A Protection Technique Against the Damages Caused by Lightning Surges on Information and Communication Facilities

Bok-Hee Lee*, Sung-Man Kang* and Chang-Hwan Ahn*

Abstract - The AC power lines and signal lines of info-communication networks are routed on overhead poles and are highly exposed to lightning strikes. Due to the potential difference between grounding points of AC power lines and signal lines, the electronic equipments connected to the signal lines can easily be damaged by lightning surges. In this work, in order to develop reliable methods of protecting information and communication facilities from lightning surges, the reliability and performance of SPDs (surge protective devices) were experimentally investigated in an actual-sized test circuit. The behaviors of SPDs against lightning surges from AC power lines and signal lines and the coordinated effects of SPD installation methods were evaluated. As a consequence, it was confirmed that the bypass arrester methods and common grounding system are both highly effective.

Keywords: Lightning protection system, Information and communication facilities, Surge protective device, Bypass arrester method, Common grounding, GPR (ground potential rise)

1. Introduction

Generally, the surge voltages occurring in low-voltage AC power lines originate from two major sources, direct lightning or indirect lightning, which have an effect on the power system and system switching transients. The electric power lines and computer data lines of info-communication networks and the signal and control lines of computerized social systems are routed on overhead poles and can be exposed to lightning strikes. High voltage surges can also be induced in low-voltage AC power lines, signal and data lines by electromagnetic field changes and lightning current transients. Many modern electronic equipments are made of IC, VLSI, smaller and faster semiconductor devices that can be damaged by relatively low transients.[1~3] There are some problems related to the fact that microelectronic circuits are becoming more vulnerable to damage or upset and they are also becoming more widely used in modern electronic devices and systems. Thus, it is of great importance that the lightning SPDs be installed accurately and logically. In addition, there is still a certain amount of information concerning appropriate lightning protection that is not yet clearly understood.

Lightning current flow resulting from nearby cloud-to-ground discharges couples onto the common paths of the grounding network. As illustrated in Fig. 1, when the lightning currents are injected to the grounding of electrode A, an induced potential can be raised to the adjacent grounding of electrode B. Although it is the most advantageous to isolate both grounding electrodes as in the case of grounding electrodes A and C, it is very difficult to install the grounding electrodes far enough away from each other in the downtown area, creating difficulties from the viewpoints of economics and construction.

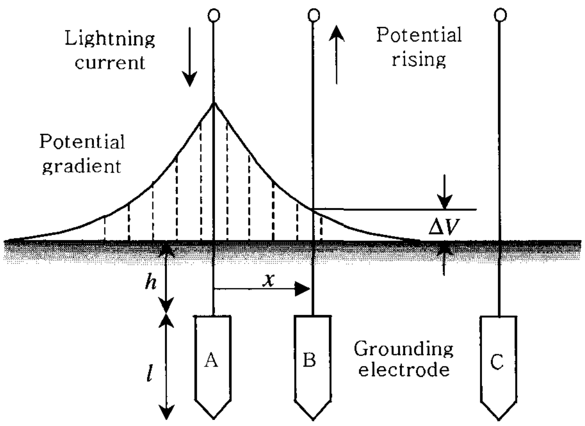

Fig. 1 The potential rising of grounding to electrodes B and C when the lightning currents are injected to the grounding of electrode A.

If an induced potential ΔV occurs between both electrode A grounding and electrode B grounding, it can be expressed as:

$$\Delta V = \frac{\rho l}{2\pi l} \ln \frac{l + h + \sqrt{(l+h)^2 + x^2}}{h + \sqrt{h^2 + x^2}} \quad [V]$$

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Since the information-oriented and computerized equipments are connected to the low voltage AC power lines and telephone lines, the potential difference due to lightning surges occurs between grounding points of the AC power lines and communication devices.[4~7] Thus, it is crucial that the SPDs be installed effectively in order to maintain normal conditions within information and communication facilities. Therefore, we have examined the behaviors of SPDs stressed by lightning surges, and the effect of a systematic protection countermeasure using an actual scaled test circuit in a customer facility has been experimentally investigated. In this paper, the proper network protection technique using SPDs that are widely utilized in computer data and signal lines is described in detail.

