INTERNATIONAL CONFERENCE ON LIGHTNING PROTECTION
33rd International Conference on Lightning Protection
25 - 30 September 2016
Estoril, Portugal

A Surge Protective Device with Dual Protection Levels for On-Hook and Off-Hook Operating Voltages in Telephone Networks

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***Abstract*— Telecommunications facilities with the advance of highly information-oriented society require a higher transmission rate, LSI and VLSI circuits based on semiconductor technologies are widely used in communication devices. Modern microelectronic circuits may susceptible to damage by lightning surges. Therefore, the protection of electronic circuits from lightning surges is highly interested. Application of surge protective devices(SPDs) are to protect the communication facilities from lightning surges. The operating characteristics of the telephone network are divided into the on-hook state and the off-hook state. A subscriber protector is normally installed telecommunication lines, but it limit the incoming lightning surges to the protection level of the on-hook state. Thus the protection of telephone from overvoltages in the off-hook state is not achieved. In this paper, in order to solve the point at issue, the hybrid surge protective circuit of protecting the telephone from overvoltages in off-hook and on-hook states was designed. The operating characteristics of the proposed surge protective circuit were experimentally investigated and analyzed.**

Keywords- Surge Proective Device, Lightning Surge, Telephone Network, Hybrid Surge Protective Circuit

I. INTRODUCTION

Information and communication equipment require fast transmission rates according to developments of information-oriented societies and electronic circuits used in communication devices have been highly integrated and miniaturized by the development of semiconductor technologies. There are increases in damages of modern VLSI circuits due to the degradations and malfunctions caused by lightning surges. In particular, numerous studies on the protection of electronic systems from lightning surges have been largely conducted with an increase in lightning together with abnormal climate changes[1-3]. Overvoltages can be caused by lightning or switching operations and the highly-qualified surge protective devices have been increasingly needed.

Surge protective devices (SPDs) connected to telephone networks protect systems and devices of ICT (information communication technology) from induced lightning surges.

Voltage limiting type ZnO varistors, voltage switching type gas discharge tubes, current limiting elements, and poly switches are used as SPD components, and SPD circuits are designed based on the maximum continuous operating voltage for surge protection. In particular, there are two states such as on- and off-hook states in telephone networks and the maximum continuous operating voltages are different in each state. However, the conventional SPDs applied to telephone networks are designed based on the maximum continuous operating voltage at the on-hook state only, and the SPDs may be vulnerable to surges in the off-hook state.

The Korea standards for the surge protective devices for telecommunication and signaling networks are coincident with IEC61643-21 and IEC61643-22[4,5]. These standards do not state the detailed voltage protection level related to the states of telephone networks.

A blind spot of the conventional SPDs in the off-hook state of handset connected to normal telephone networks was found. The objective of this study is to propose an effective surge protection method with respect to the standby and busy conditions in telephone networks such as on- and off-hook states. Thus, a new surge protective circuit for both on- and off-hook states is proposed. The withstand voltage for surges are investigated with respect to the operating characteristics in telephone networks as on-hook and off-hook states, and the maximum continuous operating voltages for each state are also verified. In addition, the characteristics of the residual voltage and signal attenuation in the SPD are investigated and analyzed through practical experiments.

II. Theoretical Considerations

A. Operating characteristics in Telephone networks

Telephone networks have been used throughout the world. Fig. 1 represents the operating characteristics with respect to the on-hook and off-hook states of telephones.

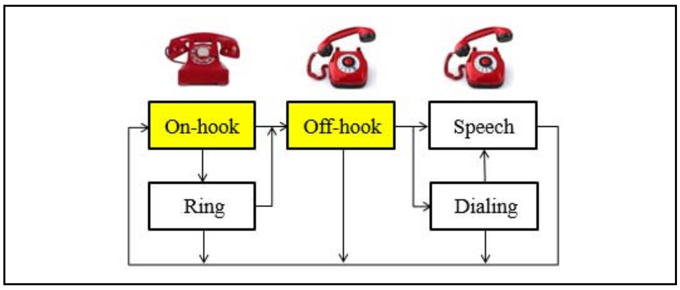

Fig. 1 Operating states of telephone networks

The circuit states in telephone networks can be divided into on-hook and off-hook states according to the operating states of a handset. As a handset receives ringing signals in an on-hook state, the bell rings, and an off-hook state is divided into dialing and speech modes. In general, an internal circuit of a telephone is configured as illustrated in Fig. 2.

