Simulation and Analysis of Lightning on 345-kV Arrester Platform Ground-Leading Line Models

Shen-Wen Hsiao, Shen-Jen Hsiao

Abstract—Due to overvoltage transients, surge arresters are required to prevent damage to the junctions in overhead and underground hybrid transmission systems and the grounding model is a key factor affecting arrester performance. The popular transient analysis tool, EMTP/ATP, is used to search for the best connecting method by simulating the responses of different grounding models to a typical lightning strike at the junction of an overhead line and underground cable in a 345-kV transmission system. An experimental lightning impulse test is performed to validate the simulated data. The simulation results could be used as a guide to find an effective design for line arrester grounding models at the connection station, such as smart grid transmission design arresters under the lead ground reference.


I. INTRODUCTION

TRANSIENT over-voltages encountered by power systems can be divided into three types: lightning strikes, switching surges, and power frequency over-voltages. They propagate along a transmission line as a traveling wave. When an overhead line is connected to an underground cable, because the surge impedance of the line is very different from that of the cable, the transient voltage travelling wave from the overhead line will both reflect and refract at the junction of the line and cable. The refracted voltage is the summation of the incident and the reflected wave, and it will be larger than the incident voltage. Therefore, arresters are installed at the junction between the overhead line and the underground cable in order to improve the insulation to protect the system. Since a 345-kV underground cable termination station employs a caisson foundation, the arrester platform is installed above the underground cable termination station and the arrester base is isolated from the steel platform.

IEEE Standard 1299/C62.22.1 [1] only considers the effect of the arrester ground lead wire length over the distribution line concrete pole to the cable protection margin. Some aspects of the arrester ground-leading wire of 345-kV power systems and platform leading methods are insufficient. In this paper, existing system data are applied to calculate the parameters for angle steel-supported arrester platforms and to build simulations. EMTP-ATP based arrester platform and ground-leading line models are built according to IEC Standard 600071-4 [2], to analyze the effect of applying the platform as part of the path to the ground, or directly connecting to the station ground network, on the lightning surge transient response performance.

II. ELECTRICAL PARAMETER CALCULATION

A theoretical analysis for the platform and downward ground-leading line was used to build the models for the termination station arrester platform for a 345-kV underground cable and ground-leading wire.

A. Parameters and Model of The Angle Steel Platform

Figure 1 shows schematic diagrams and a photograph of a 345-kV arrester grounding system. Figure 1(a) shows the platform profile with 12 loop paths; Figure 1(b) shows a photograph of the system; Figure 1(c) shows a three-dimensional schematic diagram; and Figure 1(d) shows an expanded view of the current loops. Once we had determined the parameters of the geometry for the system, we could calculate the resistance and inductance; the results are shown in Table 1.

![Platform schematic](image)

**Fig. 1.** Platform for a 345-kV arrester grounding system, (a) schematic diagram of the platform profile, (b) photograph of the platform, (c) a single section of the frame, (d) an expanded view of the current loops formed by the angle steel platform.

The angle steel bar is modelled as a resistance and inductance series, calculated using Eq. (1) and (2) [3]. The resistance is

\[ R = \frac{1}{\rho} \Omega/m \]  

(1)
And inductance is

\[ L = \frac{\mu_r \mu_0}{6} \left( \frac{t}{w} \right), \text{H/m} \]  

(2)

Where

- \( t \) : thickness of angle steel bar
- \( w \) : is width of angle steel bar.
- \( \mu_r \) : relative permeability of steel material.

### Table 1

<table>
<thead>
<tr>
<th>Summary of the parameters for the 345-kV arrester platform.</th>
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<tbody>
<tr>
<td>parameter</td>
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<tr>
<td>Thickness (b)</td>
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<tr>
<td>Width (l)</td>
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<tr>
<td>Length (h)</td>
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</table>
| Resistance (each section) | 0.57×10⁻³ Ω | 0.23×10⁻³ Ω | 1. \( \rho_r \) is 10⁻⁷ Ω·m
| Inductance (each section) | 5.91×10⁻⁶ H | 7.54×10⁻⁶ H | 2. \( \mu_s \) is 1000 H/m

The 325 mm² PE cable is used as the arrester’s ground leads. The lead is represented as a lumped parameter reactance with a typical value of 1.3 μH/m. The distance from the frame bonding point (node “N” in Figure 2) to the ground grid (node “E” in Figure 2) is about 1 m.

