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Induced Surges in Railway Signaling Systems during an Indirect Lightning Strike

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***Abstract*—This paper presents a study of lightning induced surges in railway signaling systems with the FDTD method. During an indirect lightning strike, induced surges are observed in the outdoor circuits due to electric and magnetic coupling. The induced surge currents propagate along the signal cables towards the receiving equipment in railway stations. It is found that geometry of the outdoor lines, earthing and bonding practices affect induced surge currents and voltages in the circuits. Equipotential bonding can substantially reduce the induced surge voltage impinging on the equipment in railway stations.**

Keywords- lightning, surge, signaling circuit, FDTD

I. INTRODUCTION

In modern cities, there are many railway stations which are of up to several tens of meters tall. During an indirect lightning strike, surges will be generated in signaling lines, and will propagate along the lines to the signaling equipment used in the railway stations. These surges could cause the malfunction or damage to the sensitive electronic equipment. In order to improve lightning protection measures for railway stations, it is important to study the surge voltages and currents in the railway signaling systems.

Lightning surges in buildings can be generated via electric coupling and magnetic coupling. The lightning overvoltage dispersed on railway signaling equipment have been analyzed, and protection measures of railway signaling equipment have been put forward [1-3]. The waveform and amplitude of surge current in buildings caused by lightning have been specified in IEEE standards [4-7]. These surges are generated on the lines by direct lightning strikes. However, there has not be much work done on the surge current arising from coupling [10], which propagates along the lines to the equipment inside the railway stations.

This paper discusses lightning-induced surges generated on the outdoor signal lines and the surges impinging on the equipment within a railway station. The effect of different bonding methods is discussed. In this paper the signal line and building structure are modeled using the Finite-Difference Time-Domain (FDTD) method. Simulations are then performed to reveal the impact of different factors on the induced surges. The factors including line position, earthing, bonding methods and others are considered in the simulations.

II. SYSTEM MODELS

Armored signal cables are widely used in railway signaling systems. They generally run outdoor, and connect the trackside equipment to the equipment in a control room within a railway station. During an indirect lightning strike, the lightning current emits radiated electromagnetic fields. The radiated electromagnetic fields will generate surge voltages and currents in the conductors, such as power cables and signal cables in the vicinity. The surges may be generated by inductive coupling, capacitive coupling and resistive coupling. Note that surges induced by lightning are difficult to calculate and analyze with the traditional transmission line theory. The FDTD method is then adopted in this paper to study the induced surges in the signal cables as well as the equipment inside the station.

Armored signal lines connecting the trackside equipment run horizontally above the ground. In some of stations, the platform situates on the second floor or third floor. The equipment room and signal cables are generally at the height of 10m above the ground. The signal line is generally connected to a clean earthing mat on the ground level. For safety reasons, the equipment enclosure is connected to a main earthing system provided in the station, as shown in Fig.1. Local earthing terminals are provided in signal equipment rooms for these two separate earthing systems. To minimize electromagnetic inference and reduce the risk of electric shock, earthing terminals are usually connected (a or b) in a building.

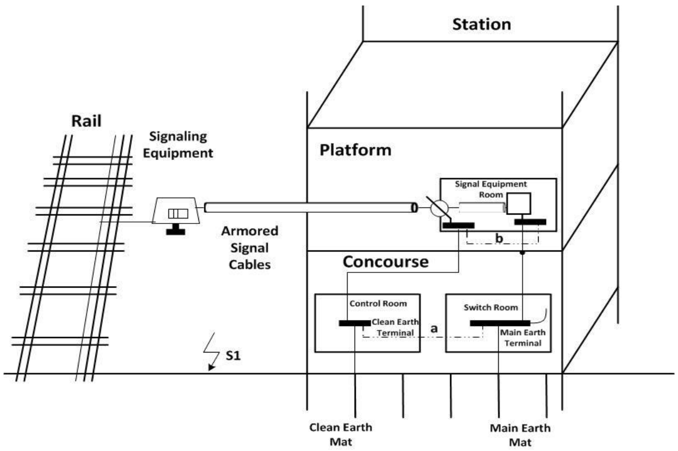

Fig.1. Railway signal system

Fig.1 shows a simple railway signal system. Fig.2 is the simplified version of the configuration without considering the building structure of a railway station. In the simulations, the armored signal cable is represented by a cylinder with the radius of 5mm. It is connected to a lossy ground with an earth resistance (R). The conductivity and relative permittivity of the lossy ground is 0.001S/m and 4, respectively. The lightning return stroke is represented by a current source with the amplitude of 10kA and the rise time of 0.25μs. The lightning channel is modeled with a vertical cylinder extended upwards. The current source is connected to the ground via an earthing electrode. In Case 1, the cable is 50m long, and is positioned at the height of 10m above the ground (L=50m, H=10m). The striking point of lightning (P1) is situated in the perpendicular direction 10m (D=10m) way from the open end of the cable. Surge current will be generated in the cable, and the current (I) at the earthing terminal for the incoming signal cable is analyzed under different conditions.

