Statistical Analysis of Lightning-Induced Voltages on Subscriber Telecommunication Lines in Korea

Ho-Seok Oh[1] · Dong-Chul Park[2]

Abstract

This paper describes the characteristics of lightning-induced voltages on subscriber telecommunication lines in Korea. Lightning parameters such as peak voltage, rise time, decay time, and steepness of the wave front were statistically analyzed from the measured results obtained using a waveform memory system. An induced voltage measurement system was also developed and installed at 286 sites in Korea to collect the induced voltage data. The distributions of lightning-induced voltages were also analyzed using these data.

Key words : Lightning, Protection, Voltage Measurement, Statistics.

Ⅰ. Introduction

Modern telecommunication systems have greater sensitivity to lightning surges because they use high-speed semiconductor devices that are easily damaged by electrical surges. Induced voltages on subscriber telecommunication lines due to a nearby lightning return stroke may cause damage to telecommunication systems. The inherent secondary and primary protection can be effective and economic countermeasures, only if the expected overvoltages and overcurrents are known with sufficient accuracy and take into account geographical, environmental, and installation plant conditions[1]~[3]. Still, properly designed and installed protective measures can only reduce the risk of damage to an acceptable level rather than completely prevent it. Many researchers have carried out lightning surveys on subscriber telecommunication lines to obtain and analyze data that are of major significance for the protection of electronic switching centers and telecommunication subscriber equipment[4]~[6]. However, Korea has been lacking in this kind of research.

This paper statistically analyzes lightning-induced voltage parameters such as peak voltage, rise time, decay time, and steepness of the wave front from the measured results obtained using a waveform memory system(WMS). An induced voltage measurement system(IVMS) was also developed and installed at 286 sites in Korea. The distributions of lightning-induced voltages were also analyzed using the data obtained from the developed system.

Ⅱ. Observation Systems

A WMS was used to record the lightning-induced voltage waveforms that are needed to analyze the lightning parameters, while an IVMS was used to collect data from many sites, which are needed to evaluate the distributions of the peak values.

The WMS has four channels and a 1.84 MHz sampling rate. Voltages over 10 V were recorded. This WMS was installed in the Central Office(CO) located near the city. The configuration of the subscriber telecommunication line is shown in Fig. 1. Fig. 2 shows the routes of the telecommunication lines under observation, and Table 1 shows the line length from the CO to each terminal. Voltages were measured between the line and the earth with high impedance at the CO, while the end of the line was grounded with 300 Ω of grounding resistance(R in Fig. 1) at the subscriber end.

Fig. 3 shows the IVMS and the four-channel measurement equipment of the IVMS, which measures the peak value of the lightning-induced voltage in the range of 100 V and 2.5 kV. The measurement equipment,

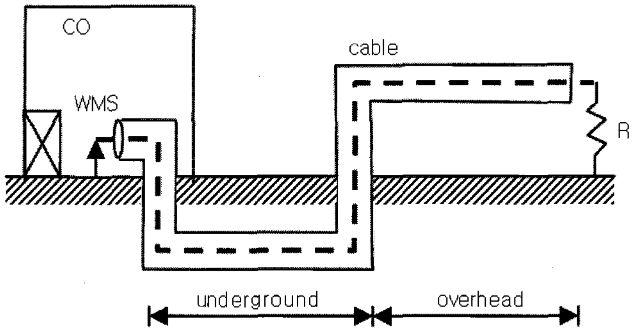

Fig. 1. Configuration of subscriber telecommunication line.

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[1]Infra Research Laboratory, KT Co., Daejeon, Korea.
[2]Radio Science and Engineering, Chungnam National University, Daejeon, Korea.

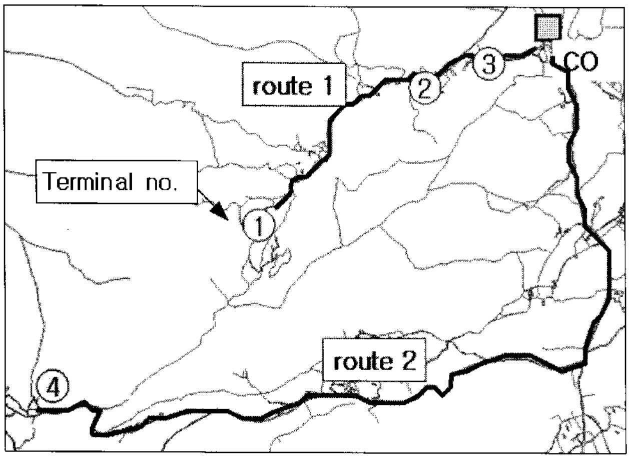

Fig. 2. Map of telecommunication lines under observation.

