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FDTD simulation of back-flashover at the transmission-line tower struck by lightning considering ground-wire corona and operating voltages

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ABSTRACT

In this paper, we simulated transient voltages across insulators and back-flashover at the transmission line tower struck by lightning in the presence of corona on the ground wires. The FDTD method and simplified (engineering) model of corona discharge were used. Three two-circuit 60-m high towers, separated by 400 m, with two overhead ground wires, and six phase conductors (two three-phase circuits) were considered. Back-flashover was assumed to occur at the upper, middle, or lower phase. Operating voltages of phase conductors were modeled by using a voltage source inserted between each phase conductor and ground. It is observed that ground-wire corona serves to reduce voltage peaks and delay the occurrence of flashover. For the upper-phase back-flashover due to a positive 50-kA stroke, the peak voltages across the upper-, middle-, and lower-phase insulators are reduced by 11%, 12%, and 12% by the ground-wire corona, and for a negative 50-kA stroke they are reduced by 8%, 9%, and 9%. Influences of ground-wire corona on transient voltages were also studied for the back-flashover at the middle or lower phase. Presence of operating voltages can lead to either increase or decrease of the peak of transient voltage, with the change being less than 20%. To the best of our knowledge, this is the first FDTD simulation of back-flashover at a transmission-line tower considering both ground-wire corona and operating voltages.

1. Introduction

A simplified (engineering) model of corona discharge on the overhead conductor for the finite-difference time-domain (FDTD) computations [3] has been presented in Refs. [1,2]. In the model, the progression of corona streamers from the conductor is represented as the radial expansion of cylindrical conducting region around the conductor. The validity of this model (including the assumed value of corona conductivity) has been tested in Refs. [1] and [2] against experimental data found in Refs. [4–6].

In Refs. [7–9], the simplified model of corona discharge has been applied to the analysis of transient voltages at the transmission line tower, and transient voltages computed with and without corona were compared. It was found that the transient voltages are reduced by corona discharge on the ground wire, but the reduction of transient-voltage peak is not very significant. Note that, AC operating voltages were not considered in the simulations.

In this paper, we apply the same simplified model of corona discharge to the analysis of transient voltages at a 60-m transmission line tower, for the case of direct lightning strikes to the top of the tower. Corona is assumed to occur only on the ground wires. Back-flashover is assumed to occur across the insulator string of upper, middle or lower phase. AC operating voltages of phase conductors are considered in the simulations by using a voltage source inserted between each phase conductor and ground. The effect of corona on transient voltages in the presence of back-flashover is examined. We consider four cases, (i) no ground-wire corona and no operating voltages, (ii) ground-wire corona only, (iii) operating voltages only, and (iv) both ground-wire corona and operating voltages. To the best of our knowledge, this is the first FDTD sim-

