Correlated Measurement of Vertical Electric Field and Lightning Induced Voltage on a Test Distribution Line

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1. Introduction
Lightning-induced voltages on power distribution lines or communication lines have been a matter of vital interest for many years, however, the mechanism has not been fully clarified yet. Recently, significant contributions were made in the observation of induced voltages by performing correlated measurements of vertical electric field or current. However, different theories accounted for each observational result. One theory calculated induced voltages based on the vertical electric field associated with lightning strokes. The other attributed them to the horizontal electric field generated by the finite conductivity of the earth.

Simultaneous observation of lightning current to a tower, induced voltages on a test distribution line, and vertical electric field waveforms have been carried out since 1987. The obtained results are compared with those of previous studies.

2. Measurement
The measuring site is on the coast of the Sea of Japan where thunderstorms in winter are notable. The 530 m long test distribution line was constructed in the closest distance of 400 m from a 150 m tower, where the line was open-circuited (point A), and the other end (point C) was terminated with 400 Ω. The average height of the test line was 11 m, and a horizontal neutral wire grounded at several points was placed 1.15 m below the test line. A resistive voltage divider of 10 kΩ was connected to the line at point A. At about the middle point of the test line (point B), another voltage divider was connected. The 150 m tower was built at a point 128.5 m above the sea level and halfway up a hill. An electrostatic antenna was placed near point B in the distance of 15.8 m from the line and 480 m from the tower.

3. Results and Discussion
Nine correlated recordings of the vertical electric field and the induced voltage were obtained during winter from 1987 to 1988. From the magnitude and the waveform of the observed vertical electric field changes, all the lightning strokes related to these records were estimated to be within 3 km from the electric field antenna. The data of signal amplitudes are summarized in Table 1. The polarities of the measured induced voltages were the same at both points A and B. The amplitude measured at point B was considerably smaller than that at point A, however, as a result of calibration, it was found that the sensitivity of the voltage measuring system of point B was not accurate, so the data for point B are not shown in the table.

A lightning stroke to the tower was confirmed by the simultaneous triggering events of the current recording system and the field recording system. In addition, the direction to a stroke, which was estimated from the time difference of the peaks in the waveforms of the electric field near point B and the induced voltage at point A.

In two cases (87-01, 07), the polarities of the induced voltage and the vertical electric field were
Table 1. Result of measurement of vertical electric field and induced voltages on the test line.

<table>
<thead>
<tr>
<th>Stroke</th>
<th>Type</th>
<th>Vertical electric field (E)</th>
<th>Induced voltage at A (V_A)</th>
<th>V_r/E</th>
<th>10~90% Rise time of E</th>
</tr>
</thead>
<tbody>
<tr>
<td>87-03</td>
<td>CG</td>
<td>-1.2 kV/m</td>
<td>+5.6 kV</td>
<td>-4.7</td>
<td>12.5 μs</td>
</tr>
<tr>
<td>87-04</td>
<td>-CG</td>
<td>+0.53</td>
<td>+3.5</td>
<td>+6.6</td>
<td>11.4</td>
</tr>
<tr>
<td>87-04</td>
<td>-CG</td>
<td>+0.20</td>
<td>+3.6</td>
<td>+18.0</td>
<td>0.3</td>
</tr>
<tr>
<td>87-06</td>
<td>T</td>
<td>+0.70</td>
<td>+9.0</td>
<td>+12.9</td>
<td>4.3</td>
</tr>
<tr>
<td>87-07</td>
<td>+CG</td>
<td>-0.32</td>
<td>+3.1</td>
<td>-9.7</td>
<td>4.6</td>
</tr>
<tr>
<td>87-08</td>
<td>+CG</td>
<td>-0.31</td>
<td>-3.3</td>
<td>+10.6</td>
<td>7.6</td>
</tr>
<tr>
<td>87-09</td>
<td>+CG</td>
<td>-1.5</td>
<td>-6.7</td>
<td>+4.5</td>
<td>18.6</td>
</tr>
<tr>
<td>87-11</td>
<td>+CG</td>
<td>-0.46</td>
<td>-7.4</td>
<td>+16.0</td>
<td>2.7</td>
</tr>
<tr>
<td>87-13</td>
<td>T</td>
<td>+0.80</td>
<td>+12.5</td>
<td>+16.0</td>
<td>1.1</td>
</tr>
</tbody>
</table>

CG: Cloud to ground return stroke, T: Lightning stroke to the tower

opposite. By the theory of the induced voltage without taking into account explicitly the horizontal electric field\(^3\), these cases cannot be accounted for. In these two cases, the directions to strokes as seen from point A, estimated by the above-mentioned method, were to point C of the line. The directions of the strokes for the rest 7 data were not to point C. This result could be explained by considering the horizontal electric field deduced from the wavelike formula\(^4\).

It is pointed out that the effect of the horizontal electric field sometimes needs to be taken into account in analyzing the mechanism of the lightning-induced voltage on a line, even in the event that a stroke hit the ground within 3 km of a line.

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References