Measurement Results for Lightning Surge Current on AC Mains Line Connected to Access Network Equipment

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Abstract

Malfunctions of power units frequently occur due to lightning surge currents induced on ac mains lines of access network equipment installed at outdoor locations. The cause of such malfunctions is thought to be a circuit breaker in the power unit being tripped unnecessarily by the lightning surge current. To clarify the mechanisms of the malfunctions, we measured the lightning surge current on ac mains lines of access network equipment. The measured waveforms of the lightning surge current were much longer than those of combination waves defined by K.44 of ITU-T, and the occurrence probability of surge currents on ac mains lines was 20 times higher than that on telecommunication lines. This paper presents the measurement results and statistical properties of surge currents and shows the need for lightning surge immunity tests of ac mains lines of access network equipment.

1. Introduction

Access network equipment has been installed at outdoor locations to provide broadband and high-speed telecommunication services. It is connected to the trunk network by optical fibers. This equipment is usually powered directly from the by ac mains and is designed to save power according to environmental requirements. It is controlled by operation systems at remote sites. The power unit has a circuit breaker to prevent network problems caused by overcurrents when faults on the ac mains lines cause short-circuits. However, the equipment is usually exposed to the outdoor environment and lightning-induced surge currents can enter it via the ac mains lines and telecommunication lines. There have been several cases in which the overcurrent breaker and internal circuits of telecommunication equipment installed at the outdoor location have malfunctioned due to lightning surges [1]-[4]. It is estimated that the malfunctions are caused by lightning surges because the setting of the overcurrent breaker is low compared with a lightning surge current. The operating current of the circuit breaker is 3 to 5 A per power unit, while a lightning surge current, which is not always high, may be 10 to 1000 A.

To mitigate the lightning surge problem, we must first measure lightning surge currents on ac mains lines. We also need to establish a lightning surge immunity test. The measured data can be used to design not only resistibility levels but also the immunity level of the equipment. This paper presents lightning measurement data and statistical properties of lightning surge currents on ac mains lines and proposes the need for lightning surge immunity tests of ac mains lines of access network equipment.

2. Lightning surge current measurement

2.1 Surge currents measurement locations and points in an access network equipment

The access network equipment that we tested and the measurement system are shown in **Fig. 1**. The access equipment is located outdoors and is directly fed by an ac power mains line. The measurement system is also connected to the ac power mains line through an isolation transformer. The access equipment has power units and telecommunication units.

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Measurements were carried out at ten locations in Tochigi Prefecture (Kuroiso and Utsunomiya) and in Saitama Prefecture (the outskirts of Tokorozawa). These towns are recognized as areas having a lot of lightning. The period for measurement was from July 5 to October 4, 2002. The measurements were carried out over about three months.

The configuration of a power unit is schematically shown in **Fig. 2**. Electromagnetic compatibility (EMC) mitigation devices are attached to the power unit, for example, a filter for protecting against radio waves and switching noise and devices for protecting against lightning, as shown in Fig. 2. An overcurrent breaker (rated current: 4 A) is also attached to protect against short-circuits and overload and for safety reasons. To clarify the mechanisms of unnecessary breaker tripping, we measured lightning currents on the ac mains lines and the grounding line. The measurement points, which are shown in Fig. 2, were as follows:

- Ig: Grounding line current
- Ic: Common mode current
- Id1: Power line current
- Id2: Power line current between ac power mains and package lines

Fig. 1. Access network equipment.

2.2 Measurement system

The measurement system (**Fig. 3**) was composed of a waveform recorder, an isolation transformer, an ac power mains, a battery, fans, and a metal enclosure. The recorder was a HIOKI 8835 oscilloscope with four channels for wave shape measurement. The sampling interval was set to 1 µs. The waveform recorder shared the ac power mains for the access equipment. The isolation transformer isolated both the measurement system and the access equipment, and its impedance in the lightning surge frequency band was high enough to not influence the lightning surge current flowing into the access equipment.

To measure lightning surge currents, we used four Rogowski coils (**Fig. 4**). Figure 4(a) shows the Rogowski coil and Fig. 4(b) shows its equivalent circuit. The Rogowski coil does not have current saturation properties, so it is useful for measuring high currents such as lightning surges. Moreover, it exhibits time derivative properties, so an integral circuit was attached to the coil as shown in Fig. 4(b). As shown in **Fig. 5**, the Rogowski coil covers a sufficiently wide frequency range for lightning surge current measurement, and its frequency band is from about 0.1 to 100 kHz.