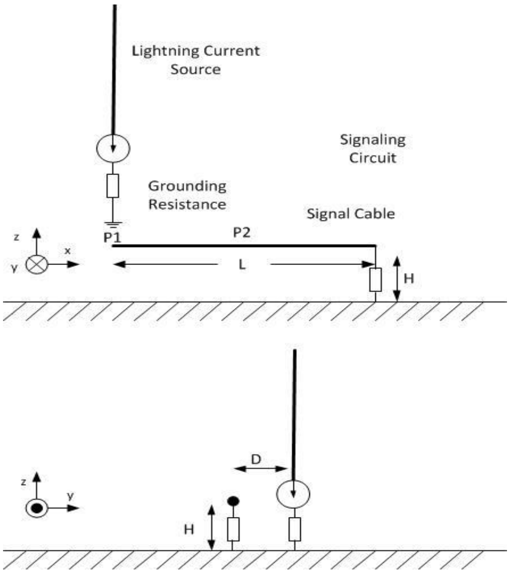

Fig.2. Configuration of the signaling circuit and lightning models

In Case 2, the receiving signal equipment is included in the simulation model, as shown in Fig. 3. The equipment is grounded via a protective conductor running 17m horizonatally and 10m vertically to the ground. Earthing is made by a mat similar to the clean earth mat. These mats are 10m long and 10m wide, and have a grid of 5m × 5m. The terminals connecting points a and b are 1m and 9m vertically to the ground respectively. The signal cable model and lightning stroke model are the same as that in Case 1. The lightning striking point is positioned in the perpendicular direction 10m away from the open end of the cable. The current of the singal cable and protective conductor and voltage between the cable core and equipment enclosure with different bonding methods as shown in Fig.1 are analylized.

In Case 3, the building structure of a railway station is taken into account. Fig.4 shows the structure frame of part of a station. The building frame is a two-layer-structure with the dimension 30×30×60 m (L×W×H) as shown in Fig. 4. It is made of 16 cylinders. The equipment enclsoure is bonded to one of these codncutors. The current in the cable and protrctive conductor are measured, as well as the votlage between the cable core and the equipment enclosure.

