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Surges induced in building electrical systems during a lightning strike

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ABSTRACT

This paper presents an investigation into lightning surges induced in buildings with the FDTD method. When down conductors (DCs) in a building discharge a lightning current, induced surges are observed in adjacent distribution circuits due to electric and magnetic coupling. The induced voltage in an open circuit and the induced current in a close circuit are, respectively, determined by the current surge and voltage surge on the DC. It is found that connected capacitors can reduce the induced surge voltages, but may not be effective. SPDs are then recommended installing at two far ends of a distribution circuit. They are not required to dissipate substantial lightning surge energy observed in the down conductors. The surge currents in SPDs can be estimated using the closed-form formula.

1. Introduction

Electronic equipment has proliferated in buildings to meet the ever-increasing demand of businesses. Such equipment is susceptible to electrical disturbances generated by lightning. In the past few years the surge environment in buildings has become worse, particularly when insulated down conductors were adopted in lightning protection systems. To protect sensitive equipment against lightning it is necessary to evaluate and characterize the surge environment in buildings.

Lightning surges in buildings can be generated via (a) inductive/capacitive coupling and (b) resistive coupling. The mechanism of resistive coupling has been discussed widely in past decades [1,2]. The surge currents/voltages dispersed on low voltage systems have been analyzed under different scenarios, and were well documented [3–6]. Location categories have been introduced in IEEE standards [7–9]. The lightning surges experienced in buildings have been characterized, and the waveform and amplitude of the surges in different locations have been specified. These surges generally impinge at the service entrance from the circuits outside the buildings. However, little work has been done on the surges arising from inductive/capacitive coupling in buildings during a direct lightning strike.

This paper presents an analysis of induced surge voltages and currents in a building distribution system during a direct lightning. The building is protected by a lightning protection system with insulated down conductors placed in the vicinity of building distribution circuits. In this paper both the lightning protection system and distribution circuits are modeled using the Finite-Difference Time-Domain (FDTD) method. Simulations are then performed to study the induced surges in the distribution circuits. Different circuit parameters, such as spacing and distance, are considered in the study, and their impact on the induced surges is revealed. The impact of loads connected to the circuits is investigated as well. A protective measure for suppressing induced surges in a distribution system is presented finally. This is an extended version of the paper submitted to ICLP2014 [12].

2. Simulation models

Insulated down conductors (IDCs) are adopted in modern buildings. They are installed in electrical duct, and run in parallel with power distribution circuits. When a building is struck by lightning, the lightning current in the down conductors emits electromagnetic fields and propagates downwards to the ground. The lightning electromagnetic pulses will induce surge voltages and currents in the adjacent conductors, such as distribution power cables. These conductors are finite in length, and run vertically above the ground. The traditional transmission line theory is not applicable for surge analysis in such cases. The FDTD method is then applied to study the induced surge voltages and currents in these conductors.

The power distribution circuits in the buildings are made with single-core cables. These cables run vertically from distribution transformers to users' equipment on different floors. Note that a transformer is normally modeled as an entrance capacitance in fast transient analysis. For simplicity of discussion, the entrance

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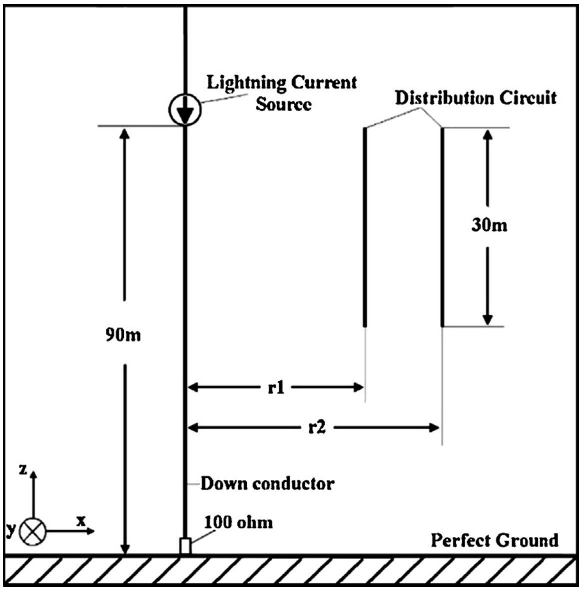

Fig. 1. Configuration of the down conductor and an adjacent distribution circuit.

capacitance is removed in the reference configuration, as shown in Fig. 1.

Fig. 1 shows the configuration of a simplified system under investigation. It consists of a single down conductor and two single-core cables situated over the ground. For worst-case analysis the contribution from the currents in other DCs is not taken into account. The down conductor is represented by a 90 m-tall cylinder with the radius of 5 mm. It is connected to a perfect ground via a 100 ohm lumped resistance, and to a current source at other end. An upward conductor is placed at the upper end to mimic a lightning channel. Two distribution cables are modeled by cylinders as well with the height (l_0) of 30 m and the radius (r_0) of 5 mm. The distances of the down conductor to two conductors are r_1 and r_2, respectively. In the reference case, both r_1 and r_2 are equal to 0.5 m and 0.7 m, respectively. The bottom end of the distribution circuit is 60 m away above the ground. A lightning return stroke current is injected at the top end of the down conductor.