2. Experimental Setup

Fig. 2 illustrates the schematic diagram of measurement circuit and installation methods of SPDs. Resistor R_1 provides ground resistance to SPDs on the AC power lines, resistor R_2 simulates the potential difference between the two grounds and resistor R_3 indicates the SPD ground resistance on the signal lines. The combination of these values is 10 Ω.

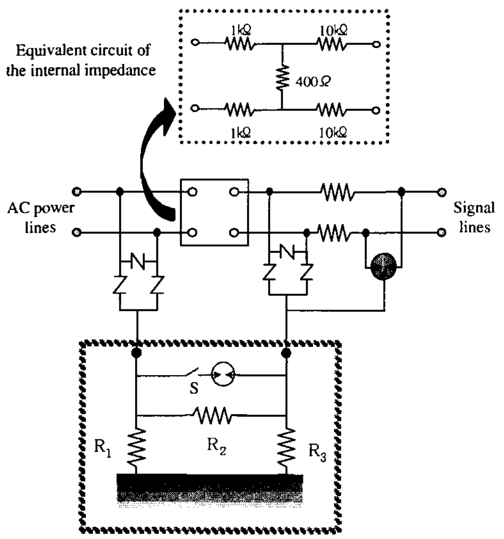


Fig. 2 Installation methods of SPDs on AC power lines and signal lines.

In Fig. 2, independent grounding is the case of omitting resistor R_2 and spark gap G, common grounding is the case of eliminating spark gap G and assigning resistance R_2 as zero. Also, in order to evaluate the effect of the induced potential due to the grounding of electrodes, the equivalent circuits for simulation of potential rise are shown in Fig. 3. The rates of potential rise 0(a), 35(b), 50(c), and 100%(d) in which case (a) is the independent grounding and case (d) is the common grounding. The bypass arrester method is the condition in which switch S is closed.

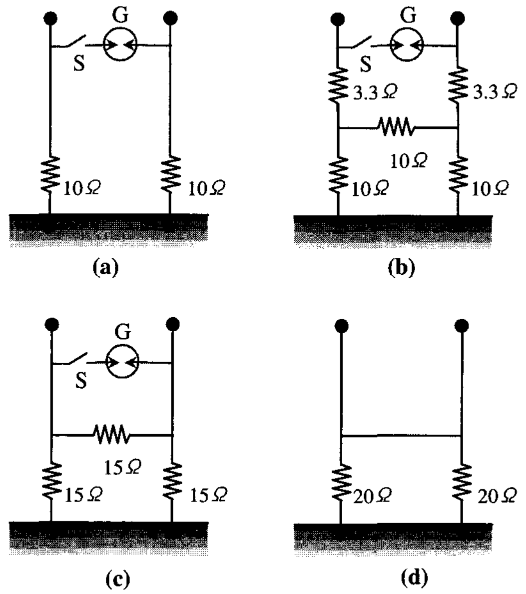


Fig. 3 Equivalent circuits for simulation of the potential rise.

In this work, we used two types of facsimile telegraphs as test specimens. One has infinite internal impedance, and the other has internal impedance that is 2.4 kΩ for the power line-side and 20.4 kΩ for the signal-line side. The nominal conduction voltage of ZnO varistors for the power line SPDs is about 700V, and the dc firing voltage of spark gap for the signal lines is 400V. The combination voltage and current surge simulator used in this work produces the 1.2/50 μs impulse voltage under open-circuit conditions and the 8/20 impulse current under short-circuit conditions. The test surge voltages were injected between the hot line and ground or between the signal line and ground called common mode. At that time, the surge currents were measured with the current transformer using a wide frequency band and the voltages across the SPDs were observed by high voltage probe. Also, we investigated induced voltages such as the signal line voltage to power lines, the signal line voltages to ground and the power line voltages to ground. The waveforms of the incident voltage, incident current and GPR (ground potential rise) of R_2 were observed through a digital storage oscilloscope.

