2015 PES Annual Meeting

Lightning WG Meeting – Update to:

Panel Paper 2010TD0683: Grounding of Overhead Transmission Lines

William A. (Bill) Chisholm
Kinectrics / UQAC
W.A.Chisholm@ieee.org

Emanuel Petrache, Kinectrics

Fabio Bologna, EPRI

KINECTRICS

Experts Teaching from Practical Experience

2010 IEEE T&D Expo
Panel Session on Lightning Performance of Overhead Lines

How Grounding Affects Overhead Groundwire (OHGW) Protection

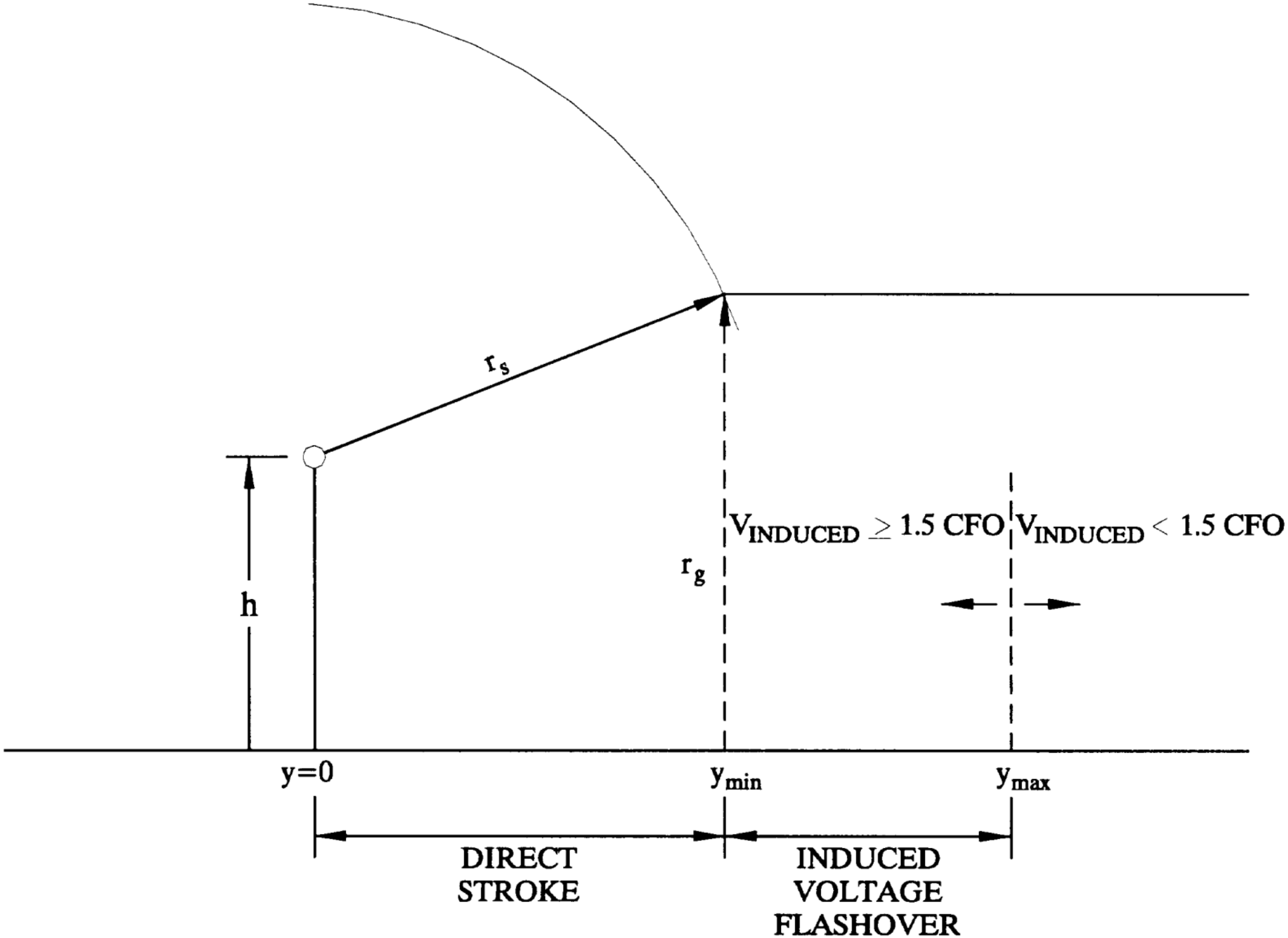
KINECTRICS

Experts Teaching from Practical Experience

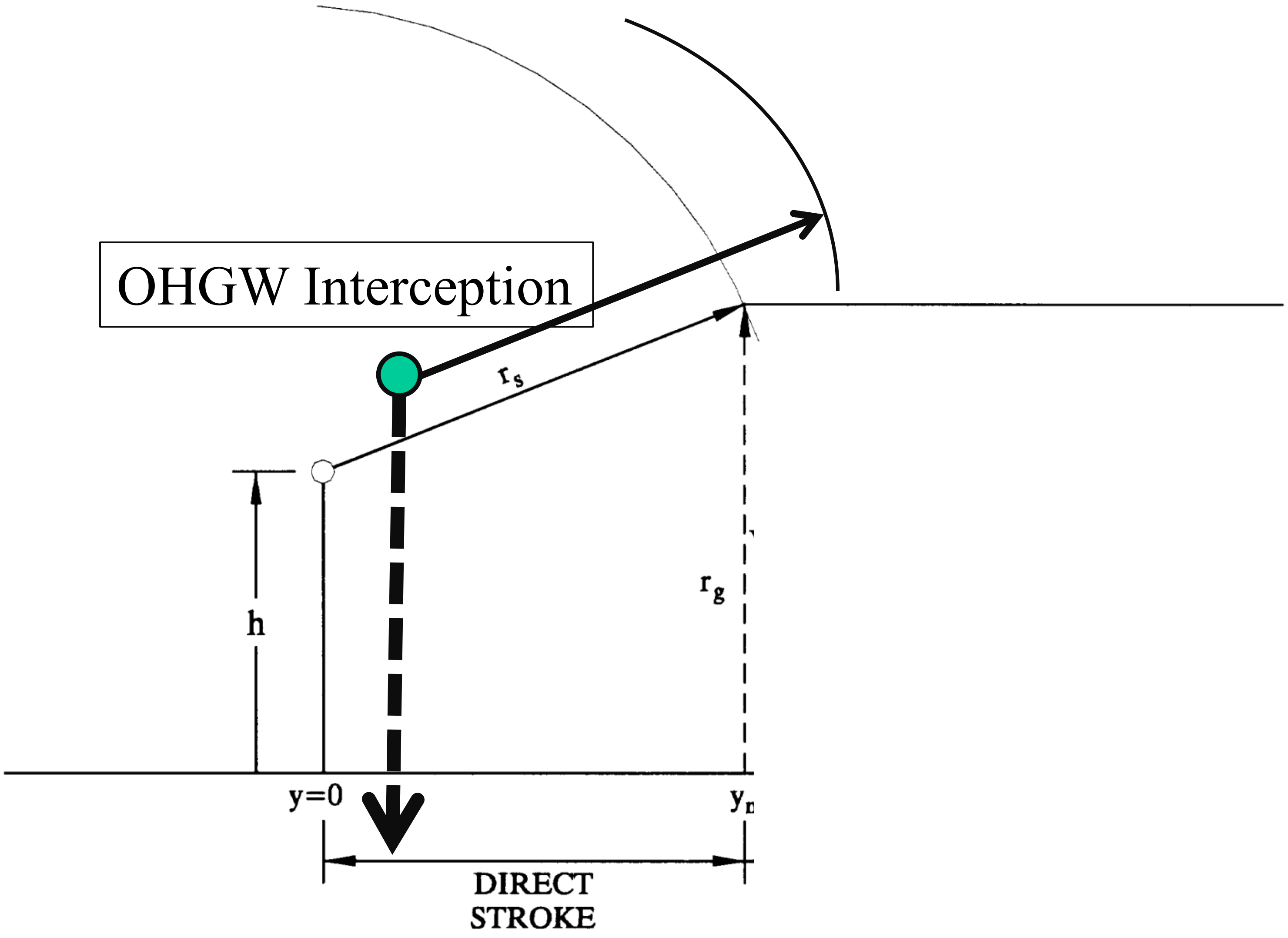
Dealing with Lightning Challenges

- Direct Stroke Termination
  - Directly to the unshielded line
  - To ground or an object near the line
- Grounding of the Stroke Current
  - Into Normal Soil
  - Across surface of High-Resistivity Soil
- Equalization of Potentials
  - Electromagnetic coupling
  - Surge arresters

