ANALYSIS ON INDUCED LIGHTNING OF AN EXISTING DISTRIBUTION LINE AND A DISTRIBUTION LINE INCLUDING A NEUTRAL WIRE USING A DOWN SCALED SIMULATION LINE MODEL

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ABSTRACT

This paper presents the most efficient induced lightning shielding method by changing ground resistances and grounding places in various ways in order to analyze the effect of ground resistance according to grounding places suitable for multi-grounding, as well as the effect of ground resistance according its connection. This study proposed a distribution line including an overhead wire commonly used as a neutral wire and examined the induced lightning shielding effect by proposing a line consisting of an overhead ground wire and a neutral wire in a 22.9kV transmission line structure. To do so, this study made a simulation line by down scaling the structure of an existing multi-grounding type 22.9kV distribution line to 50:1 and performed tests on this simulation line. As a result, it is thought that even though an existing line is replaced with a line that includes a neutral wire, system stability can be secured. It can be seen that for every distribution line it is more efficient for the improvement of system stability to ground all poles even though ground resistance is a little higher, rather than to install a ground wire with low ground resistance.

INTRODUCTION

Lightning, which occurs due to electric discharge between thunderclouds or between thunderclouds and the earth, generates an abnormal voltage which affects power lines located below thunderclouds [1]. A direct lightning strike refers to when lightning strikes equipment directly, while induced lightning refers to that which strikes around equipment, affecting communications, electrical and other equipment. Compared to direct lightning, induced lightning occurs more frequently and may cause flashover to occur to distribution lines with voltage less than 60kV. Since a distribution line has a lower insulation performance than a transmission line, its insulation materials and equipment may be easily damaged by induced lightning voltage. Studies have been performed in other countries regarding the calculation theory and experiments by observing existing distribution lines [2]. However, in Korea, a study was recently performed on the influence of induced lightning according to the size of ground resistance and the number of grounding places taking into consideration the multi-grounding method [3].

Therefore, this study proposed a distribution line that includes an overhead ground wire commonly used as a neutral wire and analyzed the lightning shielding effect according to the distribution line structure, size of ground resistance and number of grounding places using a down scaled simulation line. To do so, this study made a simulation line to be used for tests by downscaling the structure of an existing multi-grounding type 22.9kV distribution line to 50:1. Tests were performed on an existing distribution line (5 wires) including an overhead ground wire, power line (3 phases) and neutral wire, as well as a distribution line (4 wires) including a neutral wire commonly used as overhead ground wire and power line (3 phases)

PROPOSED DISTRIBUTION LINE INCLUDING A NEUTRAL WIRE COMMONLY USED AS AN OVERHEAD GROUND WIRE

Fig. 1 shows the structure of existing and proposed distribution lines. The existing distribution line consists of overhead ground wire, neutral wire and power line, while the proposed line includes a neutral wire commonly used as an overhead ground wire and is installed at the position of the overhead ground wire [4].

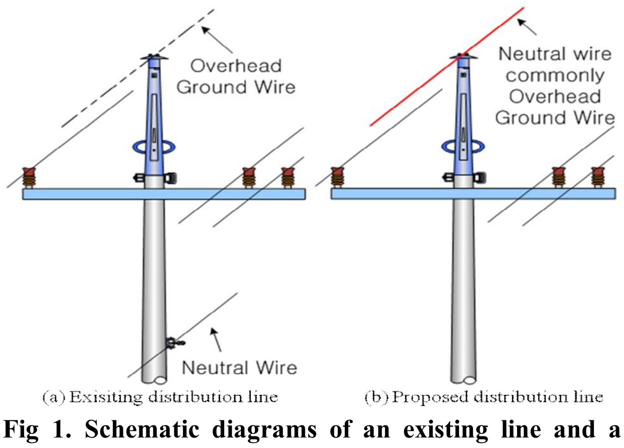

Fig 1. Schematic diagrams of an existing line and a proposed line including a neutral wire