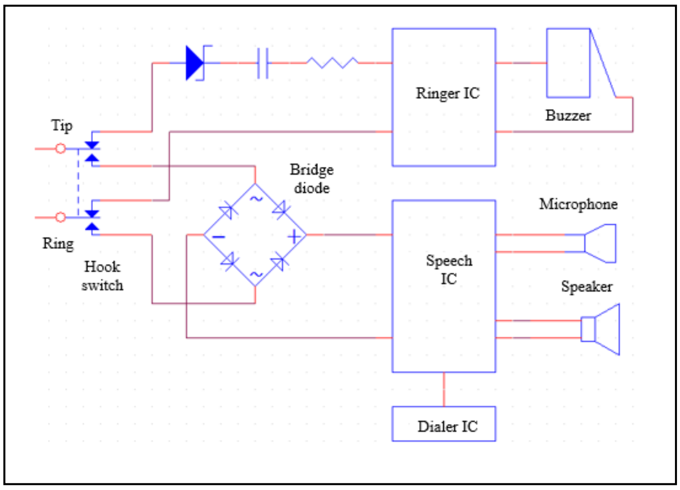

Fig. 2 Internal circuit of a normal telephone

A normal telephone circuit is divided into on-hook and off-hook states according to the operating conditions of a hook switch, and in the on-hook state the Ringer IC sends ring signals to a buzzer. A bridge diode is used to operate the phone regardless of its polarity because the Tip and Ring terminals are not identified in an off-hook state. In dialing and speech modes, the speech IC and Ringer IC are selected, respectively.

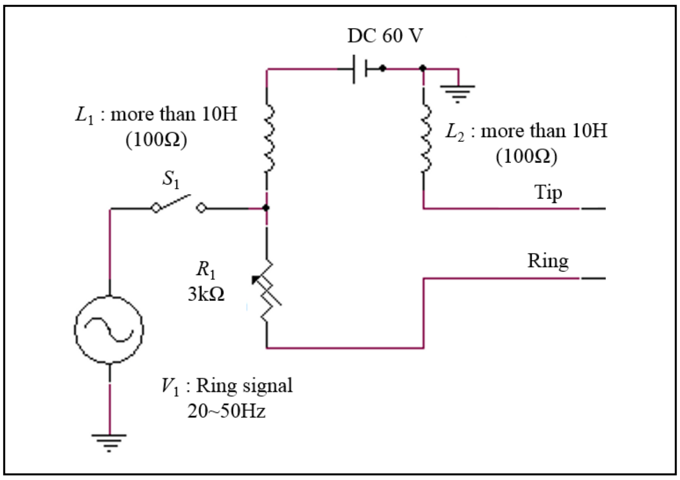

Fig. 3 Equivalent circuit of telephone networks

Fig.3 shows a typical equivalent circuit of telephone networks in which the switch S_1 is closed in an on-hook state and the ring voltage is supplied to the Tip and Ring terminals. Also, a value of DC 60 V is supplied through L_1, L_2(more than 10H/100 Ω), and 3kΩ variable resistor (R_1). In the equivalent circuit, L_1 and L_2 represent enough inductance for preventing the attenuation of voice signals to the direction of supplying the voltage of DC 60 V and the resistor R_1 represents the maximum distance of 7 km between a telephone station and the telephone. The *I/V* characteristics in the off-hook state is collected from ETSI TBR21 [6] and the maximum current and voltage are up to 60 mA and DC 40V, respectively, as shown in Fig. 4.

