

Distribution Properties of Lightning Surge Current Induced from Earth Electrodes in Household Wiring

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Abstract—In the modern information society, lightning surges represent a serious risk to home electronics and telecommunication equipment. In this study, the distribution properties of a lightning surge current from the earth through indoor wiring were investigated by using model circuits of common home electronics. The distribution properties of the surge current were significantly affected by the conditions of the grounding systems, protection devices, and the circuits of home electronics. To protect the electrical circuits from the lightning surge, it is necessary to adopt a common grounding system and to introduce appropriate protection devices.

Keywords—lightning surge; surge current; protection device; grounding system; household wiring

I. INTRODUCTION

In the modern information society in Japan, the risk posed by lightning surges has increased for home electronics and telecommunication equipment. The current flow paths of a lightning surge along household wiring can vary significantly for power lines, antennas, earth conductors, and so on. A recent survey found that lightning damage to electrical equipment has increased [1, 2]. This damage occurs owing to the configuration of the earthing system used in Japan. In the U.S and Europe, the TN and/or TN-CS earthing systems are used, whereas the TT system is used in Japan. In the TT earthing system, different earth electrodes are used for the PE line and the neutral (N) line, namely, Class D grounding and Class B grounding, and another separate earth electrode is used for the communication line. Therefore, with this configuration, a potential difference can easily form between the various earth electrodes during a lightning strike. In 2003, the equipotential bonding scheme was introduced to the JIS A4201 standard [3]. However, almost all household wiring systems still have the conventional separate grounding system.

With such a grounding system, the introduction of surge protection devices (SPDs) for the electrical equipment is an effective means of protection from a lightning surge current. Given this background, many investigations have been carried out on the distribution properties of a lightning surge current along power lines and communication lines in household wiring using a model circuit for SPDs [4, 5]. However, the lightning surge current flows directly into the SPDs of

electrical equipment with Class D grounding when lightning directly strikes the structure of the building. In addition, when lightning strikes a tower near a house, the lightning surge invades the household wiring from Class D grounding and affects the N line (Class B grounding) because of the difference in their earth potentials. Therefore, in this research, the distribution properties of a lightning surge current induced from the earth conductor of the PE line (Class D grounding) toward the N line (Class B grounding) through the household wiring were investigated. In particular, the effects of differences in connection methods for the grounding line with the TT system and differences in the types of the protection devices and the collective properties of SPDs on electrical equipment were investigated. In addition, a simulation method for the lightning surge distribution in household wiring was examined.

II. EXPERIMENTAL METHOD

A. Circuit Model for Household Electronics

Model circuits for four types of SPDs used in power supply modules were used in the experiments. These electrical circuits are shown in Fig. 1. Model A is a power supply circuit in which the PE line is grounded using the protection device. The other equipment includes the protection device (Model B), a model circuit for telecommunication equipment (FAX Model), and a model circuit for an air-conditioner unit. The voltage values shown in Fig. 1 are the clamping voltage of ZnO varistors (MOV) and the impulse sparkover voltage of gas discharge tubes (GDTs). In the experiments, to investigate the effects of different protection devices on the surge current distribution, the MOV (clamping voltage of 1800 V) in the model circuit of the air-conditioner outer unit was replaced with a GDT (discharge voltage of 2400 V). Furthermore, to investigate the effect of the filter circuit of the power supply module, filter units were added to the model circuit of Model A and the FAX Model (the parts surrounded by the dashed lines in Fig. 1). The coil in the filter circuit is a common-mode choke coil. Table 1 lists the elements used in the experimental circuits.

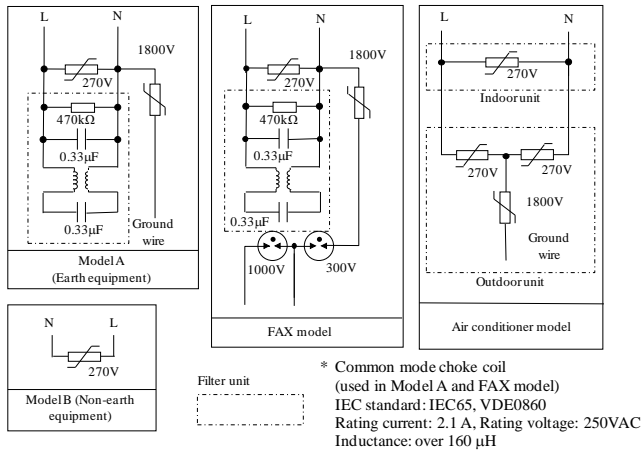


Figure 1. Model circuits of the household electronics.