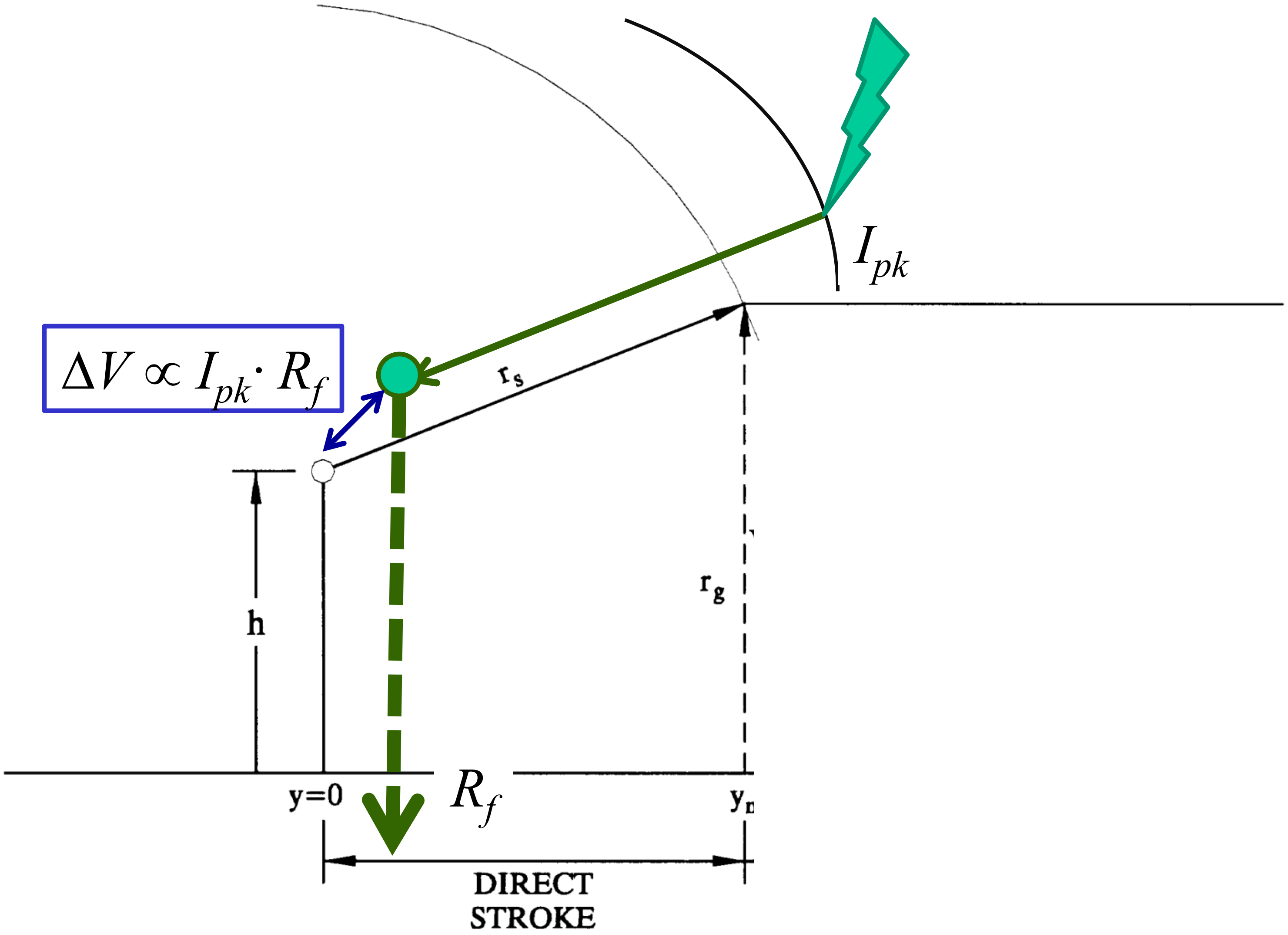
Stroke Incidence – Side View



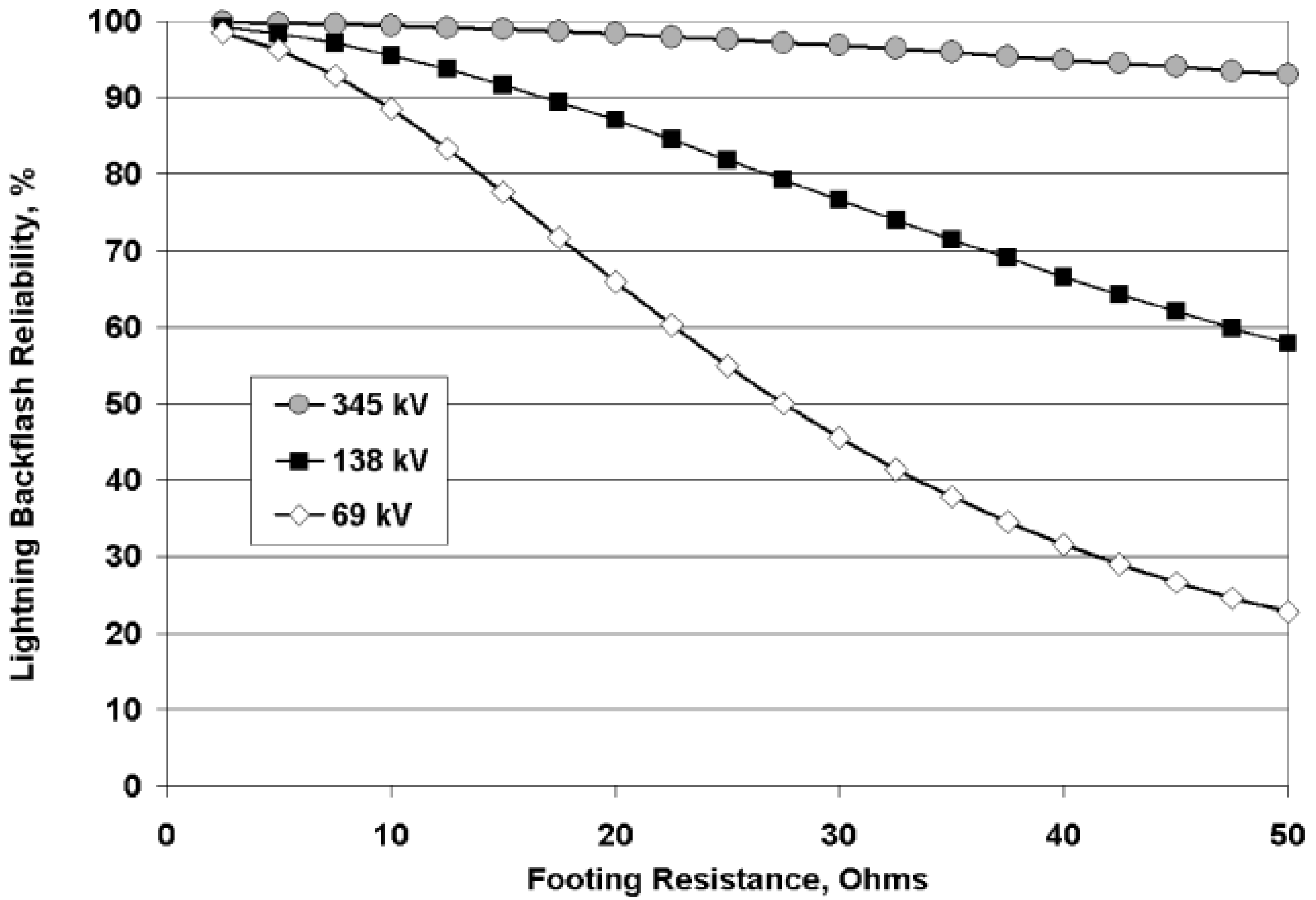
Stroke Incidence – Side View



Stroke Incidence – Side View



Effectiveness of OHGW



W.A. Chisholm and J.G. Anderson, "Guide for Transmission Line Grounding: A Roadmap for Design, Testing, and Remediation", EPRI, Palo Alto, CA: 2004. 1002021. Available: mydocs.epri.com/docs/public

2010 IEEE T&D Expo
Panel Session on Lightning
Performance of Overhead Lines

Calculating Low Frequency Resistance R_f using the "Chiz-Whiz" Method

KINECTRICS

Experts Teaching from Practical Experience

Geometric and Contact Resistance

- **Grounding of the Stroke Current**
  - **Into Normal Soil of Resistivity ρ (Ωm)**
  - **Split into "Geometric" and "Contact" Resistance**
  - **Solid Disc, Ring have:**
    - ***SAME* Geometric Resistance**
    - ***DIFFERENT* Contact Resistance (Disc $R_{contact} \approx 0$)**

$$R_{Geometric} + R_{Contact} = \frac{\rho}{2\pi}\left(\frac{1}{g}\ln\left(\frac{11.8g^2}{A}\right) + \frac{1}{L}\ln\left(\frac{A}{F \cdot A_{Wire}}\right)\right)$$

Geometric and Contact Resistance

Resistivity (local soil near tower)

$$R_{Geometric} + R_{Contact} = \frac{\square}{2\pi}\left(\frac{1}{g}\ln\left(\frac{11.8g^2}{A}\right) + \frac{1}{L}\ln\left(\frac{A}{F \cdot A_{Wire}}\right)\right)$$

Geometric and Contact Resistance

Size (geometric radius)

$$R_{Geometric} + R_{Contact} = \frac{\rho}{2\pi}\left(\quad \ln\left(\frac{11.8g^2}{A}\right) + \frac{1}{L}\ln\left(\frac{A}{F \cdot A_{Wire}}\right)\right)$$

Geometric and Contact Resistance

Shape Factor, pointy = larger

$$R_{Geometric} + R_{Contact} = \frac{\rho}{2\pi}\left(\frac{1}{g} \quad + \frac{1}{L}\ln\left(\frac{A}{F \cdot A_{Wire}}\right)\right)$$

Geometric and Contact Resistance