![Fig. 2. Model of 345 kV cable termination steel framework.](image)

\[ L \approx \frac{\mu_r \mu_0}{2\pi} \times \left( \ln \frac{2l}{a} - 1 \right) \]  

(3)

B. Surge Arrester with Frequency Dependent Model

For the modeling of the surge arrester in the EMTP-ATP study, two typical configurations are proposed by IEC60071-4 [2]. The non-linear resistance model is recommended first where the behavior of the surge arrester is related to the voltage-current curve based on the lightning impulse testing of the manufacturer. However, this simple model can only present well at one frequency. With a given inception current magnitude in surge arrester, when the time to the crest of the current is decreased from 8 us to 1.3 us, the voltage developed across the arrester can increase by approximately 6% [4]. In the lightning overvoltage phenomenon, the lightning current impulse incepted into the surge arrester would not normally be the standard impulse shape as in the manufacturer’s testing. Thus another frequency-dependent surge arrester model is recommended by the IEEE working group, whereby the non-linear V-I characteristic of an arrester is represented with two sections of non-linear resistance designated by different V-I curve to represent different fronts separately. There are two R-L filters adopted to separate these two sections. Under the slow-front surges, this R-L filter has very little impedance and the two non-linear sections of the model are in parallel. Under fast-front surges, the impedance of the R-L filter becomes more significant. Thus, this frequency-dependent model will give good results for current surges with times to the crest from 0.5 us to 40 us [4]. The overhead line (“OH” in Figure 3) and underground power cable are modelled as distributed components with surge impedances of 400 Ω and 50 Ω respectively.

In Figure 2, four additional switches ‘SW1’~‘SW4’ are added to illustrate the different connected configuration. The downward ground lead is divided into three segments (nodes G1–G3 in Figure 2) corresponding to the position of each stage of the framework (nodes F1–F3). The common bonding point on the framework is denoted as node “N”, and the ground grid is denoted as node “E”.

The impedance of the ground grid is modeled as a single 5-Ω resistance [5], the node ‘O’ is regarded as the zero potential reference point.

C. Parameters and Models of The Grounding Network

The area of the 345-kV termination station is approximately 35 m × 125 m. It is divided into eight grids, each approximately 18 m × 32 m. The grounding conductor consists of a 200 mm² solid copper wire. A high-frequency distribution component model was used to describe the grounding wire, as shown in Figure 3, and the parameters were calculated from Equation. 3 ~ 6 given below [6]:

![Fig. 3. High-frequency distribution component model.](image)
2. By examining the arrester discharge current, Cases 2 and 5 result in a maximum current of 14 kA and a minimum current of 7.9 kA.
3. In Case 4, the arrester is isolated from the platform, and the downward ground lead line and platform are independently grounded. This results in the most favorable metrics in terms of personnel safety [8].

III. SIMULATION AND ANALYSIS

A. Simulation Conditions and Results

The lightning surge was modeled as a 918 kV transient lasting for 1.2 × 50 μs, and the lightning strike point was the overhead ground wire at the outlet of the cable termination station. The five different simulated case are described in Table 2. The EMTP-ATP [7] simulation circuit for the 345-kV hybrid transmission system was as shown in Figure 4, where the connected line length between the platform and the grounding networks is approximately 25 m, and the total calculated inductance is 0.0325 mH. Voltage peak values of the simulation results are shown in Table 3.

Table II
Simulated cases of the 345-kV arrester grounding system.

