induced voltage, outages**

Ⅰ. INTRODUCTION

Experiments related to lightning induced overvoltages on power distribution lines have been conducted using scale models of one two hundredth - one fifth in order to clarify phenomena of induced overvoltages on power distribution lines due to nearby lightning hits [1-6]. If the values of the size of a scale model and time are divided by a scale factor, phenomena are thought to be reproduced in a real size and real time.

But scale model experiments have some limitations as follows;

a. As the actual surface of the ground is not perfectly conductive, the scale model simulation cannot express the same electric field in the actual field.

b. A surface effect of the ground on the attenuation of induced voltages along a distribution line cannot be clarified sufficiently by a small scale model.

c. The conductivity of a scale-model conductor should be larger than that of an actual conductor by inverse number of a scale factor. But conductors with the same conductivity as an actual distribution line were used for the scale-model experiment. It may cause the effect of a thin conductor on the induced voltages.

It is better to produce the induced voltages on a real-size distribution line in order to overcome above problems.

The authors produced induced voltages on a real-size overhead distribution line according to a following process.

(1) A balloon lifts a 150 meter-long copper conductor near the testing overhead distribution line.

(2) A pulse current is applied to the above conductor.

(3) Induced voltages on a testing overhead distribution line are observed.

Ⅱ.EXPERIMENTAL CONDITIONS

An overhead distribution line used for experiments is the same as one which was constructed for observing induced overvoltages produced by lightning strokes to a high stack of the Fukui steam power station of Hokuriku Electric Power Company simultaneously with lightning currents [7-9].

A balloon lifted a 150 meter-long copper conductor near the testing overhead distribution line. Pulse currents were applied to the above copper conductor. Electromagnetic fields produced around a copper conductor reached a distribution line resulting in production of induced voltages in a distribution line. Produced voltages in the distribution line were measured at three points on the distribution line including the closest point to the balloon.

The authors measured the waveforms of induced voltages on the distribution line for the various conditions such as the distance between the point of a grounding end of the conductor connected to the balloon and the distribution line, the height of the distribution line , magnitude of a pulse current and the grounding resistance of an oscilloscope.

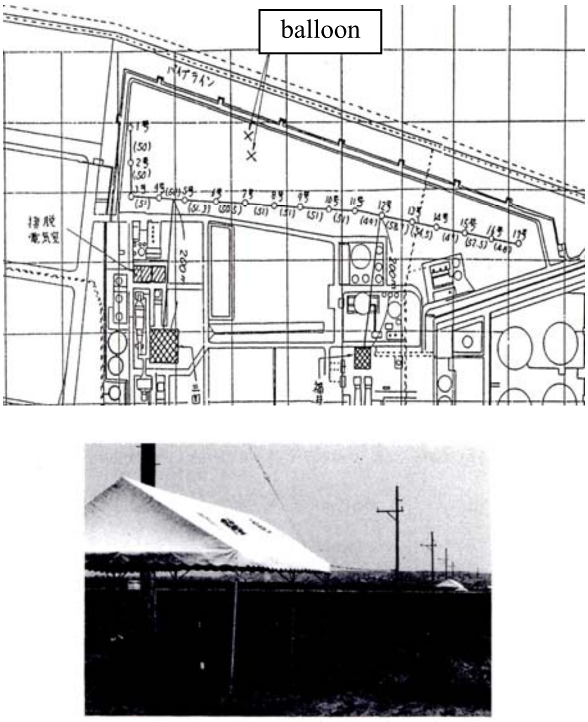

Figure 1. Location of a distribution line and a position of a balloon

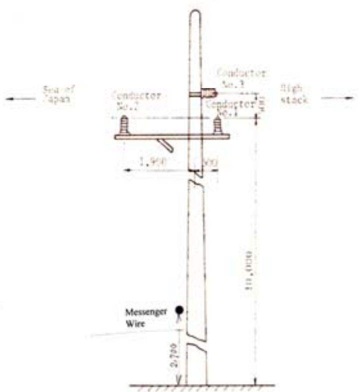

Figure 2. Configuration of a distribution line

A. *Experimental distribution line*

Figure 1 shows the location of a distribution line and the position of a balloon. The line measures a total of 820 m from the pole No.1 to the pole No.17.

