Measurement results of Lightning surge current on ac mains line connected to access network equipment

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Abstract
Malfunctions on power units frequently occur due to lightning surge currents induced on ac mains lines of access network equipment installed at outdoor locations. It is believed that the reasons for malfunctions are that a circuit breaker of the power unit is unnecessarily tripped by the lightning surge current. To clarify the mechanisms of the malfunctions, we have measured the lightning surge current on ac mains lines of access network equipment. The measured waveforms of the lightning surge current are much longer than that of combination waves defined by K.44 of ITU-T, and the occurrence probability of surge currents on ac mains lines is 80 times higher than that on telecommunication lines. This paper shows the measurement results and statistical properties of surge currents, and the necessity of the lightning surge immunity test of ac mains lines of access network equipment.
Key words: access network system, lightning surge current measurement, ac mains, malfunction.

1. Introduction

Access network equipment has been installed at outdoor locations to provide broadband and high-speed telecommunication services. Optical fibers connect the equipment to the trunk network. The access equipment is usually directly fed by ac mains and is designed to save power according to environmental requirements. The equipment is controlled by remote sites. The power unit has a circuit breaker to prevent network problems caused by lightning-induced current surges. The operational current of the overcurrent circuit breaker is 3 to 5 A for each power unit.

The access equipment is usually exposed at outdoor locations and it malfunctions due to lightning surge currents through ac mains lines and telecommunication lines. In fact, there are several cases in which the overcurrent breaker and internal circuit of telecommunication equipment installed in the outdoor location have malfunctioned due to lightning surges [1-3]. It is estimated that the malfunctions are caused by lightning surges because of the small capacity of the overcurrent breaker with respect to the lightning surge current which is not always at high levels, for example, 10 to 100 A.

To mitigate the lightning surge problem, it is necessary to measure lightning surge currents on the ac mains line. It is also necessary 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 shows lightning measurement data and statistical properties of lightning surge currents on ac mains lines and proposes the necessity of the lightning surge immunity test of ac mains lines of access network equipment.

2. Lightning surge current measurement

2.1 Access network equipment

The access network equipment being tested and 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 isolation transformer. The access equipment has power units and telecommunication units. Measurements have been carried out at ten locations in Tochigi Prefecture (Kuroiso and Utsunomiya) and 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.

Fig.1 Access Network equipment

A schematic configuration of the power unit is shown in Fig. 2. Electromagnetic compatibility (EMC) mitigation devices are attached to the power unit, for example, a filter protecting against radio waves and switching noise, and protection devices for lightning as shown in Fig. 2. The overcurrent breaker(Rated current: 3 [Arm]) 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 current on ac mains lines and grounding line. The measurement points are shown in Fig. 2 and are as follows:

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

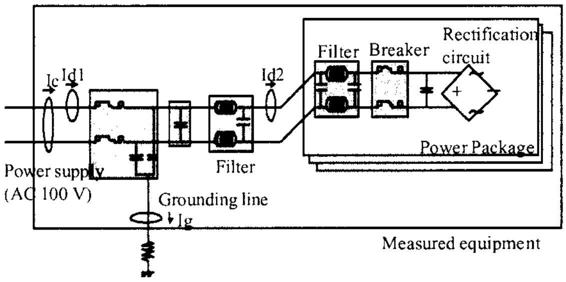

Fig. 2 Schematic composition of power unit and measurement points

2.2 Measurement system

The measurement system shown in Fig. 3 is composed of a waveform recorder, an isolation transformer, a power supply, a battery, fans, and metal enclosure. The isolation transformer is used to isolate the measurement system and the access equipment. The recorder is a HIOKI 8835 oscilloscope and has 8 channels for wave shape measurement. Four channels of the recorder are used to measure lightning surge current. The power supply of the waveform recorder is shared with the access equipment. A transformer that has high impedance between lines to access equipment in the band of a lightning surge waveform is used, so that it does not influence the measurement. For this experiment, the sampling interval was set to 1 μs.

