# Mitigating Lightning Outages On 138 kV Transmission Lines

By Steve Lodwig

## Mitigating Lightning Outages

- 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 <u>needed</u> 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

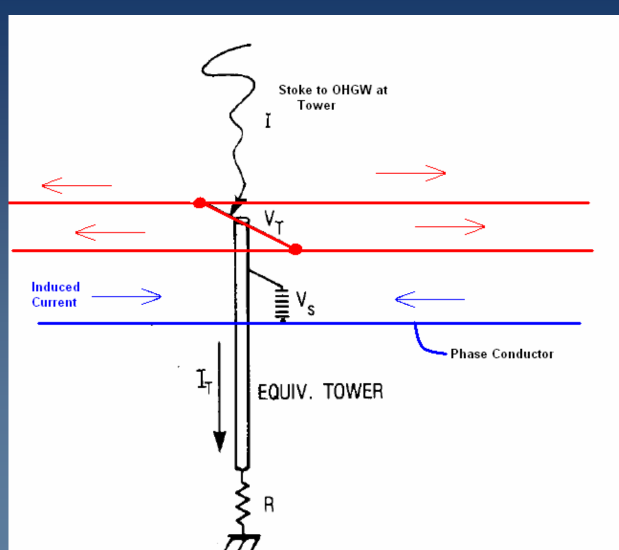
## What Was The Problem?

- 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.

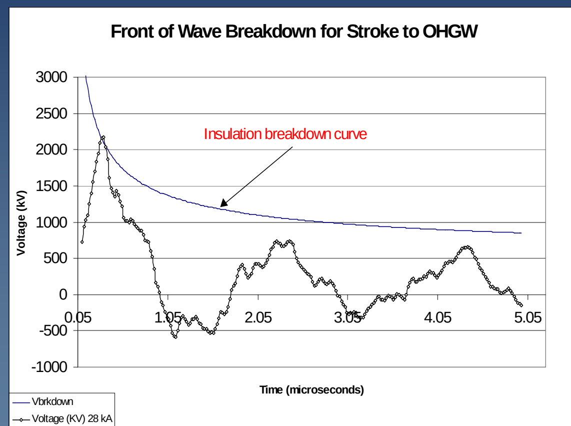
# Lightning Strike to a Shield Wire



# Lightning Strike to OHGW and Backflash Across Insulator

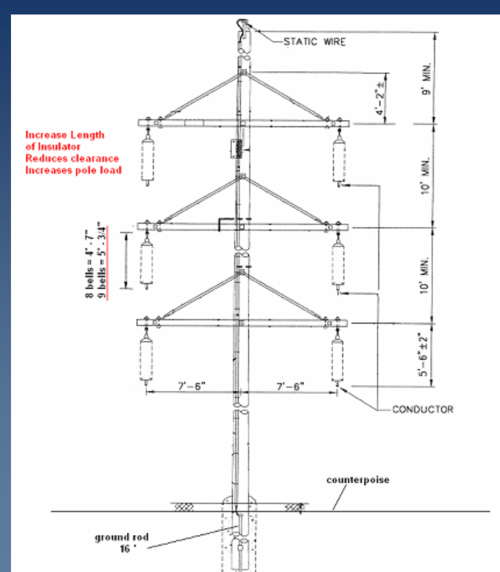
- TFlash output: Front of Wave On the Suspension insulator
- Breakdown voltage $V_B$ formula:

$$V_B = CFO * (0.58 + \frac{1.39}{\sqrt{t}})$$



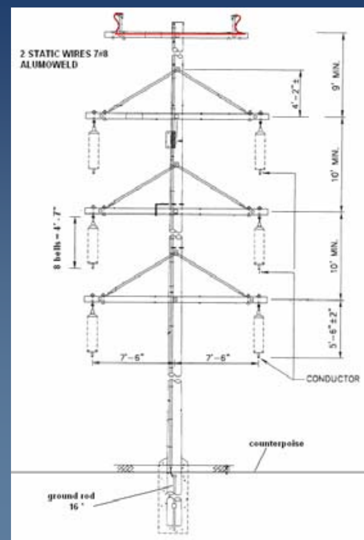

# Increasing Insulator Length - Option 1

- 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



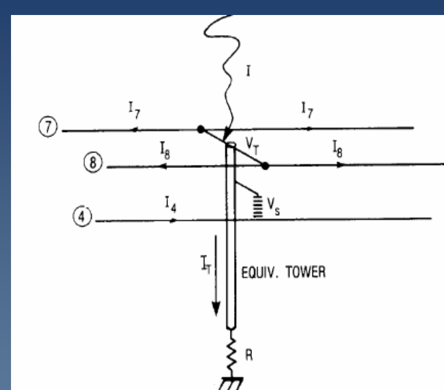
## Add an Extra OHGW – Option 2

- 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

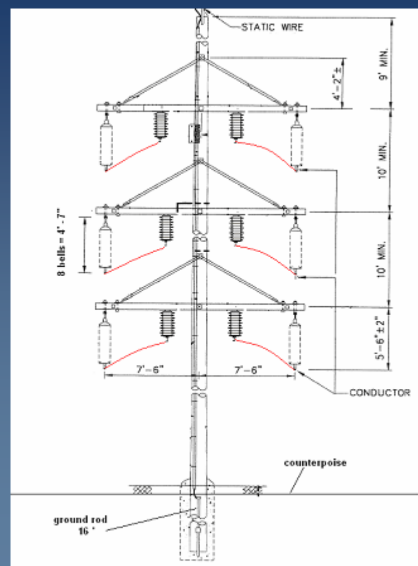
- The OHGW Surge impedance of 2 wires is less than a single OHGW.
- The shielding angle for 2 wires is less than for 1 wire & will increase direct stroke protection




Stroke current at a tower splits between shield wires and ground.