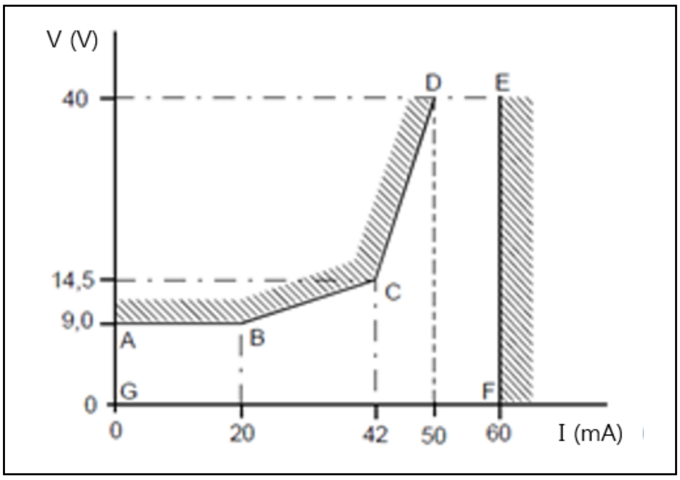

Fig. 4 *I/V* characteristics of the off-hook state

As the value of resistor R_1 in Fig. 3 is 3 kΩ, the between telephone station and telephone. Thus the current and voltage can be varied by the length of telephone lines. The electrical characteristics of ring signal generated in the on-hook state is determined by international and Korean standards, ETSI TBR21 and TTAS.KO-05.0028/R1, respectively, as described in Table 1[6,7].

Table 1. the electrical characteristics of ring signals

Standard	ETSI TBR21 (Europe)	TTAS.KO-05.0028/R1 (Korea)
Maximum ring signal voltage	90 Vrms	130 Vrms
Ringing signal frequency	25 ~ 50 Hz	15.3 ~ 68 Hz

B. *Problems of conventional SPDs for telephone networks*

The specifications of the SPDs for normal telephone networks were described in Table 2.

Table 2. Specifications of the SPDs for telephone networks

Item	Specifications
Varistor1,2,3	AC 130 Vrms
Gas Discharge Tube (GDT)	DC Sparkover voltages 230 V
Voltage protection level	Less than 600 Vp @ 10 kV/5kA Combination wave
Operating frequency (Hz)	300 – 3,400

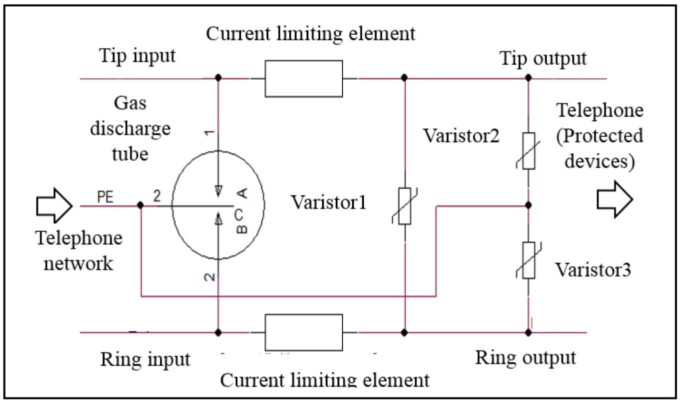

Fig. 5 Generic SPD circuit for normal telephone networks

A SPD circuit for normal telephone networks is consisted as a hybrid type as shown in Fig. 5. A gas discharge tube(GDT) is connected upstream and current limit devices are connected downstream. The design of conventional SPDs is performed based on the on-hook state in telephone networks. The bidirectional voltage limiting diodes or varistors are connected in order to limit the surge voltages to the withstand voltage level or less. Thus the SPDs protect the telephone through limiting the induced lightning surge at a standby or ringing state.

However, the lightning surge can be induced during an off-hook state, such as dialing or speech states, and the voltage protection level is not considered for the maximum continuous operating voltage of DC 40 V. Thus the conventional SPDs cannot limit the lightning surge to the protection voltage level or less at an off-hook state of normal telephones. i.e., there exists a blind spot of damaging telecommunication facilities at the off-hook state. In the internal circuit of normal telephones, it is verified that the rated and maximum allowable voltages in the electrical immunity of a speech IC which is connected at an off-hook state are DC 4 V and DC 12 V, respectively.

Fig.6 shows an application circuit of speech IC in telephones. The speech IC is operated at DC 4 V, and its electrical immunity voltage is about DC 12 V and it is vulnerable to surges.