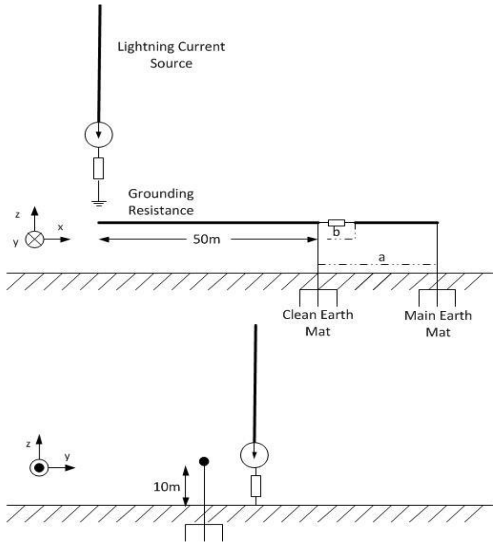

Fig.3. Configuration of the signaling cable and connected equipment

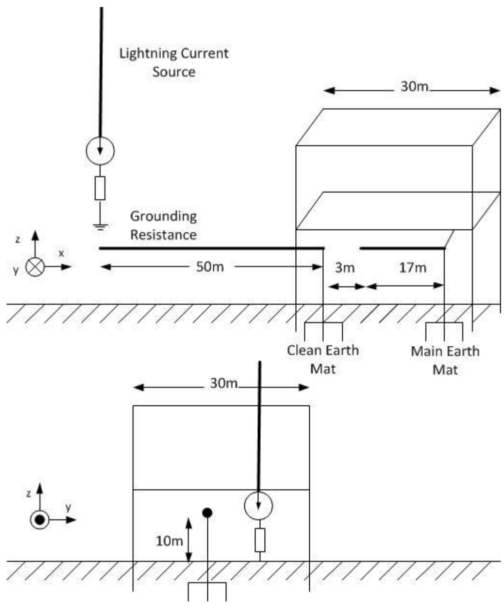

Fig.4. Configuration of the signaling circuit in a building

The working volume of the simulation model is 125m×120m×180m. It is surrounded by six planes of perfectly-matched layers (PML) with absorbing boundary conditions being enforced, so that the unexpected reflection wave on the planes can be effectively reduced [7]. PML absorbing boundary conditions are then applied at the height of 92.1m in the simulation model. The working volume is divided into uniform cubic cells. The side length of cubic cells in the three directions is all 0.5m. Time step is determined by the Courant condition, as follows:

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

where c is the speed of light, and △x, △y, △z are the side lengths of the cell in meter.

III. SIMULATION RESULTS

A. Induce surges in circuits grounded at one end (Case 1)

Fig.5 shows waveforms of the current with different source positions. The current has a ring wave basically, and tends to be zero in a couple of microseconds. It is caused by the wave oscillations due to reflection at the ground. The oscillation frequency is not determined by the source position. When the striking point is moved away from the line or is moved to middle position of the line, there is no significant change of the freuqnecy. However, the source position could influence the peak value of an induced current. It is found that the peak of the ring wave is decreased from 450A to 300A when the strikign point is moved 20m away from the line. But the peak of the current is increased to 700A when the striking point is moved to the middle point of the line. So the peak of the ring wave is significantly affected by the distance between the source position and the earthing terminal on the ground. Note in Annex E of IEC standard 62305-1 [8] that the induced current has a waveform of 8/20μs in circuits when a 10/300μs lightning return stroke near to the structure.

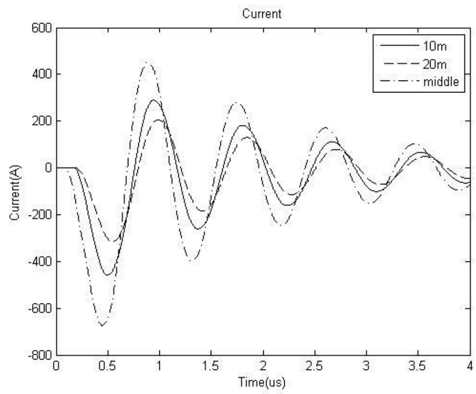

Fig.5. Waveforms of the current in the singal cable with different source positions

The earthing method could influence the induced current in a signal circuit, as shown in Fig.6. The surge current with three different earthing electrodes are analyzed; that is (1) single rod with a radius of 5mm, (2) a single rod with the radius of 114.5mm, and (3) a mat of 10m x 10m with the grid size of 5m x5m. In these three cases, oscillation frequencies of the current are the same while the peak values are quite different. The peak value of the surge current increases with increasing rod diameter. And it increases further to 450A if an earth mat is adopted. This indicates that the peak current increases when the earthing resistance decreases. It is noted that the induced surge current drops to zero quickly when the earthing resistance is large.

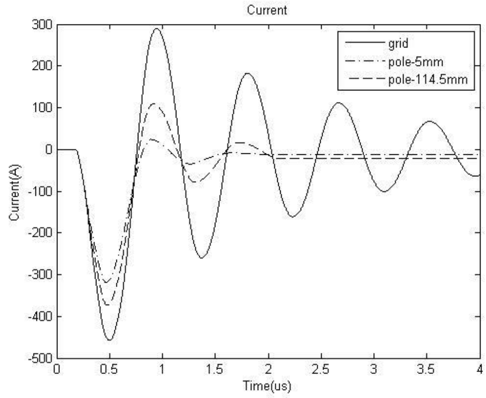

Fig.6. Waveforms of the current in the signal cable with different earthing methods

In Fig.7, waveforms of the current in the signal cable are presented for different lengths and heights of the signal cable. When the cable is moved down from 10m to 1m above the ground, oscillation frequency of the current does not change generally, but its peak value decreases. When the cable length is increased from 50m to 100m, the oscillation frequency decreases. In this case, the time period is increased to 1.5 μs, compared with 0.75μs in a 50m long cable. Therefore, the time period of the induced surge current is linearly proportional to the cable length.