The configuration of the distribution line is shown in Figure 2. Three conductors are arranged on an electric pole in an unconventional manner. The reason is shown in author's paper [7]. The conductors are made of a copper wire with a diameter of 4mm. All connecting points are connected by soldering, because produced voltages are not so large that they may be separated electrically at the connected position.

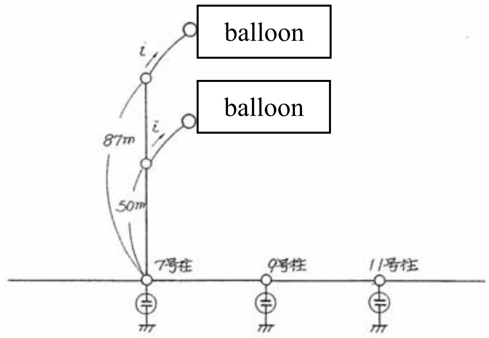

Figure 3. Measuring points of induced voltages

Figure 4. Balloon used in the experiment

When the authors investigated the effect of the conductor height on induced voltages, a messenger wire, which supports the optical fiber cables for the signal transmission of actual lightning induced voltages, was used for the conductor. The height of the messenger wire above the ground is 2.7m and the length of it is around 400m between the No.3 pole and the No.9 pole. Usually the terminal of the messenger wire was open but it was terminated with a resistance of 100 ohms in order to reduce noise of radio frequency.

As shown in Figure 3 induced voltages were measured at the No.7 pole, which is the closest to the balloon, the No.9 pole and the No.11 pole. The distance between the No.7 pole and the No.9 pole is 102 meters and that between the No.9 and the No.11 is also 102 meters.

B. *Simulation of lightning path*

A balloon lifts a 150 m long copper wire, which simulates a lightning path. The distances between the grounding point of copper wire and the distribution line are 50meters and 87 meters. The balloon is shown in Figure 4 and it was filled with helium gas.

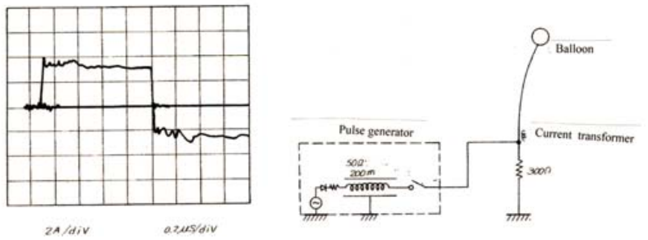

Figure 5. Simulated return stroke current and its generating circuit

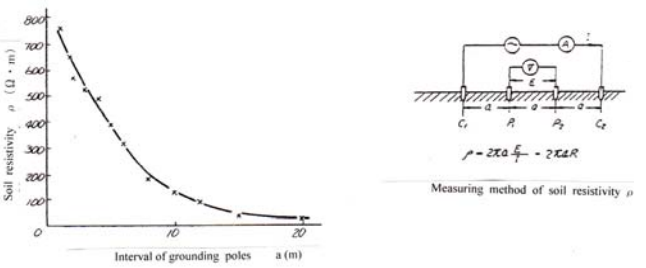

Figure 6. Relation between soil resistivity and interval of electrodes

As induced voltages are affected by the position of a copper wire in the air, the authors checked the position of a copper wire and measured induced voltages at the time when a copper wire was extended vertically.

The upper end of a copper wire is open.

C. Simulated lightning current

A current generator produces a pulse current as shown in Figure 5. This pulse current is applied to a copper wire to simulate a return stroke current. Waveforms of simulated pulse currents were measured on the ground by an oscilloscope. The peak value of the pulse current is 3.5 A. As the pulse current is reflected at the upper end of the copper wire, the progressing velocity of a pulse current can be checked. It is almost same as the velocity of light, 300m/μ s.