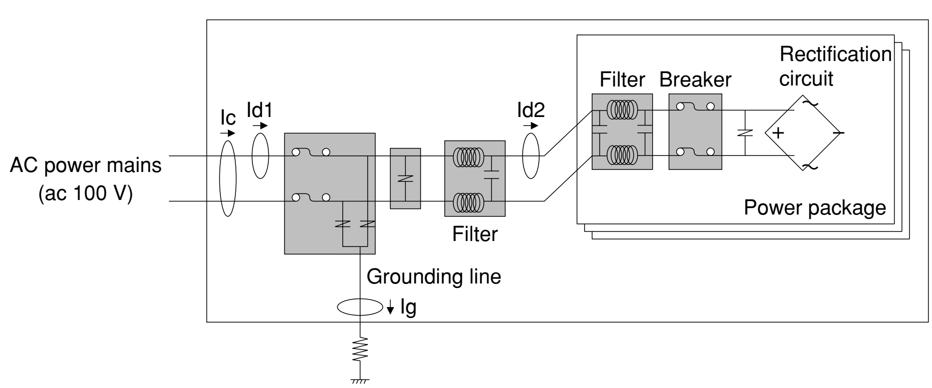

Fig. 2. Schematic composition of power unit and measurement points.

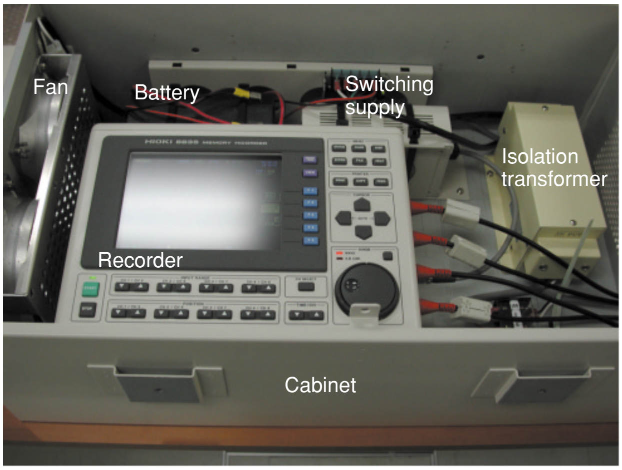

Fig. 3. Measurement system.

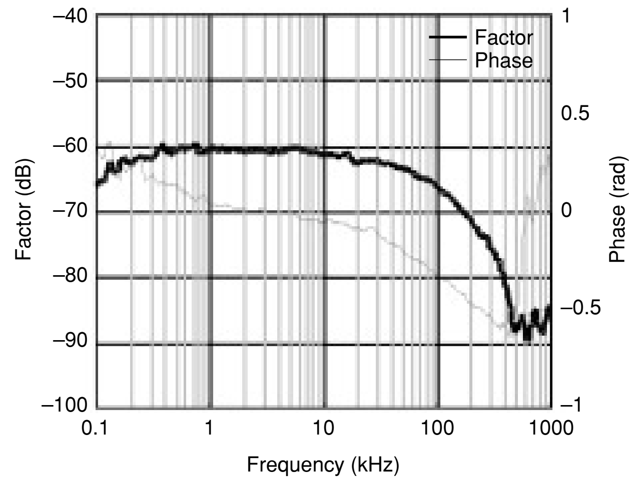

Fig. 5. Frequency characteristics of Rogowski coil.

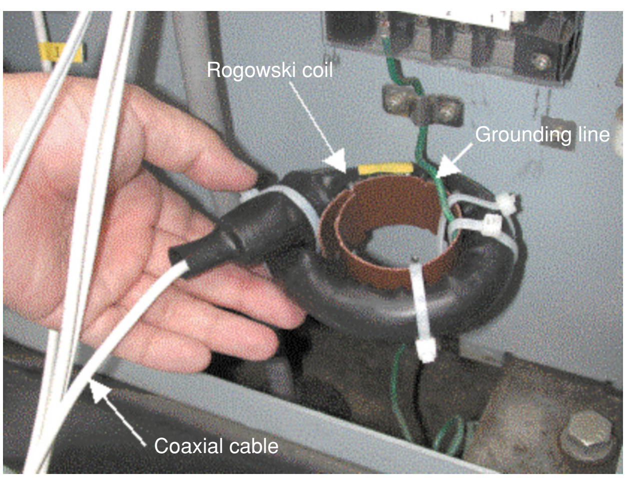

Fig. 4(a). Appearance of Rogowski coil.