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

3. Measurement results

3.1 Measured waveforms

We obtained 1264 waveform records and had 164 lightning strikes during the measurement. About 1100 of the 1264 records are 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 JDLN (Japan Lightning Detection Network) database. Typical examples of current waveforms are shown in Figs. 6 and 7. Many damped-oscillation waveforms whose peak value is from about 20 to 50A have been obtained as shown in Fig. 6. Triangular waveforms whose peak value is greater than 100 A have been also measured as shown in Fig. 7.

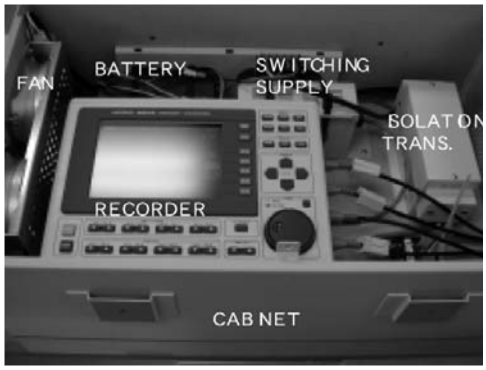

Fig. 3 Measurement system

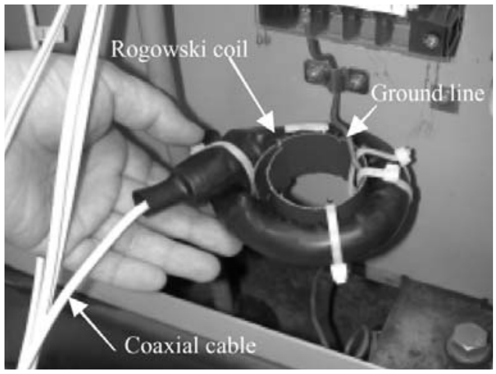

Fig. 4(a) Rogowski coil Outlook

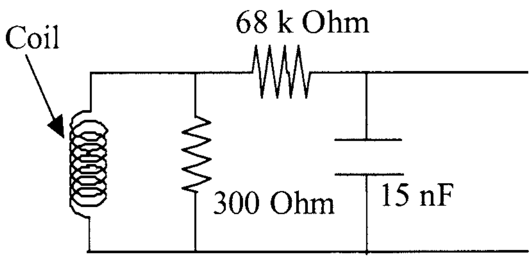

Fig. 4(b) Rogowski coil Equivalent circuit

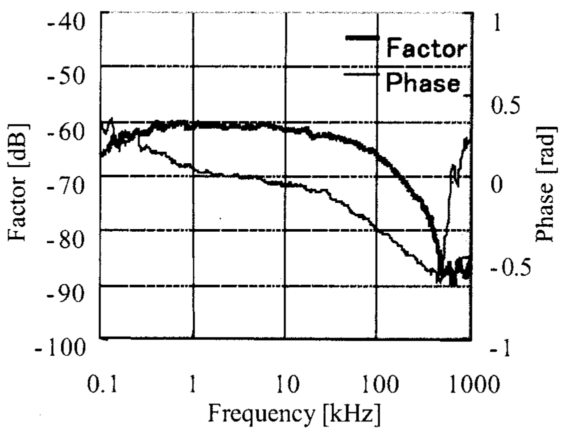

Fig5 Frequency characteristics of Rogowski coil

In Fig. 6, currents Id1 and Id2 are obviously measured and they exhibit a normal mode current, not common mode current. The peak current is about 20 A peak-to-peak. The currents flow between ac mains lines. The Id2 current may flow 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 flow through the ac mains line and the ground lines, respectively. The peak level of the current is more than 400 Ap-p.

