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

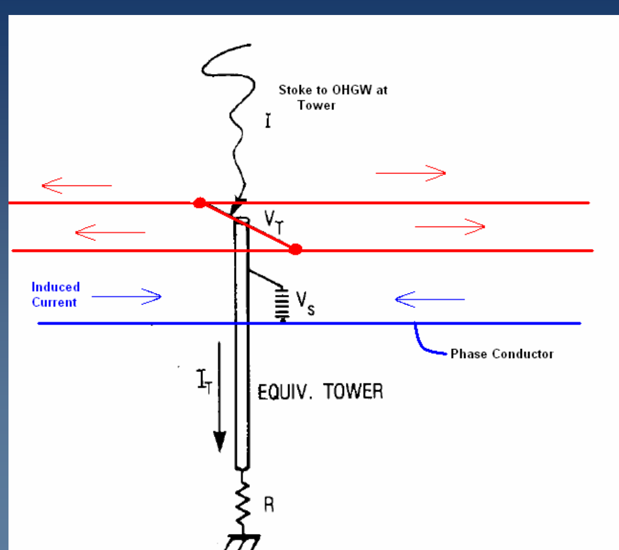
What Was The Problem?

- 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.

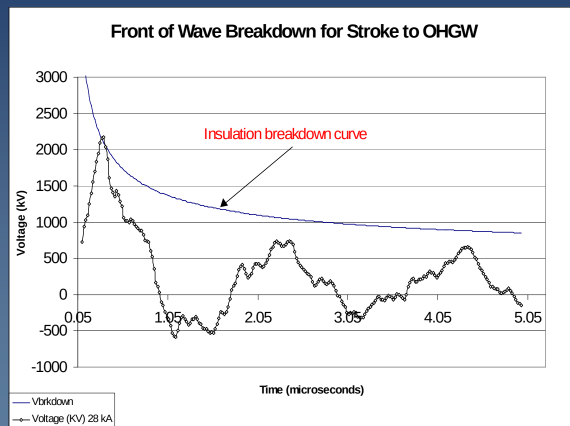
Lightning Strike to a Shield Wire



Lightning Strike to OHGW and Backflash Across Insulator

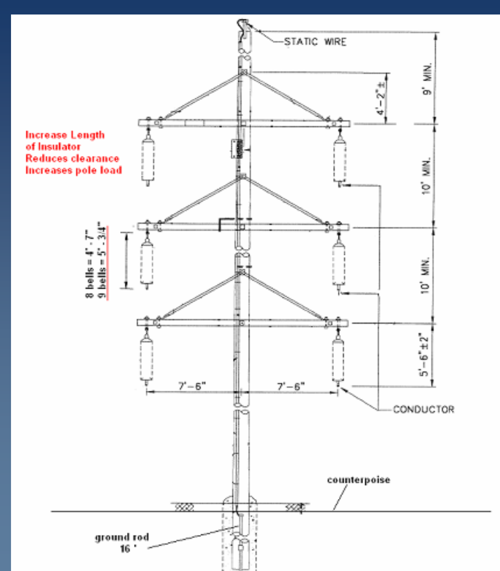
- TFlash output: Front of Wave On the Suspension insulator
- Breakdown voltage V_B formula:

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



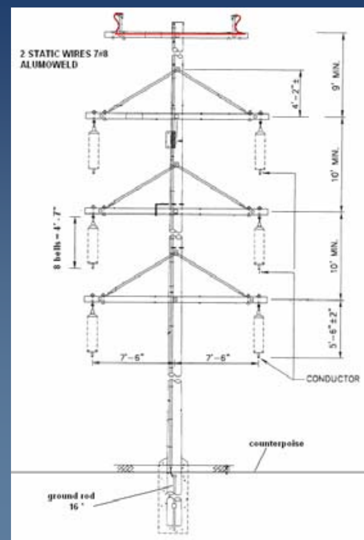
Increasing Insulator Length - Option 1

- 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



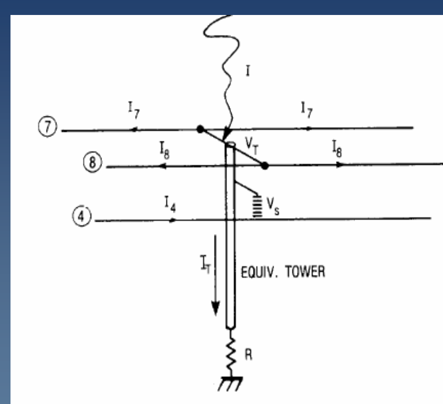
Add an Extra OHGW – Option 2

- 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

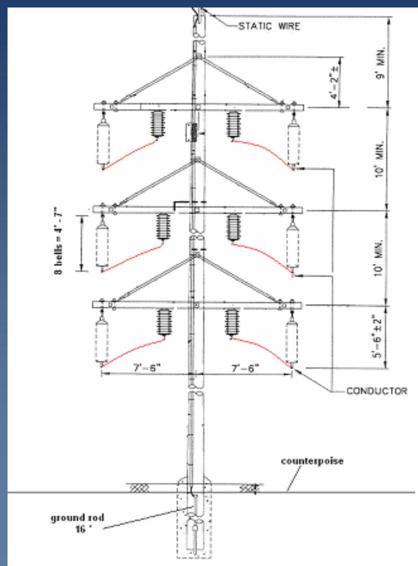
- The OHGW Surge impedance of 2 wires is less than a single OHGW.
- The shielding angle for 2 wires is less than for 1 wire & will increase direct stroke protection



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

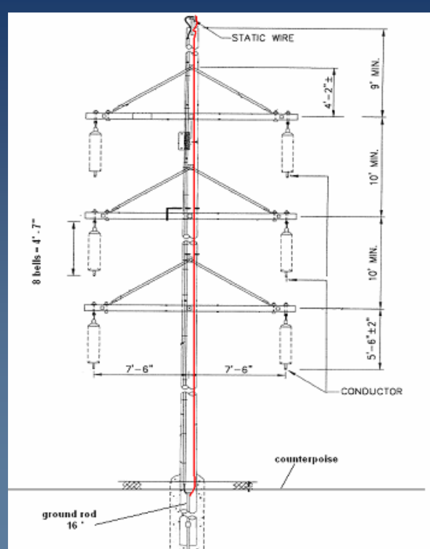
Install Phase Arresters – Option 3

- 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

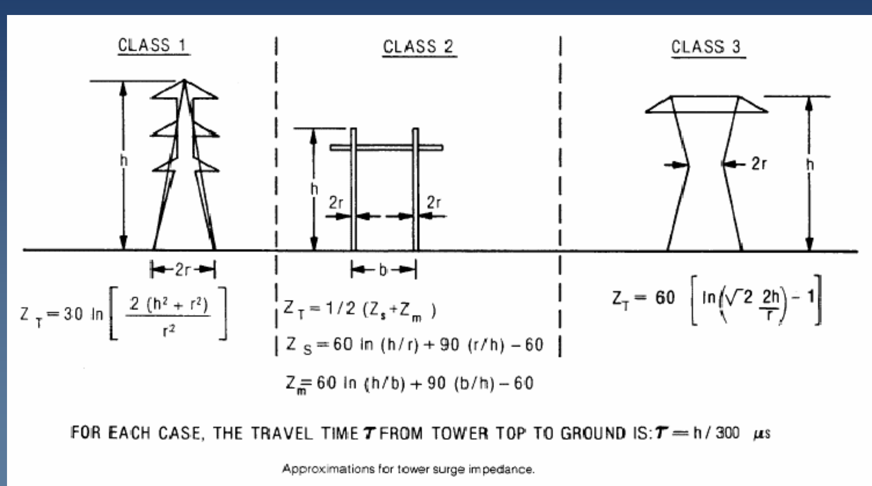
- Single Down Lead
- #2 AWG copper wire, radius r = 0.01229 ft.
- 80-foot long down lead = h
- Z_{surge} = 529.24 ohms

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

- 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

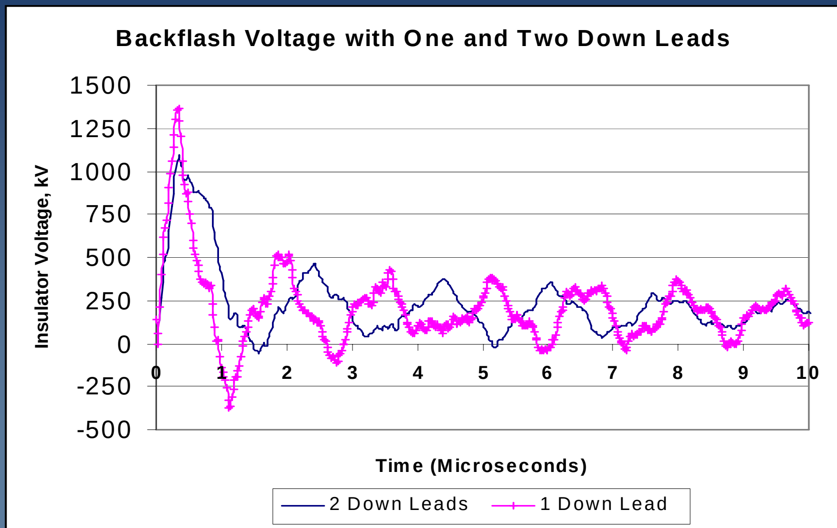
- Steel Structures will always produce the lowest surge impedance.
- Larger footings on the steel towers will also have lower footing resistance vs.a ground rod

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 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 Download	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.