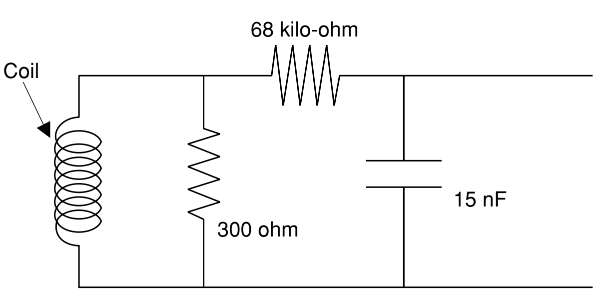

Fig. 4(b). Equivalent circuit of Rogowski coil.

3. Measurement results

3.1 Measured waveforms

We obtained 1264 waveform records and there were 164 lightning strikes during the measurement period. About 1100 of the 1264 records were related to lightning surges or the operation of power switches according to their wave shapes and timing. The number of lightning strikes was obtained from the JLDN (Japan Lightning Detection Network) database. Typical examples of current waveforms are shown in **Figs. 6** and **7**. Many damped-oscillation waveforms with a peak value of about 20–50 A were obtained, as shown in Fig. 6. Some triangular waveforms whose peak value was greater than 1000 A were also measured (Fig. 7).

In Fig. 6, currents Id1 and Id2 were obviously measured and they exhibited a normal mode current*1 rather than a common mode current*1. The peak cur-

*1 Signal-mode definitions: Electrical signals carried on cables can be described as normal mode or common mode. A normal-mode signal is any type (other than common mode) that appears between a pair of wires, or on a single wire referenced to (or returned via) the earth, chassis, or shield. Normal-mode signals are read between two wires in a balanced or unbalanced transmission path. (For a balanced 2-wire path, one wire is driven positive while the other is driven negative an equal amount, both with respect to a static or no-signal condition in which both lines assume the same voltage level relative to circuit common.) A common-mode signal appears equally (with respect to local circuit common) on both lines of a 2-wire cable not connected to earth, shield, or local common. Usually but not always, it is an unwanted signal that should be rejected by the receiving circuit. Common-mode voltage is expressed mathematically as the average of the two signal voltages with respect to local ground or common.
(http://www.maxim-ic.com/appnotes.cfm/appnote_number/2045)

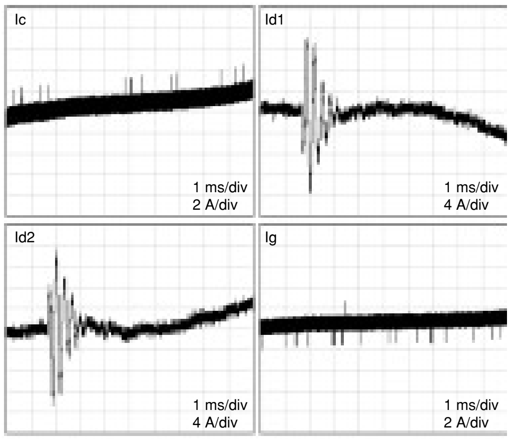

Fig. 6. Typical examples of damped oscillation waveforms.

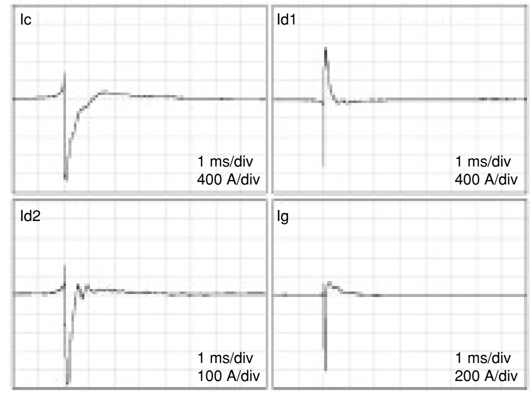

Fig. 7. Typical examples of triangular waveforms.

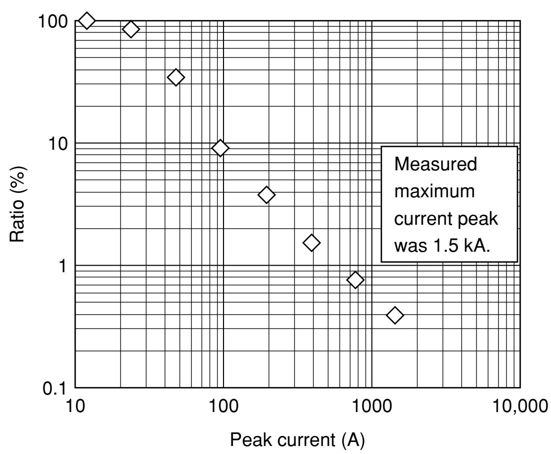

Fig. 8. Accumulation ratio of current peak levels Id2.