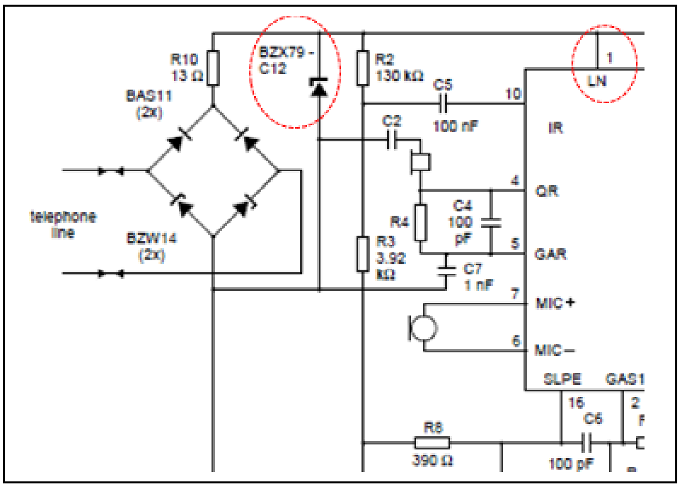

Fig. 6 Example of an application circuit using the speech IC

III. Design of a Surge Protective Device Working in On- and Off-Hook States of Telephone Networks

As shown in Fig. 5, it is verified that the conventional SPDs are designed based on the ring voltage generated at an on-hook state and the withstand voltage level in the off-hook state is not considered. Also, as represented in Fig. 6, the telephone circuit will be damaged during an off-hook state because the speech IC in an off-hook state is very vulnerable. A dual state operating type surge protective circuit that limits lightning surges to the different voltage protection levels by the operations in on-hook and off-hook states was designed to solve the problems originated from the conventional SPDs. That is, the surge protective circuit that can be operated in both on-hook and off-hook states of a telephone was proposed as shown in Fig. 7.

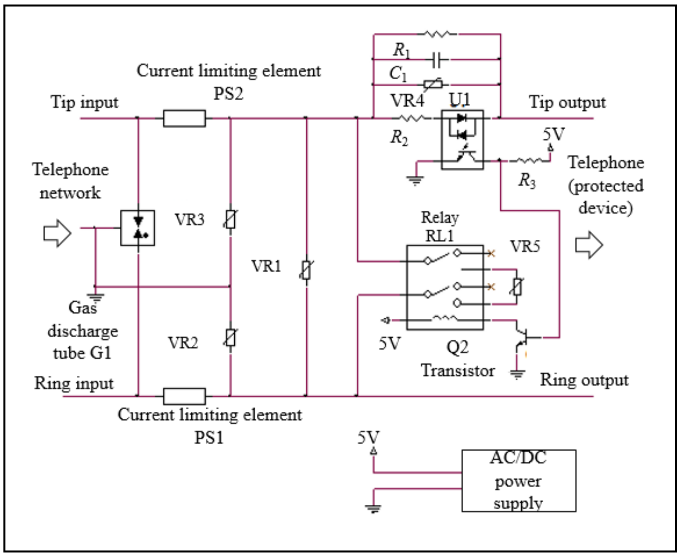

Fig. 7 Surge protective circuit operating in both on-hook and off-hook states

Fig. 7 shows the circuit diagram of the proposed surge protective circuit with the gas discharge tube (G1), the current limiting components (PS1 and PS2) , the voltage limiting components (VR1 and VR2 and VR3). The operating sequence of the circuit is basically the same with the conventional surge protective device circuit for normal telephone networks shown in Fig. 5.

The core point of the proposed surge protective circuits is the application of the circuit that selects the off-hook state by detecting DC loop current through a bidirectional photo coupler(U1) and the circuit with R_1, R_2, C_1, and VR4 protecting the bidirectional photo coupler from overcurrent and overvoltage.

The reason that uses the bidirectional photo coupler(U1) is to prepare a possible change in the signal polarity between the Tip and Ring terminals.

As an off-hook signal is detected, the relay(RL1) is operated by the transistor(Q2) and then varistor (VR5) is connected between the Tip and Ring terminals. The varistor (VR5) having the limiting characteristic of DC 40 V was employed based on the *I/V* characteristics of the off-hook state presented in Fig. 4.

That is, the varistor (VR5) is only connected at an off-hook state and is not connected at an on-hook state. Thus, the proposed surge protective circuit does not affect the communication performance in relation to the state of telephone networks.

