Optimizing Substation Grounding for Distribution System Faults

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Ryan Conger, Rob Schaerer, Josh Brown, Aaron Wilson

Agenda

- Distribution fault ground potential rise (GPR) behavior
- Modeling approaches
- Results
- Conclusion

Objectives

- Understand GPR for distribution faults
- Provide guidance for analysis

Background Information

Background – Fault Behavior

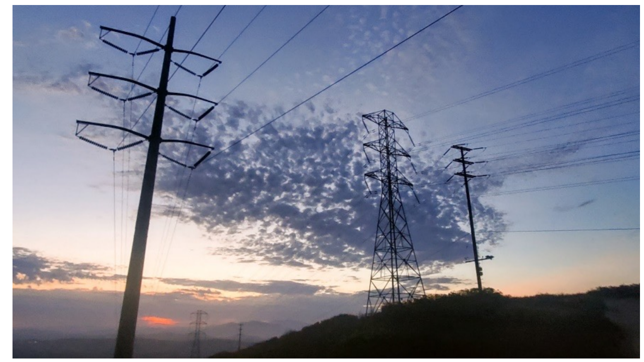


Photo credit: Rob Schaerer

- Transmission faults
  - Typically remotely sourced current
  - Returns through earth and shield wires
- Distribution faults – in substation
  - Effectively no GPR for typical delta-wye ground transformers
- Distribution faults – on feeder
  - Complex behavior

Background – IEEE Std 80-2013 Guidance

- "For ground faults outside the substation on a distribution feeder (far enough to be at remote earth with respect to the ground grid), a large portion of the fault current will return to its source (the transformer neutral) via the substation grid, thus contributing to the substation GPR." (IEEE Std 80-2013)

- Questions:
  - What is "a large portion"?
  - How much will it contribute to substation GPR?

Parametric Analysis

Parametric Analysis Intro

Variations on:

- Phase conductor
- Neutral conductor
- Pole ground conductor
- Substation size
- Distribution pole (and ground) spacing
- Fault location along a feeder
- Soil resistivity/layering

Photo credit: Rob Schaerer

Conductors Considered

- Phase
  - #6 AWG ACSR
  - #2 AWG ACSR
  - 1/0 AWG ACSR
  - 2/0 AWG ACSR
  - 3/0 AWG ACSR
  - 336 kcmil ACSR

- Neutral and downlead
  - #6 AWG
  - #2 AWG
  - 1/0 AWG
  - 2/0 AWG
  - 3/0 AWG
  - 4/0 AWG

Final Conductors Utilized After Initial Screening

GPR Scenario	Phase Conductor	Neutral and Download Conductor
Highest	Oriole (336 kcmil 30/7)	Penguin (#4/0)
Lowest	Turkey (#6 AWG)	Turkey (#6 AWG)

Substation and Distribution Lines Considered

- Substation
  - 100 feet by 100 feet
  - 200 feet by 200 feet
  - 500 feet by 500 feet
  - Grid for all
    - 4/0 AWG copper
    - 20-foot spacing
- Distribution Line
  - All 15,000 feet (~3 miles)
    - Faults every 1,500 feet (10%)
  - Span lengths:
    - 300 feet
    - 500 feet
    - Ground rod on each pole

