Abstract — Japanese railway systems run throughout Japan and are the main means of transportation for many people. In recent years, with the development of energy-saving techniques in these railway systems, they are recognized as an ecologically friendly means of transportation with low CO2 emissions. In particular, signal facilities used in the railway systems have been progressively computerized, and the railway systems have had weak resistance to an overvoltage caused by lightning. Thus, for insulating AC power sources, railway companies use devices such as insulation transformers or lightning isolation transformers, which can withstand high voltages. This document presents results obtained by examining surge characteristics of the insulation transformer and the lightning isolation transformer which are used in one of the methods of taking countermeasures against lightning damage. To recognize the lightning isolation transformer’s response to lightning-caused overvoltage, frequency characteristics among terminals were determined using an impedance analyzer to construct an accurate circuit analysis model.

Keywords— Railway, Lightning protection, Lightning isolation transformer

I. INTRODUCTION

Japanese railway systems run throughout Japan and are the main means of transportation for many people. In recent years, with the development of energy-saving techniques in these railway systems, they are recognized as an ecologically friendly means of transportation with low CO2 emissions. However, on the other hand, railway facilities widely laid on over the country are disadvantageously in an environment suffering from natural disasters. When the natural disasters such as typhoons, earthquakes, and lightning occur, influences by the disasters on users of the railway facilities are not negligible. In particular, signal facilities used in the railway systems have been progressively computerized, and the railway systems have had weak resistance to an overvoltage caused by lightning. For this reason, transport disorders the number of which is increased by lightning damage are concerned [1]. In the railway facilities, the safety, security, and reliability of transport services are importantly secured, and countermeasures against lightning damage are absolutely imperative.

Most signal facilities are connected to AC power sources, and they may supply electric power to external devices. As a result, power lines serve as paths for lightning, potentially damaging signal facilities to which power source lines are connected [2]. Thus, for insulating AC power sources, railway companies use devices such as insulation transformers or lightning isolation transformers [3], which can withstand high voltages. A common insulation transformer aims at insulation, and a common lightning isolation transformer aims at insulation and suppressing surge transition.

This document presents results obtained by examining surge characteristics of the insulation transformer and the lightning isolation transformer which are used in one of the methods of taking countermeasures against lightning damage. To recognize the lightning isolation transformer’s response to lightning-caused overvoltage, frequency characteristics among terminals were determined using an impedance analyzer to construct an accurate circuit analysis model [4].

Shunichi Yanagawa
Technological Development Department
SHODEN CORPORATION
Tokyo, Japan
yanagawa@sdn.co.jp

Yuta Naito
Technological Development Department
SHODEN CORPORATION
Tokyo, Japan
naitoyu@sdn.co.jp

Kazuo Yamamoto
Dept. of Electrical Engineering
Faculty of Engineering
CHUBU UNIVERSITY
Aichi, Japan
kyamamoto@isc.chubu.ac.jp
II. HOW TO USE THE INSULATION TRANSFORMER AND LIGHTNING ISOLATION TRANSFORMER

In general, to protect facilities from lightning, a surge protective device (SPD) is installed at the preceding stage of facilities to be protected (Figure 1). However, when an SPD is built in the facilities in advance, the SPDs cannot cooperate with each other, the SPDs may be damaged. In particular, when the SPD built in the facilities, the SPD may also damage the facilities themselves. In addition, in the railway signal system, there is a line that cannot install the SPD on the relationship of the fail-safe (move on the safe side in the event of an accident). These damaged facilities take a long time to be repaired or replaced, significantly limiting railway transportation. Thus, in such a case, it insulates the circuit using a transformer.

III. SURGE CHARACTERISTICS OF THE INSULATION TRANSFORMER AND LIGHTNING ISOLATION TRANSFORMER

A. Test Conditions

Surge transition ratios were determined via a surge characteristic test for an insulation transformer and lightning isolation transformer. The transformer specifications used in the test are shown in Table 1.

Figure 2 shows a test circuit of the insulation transformer. In this test, an impulse generator (IG) applied a voltage across a primary site and the frame ground terminal, and an oscilloscope measured the voltage generated across a secondary site and the frame ground terminal.

B. Test Results

Figures 4 and 5 show the test results for the insulation transformer and lightning isolation transformer, respectively. We observe that when the insulation transformer is used, a lightning-caused overvoltage applied at the primary site is transferred to the secondary site without significant attenuation (Figure 4).