D. Grounding condition and soil resistivity

At every measuring point the authors tried to get low grounding resistances. Also the authors measured the resistivity of the soil at the halfway point between the No.5 pole and the No.6 pole of the distribution line. Measuring methods and the results are shown in Figure 6. Based on a ρ - a curve the authors can estimate the water level as 2meters under the ground level.

E. Items of experiments

Table 1 shows the experimental conditions.

Table 1. Experimental conditions

Case No	Pulse Generator Peak Value	Balloon				Distribution line	
		X m	Yd m	Actual Position (X, Y)	Height (m)	Height (m)	Grounding of Ocillo.
Hokuriku-1-1	A: 3.5A	0	50	0,50	150	10	low
Hokuriku-2-1	A: 3.5A	0	87	0,87	150	10	low
Hokuriku-3-1	A: 3.5A	0	50	0,50	150	2.7	low
Hokuriku-3-2	A: 3.5A	0	50	0,50	150	10	low
Hokuriku-4-1	A: 3.5A	0	87	0,87	150	2.7	low
Hokuriku-4-2	A: 3.5A	0	87	0,87	150	10	low
Hokuriku-5-1	B: 8.8A	0	50	0,50	150	10	low
Hokuriku-6-1	A: 3.5A	0	50	-10,50	150	10	high
Hokuriku-6-2	A: 3.5A	0	50	-10,50	150	10	low

(1) Distance between the grounding point of a copper wire simulating a lightning path and an overhead distribution line(Yd):

50meters, 87meters

(2) Height of an overhead distribution line:

10meters, 2.7meters (a messenger wire of optical fiber cables)

(3) Peak values of pulse currents:

3.5A, 8.8A

Ⅲ. EXPERIMENTAL RESULTS

A. Effects of the distance between the grounding point of a copper wire and an overhead distribution line

Experimental results under the condition of case Hokuriku-1-1 and case Hokuriku-2-1 of Table 1 are shown in Figure 7. A pulse current flowing in a copper wire lifted by a balloon progresses toward the sky at the velocity of electromagnetic wave, 300m/μ sec. A negatively reflected wave at the upper end of the copper wire affects induced voltages of an overhead distribution line after the electromagnetic wave from a negatively reflected current reached the distribution line.

In Figure 7 the authors show the starting time when the above effect of reflected waves arises on a measuring point of induced voltages on the distribution line. Waveforms of Induced voltages on the closest point to the balloon (Pole No.7) are quite different from other points (Pole No.9 and Pole No.11), showing that the formation manner of an induced

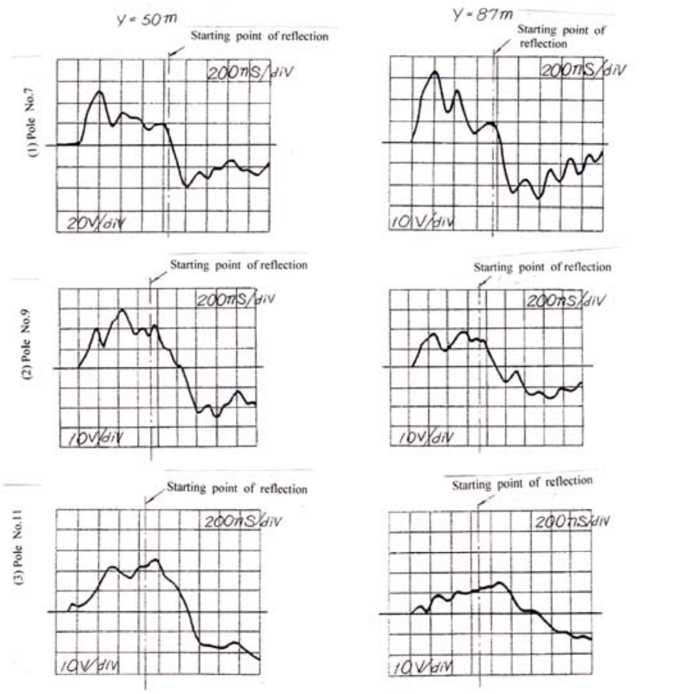

Figure 7. Effect of the distance between the position of a balloon and a distribution line upon induced voltages

voltage waveform is different from that of a regular travelling wave, which is caused by an invading current at single point. As the distance between the grounding point of a copper wire and an overhead distribution line(Yd) becomes short, the induced voltage becomes large.