TABLE I. ELECTRICAL ELEMENTS USED IN THE MODEL CIRCUITS

Electrical elements	Manufacturers	Types
Capacitor	Okaya Electric Industries	LE334
Common mode Choke coil	Murata Manufacturing	PLH10AS1612R1P2B
Resistance	KOA series	MFS1/4C
Varistor (270 V)	Panasonic	ERZV20D271
Varistor (1800 V)	Panasonic	ERZV20D182
Gap arrester (300 V)	Okaya Electric Industries	R28-301-BHL
Gap arrester (1000 V)	Okaya Electric Industries	R28-102-BHL
Gap arrester (2400 V)	Okaya Electric Industries	R28-242-BJL

B. Experimental Method

In the experiments, effects of the following three factors on the lightning surge current distribution were investigated:

- 1) Differences in the grounding system
- 2) Differences in the protection devices
- 3) The presence of a filter circuit

The grounding systems examined in this experiment were the three types of conventional separate grounding systems, the bonding grounding system, and the common grounding system. In the experiment, to examine the effect of filter units, a filter circuit was added to Model A and the FAX model.

A schematic of the conventional grounding system for a house is shown in Fig. 2. The experimental circuits for the three types of the grounding systems are shown in Fig. 3. The protective device connected to the FAX model was a 6th subscriber arrester. The primary side of the power distribution

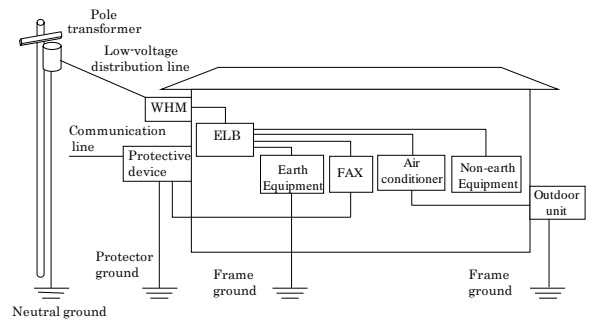
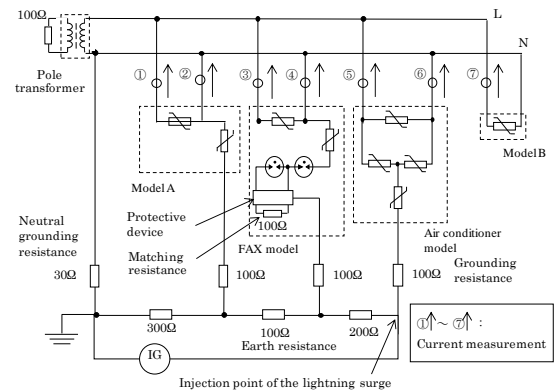
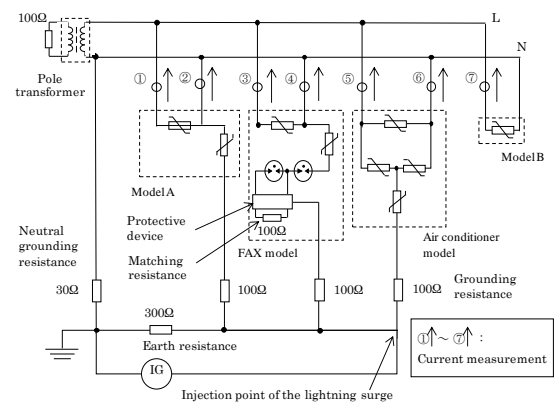


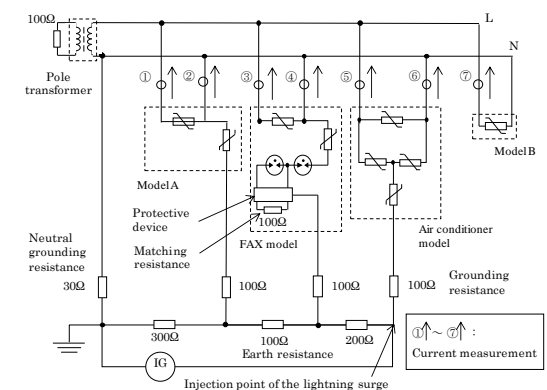
Figure 2. Schematic of the conventional grounding system.