IV. RESULTS AND DISCUSSION

A series of performance evaluation tests were carried out to verify the residual voltage and the attenuation characteristic of signal with the application of the proposed surge protective circuit. The equipment used in the experiments are presented in Table 3. Table 4 lists the conditions of surge tests [8,9].

Table 3. Equipment used in this experiment

Equipment	Specification
Surge generator	15 kV / 7.5KA
Oscilloscope	500 MHz, 2.0 GS/s
Probe	Bandwidth : 500 MHz

Table 4. Conditions of the surge test

Related standards	Open circuit voltage	Short circuit current
IEC61643-21 Category C2	2 – 10 kV 12/50㎲	1 – 5 kA 8/20㎲

A surge protective performance test was implemented for both on-hook and off-hook states in the proposed surge protective device connected to normal telephone networks. Also, the conventional surge protective devices for telephone networks was evaluated to compare their performance with the results of the proposed surge protective circuit.

For verifying the operational characteristics of the circuit based on measurements of the waveform of the current and voltage applied to each surge protective component, the combination waveform surge (open circuit voltage : 1.2/50㎲, short circuit current : 8/20 ㎲) was injected to the test sample. .

As the surge was applied to the test specimen at a condition of a combination waveform surge generator charged with 2 kV, the waveforms of the currents and voltages of both the upstream gas discharge tube (G1) and the downstream varistor (VR5) were displayed in Fig. 8.

The voltage of the voltage limiting component (VR5) , at an off-hook state was measured with a value of 126 Vp and the measured value of current (VR5) was 21.1 A. In addition, the measured values of the voltage and current of the gas discharge tube (G1) were 580 Vp and 1.0 kA, respectively.

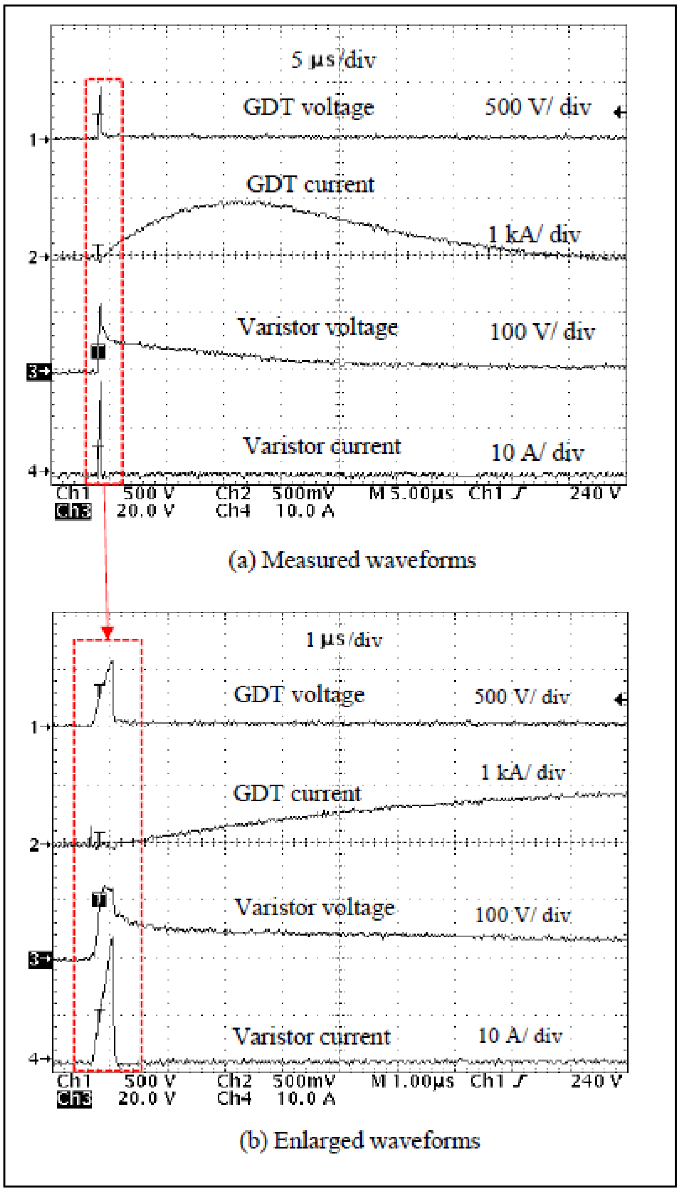

Fig. 8 Typical waveforms of the currents and residual voltages of the SPD

By applying the combination wave impulses to the proposed surge protective circuit and the conventional surge protective circuit under the conditions of surge tests described in Table 4., the measure results of the residual voltages as a function of the amplitude of surge currents are illustrated in Fig. 9. .