On the other hand, when the lightning isolation transformer is used, a lightning-caused overvoltage applied at the primary site is attenuated to approximately 1/1000 and is then transferred to the secondary site (Figure 5). Thus, it can be concluded that insulation measures are more effective using the lightning isolation transformer.
Table 1. Transformer specification used in the test

<table>
<thead>
<tr>
<th></th>
<th>Insulation transformer</th>
<th>Lightning isolation transformer</th>
</tr>
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<tbody>
<tr>
<td>Capacity</td>
<td>0.5 kVA</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>50Hz/60Hz</td>
<td></td>
</tr>
<tr>
<td>Voltage ratio</td>
<td>100V:100V</td>
<td></td>
</tr>
<tr>
<td>Withstand voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary-Secondary</td>
<td>AC 6 kV 1 min.</td>
<td>1.2/50 μs 30 kV AC 10 kV 1 min.</td>
</tr>
<tr>
<td>Primary-Ground</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary-Ground</td>
<td></td>
<td>1.2/50 μs 10 kV AC 3 kV 1 min.</td>
</tr>
<tr>
<td>Surge attenuation rate</td>
<td></td>
<td>Less than 1/1,000</td>
</tr>
</tbody>
</table>

Table 2. Test equipment specifications

<table>
<thead>
<tr>
<th>Measuring instrument</th>
<th>Model</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>IG</td>
<td>L58-15AX-B1 (Noise Institute)</td>
<td>1.2/50 μs 15 kV</td>
</tr>
<tr>
<td>Oscilloscope</td>
<td>TDS5054C (Tektronix Co.)</td>
<td>500MHz, 5GS/s</td>
</tr>
<tr>
<td>High voltage probe</td>
<td>P6015A (Tektronix Co.)</td>
<td>75MHz, 100MO, 3pF, 20kV</td>
</tr>
<tr>
<td>Passive probe</td>
<td>P6139B (Tektronix Co.)</td>
<td>500MHz, 10MO, 8pF, 300V</td>
</tr>
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</table>

IV. CIRCUIT ANALYSIS MODEL OF THE LIGHTNING ISOLATION TRANSFORMER

A. Frequency Characteristics of the Lighting Isolation Transformer

In this experiment, the primary and secondary protecting elements between lines were removed to measure the frequency characteristics of the lightning isolation transformer. Primary terminals P+ and P−, secondary terminals S+ and S−, and a ground terminal E of the lightning isolation transformer were set as measurement sites.

The frequency characteristics between the terminals were measured at 4 Hz–5 MHz using an impedance analyzer. The terminals P+ and P− and the S+ and S− were short-circuited to measure the characteristics between the terminals P+, S+, and E, and between the terminals P− and E. Based on the measured frequency characteristics, an equivalent circuit model of the lightning isolation transformer was formed.

B. Equivalent Circuit Forming Conditions

Figure 6 shows the formed equivalent circuit model. The measured values, between the terminals P+ and P− and between the terminals S+ and S−, and the frequency characteristics of the equivalent circuit model were compared (Figure 7 and Figure 8). The measurements between the terminals P+ and P− indicate resonance points at 7.3 kHz and 348 kHz (Figure 7); the resonance at 7.3 kHz has a large Q value, and a measurement result in a low-frequency band must be simulated.

For this reason, serial connections between L4 and R4, and between L2 and R2 were constructed in parallel with C1. Accordingly, in the secondary site, simulation was performed using serial connections between L4 and R4 and between L3 and R3 in parallel with C3.
C. Comparison between the Measured and Analyzed Value Equations

The measured values match the analyzed values well (Figure 7 and Figure 8). The frequency characteristics between the terminals P and P+ and between the terminals S and S+ could be reproduced with high accuracy. The comparison results between the measurements at the primary and the secondary site, as well as the circuit model are not presented due to limitations of space. Nevertheless, it is noted that the measurement results between the primary and the secondary site are accurately reproduced by the simulation executed with capacitances (C4, C5, and C6) shown in Figure 6.
V. CONCLUSION

In this study, we have conducted an experiment for the surge characteristics of the insulation transformer and lightning isolation transformer. Experimental results are shown as follows:

- When using an insulation transformer, the lightning overvoltage on the secondary site is not much attenuated.

- When using the lightning isolation transformer, the overvoltage on the secondary site is attenuated to approximately 1/1000.

Therefore, it was found that it is possible to perform effective lightning protection by using a lightning isolation transformer. Also, the lightning isolation transformer was performed to construct a circuit analysis model considering the frequency characteristics. As a result:

- The measured values and analysis are in good agreement.

From the above, damage causes and lightning protection in the field can be expected to efficiently perform.

In the future, we are going to verify the accuracy done to continue to further experiment of creating and overvoltage of high-precision good circuit model.

REFERENCES


