HOW ACCURATE IS THE ZERO SEQUENCE IMPEDANCE ON YOUR TRANSMISSION LINES?

PRESENTED AT TEXAS A&M 74TH ANNUAL CONFERENCE FOR PROTECTIVE RELAY ENGINEERS

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OUTLINE

- Traditional methods for calculating transmission line impedance
- Testing of Transmission lines
- Test cases
- Results
- IEEE Standard 1870-2019
- Conclusion

MODELING METHODS

- Tower by Tower
  - More effort, but allows a unique record for each span and better precision
- Grouped
  - Lumps similar tower designs together to reduce effort, still accurate

PARAMETERS NEEDED TO CALCULATE LINE IMPEDANCE

- Soil resistivity (100 Ω-m if not known)
- Phase and Shield Conductors
- Conductor Spacing
- Tower Height
- Tower Spans
- Line Sag
- Conductor Temperature

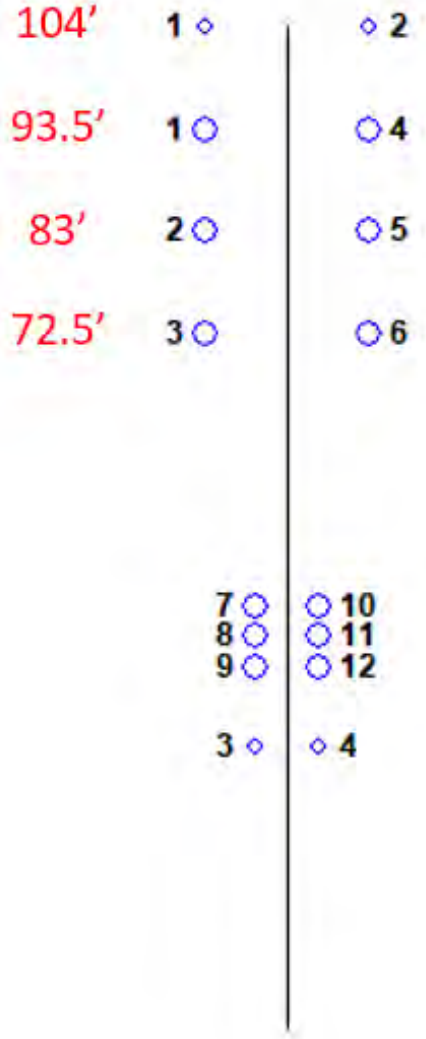
HOW UTILITIES TRADITIONALLY CALCULATE LINE IMPEDANCE

Transmission Modeling Software

- Disadvantages of this method
- Advantages of method

TYPICAL TRANSMISSION TOWER DESIGN

Double Circuit 230kV Transmission Tower w/ Distribution Underbuild



Coordinate Units: Feet

Phase Conductor Coordinates

Position	X	Y
1	-8.50	93.50
2	-8.50	83.00
3	-8.50	72.50
4	8.50	93.50
5	8.50	83.00
6	8.50	72.50
7	-3.25	44.50
8	-3.25	41.25
9	-3.25	38.00
10	3.25	44.50
11	3.25	41.25
12	3.25	38.00