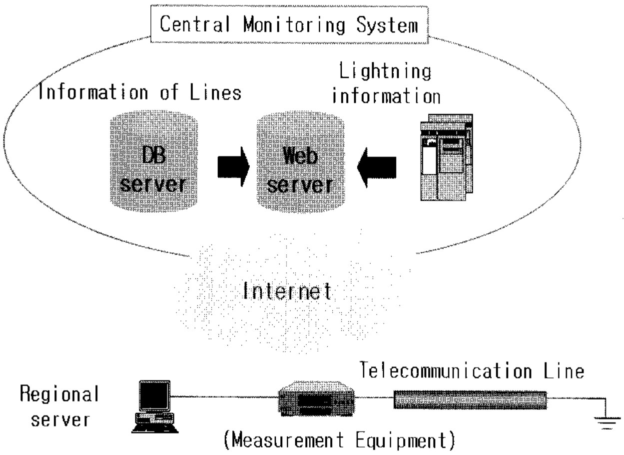

Fig. 3. Induced voltage measurement system.

Table 1. Length of telecommunication lines from CO to terminal.

Line length \ Terminal no.	①	②	③	④
Total line length (km)	2.3	1.3	0.6	5.3
Overhead line length (km)	2.1	1.1	0.2	1.3

which was installed at 286 CO sites in Korea, can collect measured data for 24 hours when connected to a regional server by telephone line or Internet. Overvoltage data were also measured at the CO, with the subscriber end grounded. All protective devices were removed from the lines under observation.

Ⅲ. Analysis of Lightning-Induced Voltage Parameters

Based on data from 392 WMS recordings, the number of strokes per waveform was analyzed as shown in

Table 2. Distribution of strokes per lightning flash.

Number of strokes per flash	Frequency of occurrence (%)
1	76
2	14
3	4
4	2
≥ 5	4

Table 2. For 71 % of the total data, the peak value of the subsequent stroke was lower than that of the first stroke. The interval time between the first and second stroke was distributed from 5.8 ms to 131 ms, and its median value was 62 ms. The rise time of impulse voltage is defined as the time interval between 30 % and 90 % of peak value in this paper. The decay time is the time interval between 30 % of the peak value on the front and 50 % of the peak value on the tail. The steepness of the front can be determined by the ratio of the peak value to the rise time[7].

Using the measured data, the statistical variation of the lightning stroke parameters can be approximated by a log-normal distribution[7], where the statistical variation of the logarithm of a random variable, x, follows the normal (Gaussian) distribution. In these cases, the probability density function, $p(x)$, is given by[8] (1):

$$p(x) = \frac{1}{\sqrt{2\pi}x\sigma_{\ln x}} \exp\left[-0.5\left(\frac{\ln x - \ln x_m}{\sigma_{\ln x}}\right)^2\right] \qquad (1)$$

where $\sigma_{\ln x}$ is the standard deviation of $\ln x$, and x_m is the median value of x. If $u = (\ln x - \ln x_m)/(\sqrt{2}\sigma_{\ln x})$, the cumulative probability, P_c, that the parameter will exceed x is given by (2), integrating (1) between u and ∞:

$$P_c(x) = \frac{1}{\pi}\int_{u_0}^{\infty} e^{-u^2}du = 0.5erfc(u_0) \qquad (2)$$

The data obtained from the WMS at one site for August 2006 to July 2007 were used for the analysis. Using the measured lightning-induced voltage waveforms, the parameters were calculated statistically, and the results are shown in Table 3. The median value of the measured peak values was 40 V, and the maximum value was 2,153 V. The median values for the rise and decay times were 100 μs and 327 μs, respectively. Fig. 4~5, and Fig. 6 show the cumulative probability distribution of peak values, rise times, decay times, and steepness as calculated by (2), respectively. About 75 % of the impulses have peak values of less than 100 V,

Table 3. Statistical parameters of lightning-induced voltages.

Parameter	Sample size	Median	$\sigma_{\ln x}$	Max.
Peak value(V)	248	40	1.33	2,153
Rise time(μs)	194	100	0.64	1,009
Decay time(μs)	194	327	0.69	4,293
Steepness(V/μs)	194	0.54	1.77	66.7

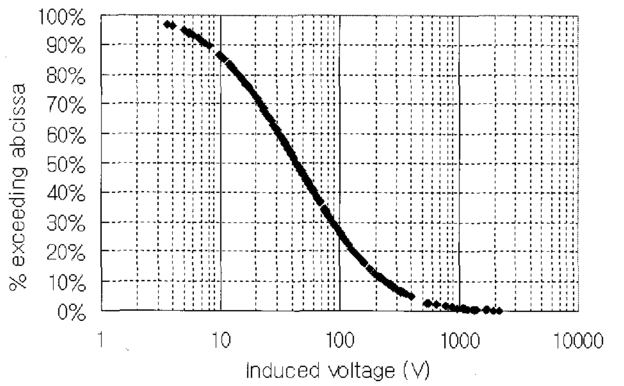

Fig. 4. Cumulative probability distribution of peak values.