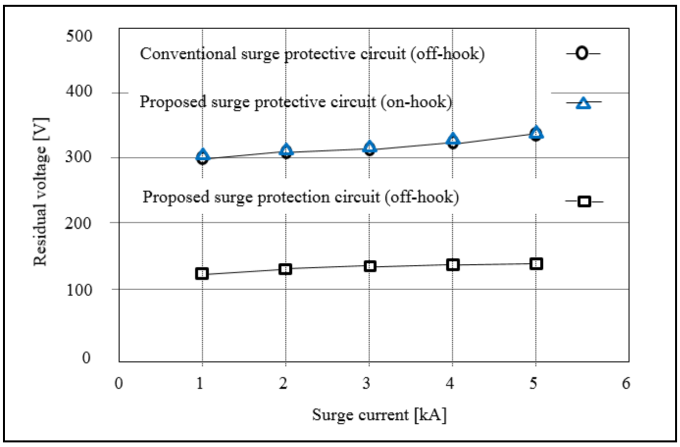

Fig. 9 Residual voltages as a function of the amplitude of surge currents

The residual voltages of the proposed surge protective circuit in an on-hook state of telephone were nearly identical to the results of the conventional surge protective circuit. However the residual voltages of the proposed SPD in an off-hook state were decreased by about 40% compared to the data of the conventional SPD. The telephone used in the surge immunity test was a normal telephone, Gs-xxxx. Fig. 10 shows the surge immunity test circuit. The combination waveform surge of 10 kV/5 kA was applied by 10 times for both the positive and negative polarities. The test results are presented in Table 5.

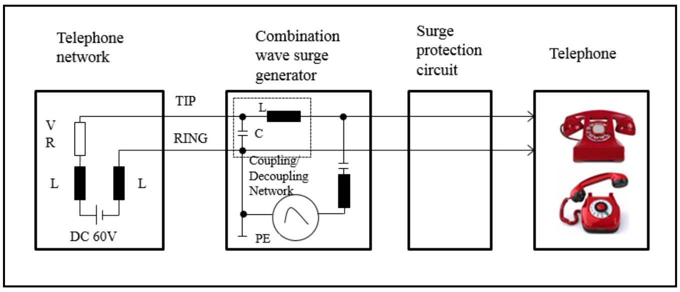

Fig. 10 Circuit for the surge immunity test

Table 5. Results of the surge immunity test

States of the telephone circuit	**Conventional surge protective circuit**	**Proposed surge protective circuit**
On-hook	Pass	Pass
Off-hook	Fail	Pass

It was found that the telephone with the conventional surge protective device for normal telephone networks at an off-hook state was damaged in the surge immunity test.

For verifying the effects of the surge protective devices on the quality of communication signal, the insertion losses were examined by applying the circuit presented in Fig. 11. The specifications of the instruments used in this test was noted in Table 6.

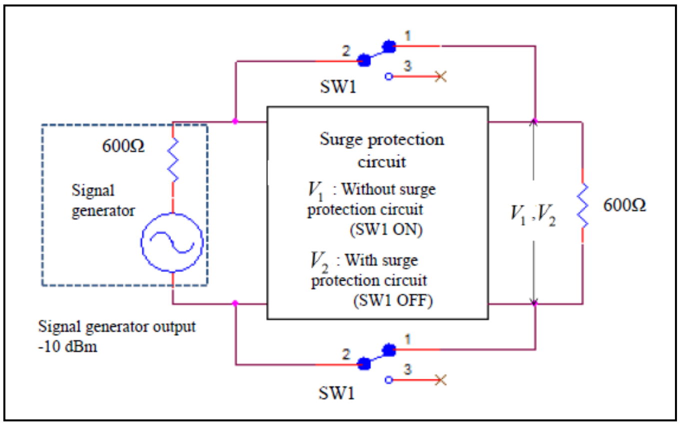

Fig. 11 Measurement circuit of the insertion loss

Table 6. Specifications of the instruments used in the insertion loss test

Instruments	**Specifications**
Signal generator	0 – 1MHz , 600 Ω
Psophometer	-100 dBm ~ +40 dBm , 600 Ω