Note that the reflection coefficient of a traveling wave is given by

$$\beta = \frac{Z_2 - Z_1}{Z_1 + Z_2} \quad (2)$$

The induced current has a positive total reflection at the short end (β=1) and then has a negative total reflection at the open end (β=-1). After twice reflections, a half-cycle waveform is developed. It is found that the oscillation frequency of an induced current is determined by the length of the conductor to the ground, which includes the single line and the conductor connected to the earthing terminal.

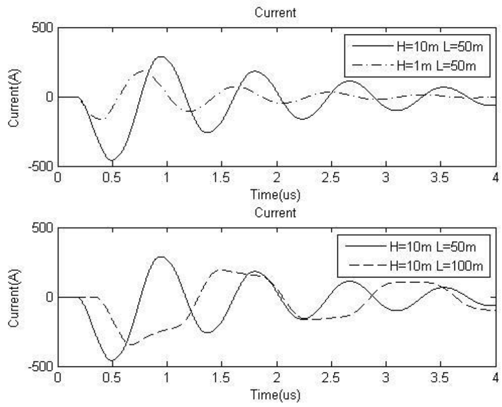

Fig.7. Waveforms of the current in the signal cable with different heights and lengths

B. Induce Surges on Connected Equipment (Case 2)

When the signal cable is connected to the receiving equipment, a surge will be developed between the core of the cable and the enclosure of the equipment during a lighting strike. The lightning surge voltage is then evaluated under different bonding conditions, that is, (1) no bonding provided between clean earth and main earth, (2) bonding provided at the ground, (3) bonding provided in the equipment room, and (4) bonding provided both at the ground and in the equipment room. These different cases are illustrated in Fig. 3.

The currents (I1) of the signal cable at the earthing terminal under these cases are showed in Fig.8. The waveforms are quite similar, and the peak currents are approximately equal to 450A. This shows that bonding measures have little influence on the lightning-induced surges in outdoor signal lines.

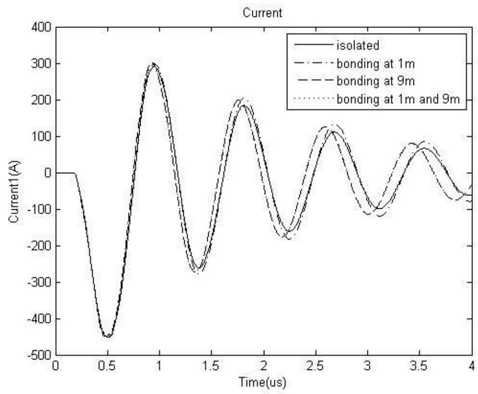

Fig.8. Waveforms of the current in a singal cable with different bonding measures

Fig.9 shows the currents (I2) in the protective conductor for the equipment. Fig.10 shows the voltage (V) between the cable core and equipment enclosure. The waveforms of I2 and V in the case without bonding are almost the same as those in the case with bonding provided at the ground. This means that bonding of CE and ME at a low position has no influence on the protection of equipment against lightning. When bonding is provided in the equipment room, the peak voltage is less than 5kV. While the peak voltage reaches 55kV in the case with bonding provided at the ground or without bonding between CE and ME. The induced surge voltage generally reduces if the open loop size is reduced.

When bonding is provided in the equipment room, the surge current in the protective conductor increases significantly, and reach 225A. Without such bonding, the surge current in the conductor is just 30A. This is because part of the current in the signal cable actually flow to the ground via this protective conductor. It is also noted that additional bonding at the ground floor does not change the surge current and voltage significantly.

C. Induced surges in the signaling circuit within a building (Case 3)

Fig.11 to Fig.13 shows the waveforms of I1, I2 and V without bonding in two different cases. In the first case, there is no building present. In the second case, a two-layer-structure building is present. It is found that the peak current is decreased from 450A to 350A, and that of I2 is decreased from 21A to 6A. The surge voltage on the equipment is decreased from 55kV to 25kV. This is because that the metal structure of the building behaves like a Faraday's cage. It reduces the electromagnetic fields emitted from the lightning channel, and lessens the electric and magnetic coupling effect.