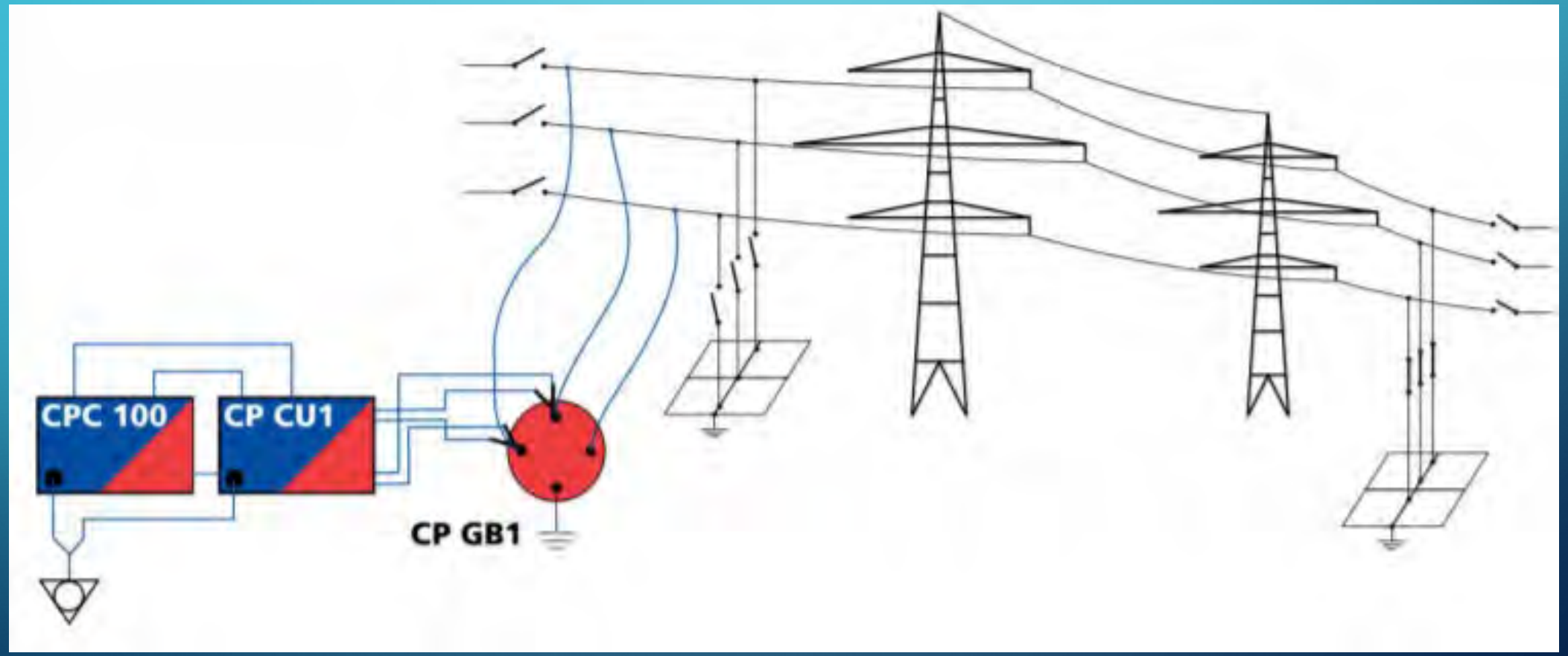
Neutral Conductor Coordinates

Position	X	Y
1	-8.50	104.00
2	8.50	104.00
3	-3.25	30.00
4	3.25	30.00

MEASURING TRANSMISSION LINE IMPEDANCE

- Benefits
  - Takes a couple of hours
  - Eliminates any error and is extremely accurate
- Costs
  - Ballpark of $40,000
  - The line has to be out of service
- Improvement in relay settings
  - Improves Zero sequence impedance and provides K-factor