Soil Models

- Two and three layers
- Various structures
- Various thicknesses

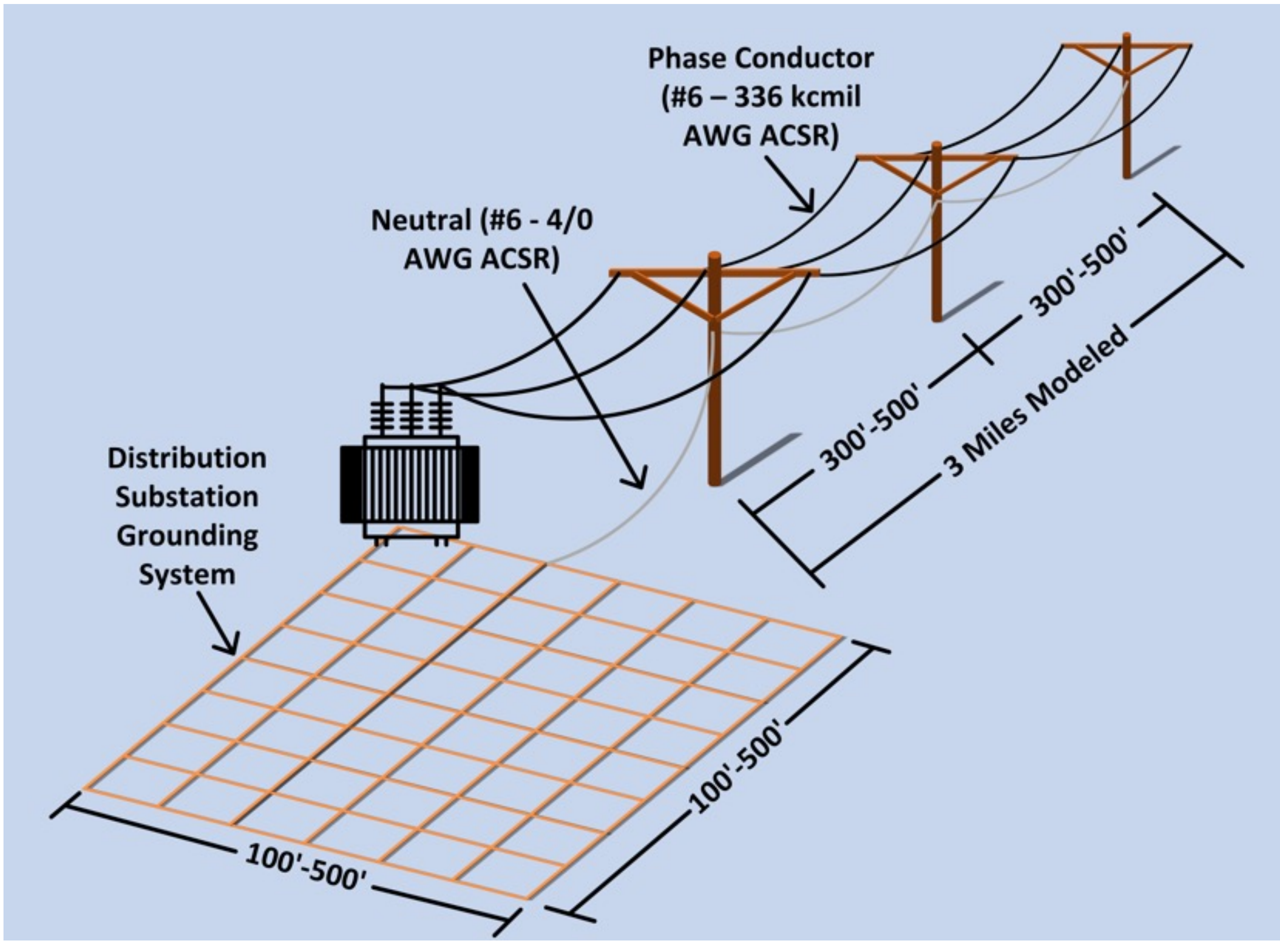
Soil Models by GPR (high-to-low)

GPR	Soil Layer	Resistivity (Ω-m)	Thickness (ft)
Model #1 (Extreme)*	Top	10	3
	Bottom	5,000	Infinite
Model #2	Top	10	3
	Bottom	1,000	Infinite
Model #3	Top	1,000	3
	Middle	10	20
	Bottom	1,000	Infinite
Model #4	Top	10	10
	Bottom	1,000	Infinite
Model #5	Top	10	3
	Middle	1,000	20
	Bottom	10	Infinite

GPR	Soil Layer	Resistivity (Ω-m)	Thickness (ft)
Model #6	Top	10	10
	Bottom	100	Infinite
Model #7	Top	100	3
	Middle	10	20
	Bottom	100	Infinite
Model #8	Top	1,000	10
	Bottom	10	Infinite
Model #9	Top	10	3
	Middle	100	20
	Bottom	10	Infinite
Model #10	Top	100	10
	Bottom	10	Infinite

