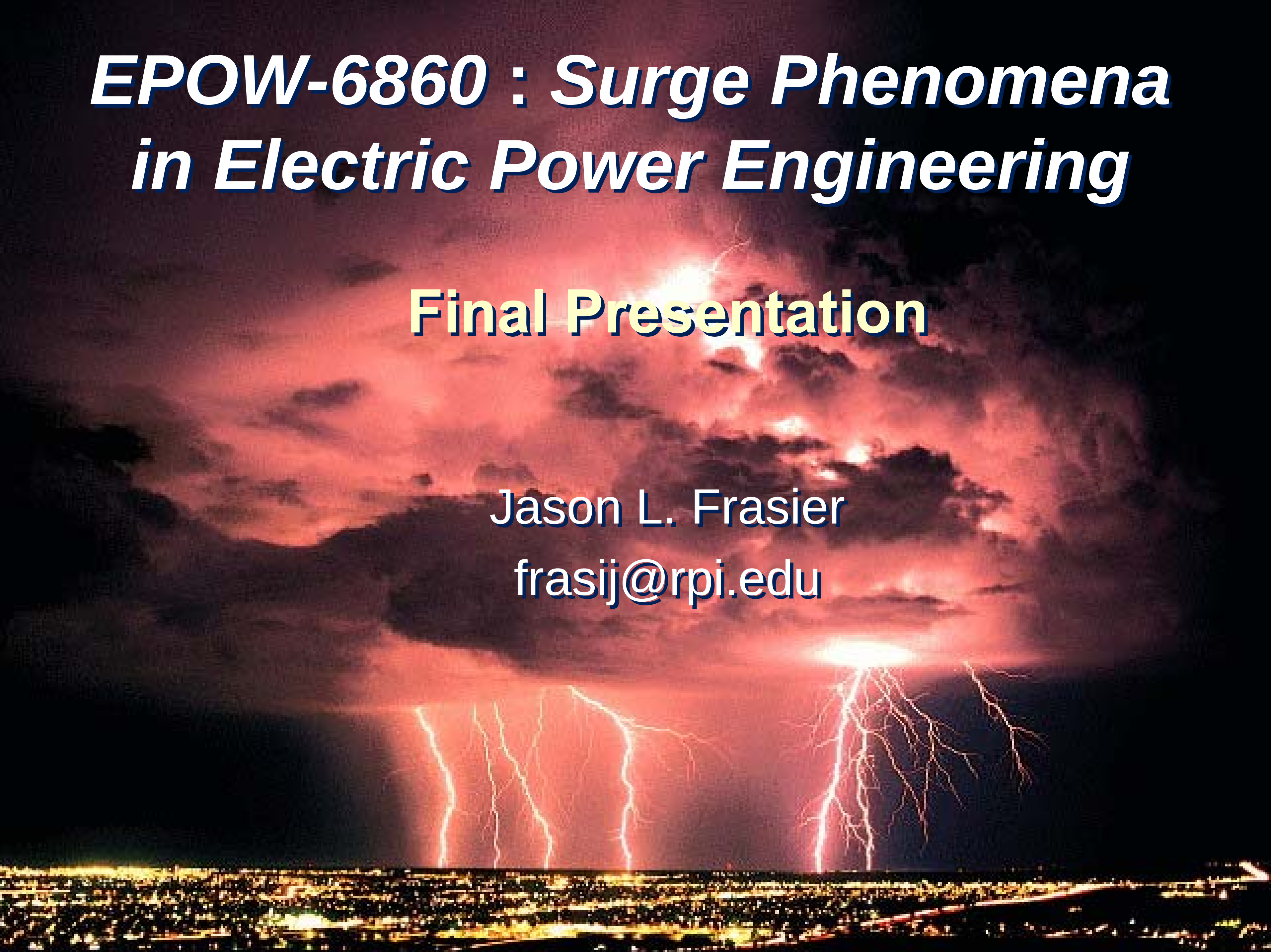
EPOW-6860 : Surge Phenomena in Electric Power Engineering

Final Presentation

Jason L. Frasier
frasij@rpi.edu



International Power System Transients Conference

- Held every 2 years since 1995
- "…promoting the study of power systems transients by offering a platform of scientific and technical excellence for its presentation…"
- Over 100 papers from 2007 meeting