Length of wire

$$R_{Geometric} + R_{Contact} = \frac{\rho}{2\pi}\left(\frac{1}{g}\ln\left(\frac{11.8g^{2}}{A}\right) + \boxed{}\ \ln\left(\frac{A}{F \cdot A_{Wire}}\right)\right)$$

Geometric and Contact Resistance

Fill Factor ($F \cong 2$)

$$R_{Geometric} + R_{Contact} = \frac{\rho}{2\pi}\left(\frac{1}{g}\ln\left(\frac{11.8g^2}{A}\right) + \frac{1}{L} \qquad \right)$$

Geometric and Contact Resistance

- **Invited paper for Industry Applications, 2015**

Evaluation of Simple Models for the Resistance of Solid and Wire-Frame Electrodes

William A. Chisholm, *Fellow, IEEE*

***Abstract*—A single, simplified, and general model for the resistance of solid or wire-frame electrodes offers insight into the performance improvements that can be expected when additional electrode components are added in parallel. This model separates the geometric and contact resistance terms $R_{\text{Geometric}}$ and R_{Contact}. For solid and wire-frame electrodes, $R_{\text{Geometric}}$ depends on the geometric radius and the overall surface area. For solid electrodes, R_{Contact} = zero; however, for wire-frame approximations, it depends on the ratio of overall to wire surface area. The simple model incorporates the effects of depth of burial and wire radius to give remarkably good estimates of resistance, as compared to reference calculations, and can be used to identify weakness in many traditional expressions when used outside their conditions of derivation.**

***Index Terms*—Electrode, grounding, soil resistivity, wire frame.**

ning surge conditions, increasing the current above a critical level causes the expansion of a zone of ionization, which is initially cylindrical around a vertical rod but then expands to a cylindrically symmetric half-ellipse, then a hemisphere.