B. Effect of the height of an overhead distribution line

Experimental results under the condition of case Hokuriku-3-1 of Table 1, where the height of the distribution line is 2.7m, and case Hokuriku-3-2 of Table 1, where the height of the distribution line is 10.0m, are shown in Figure 8 . In these cases the distance between the grounding point of a copper wire and an overhead distribution line (Yd) is 50m. For 87m of Yd experimental results are shown in Figure 9 (Hokuriku.-4-1, Hokuriku -4-2).

As the end of a messenger wire is located at the No .11 Pole, a reflected voltage wave from the pole No.11 affected the induced voltage on the No.9 pole .This effect arises 0.68 μ sec after the starting point of an induced voltage.

The comparison between the peak value of the induced voltage for a 10m- high distribution line (P10m) and that of a 2.7m-high distribution line (P2.7m) is shown in Table 2.

At the Pole No.7 the ratios of P2.7m to P10m are 0.45 for Yd of 50m and 0.38 for Yd of 87m. These values are larger than 0.27, which is the ratio of the height of a messenger wire (2.7m) to that of a distribution line (10m). Under the condition that the ground surface is perfectly conductive, the peak value of induced voltages at the closest point to a balloon should be proportional to the height of a distribution line above the ground.

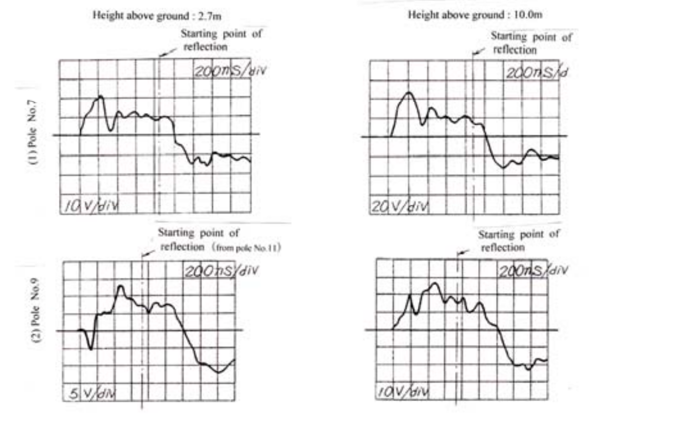

Figure 8. Effect of the height of distribution line upon induced voltages ・・・Yd: 50meters

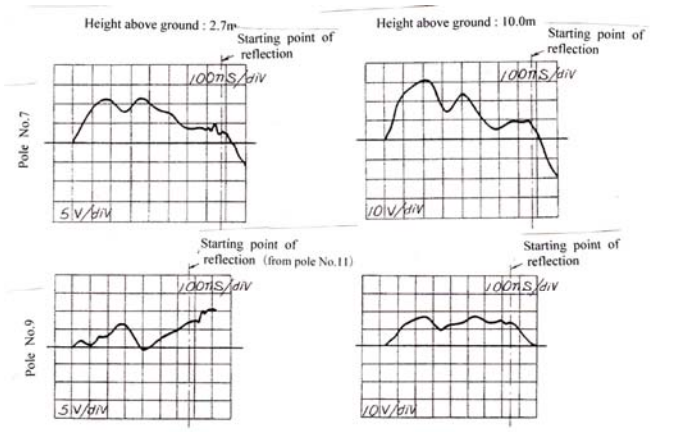

Figure 9. Effect of the height of distribution line upon induced voltages ・・・Yd: 87meters

As shown in Ⅱ-D , based on a ρ -a curve of the soil around a distribution line the water level may be estimated as 2m under the ground level. If the equivalent ground surface is assumed to be 2m below the actual ground surface, the ratio of the equivalent height of a messenger wire to that of a distribution line is 0.39, which is almost same as the ratio of the peak value of the induced voltage for a 2.7m-high distribution line (P2.7m) to that for a 10m- high distribution line (P10m) .