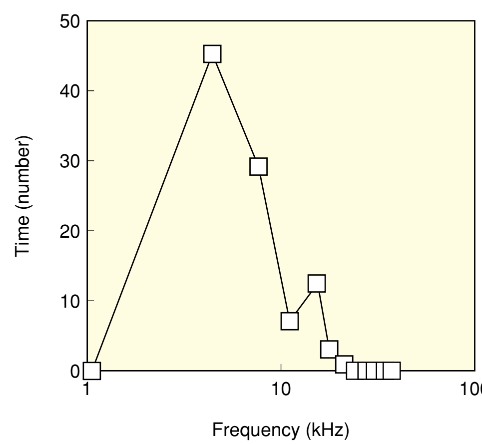

Fig. 9. Damped oscillation frequency.

rent was about 20 A peak-to-peak. The currents flowed between ac mains lines. The Id2 current may have flowed into the overcurrent breaker. Figure 7 shows an example of a triangular waveform that can be recognized as a lightning surge current. The lightning surge currents flowed through the ac mains and ground lines, respectively. The peak level of the Id2 current was about 500 A peak-to-peak.

According to the measurement results, there were several types of current flows as shown in Figs. 6 and 7, for example, from line to ground, line to line, and combinations of these. There were also many waveforms longer than 0.3 ms, which is much longer than the 8/20 μs current wave shape (front time[*2] is 8 μs and time to half value[*2] 20 μs), and there was clear evidence of normal mode currents (Id1 and Id2), which can cause malfunctions in the power unit's overcurrent breaker.

3.2 Statistical properties of current Id2

The waveform parameters for current Id2 (accumulation ratio of the peak current, damped frequency, wave front time, and wave time to half value) are shown in **Figs. 8**, **9**, **10**, and **11**. The accumulation rate of the peak value of the lightning surge current is shown in Fig. 8. The measured maximum current peak was 1.5 kA and the average value was 30 A. We found that the accumulation ratio above 100 A was about 10%, while that above 1 kA was about 1%. Therefore, small peak surge currents frequently entered the power unit and the breaker. The current

*2 "Front time" and "time to half value" are parameters that characterize a triangular waveform. When the current waveform is triangular, the front time is 80% of the time between zero and the peak. The time to half value is the time taken for the current to fall from the peak value to 50% of the peak value.

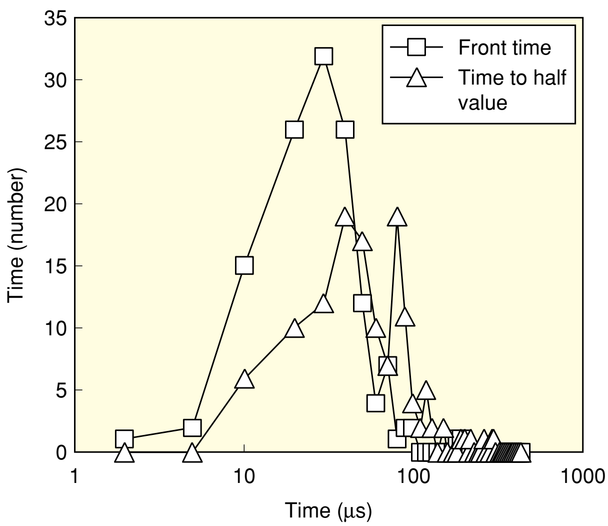

Fig. 10. Front times and times to half value.

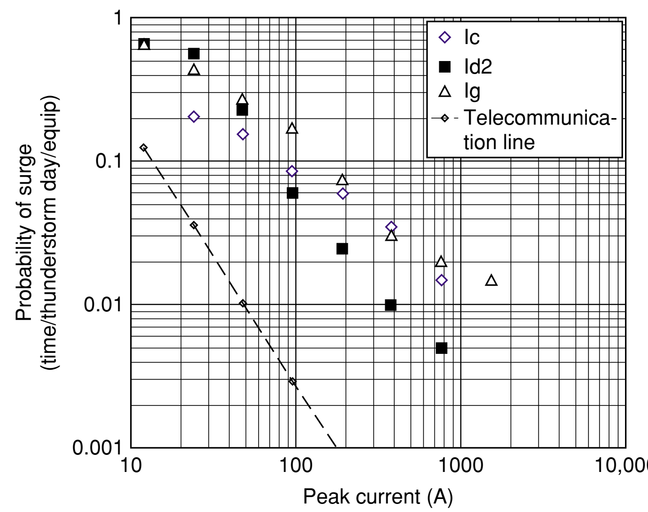

Fig. 11. Accumulated probability of surge current.

level was much lower than the resistible current levels. This finding indicates the need for surge immunity tests as well as resistibility tests.