The general expression for geometric resistance [6] proved to be useful in approximate calculation of the resistance of transmission tower ground electrodes consisting of four large piers in close proximity. IEEE Standard 1243/1997 [7] applied a box approximation to the overall electrode, giving a geometric resistance of

$$R_{\text{Geometric}} = \frac{\rho}{2\pi s} \ln\left(\frac{2\pi e s^2}{A}\right) \qquad (1)$$

Geometric and Contact Resistance

- **Worked example shows problem with *n* rods in a row formula**

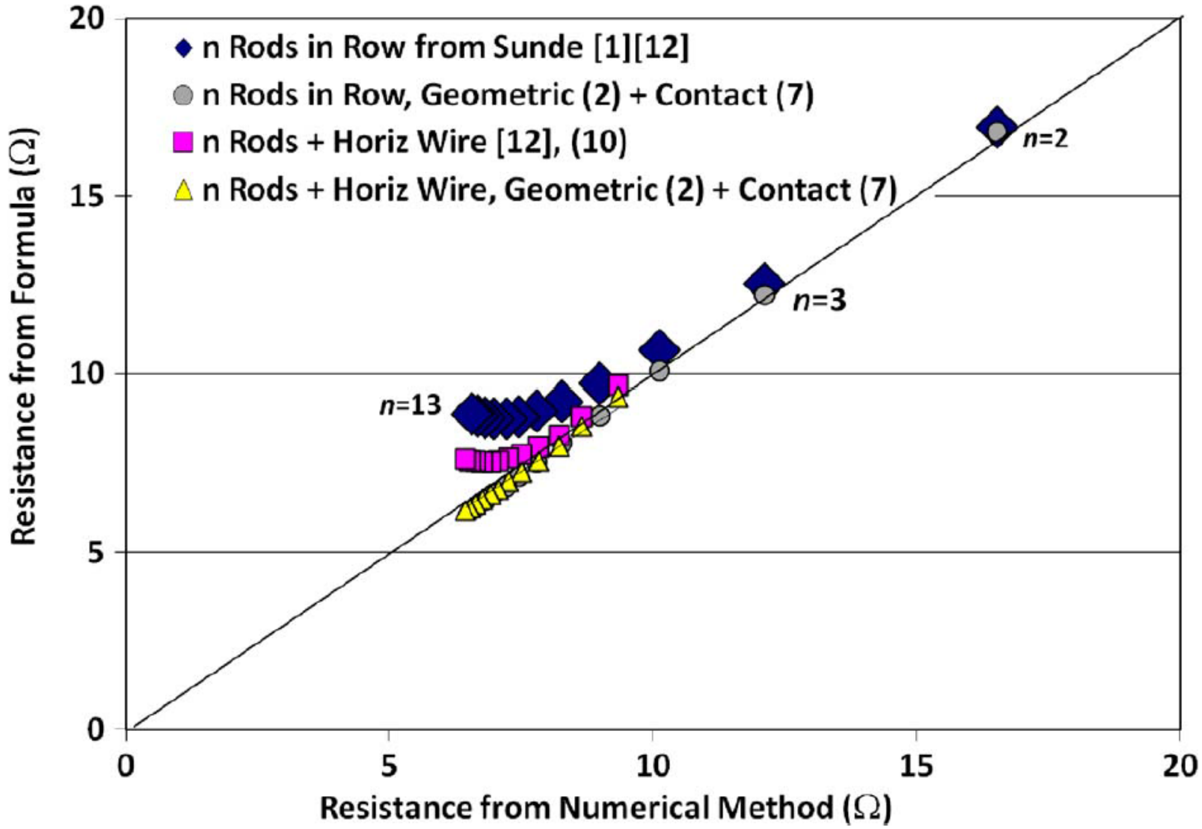


Fig. 4. Validation of the IEC/Sunde model [14] and the general resistance model (2) and (7) against the numerical reference method for rods in a row with connecting bare horizontal wire.