(a) Conventional grounding system



(b) Bonding grounding system



(c) Common grounding system

Figure 3. Experimental circuits of each household wiring.

board was connected to a single phase of the secondary side of the pole transformer. The primary side of the pole transformer was terminated by a resistance of 100 Ω . The communication line of the 6th protective device was also terminated by a resistance of 100 Ω . A vinyl-insulated vinyl-sheathed flat-type (VVF) cable (1.6 mm²) was used for connecting the distribution board to each model circuit, and an indoor PVC (IV) cable (2 mm²) was used for the grounding lines. The VVF and IV cables were 5-m long. The grounding resistance was introduced by using a non-inductive resistor. The potential difference between the earth electrodes during a lightning strike for the conventional grounding system was also introduced by using a non-inductive resistor. The waveform of the impulse voltage used in the experiments was 1.2/50 μ s, and the waveform of the impulse current was 1.1/38 μ s. The peak value of the input impulse current was 80 A. The impulse current was measured by using a current transformer (Pearson Electronics Model 110, 150, 3972), and the impulse voltage was measured by using a high-voltage probe (Tektronix P6015A).

III. EXPERIMENTAL RESULTS

A. Effect of Different Grounding Systems

The experimental results for the distribution properties of the surge current for different grounding systems are shown in Fig. 4. The distribution ratio in this figure was calculated on the basis of the peak current of the neutral grounding line of the pole transformer. The total ratio of the peak current exceeds 100% because the peak time of the surge current at each line was different. In the conventional grounding system, the surge current flowed mainly through the air-conditioner outer unit model, which is the injection point of the impulse current. The surge current flows almost evenly into the N-phase and L-phase lines. Some of the surge current flowed into the N-phase line of the FAX model, which was close to the injection point. This indicates that the surge current flows preferentially to the protection devices operating at higher voltage. Even if the injection point of the surge current was changed to the grounding lines of Model A or the FAX model, the same tendency was seen.

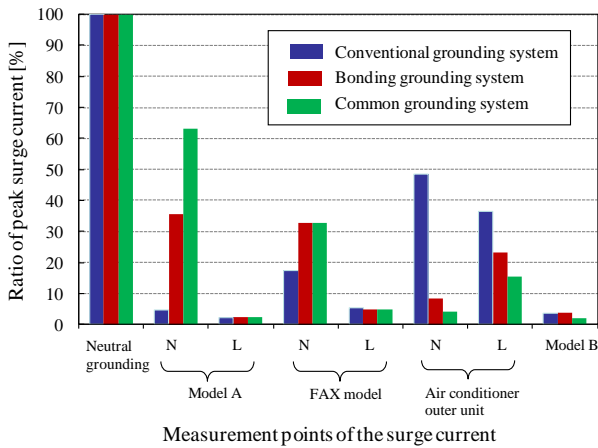


Figure 4. Distribution properties of the surge current in different grounding systems.

In the bonding grounding system, the surge current flowed almost evenly to each model circuit. This may be because the impedance of each line became dominant when connecting the grounding resistance of 100 Ω (resistance of Class D) in each grounding line; as a result, the effect of the properties of the SPDs was neglected. In the common grounding system, the flow ratio of the surge current increased in the order Model A, FAX model, and air-conditioner outer unit model. This order indicates that the surge current flowed preferentially to the model circuit with a lower clamping voltage of MOV connected between the grounding line and N-phase line.

B. Effect of Type of Protection Device

The protection element connected to the grounding line of the air-conditioner outer unit model was changed from an MOV to a GDT. A comparison of the distribution results with these elements is shown in Fig. 5. By changing the protection device from an MOV to a GDT, the surge current flowed mainly toward the air-conditioner outer unit model. In general, lightning surge currents flow selectively toward the protective device with the fastest operating characteristics. A GDT operates as a switching element for lightning surge current because it has a very small capacitance compared with an MOV. Therefore, the rapid response of the GDT in the air-conditioner outer unit model led to the surge current flowing selectively toward the model circuit that had the lowest clamping voltage (270 V) of MOV.