*Model 1 considered in analysis, but generally excluded in presentation results

General System Analyzed

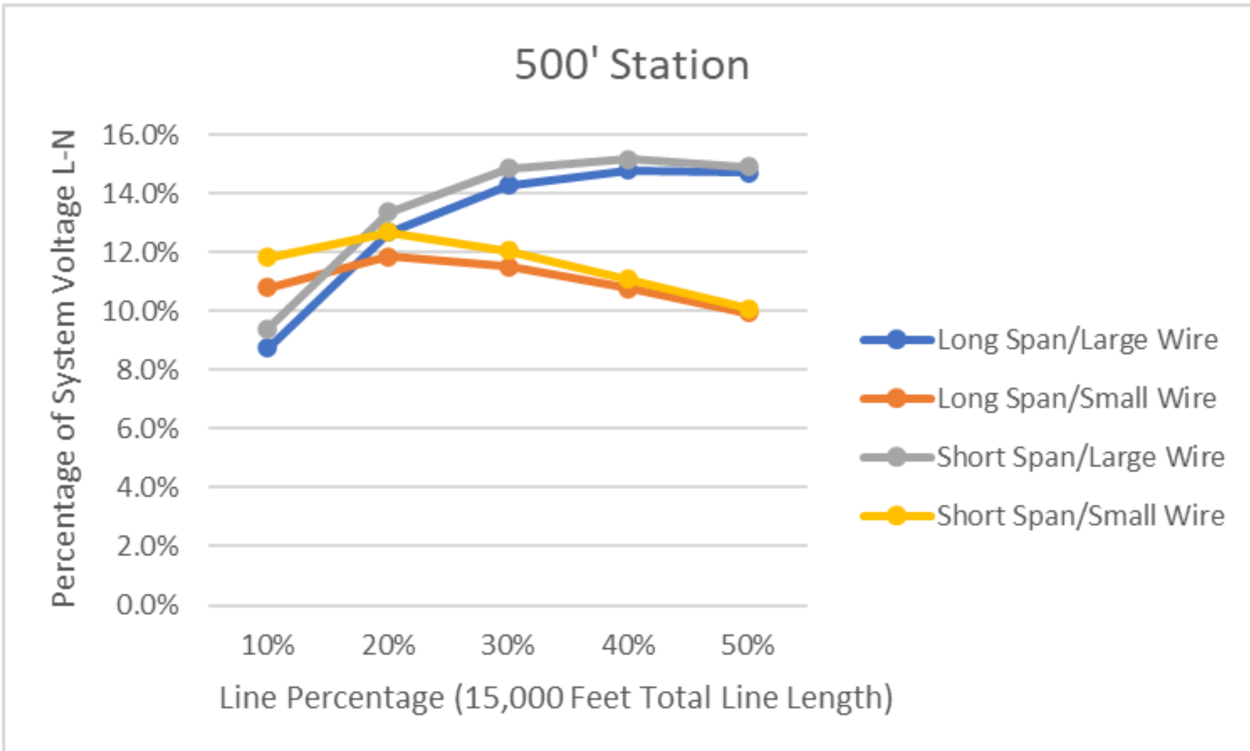


Analyzing Faults

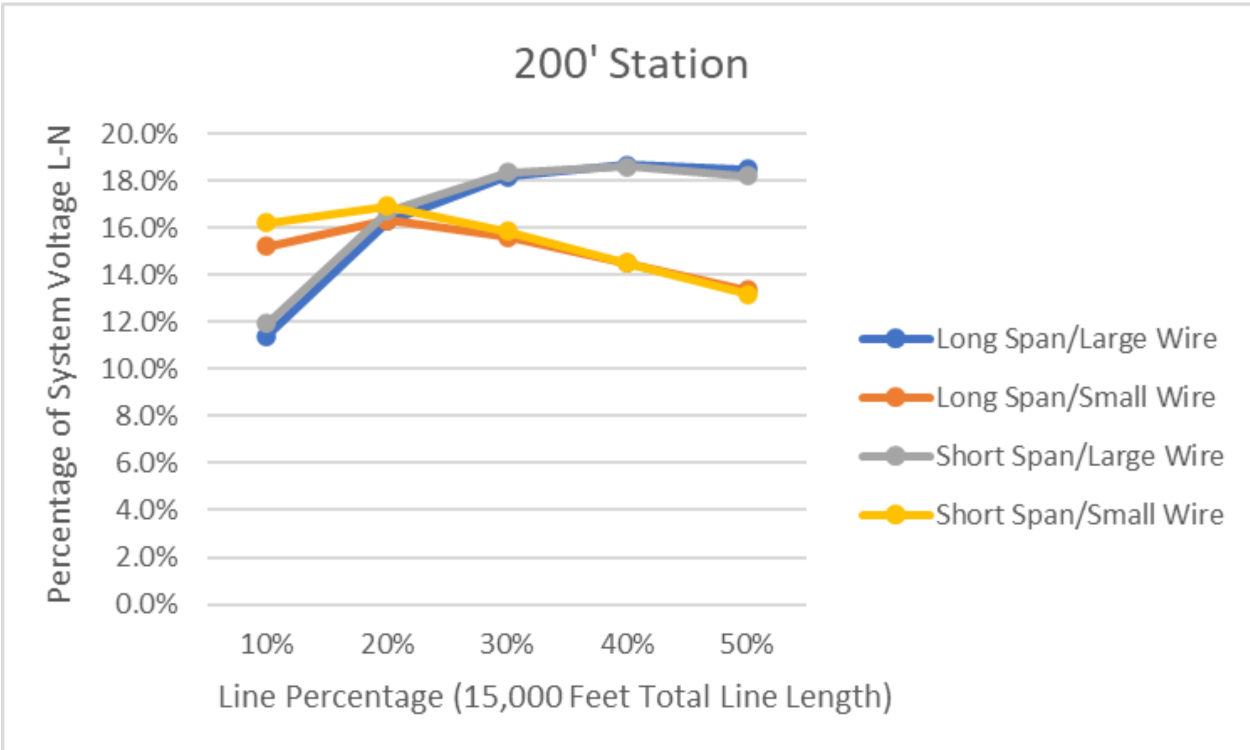
- 10 kV system voltage source applied at sub
  - 1 ohm system impedance (~15 MVA, 12.47 kV transformer at 7%)
  - Equals nominal 10 kA fault at the sub
  - Results are proportional to system voltage
- Line impedance (phase and neutral), pole ground, and earth path reduce current down the line
- Calculate GPR of substation