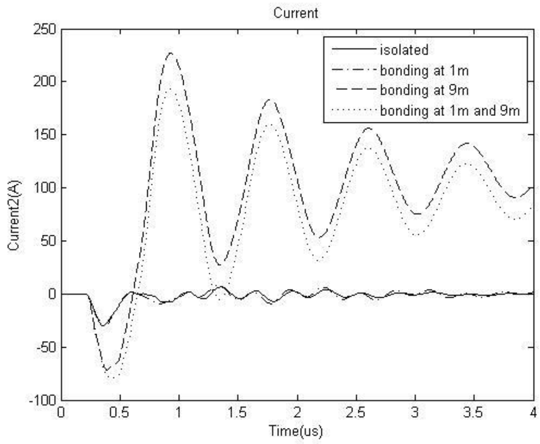

Fig.9. Waveforms of the current in the protective condcutor with different bonding measures

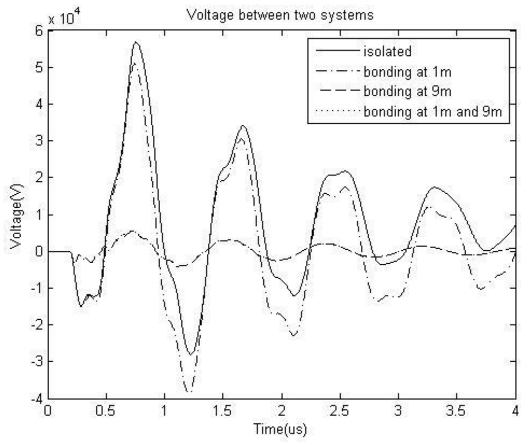

Fig.10. Waveforms of the voltage on the equipment with different bonding measures

IV. Conclusions

This paper presented a numerical investigation into lightning-induced surges in signaling circuits of railway systems. During a lightning strike in the vicinity of railway stations, induced surges are generated in the adjacent circuits due to both electric coupling and magnetic coupling. The induced surges vary with circuit configurations, earthing methods, as well as bonding measures.

It is concluded that the induced surge in the signal circuit has a ring waveform, and decays quickly to zero. The peak value of the ring wave is affected by the distance to striking point, the length of the signal cable, and the earthing methods adopted. The oscillation frequency of the ring wave is determined by the length of the signal circuit to the earthing terminal within a building.

It is also found that the presence of equipotential bonding has little effect on the surge current induced in the signal cable, but can reduce the surge voltage on the equipment significantly. Equipotential bonding provides at the equipment side can effectively reduce the surge voltage on the equipment.

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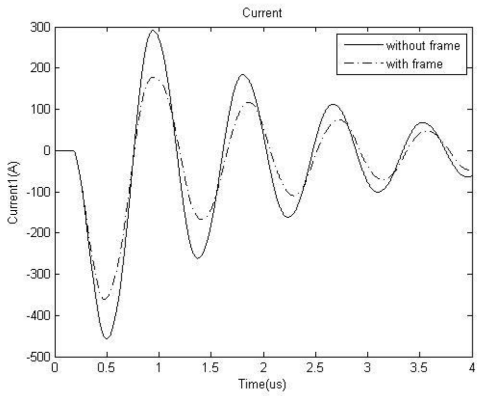

Fig.11. Waveforms of the current in the signal circuit with and without the building frame

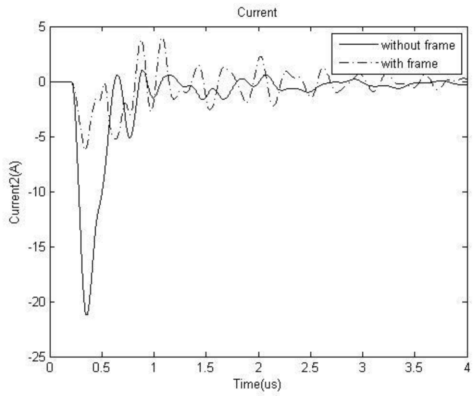

Fig.12. . Waveforms of the current in the protective condcutor with and without the building frame

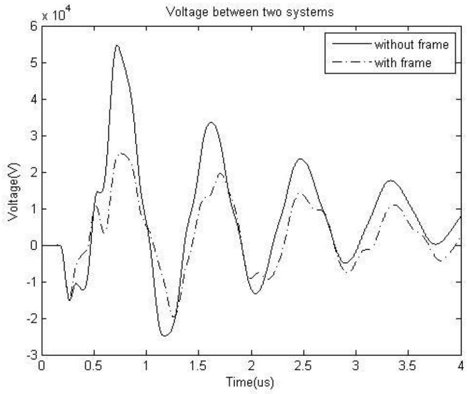

Fig.13. Waveforms of the voltage on the equipment with and without the building frame

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