C. Effect of Filter Unit

The experimental circuits with filter units added to the circuits of Model A and the FAX model are shown in Fig. 6. The obtained distribution properties of the surge current along with the results without the filter unit are shown in Fig. 7. In this experiment, an MOV was the protection device used in the air-conditioner outer unit model. The addition of filter units led to an approximately 15% increase in the ratios of the surge current flowing along the L-phase lines of Model A and the FAX model. This could be because the flow of the surge current to the circuits of Model A and the FAX model was promoted by the presence of a new route from the N-phase to

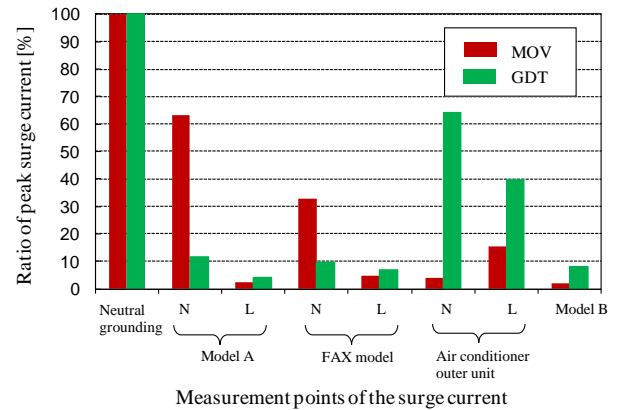


Figure 5. Effect of type of the protection device for distribution properties of surge current.

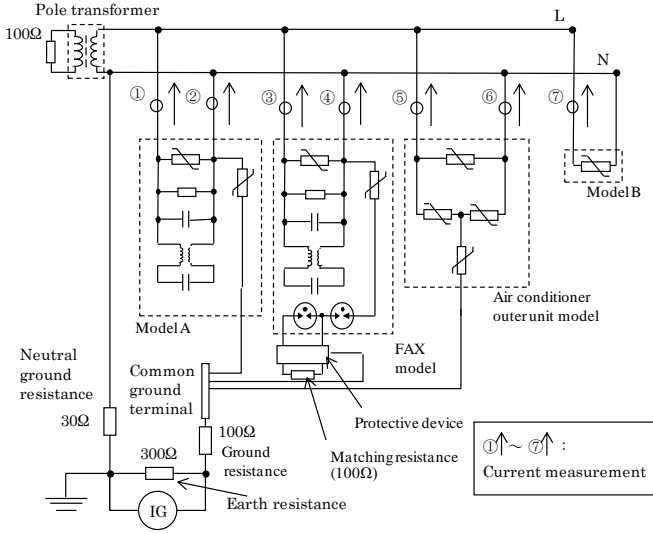


Figure 6. Experimental circuits with filter units.

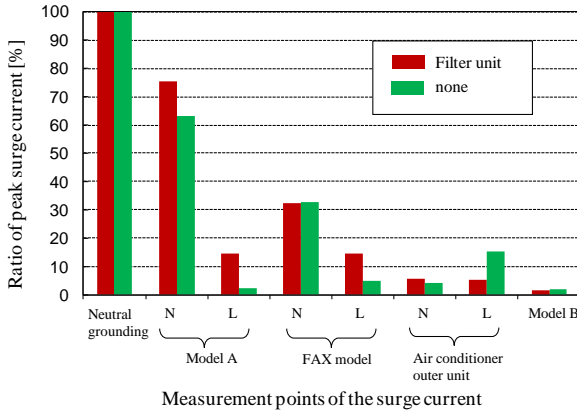
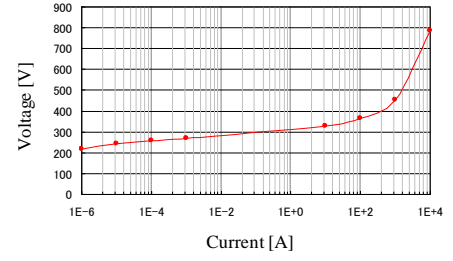


Figure 7. Effect of filter unit for the distribution properties of the surge current.