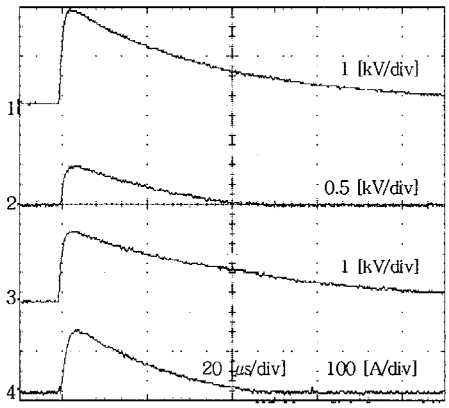
3. Results and Discussion

3.1 Lightning surges from the AC power lines

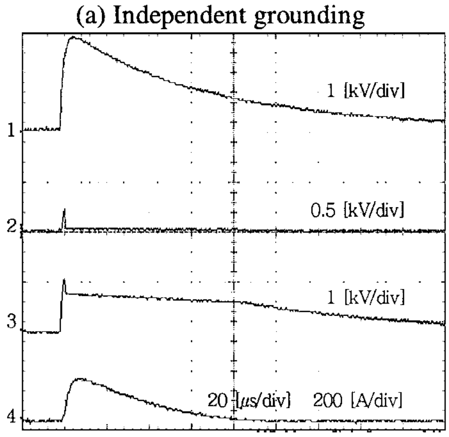
Installation methods of SPDs on the AC power lines and signal lines are usually classified into independent grounding, bypass arrester and common grounding methods according to grounding systems.[8] The incident surge currents are essentially shared with the ground resistances of the AC power lines-side SPDs and signal lines-side SPDs. For example, the signal lines-side surge problems become worse as the ground resistance of SPDs on the AC power lines is much less than that of SPDs on the signal lines. This is due to a great portion of the surge currents flowing through the ground of the signal lines-side SPDs. Generally, the grounding conductor for SPDs on the AC power lines is solidly bonded to that for SPDs on the signal lines, or the ground leads for SPDs on the AC power lines and signal lines are separated by a spark gap that easily flashes over during lightning surges.[9] This bonding and flashover of the spark gap during lightning surges are necessary in preventing excessive voltages that could breakdown the insulation of the electronic equipments to be protected.

Failures of microelectronic devices and systems caused by lightning surges can be avoided if SPDs are properly installed at the AC power lines, signal and computer data lines. The coordinated effects of the SPDs installed at the AC power lines and signal lines were experimentally examined. The SPD for the AC power lines is a single-stage circuit and the SPD for communication/signal lines is a hybrid circuit. When lightning surges invade from the AC power lines, in the case that the GPR of SPDs for signal lines is 35% to the GPR of SPDs for the AC power lines, the waveforms of the invading surge voltage, the voltage across resistor R_2 and the injection surge current were displayed in Fig. 4, where Fig. 4 (a) is the independent grounding method and Fig. 4 (b) is the bypass arrester method.

If the potential difference between the two grounds is greater than the firing voltage of the bypass arrester (G) owing to the operation of the SPDs installed at the AC power lines, the spark gap for the bypass arrester is fired and the test circuit is changed to the common grounding system. At that time, the AC power line voltages to the signal lines are decreased compared to those prior to the firing of the spark gap. On the contrary, the voltages of the signal line to the ground are increased.



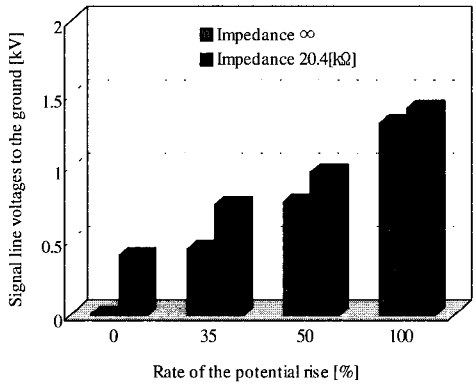
(a) Independent grounding



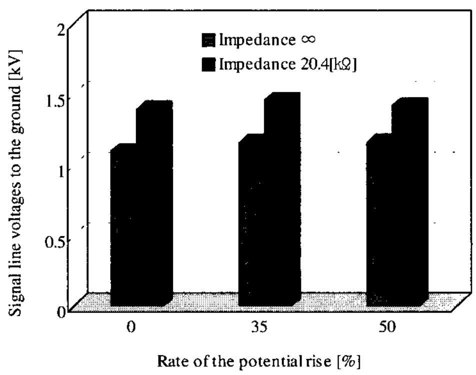
(b) Bypass arrester method

1: Surge voltage from the AC power lines
2: Voltage across the resistor R_2
3: Power line voltages to the signal lines
4: Injection surge current

Fig. 4 Waveforms of voltages and currents due to the lightning surge from AC power lines. The GPR of SPDs for the signal lines is 35% of the GPR of SPDs on the AC power lines.