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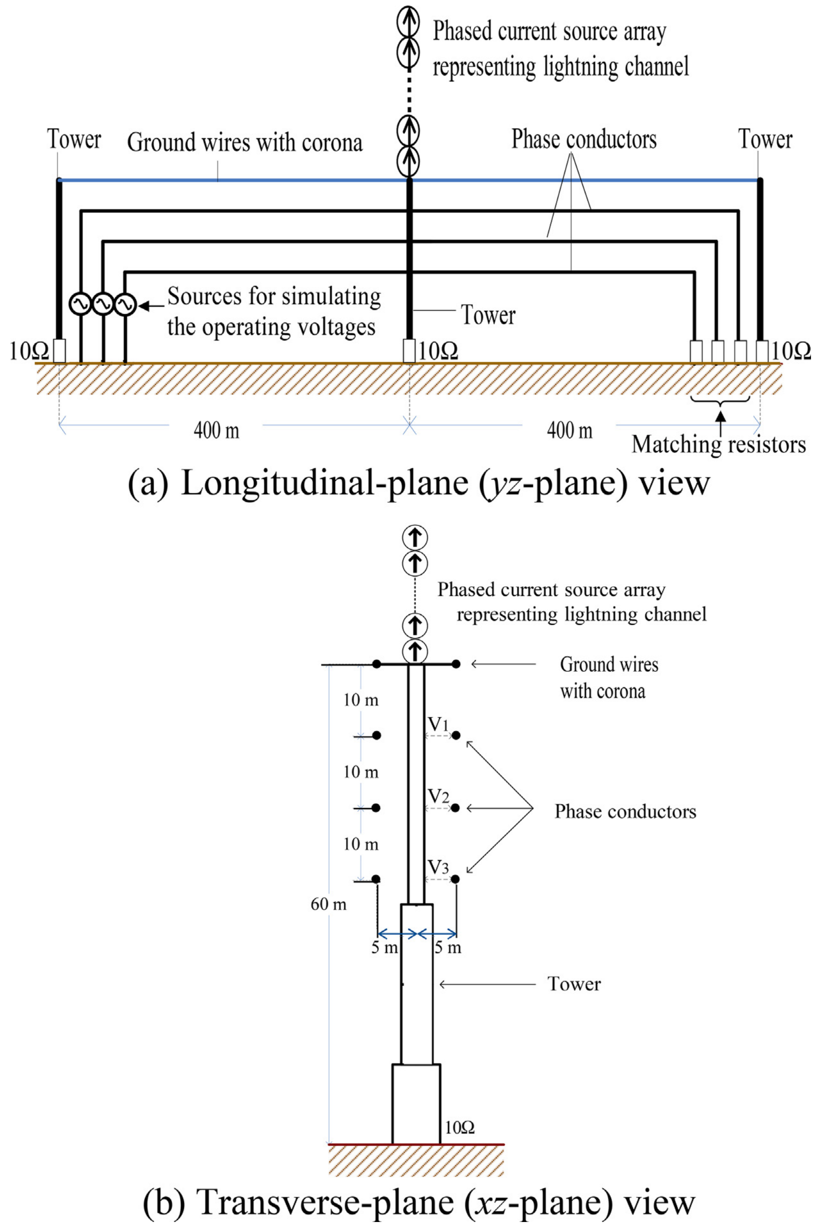

Fig. 1. Configuration of a two-span, 60-m high transmission line struck by lightning, analyzed using the FDTD method: (a) longitudinal (*yz*-plane) view, and (b) transverse (*xz*-plane) view.

ulation of back-flashover at a transmission-line tower considering both ground-wire corona and operating voltages.

2. Methodology

Fig. 1 shows the configuration considered in this paper. It is composed of three two-circuit 60-m high towers, two overhead ground wires, and six phase conductors (simulating two 275 kV three-phase circuits). Only one circuit (three vertically arranged phase conductors) and two ground wires were considered in this study. The separation distance between the neighboring towers is set to 400 m. Lightning is assumed to terminate at the top of the middle tower. Each tower is connected to two ground wires at its top and to a perfectly conducting ground plane via four 40-Ω-footing resistors at its bottom so that the overall tower footing resistance was 10 Ω. This simple tower representation is a good approximation to a typical 275-kV double-circuit tower. One end of each phase conductor is connected to the voltage source, and the other end is connected to ground via a matching resistor (510, 495, and 480 Ω for upper-, middle-, and lower-phase conductors, respectively). The total length of the ground wires and phase conductors is 800 m. Lightning channel is represented by a 600-m long, vertical phased ideal current source array [10]. The array simulates a current pulse that propagates upward without attenuation or distortion at a speed of 130 m/μs and its equivalent impedance is equal to infinity.

For FDTD computations, this conductor system is accommodated in a working volume of 400 m × 1000 m × 750 m, which is divided nonuniformly into rectangular cells and is surrounded by five planes (the top plane and four side planes) of *Liao*'s second-order absorbing boundary condition [11] to minimize unwanted reflections there. Cell sides along *x*, *y*, and *z* axes are 9.0 cm in the vicinity of the horizontal ground wires and towers, increasing gradually to 50, 100 and 500 cm beyond that region. The equivalent radius [12] of all the phase conductors and ground wires used in this paper is 21 mm (=$0.23\Delta x = 0.23\Delta z = 0.23 \times 9.0$ cm).