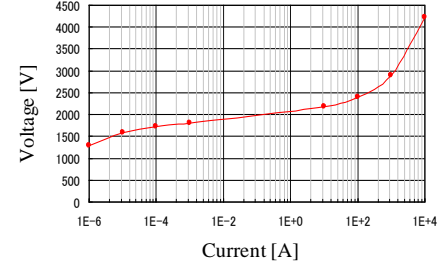
the L-phase line, that is, through the capacitor in the filter unit. Therefore, an increase in the energy consumption of SPDs connected to the grounding line of the model circuits should be considered.

IV. SIMULATION RESULTS

The distribution properties of the lightning surge in this experiment were simulated using an analysis model circuit [6]. The MOV was replaced with a nonlinear resistance whose magnitude was set on the basis of the measured current-voltage characteristics shown in Fig. 8. The GDT was replaced with a parallel circuit comprising a switch and a 1.5-pF capacitor, and the switch functioned as a short circuit when the voltage across the switch reached the impulse sparkover voltage. The pole transformer was modeled as an ideal transformer, and the inductance, capacitance, and resistance values of other elements were set to the catalog values. The VVF wire was replaced with a lumped element inductance of 1 $\mu\text{H}/\text{m}$. The input waveform in the analysis was applied as a current source, which was measured at the N phase line of the pole

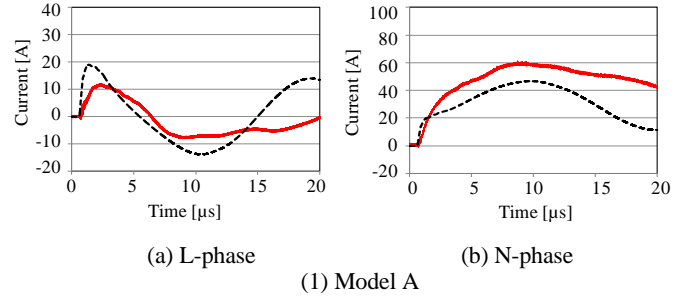


(a) Clamping voltage of 270V

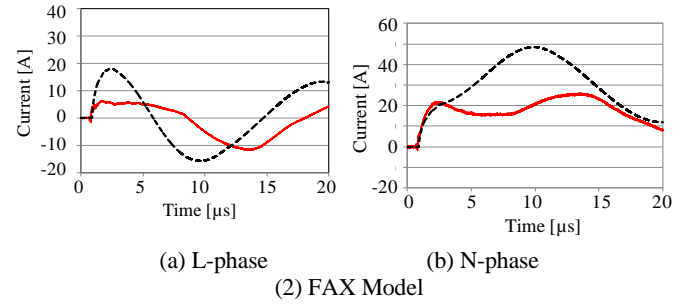


(b) Clamping voltage of 1800V

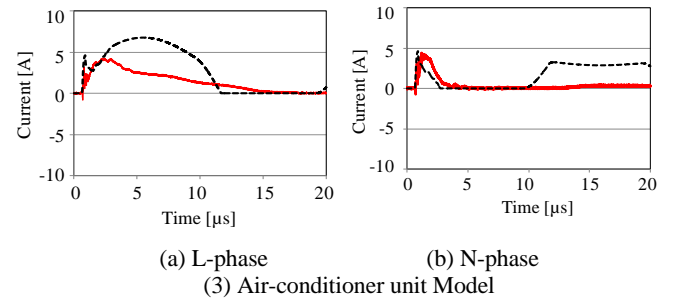
Figure 8. Current-voltage characteristics of MOV.



(1) Model A



(2) FAX Model



(3) Air-conditioner unit Model

Figure 9. Comparison of the calculation and experimental results. (Common grounding system with filter units, Solid line: Experimental results, Dashed line: Simulation)

transformer in the experiment. The calculation results are shown in Fig. 9 for a common grounding system with filter units. The calculation results some different with the experimental results due to replace VVF cable and GDT with the lumped-element inductance and the switch respectively. In the future, the simulation method will be investigated to improve these differences.

V. CONCLUSIONS

A variety of protection devices and other systems are used in the power supply circuit of household electronics for protection from a lightning surge. In addition, a variety of household wiring systems exist that follow the TT grounding system in Japan. In this research, the distribution properties of a lightning surge current induced from the earth conductor were investigated. The effects of different grounding systems, protection devices, and model circuits for the power supply were investigated. To protect electrical circuits from a lightning

surge, it is necessary to adopt the common grounding system and to install appropriate protection devices.

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