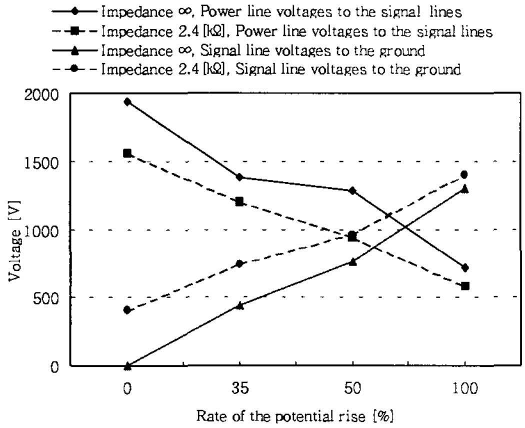
(a) Independent grounding



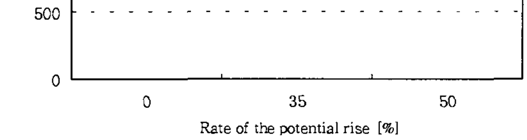
(b) Bypass arrester method

Fig. 5 Signal line voltages to the ground when the lightning surges are invaded from the AC power lines according to the rate of the GPR of SPDs for the signal lines to the GPR of SPDs on the AC power lines.

Fig. 5 shows the signal line voltages to the ground when the test surge voltages are applied between the hot-to-ground of the AC power lines. The signal line voltages to the ground are highest in the common grounding and lowest in the independent grounding. But the voltages transferred to communication devices with infinite input impedance are lower than those for devices having an input impedance of 20.4 kΩ because the voltage drop occurs as a result of the surge current flowing through the inner impedance.



(a) Independent grounding



(b) Bypass arrester method

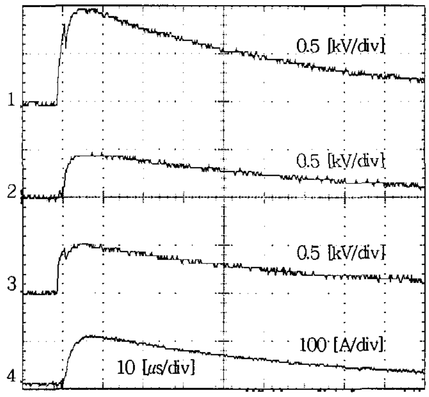
Fig. 6 Voltages transferred to the signal lines from the AC power lines according to the rate of the GPR of SPDs for the signal lines to the GPR of SPDs on the AC power lines when the lightning surges are invaded from the AC power lines.

Fig. 6 shows the common mode and differential mode voltages measured as parameters of input impedance in the independent grounding and bypass arrester methods when the lightning surges are invaded from the AC power lines. The voltages of AC power lines to the signal lines are decreased and the voltages of signal lines to the ground are increased as the potential rise increases.

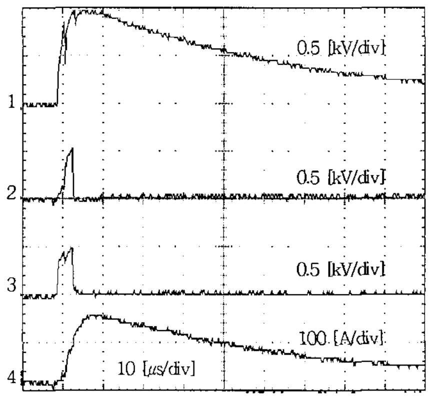
On the other hand, it was established that the voltages of signal lines to the AC power lines and the voltages of signal lines to the ground remain unchanged with the potential difference between the two grounds, because the test circuit is changed from independent grounding to common grounding due to firing of the spark gap.