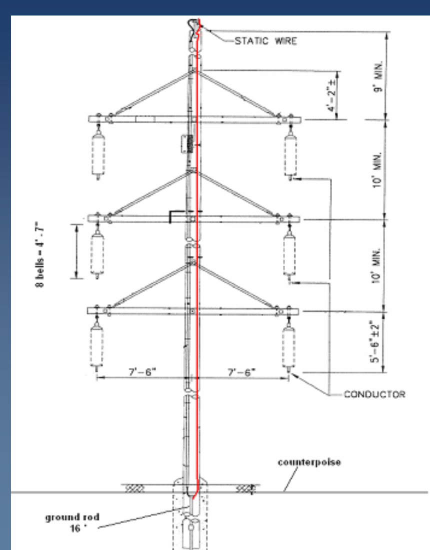
# Install Phase Arresters – Option 3

- 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

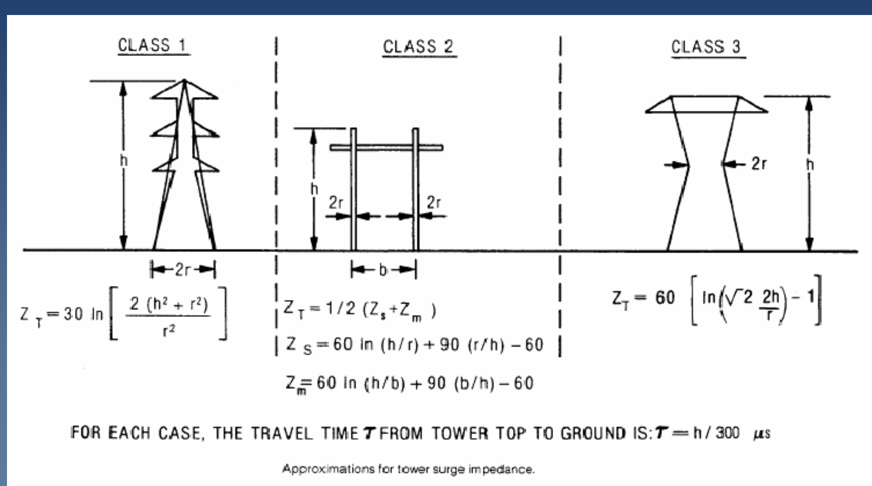
- Single Down Lead
- #2 AWG copper wire, radius r = 0.01229 ft.
- 80-foot long down lead = h
- $Z_{surge}$ = 529.24 ohms

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

- 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%.
- $Z_{surge2}$ = 308.7 ohms

$$Zsurge2 = (60\ln(h/r) + 90(r/h) - 60 + (60\ln(h/D) + 90(D/h) - 60))/2$$

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



# Comparison of Tower Surge Impedances

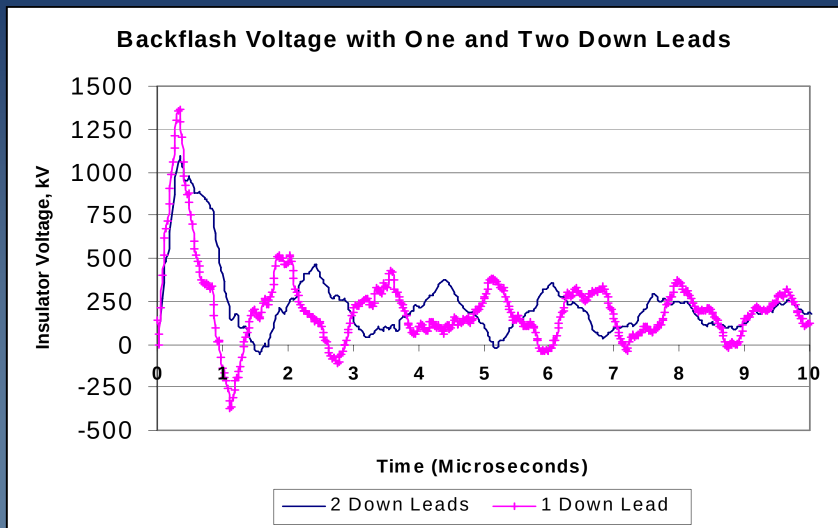
- Steel Structures will always produce the lowest surge impedance.
- Larger footings on the steel towers will also have lower footing resistance vs.a ground rod

| Type | Surge Impedance - Ohms | Height feet | Wire Radius feet | Dimensions of Towers |
|---|---|---|---|---|
| One Wire | 539 | 80 | 0.01229 | |
| Two Wires | 308 | 80 | 0.01229 | |
| Z Pole | 176 | 80 | | r = 6 ft |
| Z (H frame) | 138 | 80 | | 2r = 6 ft<br>b = 12 |
| Z Tower | 127 | 80 | | 2r = 6 ft |

# Surge Impedance of Downleads

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

# One vs. Two Down Leads – TFLASH Results




# Reliability and Cost of Improvements

| Options | Description | 3 Mile Tap Annual Outage Rate 2 Circuits | Cost as % of New Line Construction |
|---|---|---|---|
| Base option | Original Configuration | 0.541 | |
| 1 | Increase Insulator Length | 0.364 | 10% |
| 2 | Add OHGW | 0.151 | 10% |
| 3 | Install Line Arresters | 0 | 20% |
| 4 | Two Downlead | 0.286 | 3% |

## 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.