Mitigating Lightning Outages On 138 kV Transmission Lines

By Steve Lodwig

- Improve the electrical supply to industrial customers with processes susceptible to lightning momentary outages
- How to pick a method to mitigate momentary outages?
  - Weigh the level of improvement needed and cost of the modification
- This paper
  - Compares means of mitigating the outage
  - Details the effectiveness of a low cost improvement in lightning outages
IEEE Lightning Design Improvements

- IEEE 1243 Guide for Improving the Lightning Performance of Transmission Lines mentions the following means of improvement:
  - Reduce Ground Resistance & Add Counterpoise
  - Increase Insulation length
  - Add Shield Wires
  - Add Guy Wire to Steel Towers
  - Add OHGW on Separate Structure
  - Add Line Arresters

What Was The Problem?

- Lightning strikes on a wood pole line tap caused two double circuit momentary outages in one month causing two significant process shutdowns
- The 3 mile tap section
  - 5 open grounds on 64 poles
  - Strikes were recorded at sections good 10 Ω grounds
  - The pole grounds that were open were repaired
- Two additional storms occurred after the grounds were repaired causing two additional process shutdowns for the customer
- A fix was needed and needed immediately without shutting down the line
Double Circuit 138 kV Wood Pole Circuit

- Phase spacing 10’ 15’ from top phase to OHGW, 9 feet to pole
- 8 suspension insulator units, type A11 (5-3/4” x 10”)
- A single down lead (#2) from the OHGW wire to the ground
- One OHGW. The design is 7#6 AWG Alumoweld.
- A ground with a nominal 10-ohm resistance.

Lightning Strike to a Shield Wire
Lightning Strike to OHGW and Backflash Across Insulator

- TFlash output: Front of Wave On the Suspension insulator
- Breakdown voltage $V_B$ formula:

$$V_B = CFO \times (0.58 + \frac{1.38}{\sqrt{t}})$$

Increasing Insulator Length - Option 1

- Option 1 - Increase suspension insulator length
- Reduces clearance
- Increases pole load
- Requires outage to install
- Costs ~ 10% of original line cost
- Increases BIL & improves performance in polluted environments
Add an Extra OHGW – Option 2

- Option 2 – Add second OHGW
- Requires Arm on Top of Pole
- Significant load increase on poles
- Cost 20% of original line cost
- Outage required

Option 2 Improvement

- The OHGW Surge impedance of 2 wires is less than a single OHGW.
- The shielding angle for 2 wires is less than for 1 wire & will increase direct stroke protection
Install Phase Arresters – Option 3

- Option 3 - Install phase arresters
- Dramatically improves performance under lightning
- Costly & requires outages to install
- Adds an element that can flashover, adds weight to pole and arms

Install Additional Down Lead – Option 4

- Option 4 – Install additional down lead on pole
  - Least expensive,
  - Can be done live
  - Easy to install
- TFlash indicates that it is not as effective as other options – but good enough?
Option 4 Improvements

- **Single Down Lead**
  - #2 AWG copper wire, radius \( r = 0.01229 \text{ ft.} \)
  - 80-foot long down lead = \( h \)
  - \( Z_{\text{surge}} = 529.24 \text{ ohms} \)

\[
Z_{\text{surge}} = 60 \ln(\sqrt{2}*2h/r) - 1
\]

- **Two Down Leads using Two Down Leads using**
  - two #2 AWG copper wires
  - 80 foot long = \( h \)
  - 2.5-foot separation from the existing down lead = \( D \)
  - The second lead reduces the down lead surge impedance by 42%.
  - \( Z_{\text{surge2}} = 308.7 \text{ ohms} \)

\[
Z_{\text{surge2}} = (60 \ln(h/r) + 90(r/h) - 60 + (60 \ln(h/D) + 90(D/h) - 60))/2
\]

Tower Surge Impedance for Steel Towers, Poles, and H Frames

For each case, the travel time \( t \) from tower top to ground is \( t = h/300 \text{ \mu s} \)

Approximations for tower surge impedances.
Comparison of Tower Surge Impedances

- Steel Structures will always produce the lowest surge impedance.
- Larger footings on the steel towers will also have lower footing resistance vs. a ground rod.