CONFIGURATION OF A DOWN SCALED SIMULATION LINE

Overview of a down scaled simulation line

A down scaled simulation line was introduced to predict the transient phenomenon of a power system. It is used for the analysis of substation electric fields, power systems, etc. Recently, a down scaled simulation line was used together with an analytical technique that can calculate the transient phenomenon more precisely like EMTP [5-8]. The configuration of the distribution line used for this study is divided into an existing line that includes an overhead ground wire and neutral wire separately, as well as a distribution line that includes a neutral wire commonly used as an overhead ground wire. In addition, this study configured a multi neutral grounding type, double circuitedextra-high voltage (22.9kV) distribution lines: a double circuited extra-high voltage existing distribution line including overhead ground wire, power line (3 wires) and neutral wire as well as a double circuited extra-high voltage distribution line including a neutral wire commonly used as an overhead ground wire and power line (3 wires).

Configuration of a down scaled simulation line

The down scaled simulation line used for the induced lightning test consists of seven electric poles as shown in Fig. 2. The lightning-induced current generated by an impulse generator is applied to a ground plane through a 10cm gap from an electrode 2m apart from the distribution line. That is, the electromagnetic coupling causes induced voltage to be generated in the distribution line and induced current to flow through the line.

This study measured the waveform using an oscilloscope (TDS 3014, Tektronix, 100MHz, 1.25GS/s) and detected induced voltage (Tek P5100, Tektronix, DC to 250MHz 10ft, 100x, 2500Vpk 1.75ns, 10MΩ /2.75pF) and induced current (TCP 202, Tektronix, 15A peak DC to 50MHz 50A MAX pulse) at the 'A' phase.

The applied current was detected using a high frequency CT (2878, Pearson, 0.1 V/A, 400A MAX 10Arms, 6ns). The impulse generator is recharged up to 360kV and can generate a maximum current of up to 3kA. In order to prevent the generated arc from being directly discharged to the distribution line, the generator was installed in the shielded space as shown in Fig. 3 so that it received no influence from the external electromagnetic field. In addition, the applied current was adjusted by connecting a ballast resistor, 1,000 Ω , to the output section of the generator.

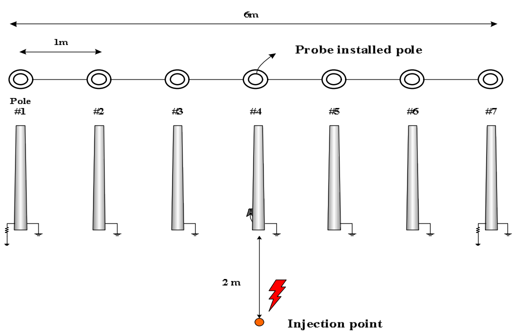

Fig. 2 Pole arrangement of the down scaled simulation line

Fig. 3 Impulse generator used for the down scaled simulation test

Impulse was applied maintaining the 10cm gap between the electrode and the ground plane electrode. The applied current, induced voltage of phase 'A' and ground (Gnd), as well as the induced current of phase 'A' were measured through Channel 1 (Ch2), Channel 2 (Ch2) and Channel 3 (Ch3), respectively. In addition, in order to prevent the influence of the reflected wave generated from the ends (Pole #1 and Pole #7) of the simulation line, matching resistors of 480Ω was installed at these ends. Fig. 4 shows the configuration of the down scaled simulation line.

Table 1. The reduce rate of the overhead line for the reduced scale model experiment

Classification	Reduce rate	Unit
Distance	50:1	[m]
Resistance	1:1	[Ω]
Current	50:1	[A]
Conductor	50:1	-
Position	50:1	[mm]

Fig. 4 Simulation line for the down scaled simulation test (50:1)

CONFIGURATION OF A DOWN SCALED SIM ULATION LINE

For the induced lightning test, this study applied current to a ground plane 2m apart directly from Pole #4 through an arc. The conditions of the lightning-induced voltage of the down scaled simulation line are as shown in Table 2. The lightning-induced voltage obtained by measuring the voltage 20 times was applied to the simulation line.