3.2 Lightning surges from the signal lines

The coordinated effects of SPDs for the AC power lines and communication/signal lines against lightning surges invaded from signal lines were examined. Fig. 4 displays the typical waveforms of the voltages on the AC power lines and signal lines and the currents flowing through each SPD.



(a) Independent grounding

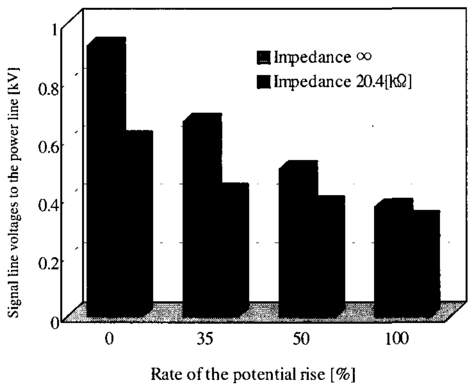


(b) Bypass arrester method

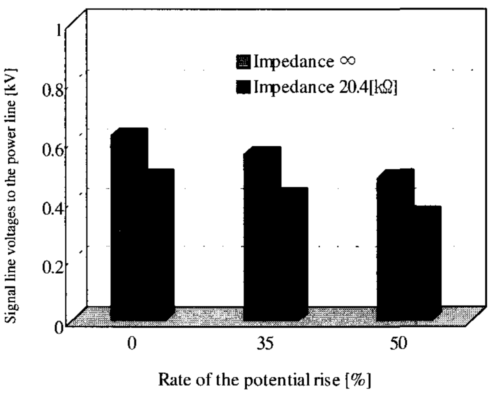
1: Surge voltage from the signal lines
2: Voltage across the resistor R_2
3: Signal line voltages to the AC power lines
4: Injection surge current

Fig. 7 Waveforms of the voltages and currents due to the lightning surges from the signal lines. The GPR of SPDs for the AC power lines is 50% of the GPR of SPDs for the signal lines.

The characteristics and sequences of each SPD for the signal circuits are clearly illustrated from the waveforms shown in Fig. 7. The SPD ground potential of the AC power lines in independent grounding is elevated as the incident surge current flowing into the SPD ground for the signal lines is increased. In the case of independent grounding, there is no potential difference between the two grounds, but the pronounced potential difference between the two grounds is produced by the ground surface potential rise around the grounding electrodes.[6] Thus, the potential difference between the two grounds can cause a dielectric breakdown of the electrical and electronic facilities to be protected.



(a) Independent grounding

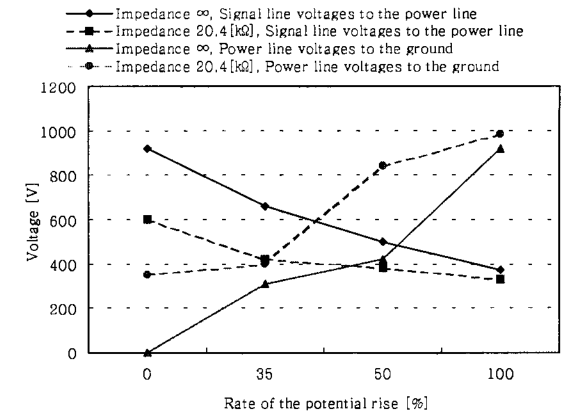


(b) Bypass arrester method

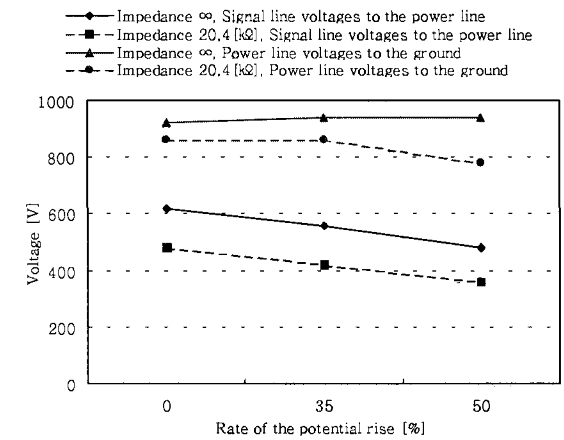
Fig. 8 Signal line voltages to the AC power lines according to the rate of the GPR of SPDs for the AC power lines to the GPR of SPDs on the signal lines when the lightning surges are invaded from the signal lines.