The working volume of the simulation model is 4 m × 4 m × 92.1 m. It is surrounded by six planes of perfectly-matched layers (PML) with absorbing boundary conditions being enforced. There are seven layers of the absorbing surfaces in the model, so that the reflection wave on the planes can be effectively minimized [10]. It is assumed that the upward conductor runs to infinity, and no reflected surge in the upward channel travels back to the down conductor. PML absorbing boundary conditions are then applied at the height of 92.1 m in the simulation model. The working volume is divided into cuboid cells. The side length of cuboid cells in the z-direction is 5 mm near the conductors, and is increased to 500 mm gradually to the boundary. The side lengths in the x and y directions are 0.5 mm near the conductors, and are increased to 500 mm gradually. Time step is determined by the Courant condition,

$$\Delta t \leq \frac{1}{c\sqrt{1/(\Delta x)^2 + 1/(\Delta y)^2 + 1/(\Delta z)^2}} \qquad (1)$$

where c is the speed of light, and $\triangle x$, $\triangle y$, $\triangle z$ are the side lengths of the smallest cell in meter.

3. Induced surges in open circuits

A subsequent return stroke current was applied in the simulation to investigate induced surges in the distribution circuit. The current source was a fast-front pulse with the rise time of 0.3 μs and the amplitude of 10 kA. Fig. 2 shows waveforms of the surge current (I_{IDC}) at different positions of the down conductor. Because of the surge reflection on the ground the surge current at a lower position of the down conductor is generally higher. The oscillation frequency is determined by the travel time of two round trips on the IDC. As the induced surge is greatly affected by the wave front of an injected surge, time-domain results of the surges for the time period of 2 μs are given in the figures.

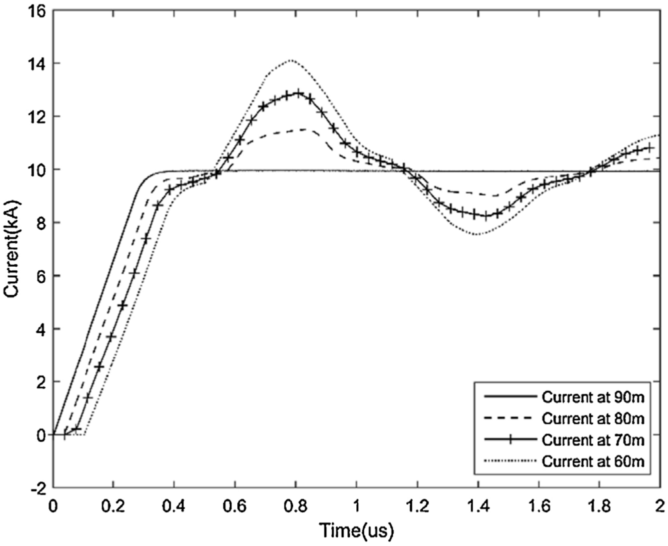

Fig. 2. Surge currents (IIDC) along the down conductor at different heights.

The induced voltages in a distribution circuit without any connected load were simulated as well. For comparison, the 10 kA source current with the rise time of 0.2 μs, 0.3 μs and 1.0 μs was respectively, applied in the simulations. The results are presented in Fig. 3. It is observed that the induced voltage increases when the surge propagates downwards. When a reflected surge travels back, the induced voltage tends to decline and continues to oscillate with the surge voltage on IDC. It is also found that the induced surge voltage does not vary significantly when the rise time of I_{IDC} is changed from 0.2 μs to 0.3 μs. However, the induced surge voltage is reduced significantly in the case of 1.0 μs rise time. This is because the reflected surge travels back to the observation point before the surge current reaches its peak value, as seen in Fig. 3.

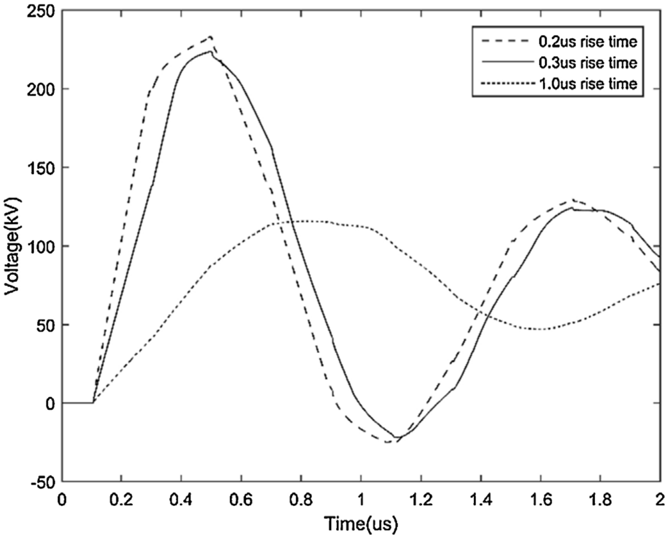

Fig. 3. Induced voltage at the bottom end of the distribution circuit.