Ⅳ. COMPARISON WITH NUMERICAL ANALYSES

Experimental results under the condition of case Hokuriku-1-1 and case Hokuriku-2-1 of Table 1 are compared with the results got by the numerical analysis of induced voltages . The method of the numerical analysis developed by the author is shown in Ref.[10].

A pulse current used in the numerical analysis is shown in Figure 10. The length of a wavefront is 0.1 μ sec and the current increases linearly from zero to the peak value of 3.5 Amperes.

As shown in Figure 5, the wavefront length of the experimental pulse current is shorter than that of a pulse

Table 2. Effect of the height of a distribution line on the peak value of induced voltages

	y = 50 m		y = 87 m	
	Pole No.7	Pole No.9	Pole No.7	Pole No.9
Distribution line	44.6V	25.8V	30.0V	① 16.9V ② 16.7V
Messenger wire	20.2V	12.6V	① 11.2V ② 11.3V	① 6.63V ② 10.3V *2
Messenger wire/ distribution line	45.3%	48.8%	37.7% *1	60.9% *1 *2

*1 ratio of peak values *2 reference value (out of effective time)

current used in the numerical analysis. The wavefront of current pulse may be thought to become long as the current progresses upwards.

Just to check the effect of the length of the wavefront, we used other lengths of a wavefront such as 0.01μsec and 0.2 μsec .

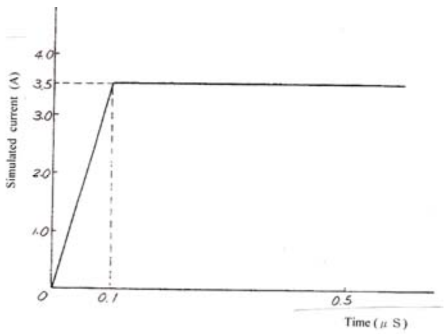

Figure 10. Simulated return stroke current for numerical analysis

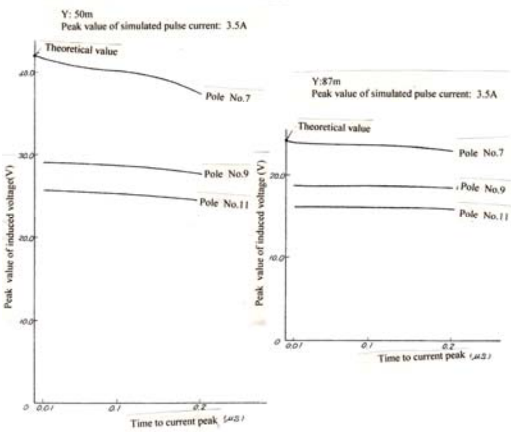

Figure 11. Relation between the front time of return stroke current and the peak value of induced voltages (numerical analysis)