2015 IEEE PES Annual Meeting

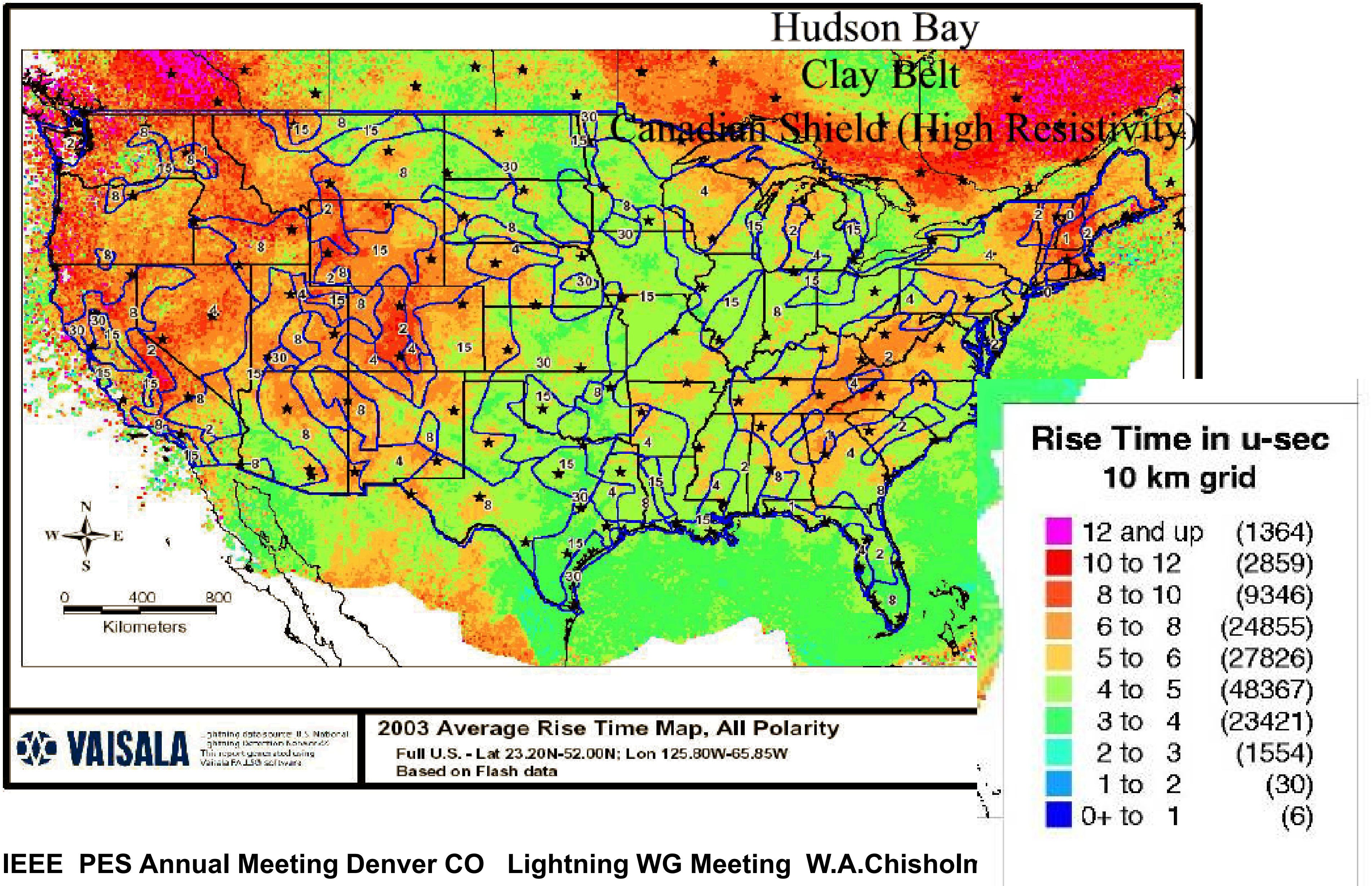
Lightning Working Group

Changes in Resistivity: Region to Region, Tower to Tower

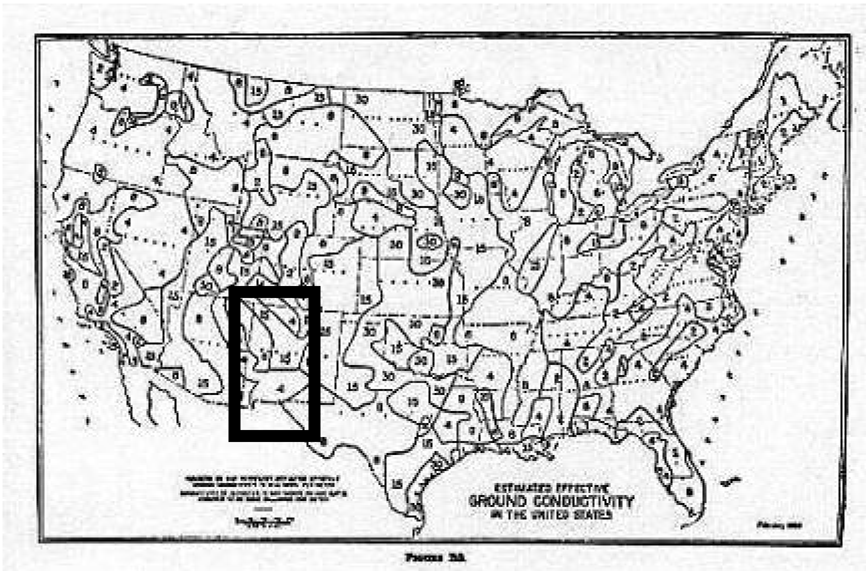
KINECTRICS

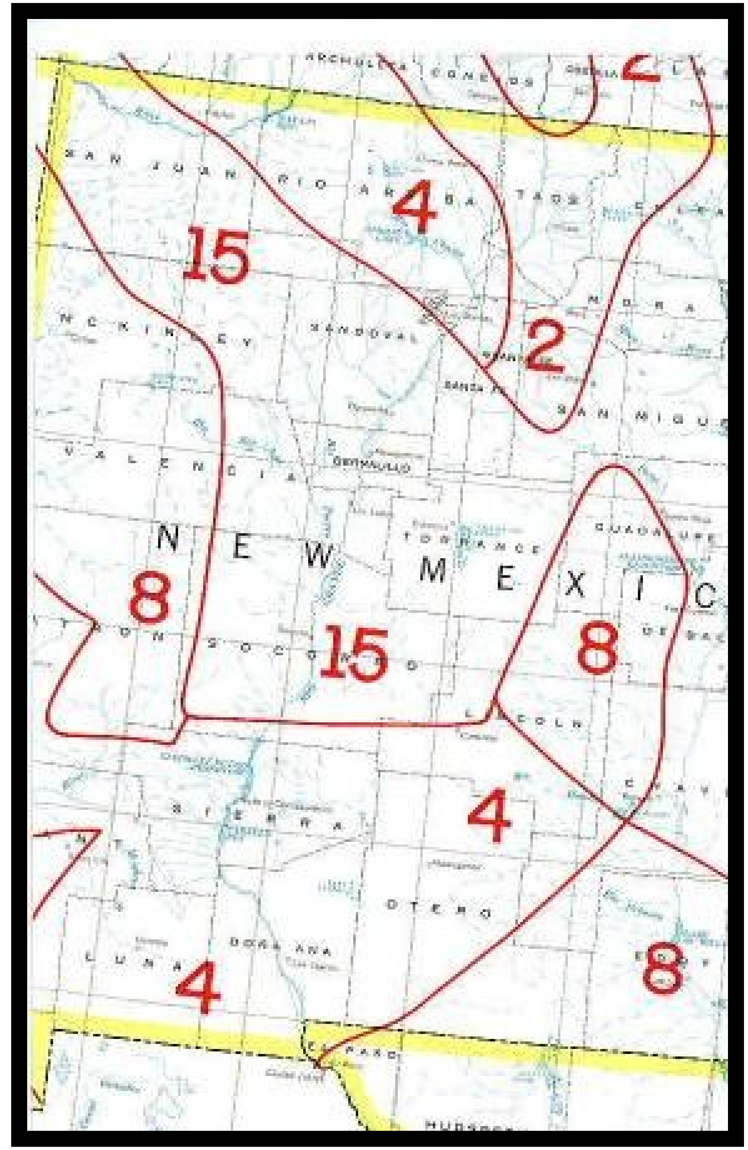
Experts Teaching from Practical Experience