Table 2. Test conditions of a distribution line for a down scaled simulation test

Classification		Resistance	Ground
Case 1	5W_50Ω_all	50	7 point
Case 2	5W_50Ω_2R	50	2 point
Case 3	5W_100Ω_all	100	7 point
Case 4	5W_100Ω_2R	100	2 point
Case 5	4W_50Ω_all	50	7 point
Case 6	4W_50Ω_2R	50	2 point
Case 7	4W_100Ω_all	100	7 point
Case 8	4W_100Ω_2R	100	2 point

Here, 5W (5 Wires) refers to one overhead ground wire, the three wires of the power line and one neutral wire. This study applied the wiring of the simulation line the same as that of the existing multi-grounding type distribution line with 3 phases and 4 wires as well as the overhead ground wire. 4W (4 Wires) refers to one neutral wire commonly used as an overhead ground wire and the three wires of the power line. This wiring was proposed for the analysis of the shielding effect of the induced lightning of the distribution line with a neutral wire commonly used as an overhead ground wire [3]. In addition, in order to analyze the influence of the induced lightning according to the size of ground resistance and grounding type, this study performed the tests by connecting a 100Ω resistance, which is higher than the current standard resistance (50Ω) for grounding work.

Table 3 shows the average of the major values measured from the 5W and 4W distribution lines when each of the seven poles was grounded. The combined resistance of the 5W distribution line was 7.4Ω . When the average applied current was 230A, the average induced voltage and induced current of the 'A' phase were 1,052V and 13.8A, respectively. At this time, the combined resistance of the 4W distribution line was 7.8Ω . When the average applied current was 235A, the average induced voltage and induced current of the 'A' phase were 1,127V and 11.7A, respectively. That is, it can be seen that the combined resistance and induced voltage increased slightly in the 4W distribution line depending on the distribution line structure, but showed no significant difference from those of an existing distribution line and that its induced current was reduced.

Table 3. Measured values when grounding down scaled electric poles in 7 locations with ground resistance less than 50Ω (Case 1, Case 5)

Case	Current [A]	Induced Voltage [V]	Induced Current [A]	Synthesis Resistance [Ω]
5W_50Ω_all	230	1,052	13.8	7.4
4W_50Ω_all	235	1,127	11.7	7.8

Table 4 shows the measurement data when two poles were grounded with resistance less than 50Ω with the measuring points not grounded. The combined resistance of the 5W distribution line was 21.8Ω and when the average applied current was 236A, the average induced voltage and induced current of the 'A' phase were 1,393V and 16.1A, respectively. In this case, the combined resistance of the 4W distribution line was 23.6Ω and when the average applied current was 242A, the average induced voltage and induced current of the 'A' phase were 1,442V and 13.6A, respectively. That is, under the same conditions, the combined resistance of the 4W distribution line increased compared to that of the 5W distribution line and its induced voltage was measured slightly higher. However, the difference between the 4W and 5W distribution lines is not great.

Table 4. Measured values when grounding down scaled electric poles in 2 locations with ground resistance less than 50Ω (Case 2, Case 6)

Case	Current [A]	Induced Voltage [V]	Induced Current [A]	Synthesis Resistance [Ω]
5W_50Ω_2R	236	1,393	16.2	21.8
4W_50Ω_2R	242	1,442	13.6	23.6

Table 5 shows the measurement data when all seven poles were grounded with resistance less than 100Ω . The combined resistance of the 5W distribution line was 14.9Ω and when the average applied current was 236A, the average induced voltage and induced current of the 'A' phase were 1,068V and 15.6A, respectively. Under the same conditions, the combined resistance of the 4W distribution line was 14.4Ω and when the average applied current was 236A, the average induced voltage and induced current of the 'A' phase were 1,229V and 14.4A, respectively. That is, it can be seen that the induced voltage measured slightly higher at the 4W distribution line compared to that of the 5W distribution line, but that the induced current was reduced. In addition, it is thought to be better to ground all poles than to ground some poles with resistance less than 50Ω even though ground resistance is slightly higher.