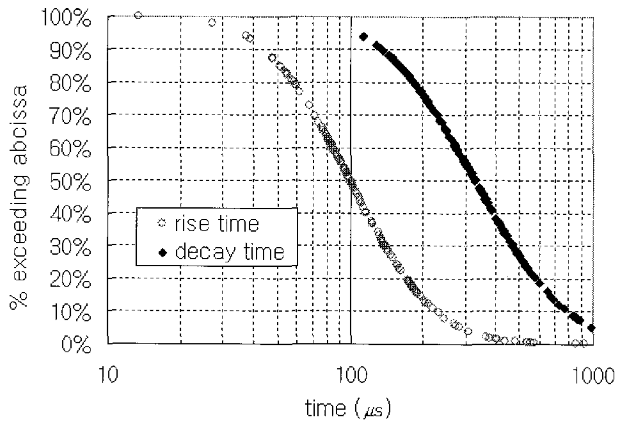

Fig. 5. Cumulative probability distribution of rise time and decay time.

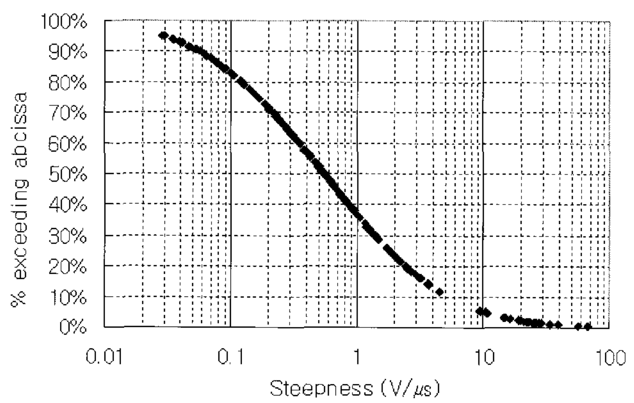

Fig. 6. Cumulative probability distribution of steepness.

Table 4. Correlation between line length and lightning parameters.

Parameters	Correlation coefficient for parameter	
	Total line length	Overhead line length
Peak value	0.021	0.265
Rise time	0.417	0.132
Decay time	0.398	0.105

and 0.9 % of the impulses have peak values of more than 1 kV.

The correlation between the line length and the lightning parameters was obtained using (3):

$$correlation = \frac{\frac{1}{n}\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sigma_x \sigma_y} \qquad (3)$$

where n is the number of data, $\bar{x}$ and $\bar{y}$ are the average values of variables x and y, and σ_x and σ_y are the standard deviations of x and y, respectively. From the results given in Table 4, it can be concluded that the magnitude of the induced voltage increases as the overhead line length increases, and the rise time and decay time also increase as the total line length increases.

Ⅳ. Lightning-Induced Voltage Distributions

Lightning-induced voltages from January 2006 to September 2007 at 286 sites nationwide were measured using the IVMS. For the peak values, 91 % of lightning-induced voltages were less than 200 V, as shown in Fig. 7. Voltages greater than 1 kV constituted 1.95 % in 2006 and 3.6 % in 2007 of voltages measured.

Fig. 8 shows the distribution of peak values in summer (July, August, and September) and winter (January, February, and December) in 2006. Although the lightning occurrence number for summer was much higher than that for winter, the peak values over 1 kV occurred

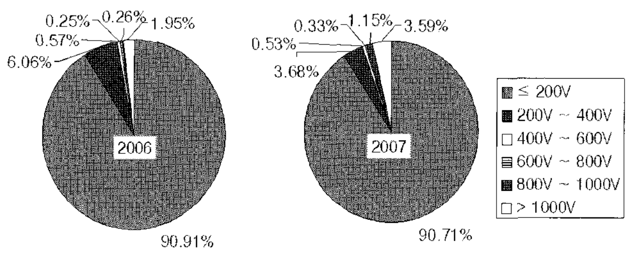

Fig. 7. Distributions of lightning-induced voltage peak values in 2006 and 2007.

more frequently in winter. This result is caused by the lightning stroke current distribution difference between summer and winter. The distribution of lightning stroke current over 90 kA was 48 % in winter compared to 9 % in summer, as shown in Fig. 9[9]. According to [10], it has been reported that the occurrences of lightning currents with positive polarity are more numerous in winter compared to in other seasons and that the magnitudes of the positive polarity lightning strokes are also high.