Rise Time Maps Ground Resistivity



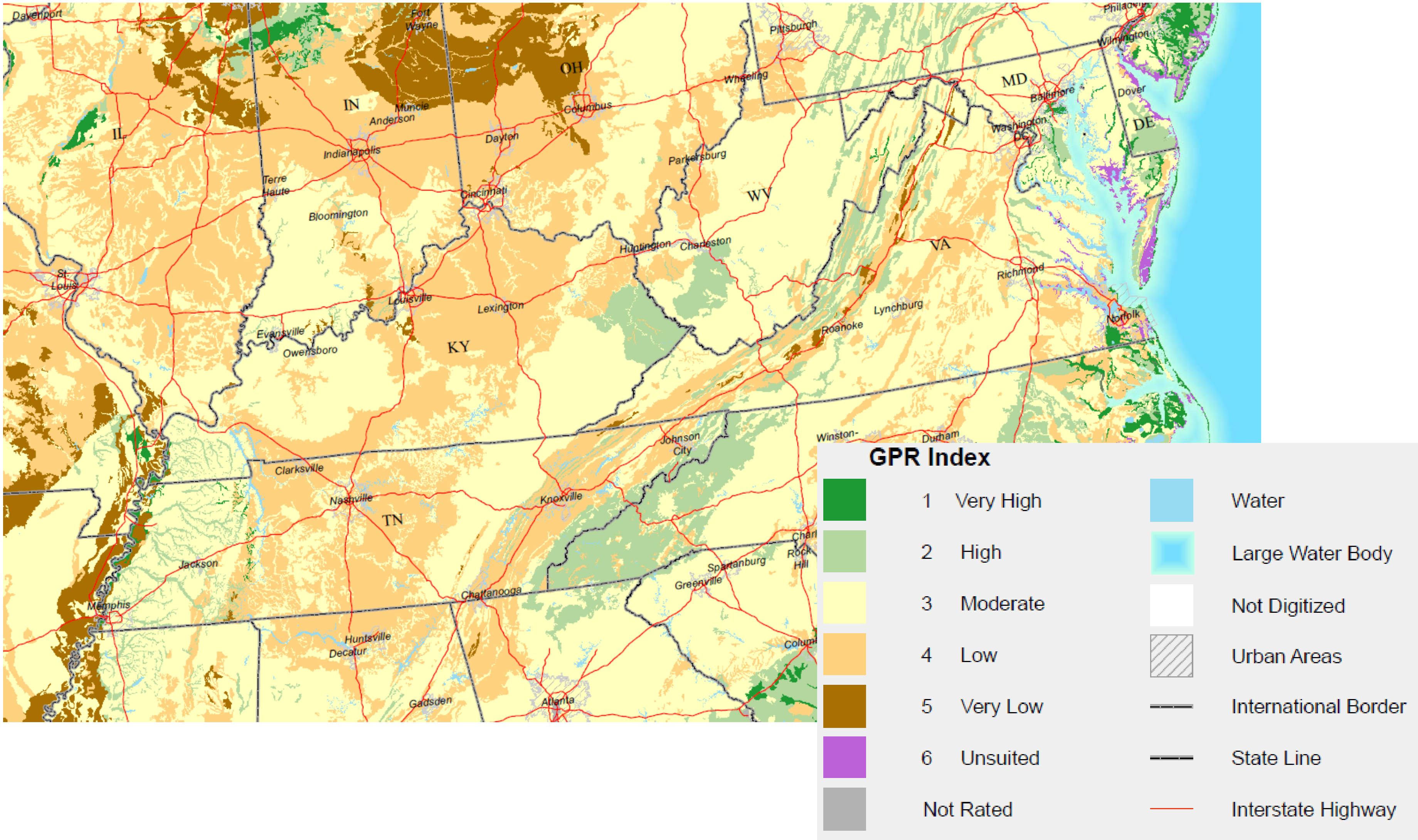
FCC M3 Conductivity Map





2 mS/m = 500 Ωm
4 mS/m = 250 Ωm
8 mS/m = 125 Ωm
15 mS/m = 67 Ωm

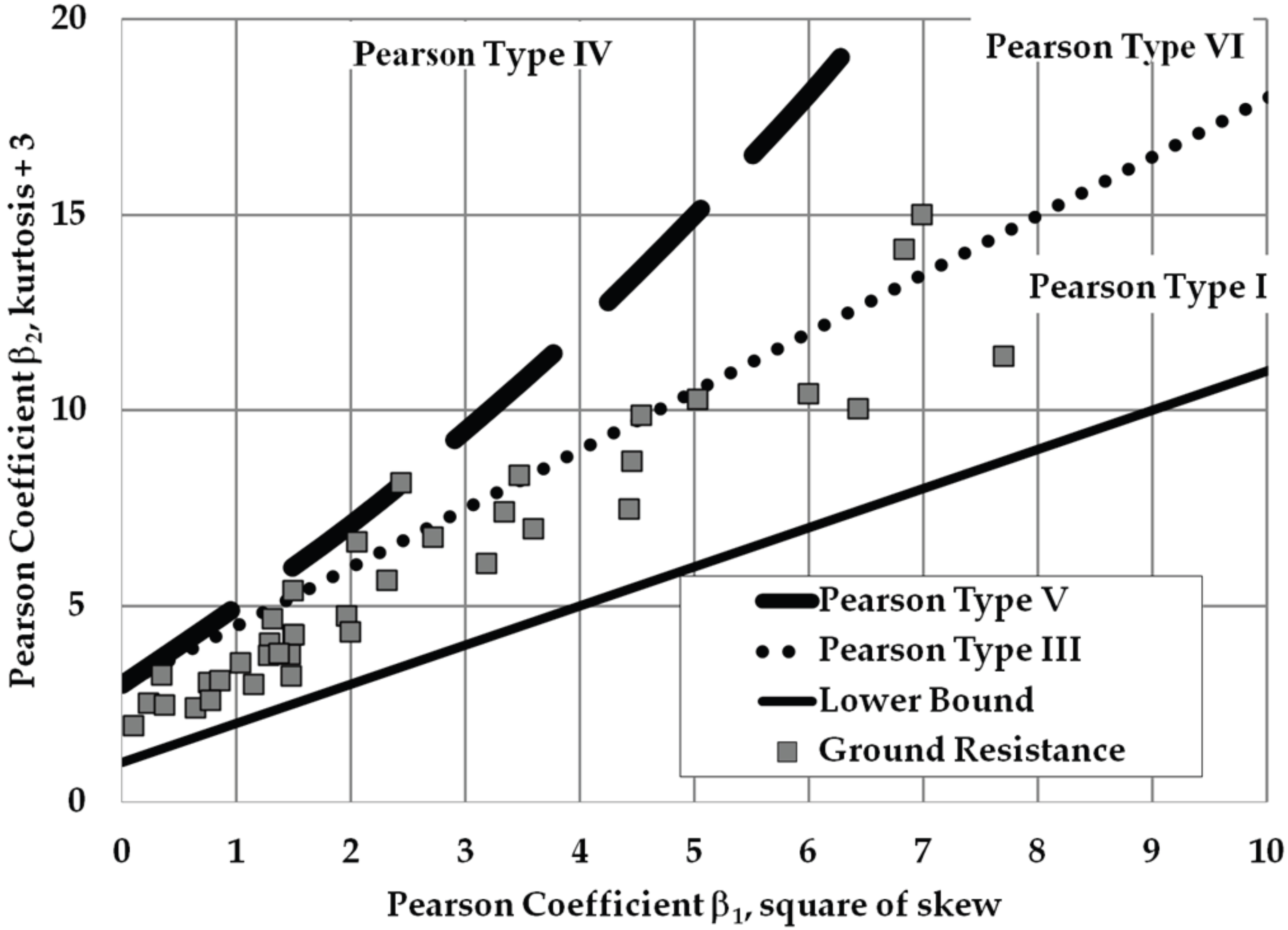
Soil Suitability for Ground Penetrating Radar