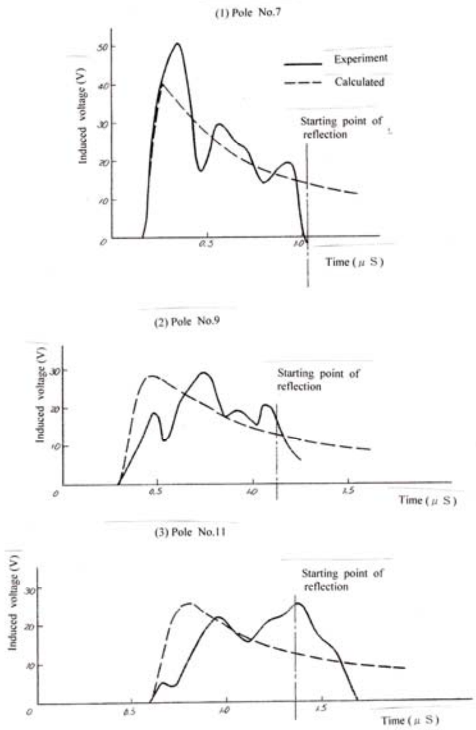

Figure 12. Comparison between experimental value and calculated one・・・Yd: 50m

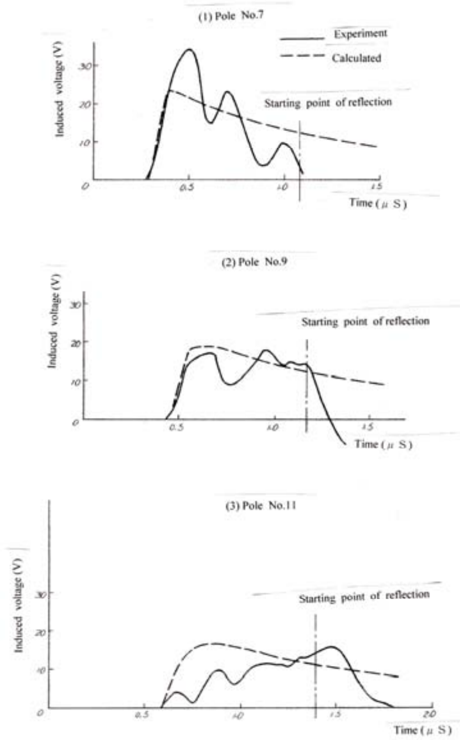

Figure 13. Comparison between experimental value and calculated one・・・Yd: 87m

The relation between the length of the wavefront and the peak value of induced voltages are shown in Figure 11. It is obvious that the effect of the length of the wavefront is not so large.

Figure 12 shows the comparison of experimental and calculated results for Case Hokuriku 1-1 (Yd:50m) and Figure 13 shows that of experimental and calculated results for Case Hokuriku 2-1(Yd:87m). The authors assumed 99% of the light velocity as the velocity of a pulse current in a copper conductor. The following results were obtained by the above comparisons;

(1) On the whole numerical analysis results agree well with experimental results.

(2) On the other hand, in the case of experimental results an oscillating wave superimposes on a waveform obtained by the numerical analysis.

(3) For the waveforms at Pole No.11 rising slopes are gentler than for that at pole No.7.

(4) For the waveforms at Pole No.9 an experimental waveform agrees well with calculated one in case that Yd is 87m but an experimental waveform doesn't agree well with calculated one in case that Yd is 50m . At Pole No.9 travelling wave is not formed fully in case that Yd is 87m , on the other hand travelling wave is fairly formed in case that Yd is 50m . Phenomena of induced voltages are something different from those of simple travelling waves.

V. CONCLUSIONS

The authors produced the induced voltages on a real-size distribution line using a 150m-long conductor for simulating as lightning discharge path

The authors had experimented according to following process. A balloon lifts a 150 meter-long copper conductor near the overhead distribution line. A pulse current is applied to the above conductor. Induced voltages on the overhead distribution line were observed using an oscilloscope.

Main experimental results are shown as follows;
(1) As the distance between the grounding point of copper wire and an overhead distribution line (Yd) becomes small, the induced voltages on the testing overhead distribution line become large.

(2)An induced voltage is largest at the nearest point to the balloon. As the distance from the nearest point to the balloon on the distribution line becomes large, the peak value of induced voltage becomes small.

(3)As the height of a distribution line becomes low, the peak value of an induced voltage becomes also small. But the ratio of the peak value of a low distribution line to that of a high distribution line is not proportional to the height of them. If the equivalent ground surface is taken into consideration, the ratio of the peak value of the induced voltage for a low distribution line to that for a high distribution line agrees well with the ratio of equivalent heights above the ground of them. .

(4) Experimental results agree roughly well with the results obtained by a numerical analysis method.

(5) On the other hand, the results obtained by a numerical analysis method are different from the results of experiments in detail, stressing the need for improving the numerical analysis method considering the existing theories [11,12].

ACKNOWLEDGEMENT

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