<table>
<thead>
<tr>
<th>Type</th>
<th>Surge Impedance (Ohms)</th>
<th>Height (feet)</th>
<th>Wire Radius (feet)</th>
<th>Dimensions of Towers</th>
</tr>
</thead>
<tbody>
<tr>
<td>One Wire</td>
<td>539</td>
<td>80</td>
<td>0.01229</td>
<td></td>
</tr>
<tr>
<td>Two Wires</td>
<td>308</td>
<td>80</td>
<td>0.01229</td>
<td></td>
</tr>
<tr>
<td>Z Pole</td>
<td>176</td>
<td>80</td>
<td>-</td>
<td>( r = 6 \text{ ft} )</td>
</tr>
<tr>
<td>Z (H frame)</td>
<td>138</td>
<td>80</td>
<td>( 2r = 6 \text{ ft} ) ( b = 12 )</td>
<td></td>
</tr>
<tr>
<td>Z Tower</td>
<td>127</td>
<td>80</td>
<td>-</td>
<td>( 2r = 6 \text{ ft} )</td>
</tr>
</tbody>
</table>

Surge Impedance of Downleads

- Single Down Lead
  - #2 AWG copper wire, radius \( r = 0.01229 \text{ ft.} \)
  - 80-foot long down lead = \( h \)
- \( Z_{\text{surge}} = 529.24 \text{ ohms} \)
- Two Down Leads using two #2 AWG copper wires
  - 80 foot long = \( h \)
  - 2.5-foot separation from the existing down lead = \( D \)
- \( Z_{\text{surge2}} = 308.7 \text{ ohms} \)
- The second lead reduces the total down lead surge impedance by 42%.
One vs. Two Down Leads – TFLASH Results

Backflash Voltage with One and Two Down Leads

<table>
<thead>
<tr>
<th>Time (Microseconds)</th>
<th>2 Down Leads</th>
<th>1 Down Lead</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td>750</td>
<td>750</td>
</tr>
<tr>
<td></td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>1250</td>
<td>1250</td>
</tr>
<tr>
<td></td>
<td>1500</td>
<td>1500</td>
</tr>
</tbody>
</table>

-500 -250 0 250 500 750 1000 1250 1500

Reliability and Cost of Improvements

<table>
<thead>
<tr>
<th>Options</th>
<th>Description</th>
<th>3 Mile Tap Annual Outage Rate 2 Circuits</th>
<th>Cost as % of New Line Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base option</td>
<td>Original Configuration</td>
<td>0.541</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Increase Insulator Length</td>
<td>0.364</td>
<td>10%</td>
</tr>
<tr>
<td>2</td>
<td>Add OHGW</td>
<td>0.151</td>
<td>10%</td>
</tr>
<tr>
<td>3</td>
<td>Install Line Arresters</td>
<td>0</td>
<td>20%</td>
</tr>
<tr>
<td>4</td>
<td>Two Downlead</td>
<td>0.286</td>
<td>3%</td>
</tr>
</tbody>
</table>
Summary

- TFlash model indicates:
  - Surge arresters are the most effective and most costly improvement
  - The least costly improvement is to add a second down lead.
  - The model predicts a 55% reduction in the double circuit outage rate compared to the original installation

Results & Conclusions

- In the 9 years since the leads were installed, no outages have occurred to the customer due to lightning
- This far exceeds the expectations of the improvement
- Implies a strong relationship between the surge impedance of the OHGW, Downleads, and Pole grounds that may not be accounted for in the current computer models.
- Initial Design – Consider always using 2 downleads on a wood pole, and where feasible two OHGW’s.