A Field Study of Lightning Phenomena on Low-Voltage Distribution Lines Including Residences

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***Abstract*—As society becomes ever more dependent on electronics, interest in the patterns of lightning hazards in low-voltage distribution lines including residences is growing. However, there have been few studies on low-voltage distribution lines and many things remain unknown about the propagation patterns of lightning surges in the field, particularly the intrusion of lightning surges into residences. The Tokyo Electric Power Company has conducted field research of phenomena accompanying lightning flashes to actual distribution systems using lightning-activated cameras as well as lightning surge waveform detectors, obtaining invaluable 101 datasets of lightning flashes between 2002 and 2007. This paper analyzes typical observation examples and estimates the lightning surge propagation routes in low-voltage distribution lines. In some examples, it is inferred that a lightning current flowed in the reverse direction from the residence to the low-voltage distribution line caused by ground potential rise due to the nearby lightning to the ground. These results will be useful for clarifying lightning surge propagation patterns in low-voltage distribution lines.**

***Index Terms*—Direct lightning stroke, distribution line, field observation, lightning protection design.**

I. Introduction

As home electric appliances become more sophisticated, damage to such appliances caused by lightning have been recognized as risks to today's information society. Therefore, experimental studies on lightning surges in residences and research to elucidate lightning damage mechanisms are being conducted, and there is a growing interest in lightning damage patterns in low-voltage distribution lines including residences [1], [2].

The lightning incoming routes into a residence can be classified into several categories: from distribution lines due to direct lightning striking distribution lines, from distribution lines due to induced voltages caused by lightning near distribution lines, from the ground due to ground potential rise (GPR) caused by lightning striking the ground, and from an antenna due to direct hit to the antenna [3]–[5]. However, how lightning surge flows into actual residences remains matter for debate, and a simulation method for lightning overvoltages on low-voltage distribution lines has not yet been established. The authors have been observing lightning flashes on distribution lines using lightning-activated cameras as well as lightning surge waveform detectors in order to examine the lightning phenomena in the actual fields environment [6]. This paper reports the observations made from 2002 to 2007, and these results can serve as a valuable resource to help clarify lightning surge propagation patterns in low-voltage distribution lines including residences.

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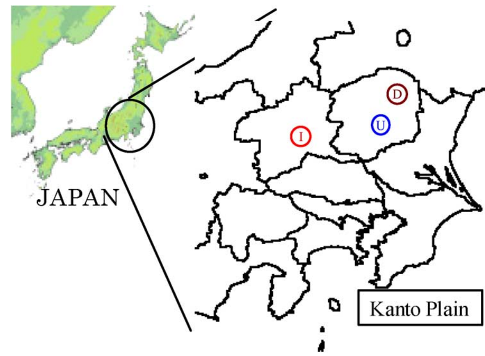

Fig. 1. Lightning observation locations (D zone U zone I zone (2002-)).

II. Outline of Observation System

A. Observation Sites

Tochigi and Gunma prefectures, which are lightning-prone areas in the Kanto region, were selected as observation sites. Observations have been conducted since 1996, with observation areas changed in 2002, using 63 lightning-activated cameras and 125 lightning surge waveform detectors (Fig. 1) [6], [7]. Table I shows the breakdown of observation apparatus locations. In 2002 and later, current sensors have been installed on service wires that supply power to residences aiming to conduct comprehensive observations on all medium-voltage to low-voltage distribution lines.

B. System Configuration

Fig. 2 shows observation apparatuses attached to a reinforced concrete pole. The lightning-activated camera and waveform detector, both equipped with a GPS clock in the time calibration unit, enable lightning stroke patterns to be analyzed and compared with data of the Lightning Positioning and Tracking System (LPATS) [8].

1) Lightning-Activated Cameras: Camera systems monitor the field sites to capture lightning flashes. Their liquid crystal shutters open 3 ms after detecting lightning and remain open

TABLE I
BREAKDOWN OF OBSERVATION APPARATUS LOCATIONS

	Number of apparatuses	
	Camera	Waveform detector
D zone	33	64
U zone	0	2
I zone	30	59
Total	63	125