The attenuation of the communication signal is given by Eq. (1) because the insertion loss is caused by the surge protective device [4].

$$\text{Insertion loss} = 20\log_{10}\frac{V_1}{V_2}\ [\text{dB}] \qquad (1)$$

The measured values of the insertion loss of the conventional and proposed surge protective circuits in the audible frequency range were tabulated in Table 7.

Table 7. Measured results of the insertion loss

Frequency		**300 Hz**	**1 kHz**	**4 kHz**
Conventional surge protective device	On-hook	0.4 dB 234 mV	0.4dB 234 mV	0.4 dB 234 mV
	Off-hook	0.4 dB 234 mV	0.4dB 234 mV	0.4 dB 234 mV
Proposed surge protective device	On-hook	0.4 dB 234 mV	0.4dB 234 mV	0.4 dB 234 mV
	Off-hook	0.7 dB 226 mV	0.7 dB 226 mV	0.7 dB 226 mV

In the evaluation of the insertion loss, a signal generator with an output impedance of 600Ω was used, then the output of the signal generator was -10 dBm (245 mV) at a condition without the surge protective circuit (SW1 ON). The insertion losses of both conventional and proposed surge protective devices for normal telephone networks for both on-hook and off-hook states was 0.4 dB (234 mV).

The measured values of insertion loss of the proposed surge protective circuit were 0.4 dB (234 mV) and 0.7 dB (226 mV) in on-hook and off-hook states, respectively. It was known that the proposed surge protective device has no effect on the quality of communication signal in telephone networks.

V. CONCLUSION

In this study, it was verified that the conventional surge protective devices used in telephone networks protect the surge at an on-hook state only and there exists a blind spot of damaging communication devices at an off-hook state. For solving the critical issue, a surge protective device with the dual limiting voltage levels determined by the maximum continuous operating voltage in both on-hook and off-hook states was proposed. It was known that the proposed surge protective device showed the excellent performance having the selective surge protection effects and the small insertion losses in practical tests. In the case of the surge protective device connected to telephone networks, it is necessary to improve the international standard of surge protective devices with protection effects in both on-hook and off-hook states.

REFERENCES

[1] Bok-hee Lee and Seung-chil Lee : "Protection of information and communication facilities against lightning" Inha University Press, 2004

[2] Bok-hee Lee, D. M. Lee, D. C. Cheong, S. B. Lee and S. C. Lee, " Protection Effects According to the Conditions of Installations of SPDs for Information-Oriented Equipments" , J. KIIEE, Vol.21, No.1, pp.35~41, 2007.

[3] Bok-Hee Lee and Hee-Kyung Shin, " Protection of Information and Communication Facilities against Lightning", Department of publication of Inha University, pp.112~115, 2004.

[4] IEC 61643-21 Edition 1.2 (2012-07), Surge protective devices connected to telecommunications and signalling networks - performance requirements and testing methods.

[5] IEC 61643-22 (2007), surge protective devices connected to telecommunications and signalling networks selection and application principles.

[6] ETSI (European Telecommunications Standards Institute) TBR 21 (January 1988), Terminal Equipment (TE); Attachment requirements for pan-European approval for connection to the analogue Public Switched Telephone Networks (PSTNs) of TE (excluding TE supporting the voice telephony service) in which network addressing. if provided, is by means of Dual Tone Multi Frequency signalling.

[7] TTAS.KO-05.0028/R1 : Test Method for Telecommunication Terminal Equipment.

[8] ITU-T K.44 : Resistibility tests for telecommunication equipment exposed to overvoltages and over current.

[9] ITU-T K.21 : Resistibility of telecommunication equipment installed in customer premises to overvoltages and overcurrents.