<table>
<thead>
<tr>
<th>Condition</th>
<th>Grounding conditions</th>
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<tbody>
<tr>
<td>Case 1</td>
<td>The arrester base connects with the platform, and the ground lead wire and platform have a common ground.</td>
</tr>
<tr>
<td>Case 2</td>
<td>The arrester base connects with the platform, and the ground lead wire and the platform connect to the grounding network separately.</td>
</tr>
<tr>
<td>Case 3</td>
<td>The arrester base and the platform are isolated, and the ground-leading line and the platform have a common ground.</td>
</tr>
<tr>
<td>Case 4</td>
<td>The arrester base and the platform are isolated, and the ground lead wire and the platform are separately connected to the grounding network.</td>
</tr>
<tr>
<td>Case 5</td>
<td>The arrester has no ground lead wire, and the platform grounding path is bypassed.</td>
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These results can be summarized as follows.

1. By examining the surge voltage at point N in the platform grounding location, the minimum surge voltage obtained in Case 4 is approximately 2.5 kV, and the threat to the safety of personnel is minimal.
1. A longer line resulted in a decrease in the voltage at point N as well as a reduction in the surge current.
2. If the arrester ground lead wire is replaced with two smaller 25 m-long parallel lines, the arrester discharge current increases from 10 to 13.4 kA and the ground lead wire current decreases from 10 to 6.7 kA.

B. Impulse Testing for an Arrester Grounding System

In order to validate the accuracy of the simulated results, we used an arrester with a duty cycle voltage rating of 72 kV (10 kA class) to examine the response to a 10 kA impulse current lasting for 8 × 20 μs, with two different grounding methods: ground lead wire with a length of 10 m and a cross-sectional area of 100 mm², and platform grounding.

The results were as follows:

1. The arrester base directly connects to the grounding network. The surge peak voltages with and without the ground lead wire (the waveforms are shown in Figures 5 (a) and 6 (a) were 174.4 kV and 189.9 kV), respectively. The difference between these two values is equal to the ground-leading line equivalent inductance voltage drop.

\[ L \times \frac{dl}{dt} = 189.959 - 174.405 = 15.554kV \]  \hspace{1cm} (7)

Where

\[ \frac{dl}{dt} = \frac{10kA}{0\mu s} = 1.25kA/\mu s \]  \hspace{1cm} (8)

Substitution into Eq. 8 gives \( L = 1.244 \ \mu H/m \), which is close to the IEEE Standard 1299/C62.22.1 suggested value of 1.3 \( \mu H/m \).

Fig. 5. Impulse current response for an arrester that connects directly to the grounding grid, (a) Measured voltage surge waveform, (b) EMTP-ATP simulated voltage surge waveform.

Fig. 6. Impulse current response for an arrester in series with the ground lead wire, (a) Measured voltage surge waveform, (b) EMTP-ATP simulated voltage surge waveform.

2. The arrester base connects with the platform and connects to the ground grid. The arrester discharge current waveform is shown in Figure 7, the peak current is 4.822 kA, and the discharging capacity is 48% of that when using only one ground lead wire.

Fig. 7. Surge discharge current waveform of arrester.

IV. CONCLUSION

We analyzed the response of different connection methods for the arrester of the ground lead wire and the ground grid to lightning surges in a 345-kV overhead line/underground cable hybrid transmission system. We derived the equations describing the ground lead wire and the angle-steel platform, and used this to establish the EMTP-ATP models, which allowed us to analyze the surge characteristics under different grounding grid. The simulation results were compared to measured data for two specific surge arrester geometries. The results can be summarized as follows.

1. The measured inductance for systems both with and without an arrester ground lead wire was approximately 1.24 \( \mu H/m \), which is very close to the 1.3 \( \mu H/m \) suggested by IEEE Standard 1299/C62.22.1.
2. The simulated data showed that when the platform was part of the discharge path, the largest surge voltage was produced at the base of the grounding point, and a high platform voltage resulted. This was the least favorable scenario from the point of view of personnel safety.
3. In the optimum design Case 4, the arrester bases were isolated from the platform, and the ground lead wire and platform were separately connected to the ground grid. The arrester discharge current was smaller with a longer ground lead wire increasing this line length from 10 to 25 m resulting in a decrease from 16.3 to 10 kA. Modifying this design to include a parallel ground lead wire resulted in the most favorable voltage surge characteristics.

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REFERENCES


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