Results – Worst Soil

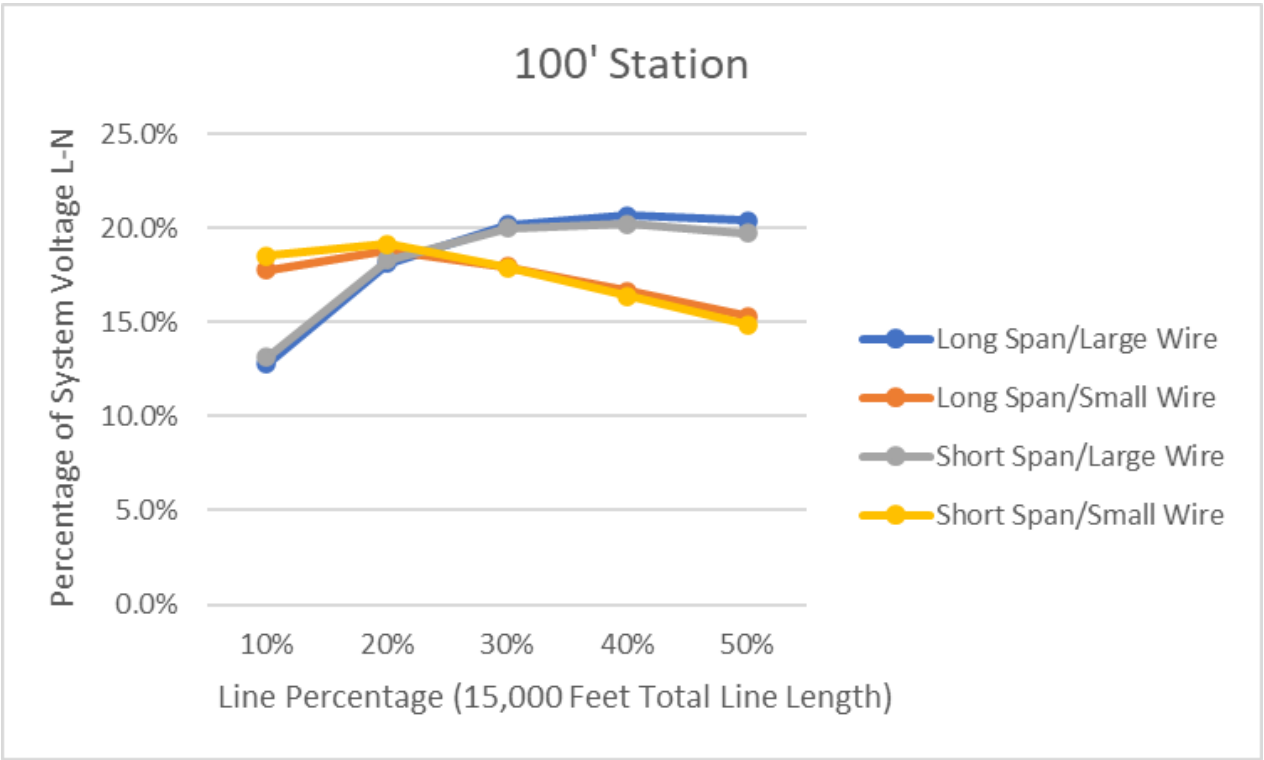
Large Substation Results



Medium Substation Results



Small Substation Results

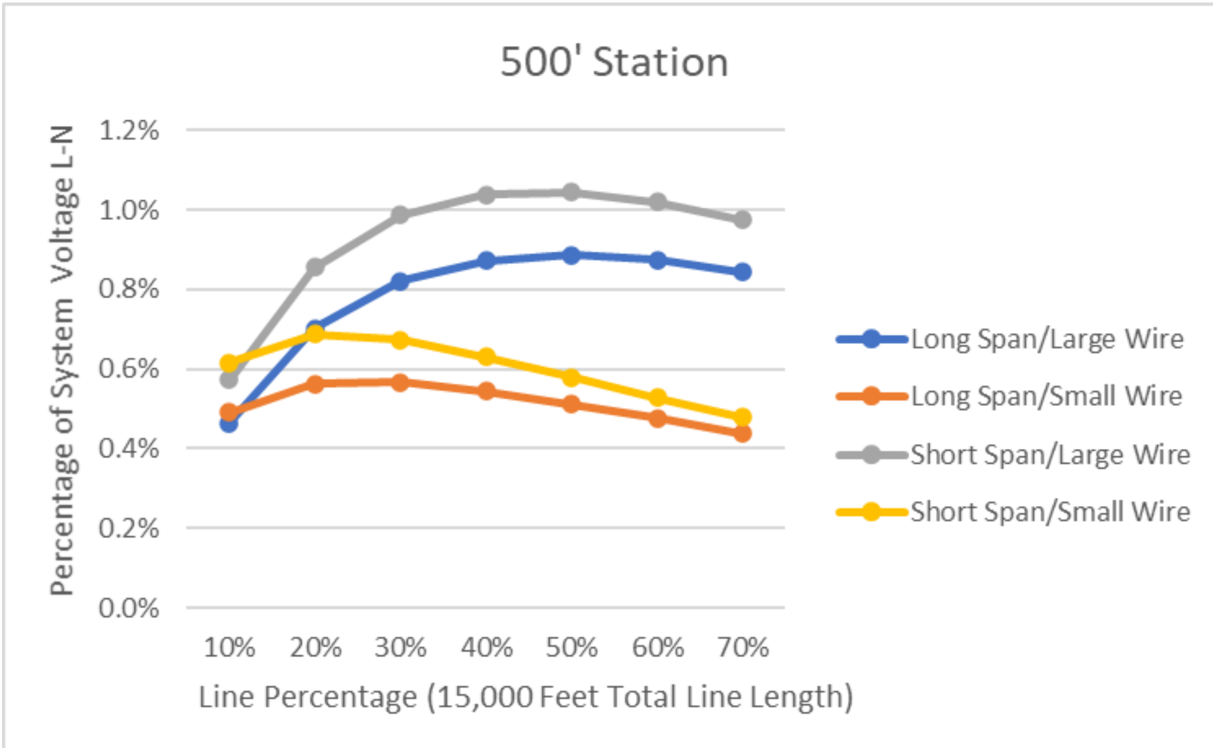


Worst Soil Summary

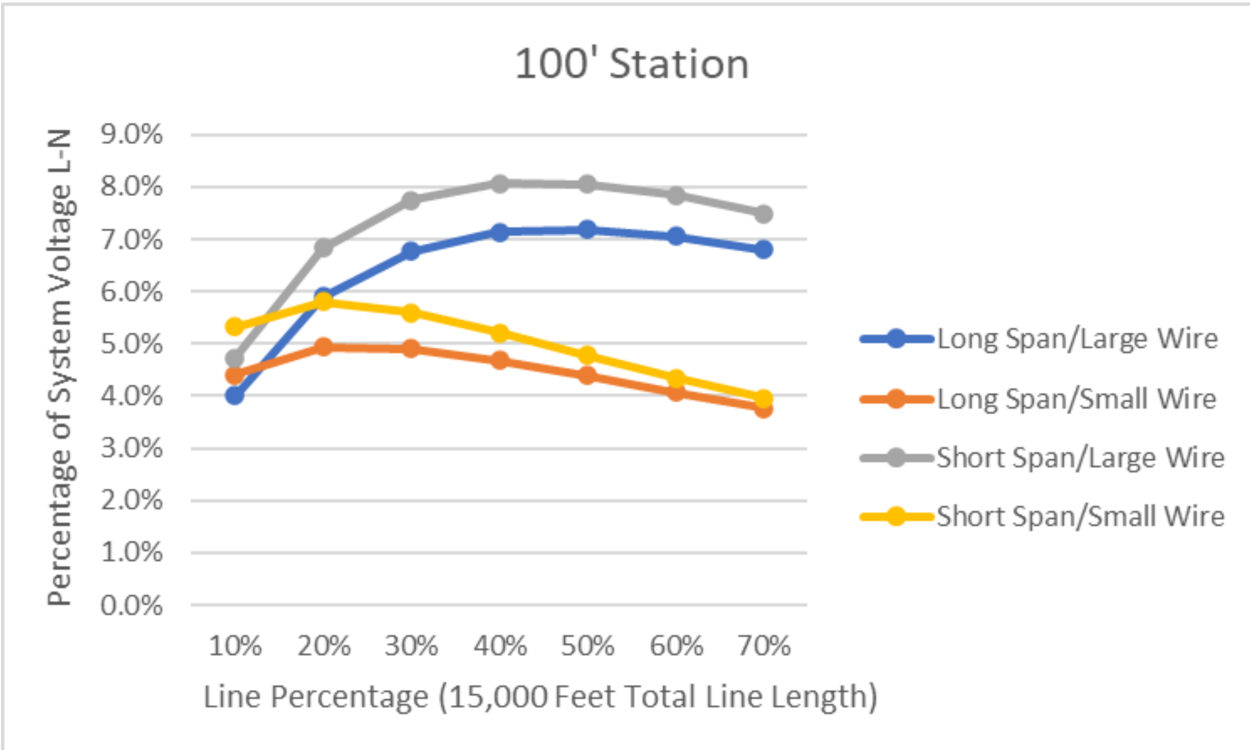
- GPR varies from about 15-20% of the system line-to-ground voltage
- For completeness, Soil Model #1 (Extreme case) peaked at ~25%
- Question: How much better can good soil be?

Results – Soil Impacts

Large Substation with Low Resistivity Soil



Small Substation with Low Resistivity Soil



Summary

- GPR for feeder faults varies from about 1-20% of the system line-to-ground voltage

- Refinement can be done for regional:
  - Soil considerations (biggest impact)
    - Higher resistivity is worse
  - Substation size (next biggest impact)
    - Smaller is worse
  - Typical distribution designs
    - Large wire, short spans are worse

Conclusions

Conclusion

- GPR varies from about 1-20% of the system line-to-ground voltage for distribution faults
  - Generally, substation GPR will be < 20% of system voltage for a fault on a multi-grounded neutral distribution system
    - Example: 12.47 kV delta-wye ground transformer
      - 12.47 kV / $\sqrt{3}$ * 20% = 1,440 V max GPR
      - If transmission GPR is significantly higher, easy to ignore distribution faults
  - Don’t forget clearing time though!

Questions?

Ryan Conger, Rob Schaerer, Josh Brown
POWER Engineers

Aaron Wilson, Xcel Energy

cigre United States

POWER ENGINEERS