Tower Footing Resistance

- Tower Voltage Effects
  - Surges
  - Insulation Needs
    - $ & Protection
- Grounding
  - Variable Soil Conditions
  - Proper Grounding

Standard Footing Resistance Values

Specific resistivity of soil (ohms/cm3)	Resistance (ohms)	
	Up to 330 kV	400/500 kV
Up to 10^4	10	10
10^4 up to $5 * 10^4$	15	13
$5 * 10^4$ up to $10 * 10^4$	20	15
$10 * 10^4$	30	30

Transient Tower Footing Resistance Model

$$R_T = \frac{R_g}{\sqrt{1 + \frac{I}{I_g}}}$$

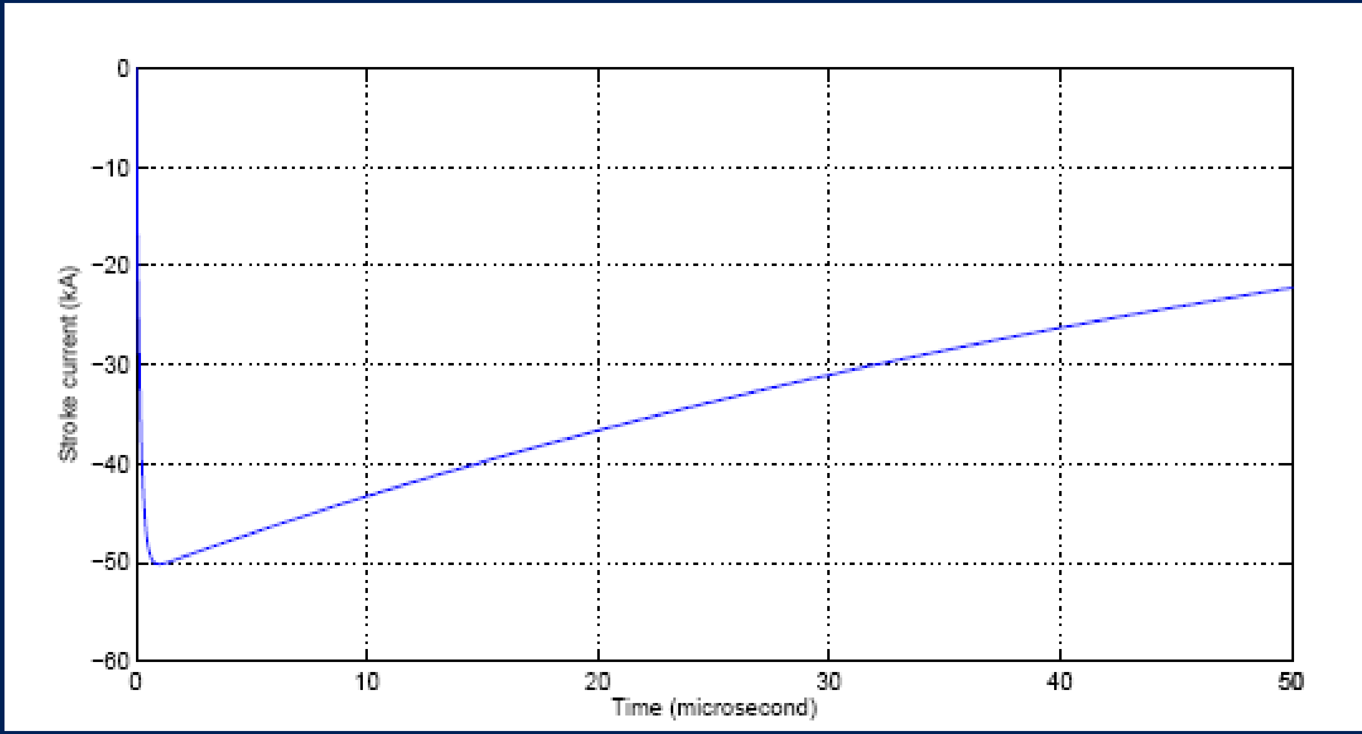
R_T is tower footing resistance (ohm),
R_g is tower footing resistance at low current and low frequency (ohm),
I is surge current into ground (kA),
I_g is limiting current initiating soil ionization (kA).

$$I_g = \frac{1}{2\pi}\left(\frac{E_o \rho_o}{R_g^2}\right)$$

ρ_o is soil resistivity (ohm-meter),
E_o is soil ionization gradient (about 300 kV/m).