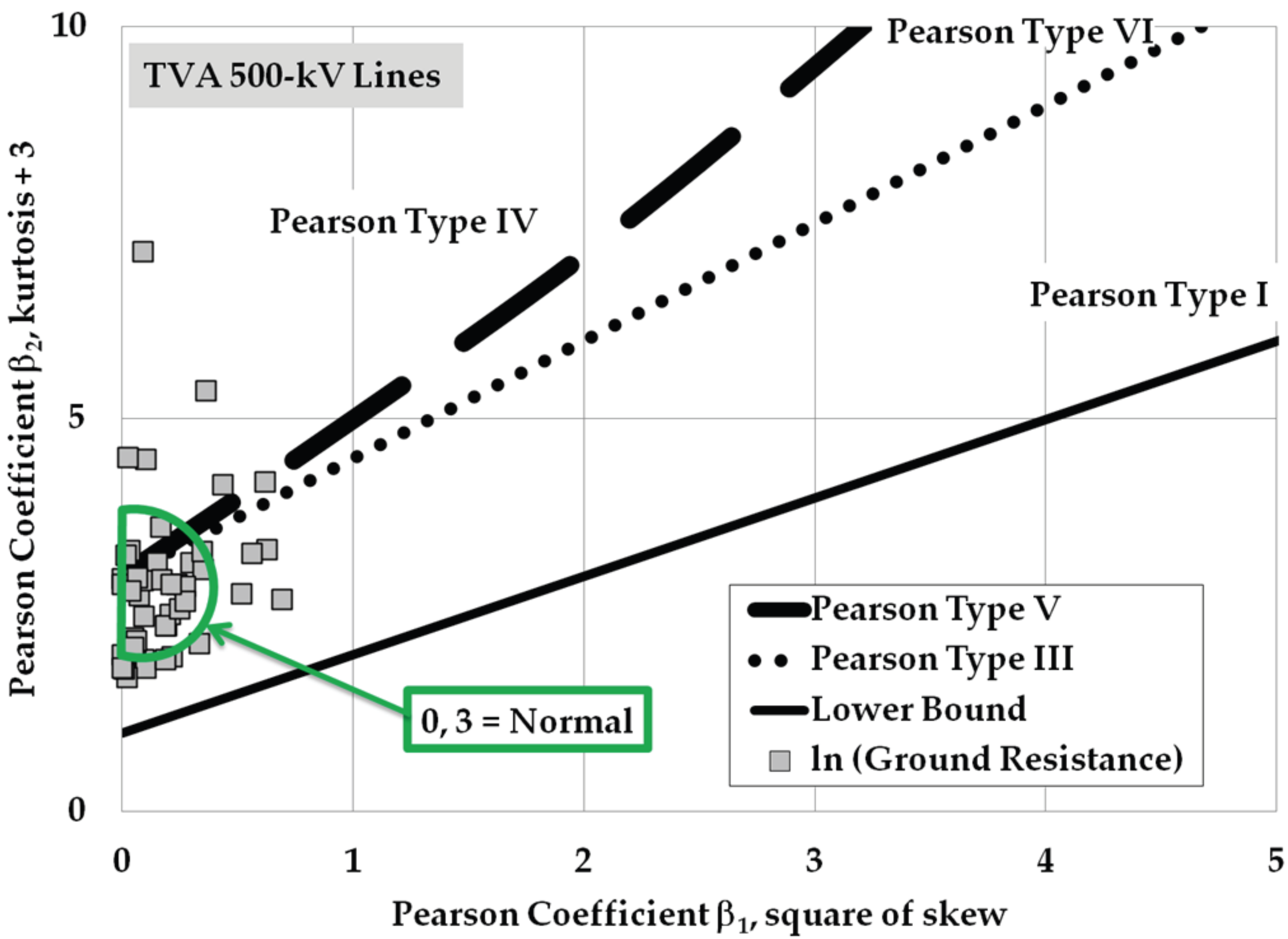
Footing Resistance Statistics

- **TVA carried out 10,600 measurements of tower footing resistance in early 1990s.**
  - **500-kV towers had insulated overhead groundwires.**
  - **For the most part, untreated with expectation that $R_f < 40\ \Omega$.**
  - **Analyzed with Pearson Classification.**