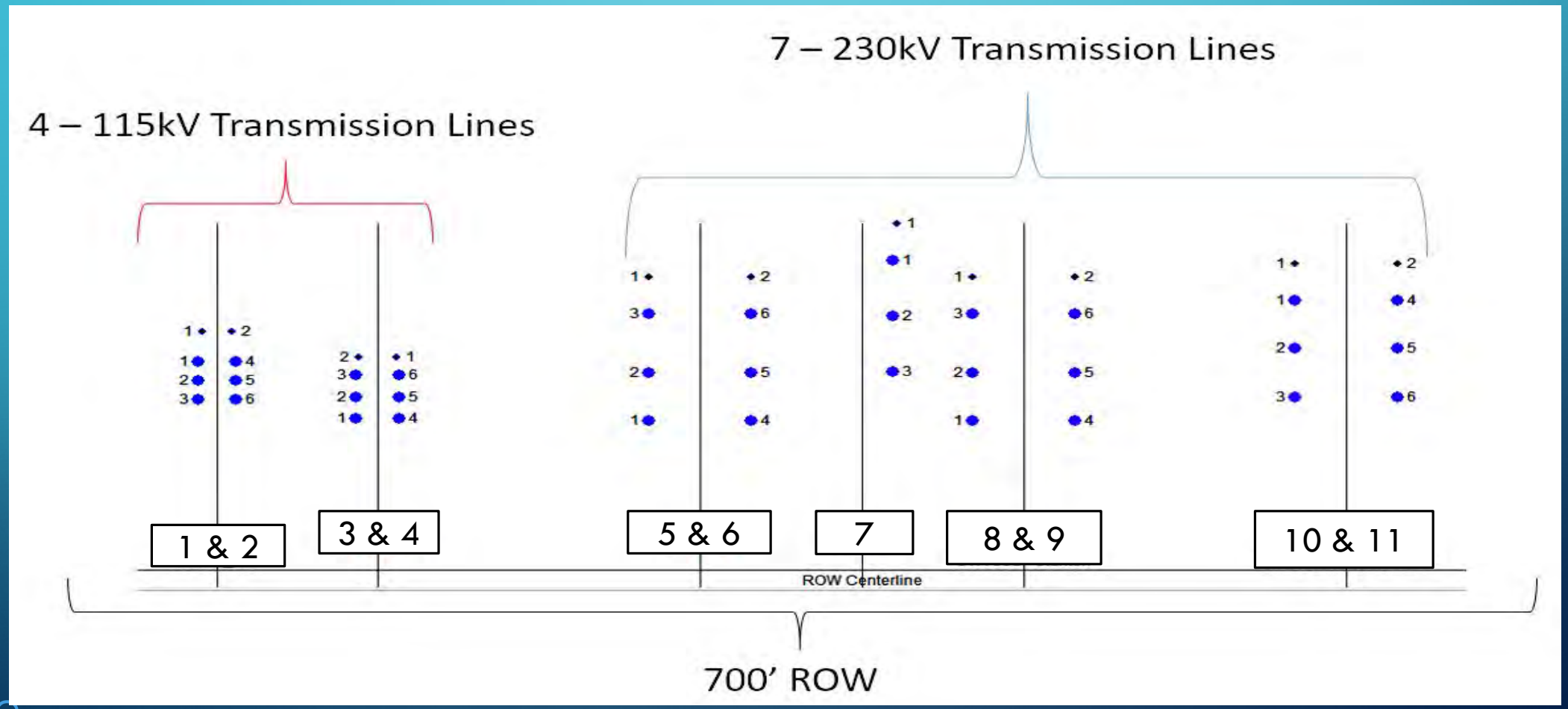
TESTING SETUP AND PROCEDURE



TEST CASES

- Congested Right of Way (ROW)
- Underground Cable sections
- Case 3

CONGESTED ROW



CONGESTED ROW RESULTS

Result	R [Ω]	X [Ω]	Z [Ω]	Phi (°)
Positive sequence impedance Z1	0.263	1.442	1.465	79.66°
Error	-8.28%	-0.67%	-0.95%	0.84°
Zero sequence impedance Z0	1.220	3.453	3.662	70.54
Error	-4.46%	-1.69%	-2.01%	0.52°