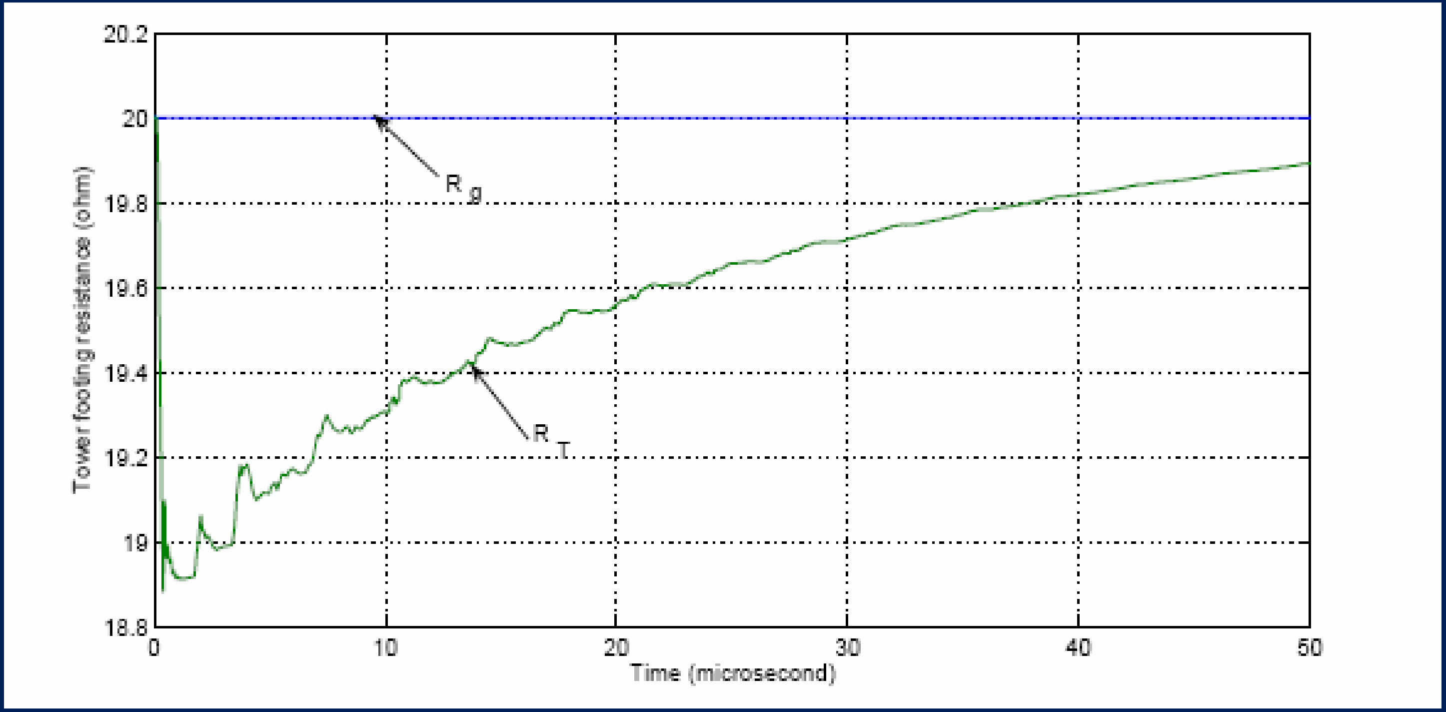
Transient Tower Footing Resistance Model (2)

- Typical Lightning Surge Current (Is)
  - Front t = 1.2 μS, Tail t = 50 μS



Transient Tower Footing Resistance Model (3)

- Tower Footing Resistance Dependency on Surge Current (I)