The main frequency of damped oscillation waves, such as those in Fig. 6, was evaluated. The results are shown in Fig. 9, where the horizontal axis is frequency and the vertical axis is the number of damped waveforms. The average damped oscillation frequency was about 6.4 kHz and the maximum frequency obtained was about 60 kHz. The percentage of damped current was up to about 74% in all measured data. Therefore, it may be necessary to include damped currents as well as triangular waveforms in the surge immunity test.

Figure 10 shows the front times and times to half value of measured waveforms. When a waveform is a damped oscillation waveform, the front time is the value of the rise time from zero to the peak, and wave time to half-value is the time from the peak to half the peak height. In Fig. 10, the average wave front time is 32 µs and the average wave time to half value is 64 µs. There are several wave shapes with a time to half value of more than 0.3 ms, and the 50% cumulative occurrence rate value of the time to half value is about 100 µs. In other words, over 50% of the measured lightning surge half-time values were five times longer than the combination wave current shape (half time value is 20 µs) defined in ITU-T K.44 for the ac mains test. Because the power in our experiment was higher, we found that longer waveforms tripped the circuit breaker rather than shorter ones. During the measurement, the breaker-tripped malfunctions occurred at the same time that a longer surge current was measured. Therefore, longer waveforms, such as over 100 µs, may be necessary to test access network equipment that is installed in outdoor locations.

Figure 11 shows the accumulated probability rate of the peak current for Ic, Id2, and Ig. In Fig. 11, measured data related to telecommunication lines is also shown. The current levels for Ig are higher than other currents.

The probability ratio of currents shown in Fig. 11 can be approximated as

$$p = kI^{-x}, \tag{1}$$

where I is the current level, p is the probability of a lightning surge per thunderstorm day, and k and x are coefficients of the approximation equation. For the current flow from a telecommunication line to ground, k is 11 and x is 1.8; for the current flow from a power line to ground (Ic), we estimated k=15 and x=1.1. Comparing the current flow from a telecommunication line to ground with that from a power line to ground, the probability of a 100-A lightning surge current was about 20 times greater in the latter case. The average of thunderstorm days per year in Japan is from 20 to 40 days, so the probability of a 100-A lightning surge current is 0.1 in Fig. 11. Therefore, a 100-A lightning surge current flows into the access network equipment two to four times per year and a lightning surge current of up to 300 A flows into it once per year.

The current flowing in common mode was from two to five times larger than that in normal mode in the range of 100 A or more, but we think this difference is not so big. Therefore, in a lightning surge test it is necessary to consider the surge current flowing into the power unit from one power line conductor to the other power line conductor.

4. Conclusion

We measured surge currents on ac power mains lines connected to access network equipment. We set up ten measurement systems on the access equipment and obtained 1264 data sets. Among these records, 1100 records were estimated to be related to lightning surges. We used Rogowski coils for surge measurement. Their frequency range is about 0.1 to 100 kHz, which is sufficiently wide to measure lightning surge current.

The measured average peak current level was about 30 A, and the maximum peak current was about 1.5 kA. The average wave front time was 32 µs, and the average wave time to half value was about 64 µs. However, there were some long waveforms with wave times to half value of more than 300 µs, and over 50% of them were up to 100 µs. Such longer waveforms are not covered by ITU-T K.44 for ac mains tests. Therefore, longer-waveform tests might be necessary for outdoor telecommunication equipment.

The probability of current flow from the power line to ground was 20 times higher than that from the telecommunication line to ground. A lightning surge current of up to 300 A will flow into the power unit of outdoor equipment every year on average. The current flowing in common mode was not so different from that flowing in normal mode: only two to five times larger. Therefore, in a lightning surge test it is necessary to consider the surge current flowing into the power unit from one power line conductor to the other power line conductor. Since the equipment is designed to save power, the rated current of the power unit is tending to decrease, becoming for example 4 A. Therefore, such lightning surge currents might affect the power unit and malfunctions might occur.

For lightning surge tests at the ac mains port of outdoor access network equipment, these measurement results will be useful in defining the test port, waveforms, and the peak levels.

References

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[2] ITU-T K.44 "Resistibility tests for telecommunication equipment exposed to overvoltages and overcurrents–Basic Recommendation," Feb. 2000.

[3] ITU-T K.45, "Resistibility of access network equipment to overvoltages and overcurrents," Feb. 2000.

[4] ANSI/IEEE C62.41-1980, "IEEE Guide for Surge Voltages in Low-Voltage AC Power."

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