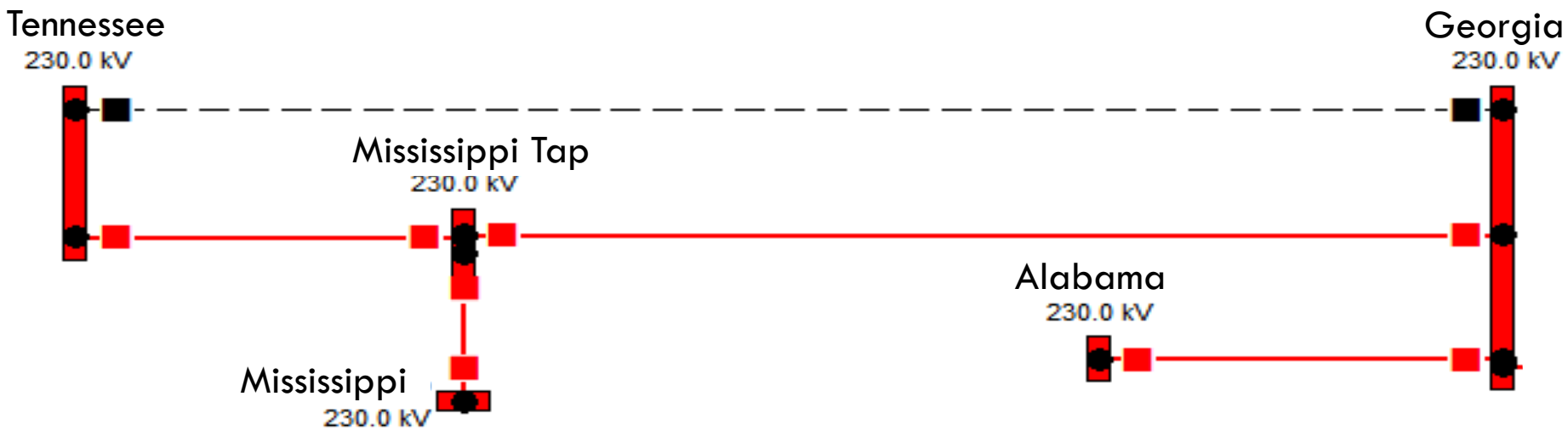
UNDERGROUND CABLE SECTION

- 11.5 mile long line
- 1 mile of underground cable
- Worked with cable manufacturer to obtain parameters and design
  - Modeled separately in cable modeling software
- The calculated vs. measured zero sequence impedance was less than 5% off, within customer margin

UNDERGROUND CABLE SECTION RESULTS

Result	R [Ω]	X [Ω]	Z [Ω]	Phi (°)
Positive sequence impedance Z1	0.199	1.526	1.539	82.55°
Error	-0.72%	0.02%	0.00%	0.07°
Zero sequence impedance Z0	1.111	4.836	4.668	76.14°
Error	-10.68%	-4.58%	-4.95%	0.82°

CASE 3 LAYOUT



CASE 3 RESULTS

- Field measured impedance

Result	R [Ω]	X [Ω]	Z [Ω]	Phi (°)
Positive sequence impedance Z1	0.773	5.769	5.821	82.37°
Zero sequence impedance Z0	4.052	13.267	13.872	73.02°

- Calculated impedance with % error

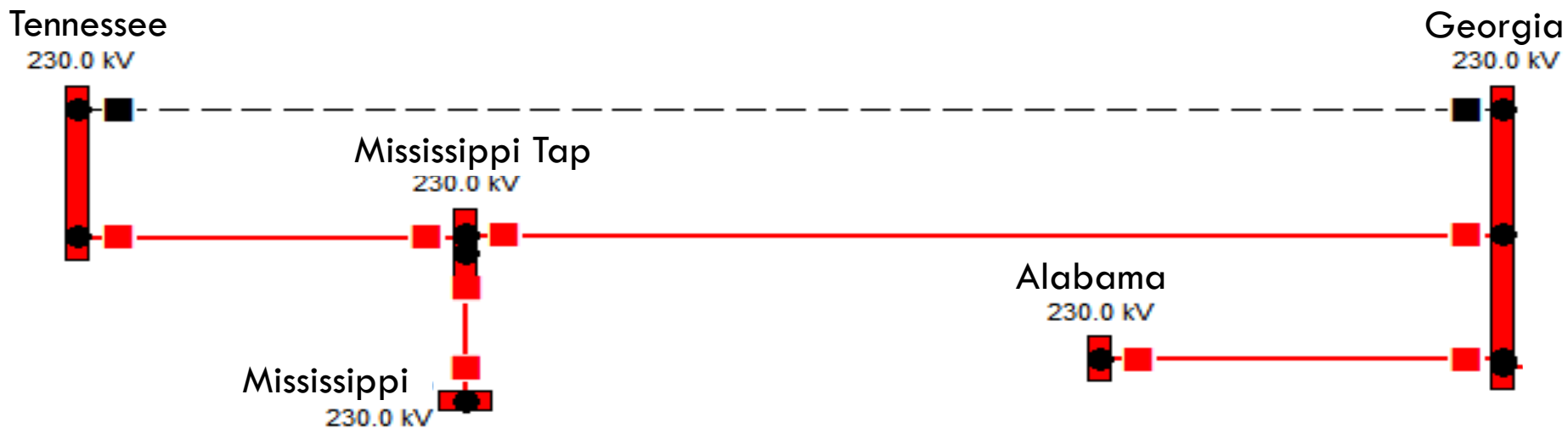
Result	R [Ω]	X [Ω]	Z [Ω]	Phi (°)
Positive sequence impedance Z1	0.772	5.946	5.996	82.60°
Error	-0.08%	3.06%	3.01%	0.23°
Zero sequence impedance Z0	3.973	15.627	16.124	75.74°
Error	-1.96%	17.78%	**16.23%**	2.72°

CASE 3 PROBLEM SOLVING

What was the cause for such large error?