Fig. 8 illustrates the signal line voltages to the AC power lines according to the grounding methods when the lightning surges are invaded from the signal lines. The fundamental operation characteristics and protection effect of SPDs are quite similar to those with respect to the surge voltages from the AC power lines.

In case that the potential rise is 0[%], the signal lines voltage to the AC power lines is the highest and common grounding potential rise is the lowest. Also, the voltages transferred to communication devices with infinite input impedance is lower than those for the devices with an input impedance of 20.4 kΩ.



(a) Independent grounding



(b) Bypass arrester method

Fig. 9 Voltages transferred to the AC power lines from the signal according to the rate of the GPR of SPDs for the AC power lines to the GPR of SPDs on the signal lines when the lightning surges are invaded from the signal lines.

Fig. 9 shows the voltages transferred to the AC power lines from the signal lines as a function of the ratio of the SPD ground potential for the AC power lines to the SPD ground potential for the signal lines.

In reality, the voltages of signal lines to the AC power lines are decreased and the voltages of AC power lines to ground are increased as the rate of potential rise increases. Alternatively, in the case of the bypass arrester method, the voltages of signal lines to the AC power lines are lower than those of power lines to ground, and the two voltages are irrelevant to the rate of potential rise.

4. Conclusion

The coordinated effects of SPDs in AC power systems, info-communication networks, signal and control networks were investigated. The common grounding of SPDs connected to the electronic equipments being protected is necessary for protection against lightning surges. Provided that the SPDs are installed with the independent grounding, the protective effect against lightning surges will be negligible, and the equipotential bonding is required. The installation of SPDs applying the bypass arrester and common grounding is significantly effective. The results obtained from this work would be extremely useful in protecting microelectronic devices from lightning surges.

Acknowledgements

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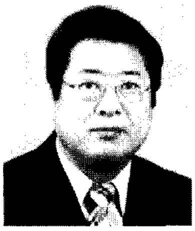
References

[1] IEC 61312-3, Protection against lightning electromagnetic impulse - Part 3: Requirement of surge protective devices (SPDs), First edition, 2000-07, pp. 25~31.
[2] Lightning protection countermeasure committee, "Lightning and highly information-oriented society", IEIEJ, pp. 132~166, 1999.
[3] R. B. Standler, "Protection of Electronic Circuits from Overvoltages", John Wiley & Sons, Inc., pp. 55~77, 1989.
[4] IEEE C62.41-91 IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits, pp. 39~52, 1991
[5] K. Nakada, S. Shimada, N. Itamoto, H. Sugimoto, H. Arai & Asakawa, "Lightning Protection Methods for Customer's Facility Using Common Grounding Wire", Proc. of the 12th Annual conference of Power & Energy Society, IEE Japan, pp. 417~423, 2001.
[6] K. Nakada, H. Sugimoto, S. Shimada, Y. Asaoka & A. Asakawa, "Countermeasures for controlling lightning-caused overvoltage on indoor wiring with communication line", Proc. of the 12th Annual conference of Power & Energy Society , IEE Japan, pp. 7~13, 2001.
[7] T. Otsuka, K. Maezaki, "Experimental study of lightning surge current condition of low-voltage distribution lines and house wires", Proc. of the 11th Annual conference of Power & Energy Society, IEE Japan, pp. 21~27, 2000.
[8] Takahasi, "Introduction to Grounding Systems", Ohmsha, pp. 37~54, 2001.
[9] M. B. Marz and S. R. Mendis, "Protecting Load Devices From the Effects of Low-Side Surges", IEEE Trans. on Industry Applications, Vol. 29, No. 6, pp. 1196~1203, 1993.



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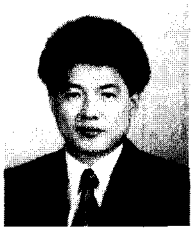

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