Table 5. Measured values when grounding down scaled electric poles in 7 locations with ground resistance less than 100Ω (Case 3, Case 7)

Case	Current [A]	Induced Voltage [V]	Induced Current [A]	Synthesis Resistance [Ω]
5W_100Ω_all	236	1,068	15.6	14.9
4W_100Ω_all	236	1,229	12.6	14.4

Table 6 shows the measurement data when two poles were grounded with resistance less than 100Ω and with the measuring points not grounded. The combined resistance of the 5W distribution line was 36.4Ω and when the average applied current was 233A, the average induced voltage and induced current of the 'A' phase were 1,386V and 14.9A. In this case, the combined resistance of the 4W distribution line was 43Ω and when the average applied current was 232A, the average induced voltage and induced current of the 'A' phase were 1,440V and 12.7A, respectively. It can be seen that the induced voltage increased slightly as the combined resistance of the 4W distribution line increased slightly, but the induced current was reduced compared to the 5W distribution line.

Table 6. Measured values when grounding down scaled electric poles in 2 locations with ground resistance less than 100Ω (Case 4, Case 8)

Case	Current [A]	Induced Voltage [V]	Induced Current [A]	Synthesis Resistance [Ω]
5W_100Ω_2R	233	1,386	14.9	36.4
4W_100Ω_2R	232	1,440	12.7	43.0

Fig. 5 shows the data measured from the down scaled simulation model. It is thought that there was a difference in the induced voltage and current between the 4W and 5W distribution lines since a slight difference occurred to the impedance depending on the configuration of the distribution line. It was found that the voltage induced by the induced lightning changed depending on whether the measuring points were grounded or not and the grounding places rather than the size of the ground resistance. That is, when all seven poles were grounded, the induced voltage was measured to be the lowest regardless of the size of the ground resistance.

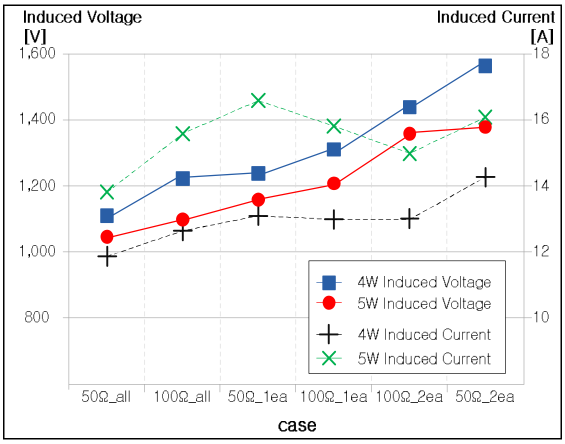

Fig. 5 Induced voltage and current measured through the down scaled simulation test

CONCLUSION

The following result was obtained from the simulation test analysis performed by downscaling the structure of the existing 22.9kV distribution line with multi-grounded neutral wire in order to analyze the induced lightning shielding effect according to the ground resistance size and the number of grounding places as well as the influence of the induced lightning according to the line structure. It can be seen that the combined resistance and induced voltage of the 4W distribution line increased slightly depending on the line structure, but they did not show a significant difference from those of the existing line and that the induced current was reduced. Under the same conditions, when the number of grounding places was reduced, the combined resistance increased and the induced voltage and current also tended to increase.

It can be seen that it is advantageous in the aspect of distribution line stability to ground all poles even though it is important to maintain the ground resistance at a low level. These characteristics were shown in the same pattern in the 5W and 4W distribution lines. It was found that even though the ground resistance is high, if there are numerous grounding places, the induced voltage was low compared to the case where ground resistance is low. In addition, the induced voltage measured was lower in the 4W distribution line than the 5W line. It is thought that, based on this, it will be possible to establish a more stable system at a distribution line where neutral wire is commonly used as an overhead ground line.

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