- Wrong conductor?
- Wrong temperature?
- Large gas pipeline running in parallel?
- Soil resistivity that far off?
- Modeling error?

CASE 3 - DISTRIBUTION UNDERBUILD



DISTRIBUTION UNDERBUILD CONT.

- The 25KV distribution lines were owned by a neighboring utility
- The measured vs. calculated was almost 20% off for the zero sequence impedance
- How many lines out there on the BES have distribution underbuild not accounted for?

DISTRIBUTION UNDERBUILD RESULTS

- Field measured Impedance

Result	R [Ω]	X [Ω]	Z [Ω]	Phi (°)
Positive sequence impedance Z1	0.773	5.769	5.821	82.37°
Zero sequence impedance Z0	4.052	13.267	13.872	73.02°

- Corrected calculated impedance with % error

Result	R [Ω]	X [Ω]	Z [Ω]	Phi (°)
Positive sequence impedance Z1	0.762	5.777	5.827	82.49°
Error	-1.42%	0.14%	0.10%	0.15%
Zero sequence impedance Z0	3.678	13.171	13.675	74.40°
Error	-9.23%	-0.72%	-1.42%	1.89%

IEEE STANDARD 1870-2019

GUIDE FOR THE PARAMETER MEASUREMENT OF AC TRANSMISSION LINES

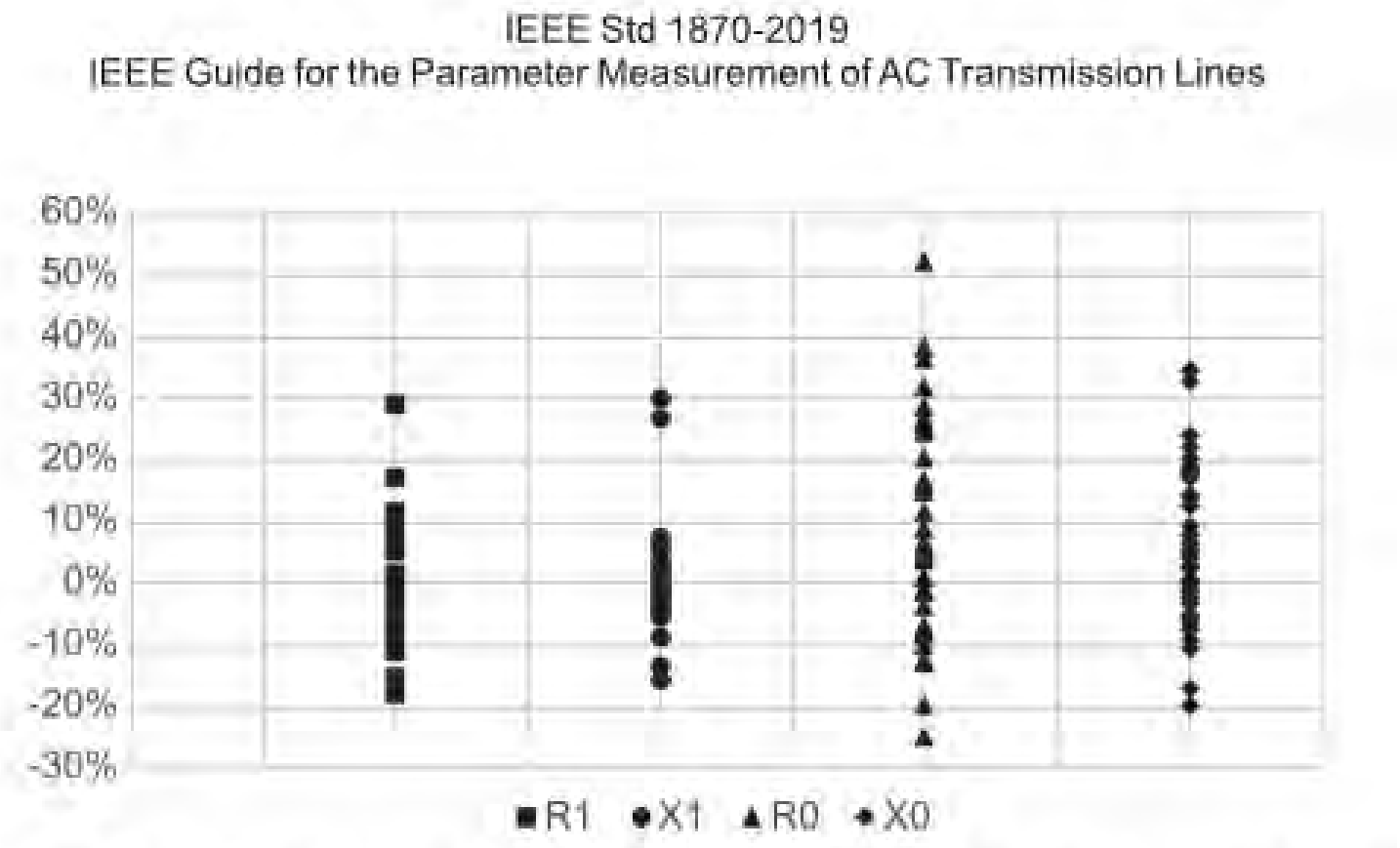


Figure 1—Deviation between measured and calculated values

IEEE STANDARD 1870-2019 CONT.

GUIDE FOR THE PARAMETER MEASUREMENT OF AC TRANSMISSION LINES

Table 1—Error calculation between measured and calculated values

Error calculation				
	Z_1		Z_0	
	R in Ω	*X* in Ω	*R* in Ω	*X* in Ω
Measured value	0.722	1.938	1.095	5.067
Calculated value	0.740	1.940	1.450	8.500
Error (ref. to measured value) in %	2.54	0.09	32.42	67.75

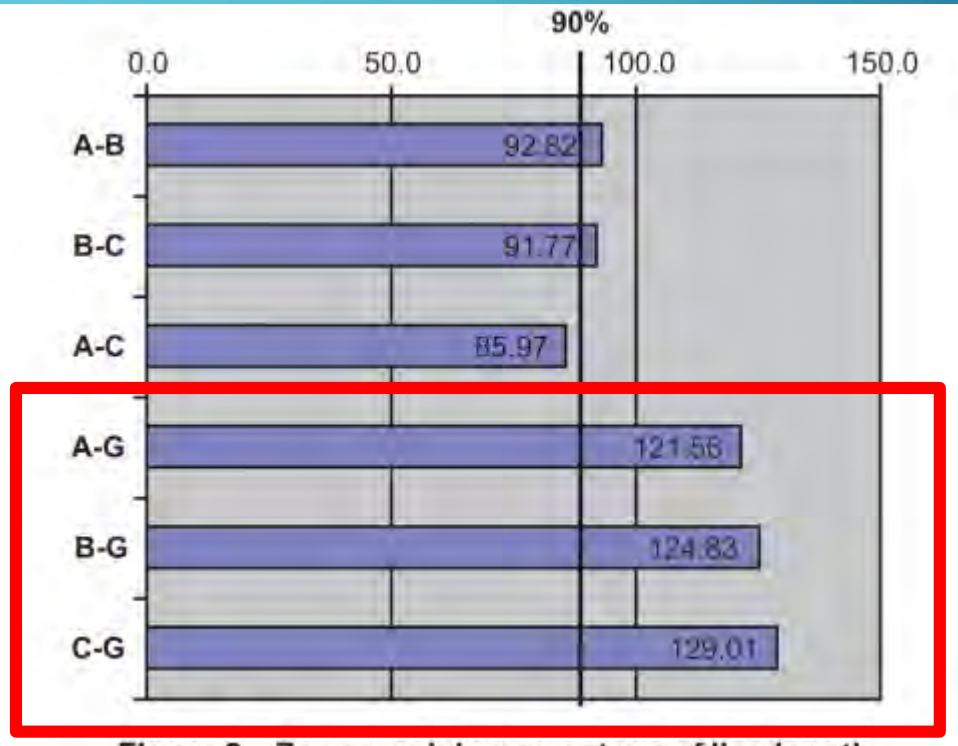


Figure 2—Zone reach in percentage of line length

CONCLUSION

- Should you be measuring your transmission lines?
- Could measuring line impedance improve your relaying?
- Does it save time?

QUESTIONS?

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