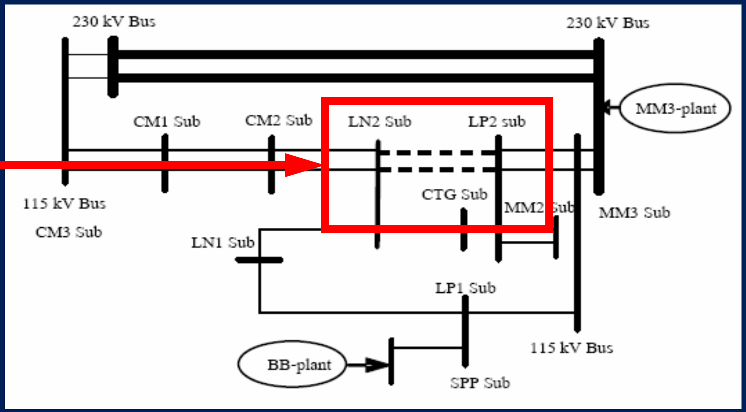
Insulator Flashover

- Stroke Current & Cross-arm Voltage
- Footing Resistance & Reflection/Refraction at Ground

$$V_{fo} = K_1 + \frac{K_2}{t^{0.75}}$$

V_{fo} is a flashover voltage (kV),
K_1 is 400*L,
K_2 is 710*L,
L is insulator length, (meter),
t is elapsed time after lightning stroke, µs.

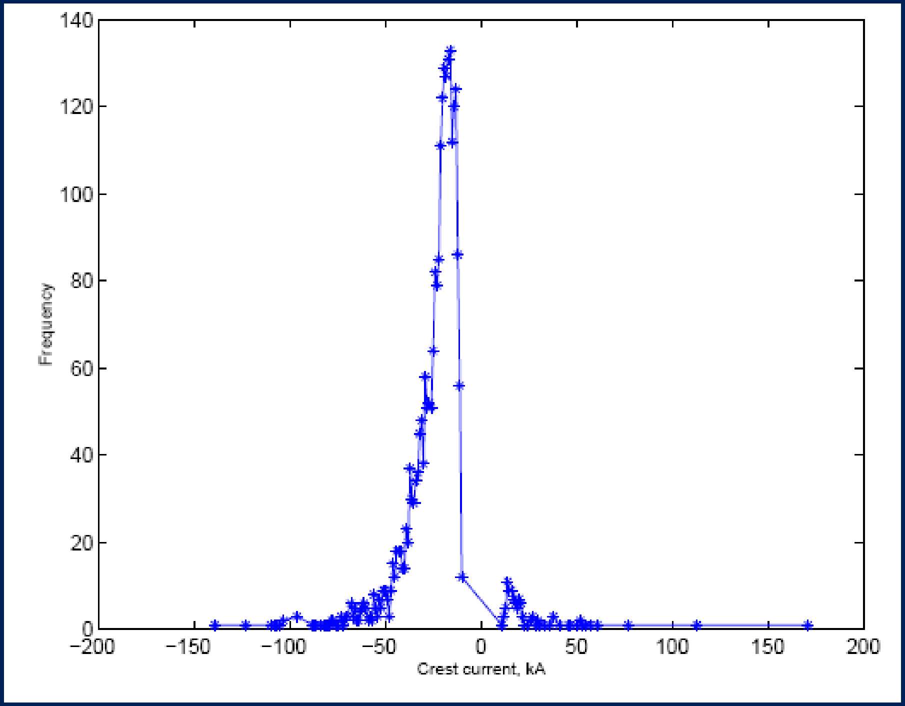
Footing Resistance Effects Case Study



- 115kV Circuit
- 73 Km Length
- 213 Towers (Steel)
- 78 Flashover Events Between 1998-2003
  - 18 Insulator Failures (18% Rate)
- High Mountain Terrains
  - Variable Footing Resistances

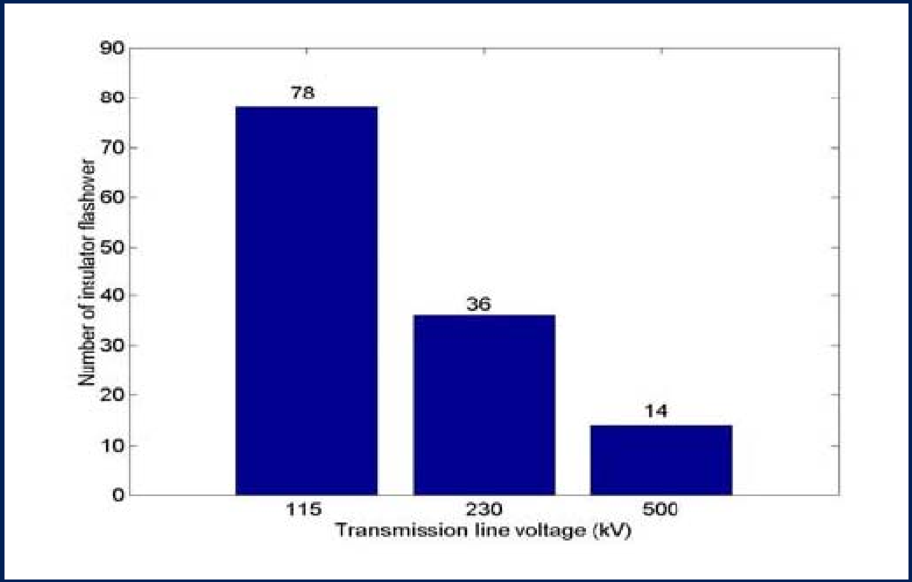
Footing Resistance Effects Case Study (2)