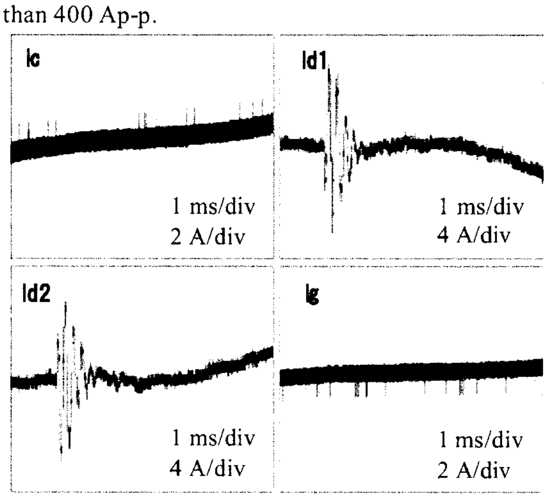

Fig.6 A typical example of damped oscillation waveforms

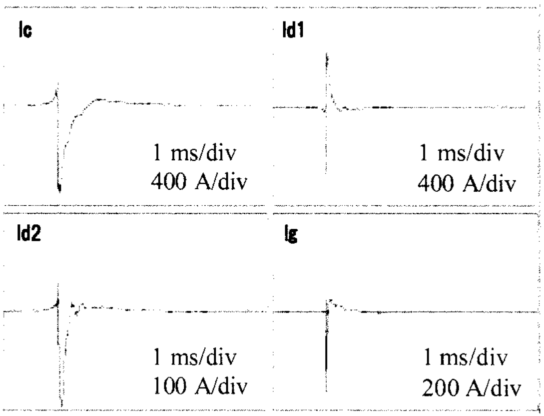

Fig.7 A typical example of triangular waveforms

According to the measurement results, there are several types of current flows as shown in Figs. 6 and 7, for example, line to grounding, line to line, and their combinations. There are also many waveforms greater than 0.3 ms in length, which is much longer than the 8/20 μs current wave shape, and the normal mode currents (Id1 and Id2) obviously exist. The normal mode current can cause malfunctions in the overcurrent breaker of the power unit.

3.2 Statistical properties of current Id2

The waveform parameter regarding 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 maximum current peak is 1.5 kA and the average value was 30 A. It is found that he accumulation ratio of more than 100 A is about 10%, and that more than 1 kA is about 1%. Therefore, small peak surge currents frequently enter into the power unit and the breaker. The current level is much lower than that of resistibility current levels. This finding indicates the necessity of the surge immunity test as well as the resistibility test.

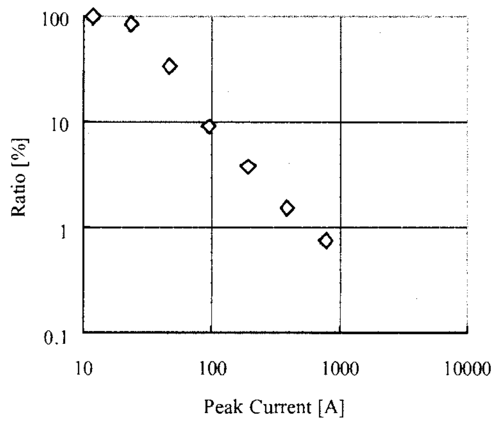

Fig.8 Accumulation ratio of current peak levels Id2

According to waveforms related to Fig. 6, a damped oscillation frequency is shown in Fig. 9. In Fig. 9, the horizontal line is frequency, and the vertical axis is the number of damped waveforms. The average damped oscillation frequency is about 6.4 kHz and the maximum frequency obtained is about 60 kHz. The percentage of damped current is up to about 74% in the measured data. Therefore, the damped-current test is required as a surge immunity test.

Fig. 10 shows the wave front time and time to half value of measured waveforms. When a waveform is a damped oscillation waveform, the wave front time is the value of the rise time from the bottom to the peak, and wave time to half-value is the time from the peak to half the peak height. In Fig. 10, an average wave front time is 32 μs, an average wave time to half value is 64 μs. There are several wave shapes with time to half value more than 0.3 ms. The wave time to half value is five times the combination wave current shape. It is estimated that this long waveform can cause bad effects on the circuit breaker of the power unit.