In Fig. 10, the distributions that give the average number of events per thunderstorm day(T_d) exceeding voltage threshold in Korea are presented and compared with data for other countries[7]. The measured data are fitted with a straight line in Fig. 10, showing the number of events on a logarithmic scale versus the voltage threshold on a logarithmic scale. It was found that the number of events in Korea was less than in other countries. This result could have been estimated, as many telecommunication lines in Korea are installed underground and average line length is shorter than those in other countries. In addition, the slope of the fitting line for Korea is slightly different from that of other countries. This result may partly imply the function of the IVMS, which records all values over 1 kV as 1 kV in order to save system memory; however, the slope may become more reliable as the data are accumulated every year.

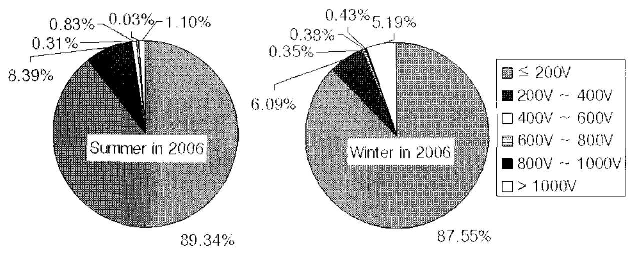

Fig. 8. Lightning-induced voltage distributions in summer and winter.

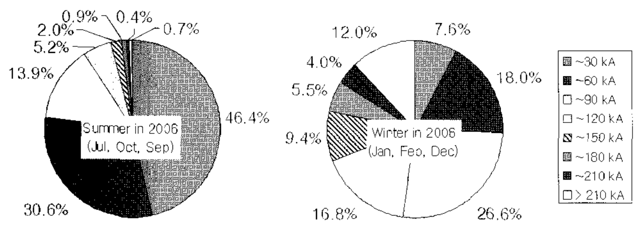

Fig. 9. Lightning stroke current distributions in summer and winter.

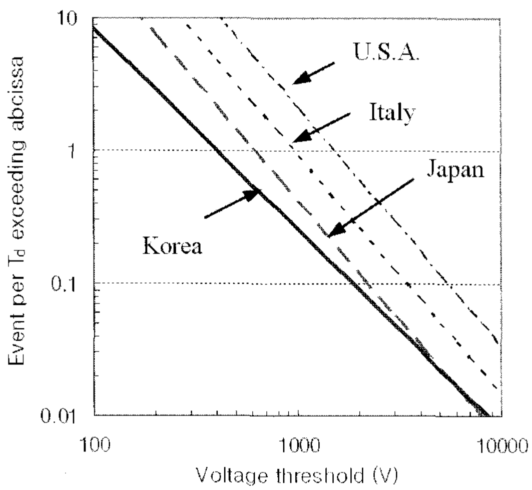

Fig. 10. Comparison of lightning-induced voltage events on subscriber telecommunication lines between countries.

V. Conclusion

The lightning-induced voltages on telecommunication lines were measured at central office ends using two types of measurement systems, namely the WMS and IVMS, from 2006 to 2007. The cumulative probability distributions of parameters such as peak value, rise time, decay time to half value, and steepness were analyzed using the formulation of the log-normal distribution. It was found that about 90 % of the lightning-induced voltages are less than 200 V, and 1.95 % are greater than 1 kV. Although the lightning occurrence numbers are much higher in summer than in winter, the peak values of the lightning-induced voltages are higher in winter. In areas where the number of thunderstorm days is high, thousands to tens of thousands of lightning surges occur in a year. This means that periodic protection processes and maintenance for the telecommunication lines are needed in these areas. In addition, our results can be utilized to define the protection process against lightning-induced voltages, to select surge protectors, and to maintain subscriber telecommunication lines in Korea.

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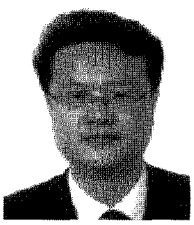
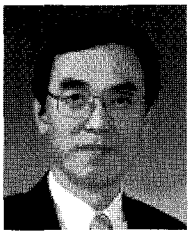
Ho-Seok Oh



received the B.S. and M.S. degrees in electronic engineering, and Ph.D. degree in radio science and engineering from Chungnam National University, Daejeon, Korea, in 1991, 1993, and 2008. Since 1993, he has been with KT, Korea, where he is a Principal Researcher in the Infra Research Laboratory. His present research interests are in EMC of telecommunication networks, electrical safety, and FTTH.

Dong-Chul Park



received the B.S. degree in electronics from Seoul National University, Seoul, Korea in 1974, the M.S. degree from Korea Advanced Institute of Science and Technology, Seoul, Korea, in 1976, and the Ph.D. degree from the University of California, Santa Barbara, in 1984. Since 1976, he has been with Chungnam National University, Daejeon, Korea, where he is a Professor in the Department of Radio Science and Engineering. From 1977 to 1978, he was a Visiting Scholar at Ruhr University, Bochum, Germany, where he worked on integrated optics. His present research interests are in microwave and millimeter-wave passive devices, EMC/EMI topics, and antennas.