Pearson Classification, TVA Lines, R_f



Pearson Classification, TVA Lines, ln R_f



Recent Work in Portugal

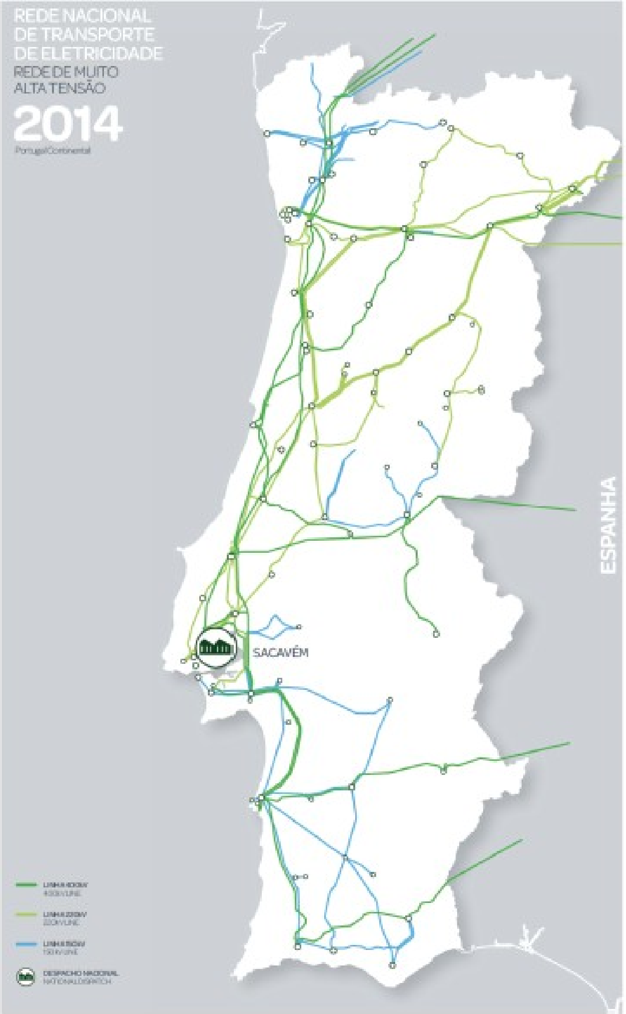
- **Campaign to test grounding of 150-kV, 220-kV and 400-kV Footing Resistance**
  - **Made use of ABB 26-kHz meter**
  - **Summarized by Susana de Almeida de Graaff**

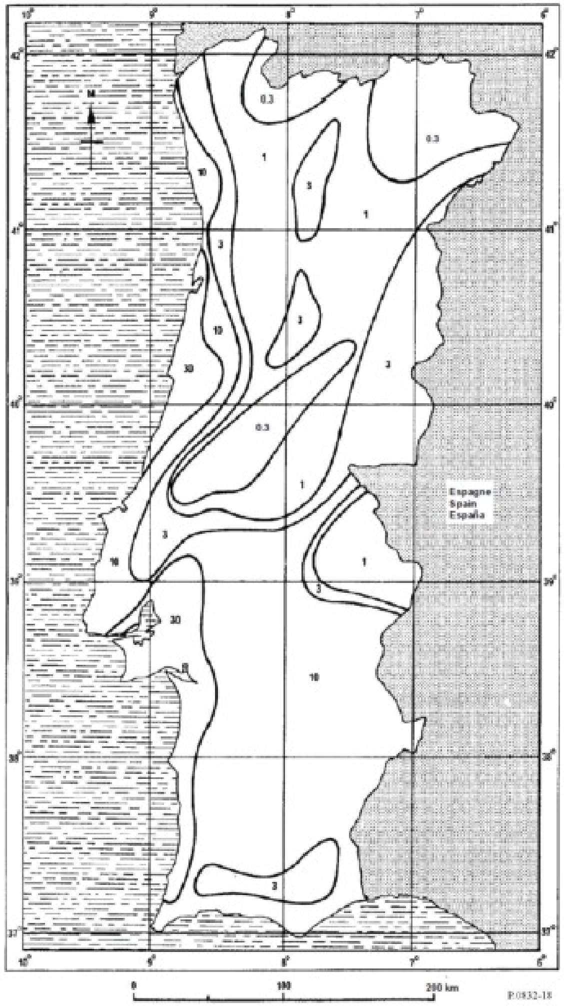
Invited Papers

PREDICTION OF FAULTS CAUSED BY LIGHTNING FOR TRANSMISSION SYSTEM OPERATIONS

SUSANA A. B. DE ALMEIDA[1,2], C.S. ENGELBRECHT[4], RUI PESTANA[1], F. P. MACIEL BARBOSA[2,3]

Portugal: REN Lines, ITU Conductivity (mS/m)





Recent Comparison Work

- **Measurements corrected for overhead groundwire connection to adjacent structures**
- **TVA and REN data evaluated in similar ways**

Voltage	Lines	Towers	Footing Resistance R_f (Ω)			
			Median	*Std. Dev*	*Skew*	*Kurtosis*
150 kV	53	4840	12.3	74.2	10.2	229
220 kV	60	5941	20.0	39.7	4.0	25.6
400 kV	23	3052	11.0	37.5	3.3	12.5

Voltage	Lines	Towers	ln (Footing Resistance R_f ,Ω)			
			Median	*Std. Dev*	*Skew*	*Kurtosis*
150 kV	53	4840	12.3	1.22	0.50	0.06
220 kV	60	5941	20.0	0.96	0.04	0.11
400 kV	23	3052	11.0	1.18	0.02	0.61

Recent Comparison Work

- **REN reported median 18.2 Ω and $\sigma_{\ln R_f}$ = 1.05 on a system-wide basis.**
- **TVA and REN data have similar (log-normal) distributions of footing resistance with values of standard deviation σ of $\ln(R_f)$ of 0.92 (TVA) and 0.73 (REN), compared the same way on a line-by-line basis.**
- **2015 SIPDA XIII Invited Lecture has details (28 September to 2 October 2015).**

2015 IEEE PES Annual Meeting

Lightning WG Meeting

Conclusions

KINECTRICS

Experts Teaching from Practical Experience

Conclusions

- Footing resistance has an important effect on the performance of overhead groundwire protection.
- Simple formulas exist for relating the resistance of structures to the local soil resistivity.
- Several different ways exist to infer the soil resistivity in regions, but not on a tower-by-tower basis.
- Tower-by-tower variation of soil resistivity and footing resistance is very large.

Conclusions

- **Regions of similar size (TN, USA and Portugal), Similar numbers transmission of towers, Footing resistance data measured with earth resistance tester (TVA) or ABB 26-kHz meter (REN).**
- **On line-by-line basis, high skew and kurtosis, so data were not normally distributed.**
- **Transformation ln (Rf) got rid skew and kurtosis.**
- **Footing resistance is log-normally distributed with wider value of standard deviation than peak current.**

2015 IEEE PES Annual Meeting

Lightning WG Meeting

Questions

KINECTRICS

Experts Teaching from Practical Experience

About the Author

KINECTRICS

Dr. William A. (Bill) Chisholm is a well-known expert in electric power reliability problems involving adverse weather including lightning, winter pollution and low wind conditions.

***IEEE Fellow in 2007*.**

Led/leading IEEE Standards 1243 and 1410 for improving lightning protection of transmission and distribution lines.

Associate at Kinectrics (former Ontario Hydro Research Division) in Transmission and Distribution group.

Principal author of EPRI Transmission Line Reference (Red Book), 200 kV and Above, Chapter 6 (lightning protection) and main technical contributor to the upcoming Grey Book (lightning and grounding).

Spent 2007-2008 at the University of Quebec at Chicoutimi, co-writing a book for and teaching lightning protection.

Columnist (Transient Thoughts) for INMR Magazine.