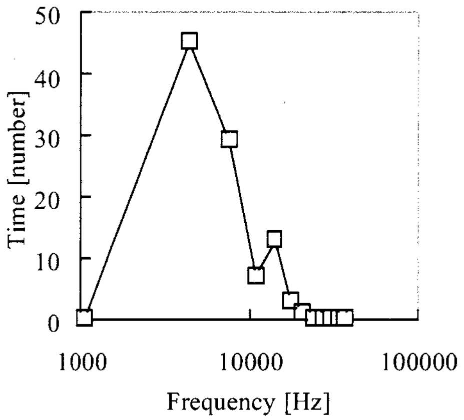

Fig.9 Damped oscillation frequency

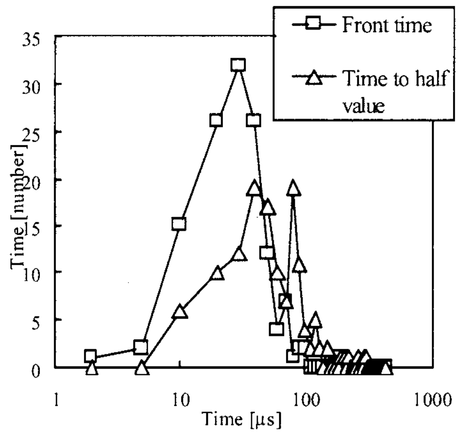

Fig. 10 The number of front time and time to half value

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

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

$$p = kI^{-x} \qquad (1)$$

I in eq. (1) is the current level, p is the probability of a lightning surge per thunderstorm day, k and x are coefficients of the approximation equation. In the case of a telecommunication line, k is 11 and x is 1.8. The coefficients are estimated as k is 15 and x is 1.1 for the power line to ground. Compared with a telecommunication line and power line to ground, it turns out that the probability of the lightning surge current of 100 A is about 80 times more than that of a telecommunication line. Compared with a line to ground and a power line to line, the probability of a lightning surge current of 100 A for power line to ground is 4 times more than that of power line to line.

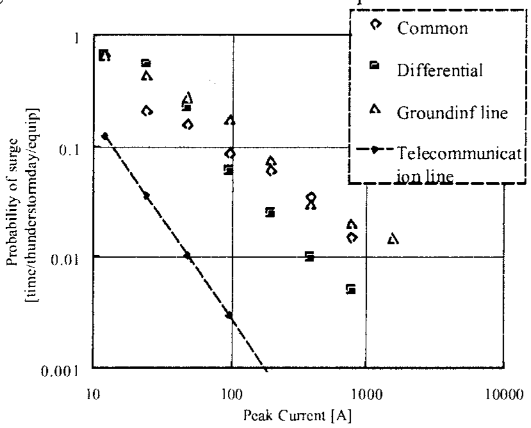

Fig. 11 Accumulated probability of surge current

4. Conclusion

We measured surge currents on ac power mains lines connected to access network equipment. We set 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 also developed Rogowski coils for surge measurement. The frequency range is about 0.1 to 100 kHz and is sufficiently wide to measure lightning surge current.

The measured average peak current level is about 30 A, and the maximum peak current is about 1.5 kA. About 74% of the damped waveforms were recorded, as well as lightning surge currents. The average wave front time is 32 μs, and the average wave time to half value is about 64μs. However, there are long waveforms with more than 300 μs wave time to half values.

The probability ratio of power line to ground is 80 times that of the telecommunication line, and the probability ratio of power line to ground is 4 times of that of power line to line. The power line to line current level is not so high but the current can frequently enter into the power unit. Therefore, it is important to consider power line testing including power line to line. It is also necessary to carry out the surge immunity test of ac mains lines of access network equipment.

References

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