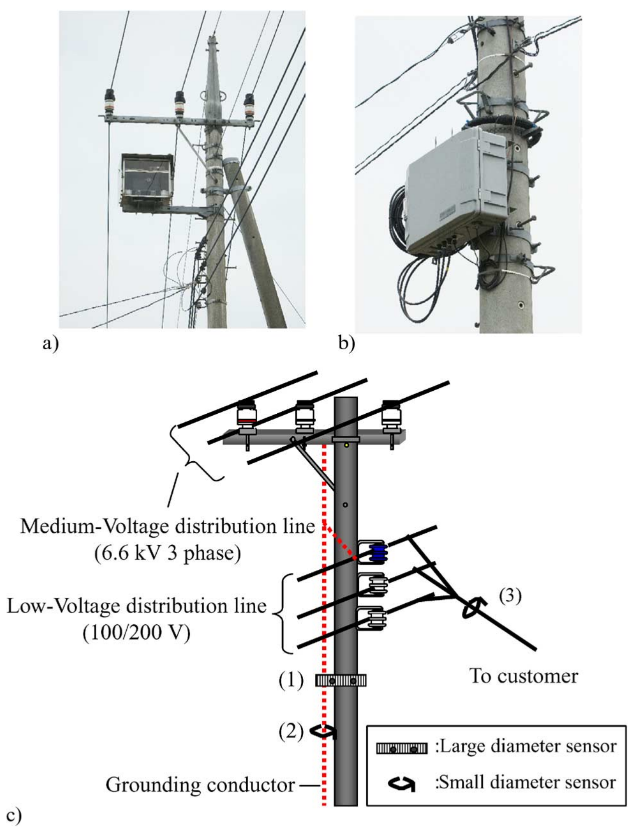

Fig. 2. Observation apparatus. (a) Camera. (b) Waveform equipment. (c) Configuration of surge current detector.

for 250 ms to expose the film. Photographs of the same flash taken from different angles can identify its location, making it possible to classify the lightning as direct or indirect.

2) Lightning Surge Waveform Detectors: Three types of sensors have been used to observe lightning surge waveforms: a current-measuring sensor with a Rogowskii coil, a medium-voltage measuring sensor consisting of a capacitive divider and optical devices, and a low-voltage measuring sensor based on the LED luminescence intensity detection method. The current sensor measures a grounding lead conductor current and a service wire current at each part of the power pole, whereas the voltage sensor measures an insulator voltage of medium-voltage distribution lines and a line-to-line voltage of low-voltage distribution lines. These sensors have two sampling frequencies: 0.1 μs and 0.05 μs. In Fig. 2(c)), the large-diameter sensor measures the total of currents that flow through the grounding lead conductor and the reinforced concrete pole but, if no grounding lead conductor is installed, measures the current that flows through the concrete pole only. Regarding the polarity of a measured lightning current waveform, the current sensor is installed so as to measure the polarity of a current that flows from the upper part to the lower part of the power pole. As shown in Table II, therefore, identifying the polarity of a current flowing through the measurement point indicates whether the current flowed out from the distribution line to the ground or to the residence. The currents passing through the measurement point were assumed to be negative polarity in Table II, and the propagation direction will be reversed if the currents are positive.

TABLE II
RELATIONSHIPS OF MEASURED POLARITIES OF WAVEFORMS AND CURRENT PROPAGATION DIRECTIONS

Measured polarity of waveform	Measurment point	
	Grounding line, concrete pole	Service wire
Negative	Power line → Ground	Power line → Customer
Positive	Ground → Power line	Customer → Power line

TABLE III
OUTLINE OF OBTAINED DATASETS OF LIGHTNING FLASHES

	Types of lightning		Total
	Direct lightning	Indirect lightning	
With LPATS data	18	43	61
Without LPATS data	5	35	40
Total	23	78	101

III. OBSERVATIONS

In this observation, 101 datasets of lightning flashes are obtained between 2002 and 2007. Table III shows the outline of these datasets. The following sections discuss typical examples from 2002 to 2007 based on camera observations and surge waveform data collected at the same time. In this paper, lightning surge propagation is inferred from the polarity of current waveforms obtained in lightning observation and lightning surge propagation patterns depending on lightning stroke points. In the following sections, a "direct lightning" refers to a lightning stroke to the power distribution facilities and an "indirect lightning" refers to any other lightning that does not directly strike the power distribution facilities.

In the distribution lines that this lightning observation is carried out, pole transformers have surge arresters. In residences, communication equipments and electric appliances, such as washing machines and air conditioners, are connected to the ground via surge protective devices.

This paper reports five observed examples of lightning flash to a residence and the ground, and of lightning flash to overhead ground wires. These examples are chosen from the viewpoint of obtaining the datasets that have several current waveforms rather than that match LPATS location data. Because it's important to infer lightning surge propagating route persuasively based on a lot of lightning surge current waveforms.

A. Indirect Lightning Example I

Figs. 3 and 4 show a photograph of a lightning flash and the conditions of the observation point, respectively. The lightning stroke time recorded by the GPS clocks of the lightning-activated camera and the lightning surge waveform detector is 14:13:31 on July 9, 2002. This lightning flash caused no relay