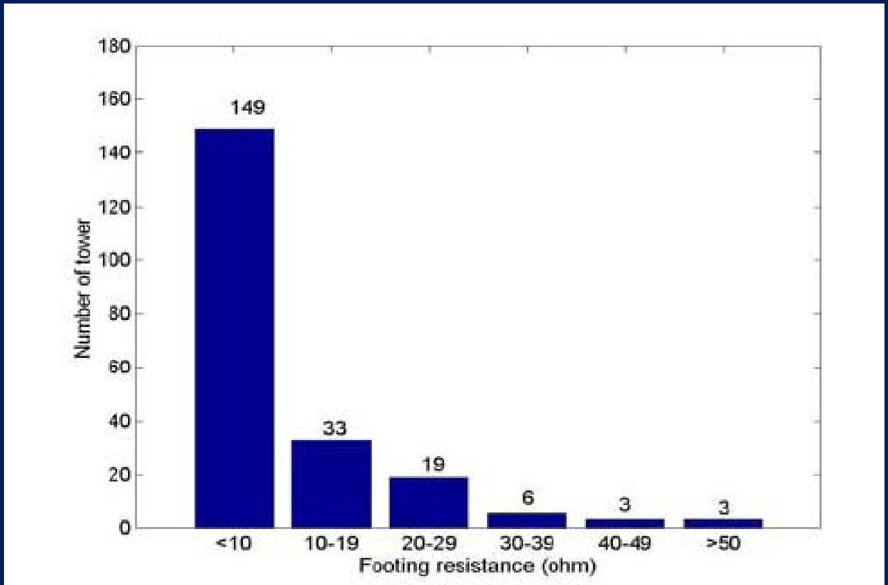
- Stroke Current Magnitude Data for Area (Statistical Distribution)



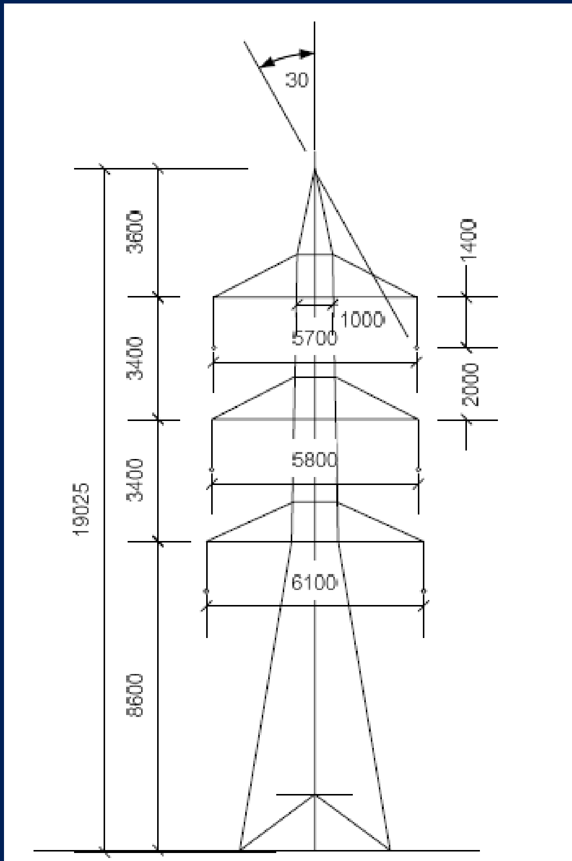
Footing Resistance Effects Case Study (3)

- 115kV Line Data
  - # of Flashovers
  - Footing Resistance Distributions





Transmission Line Model

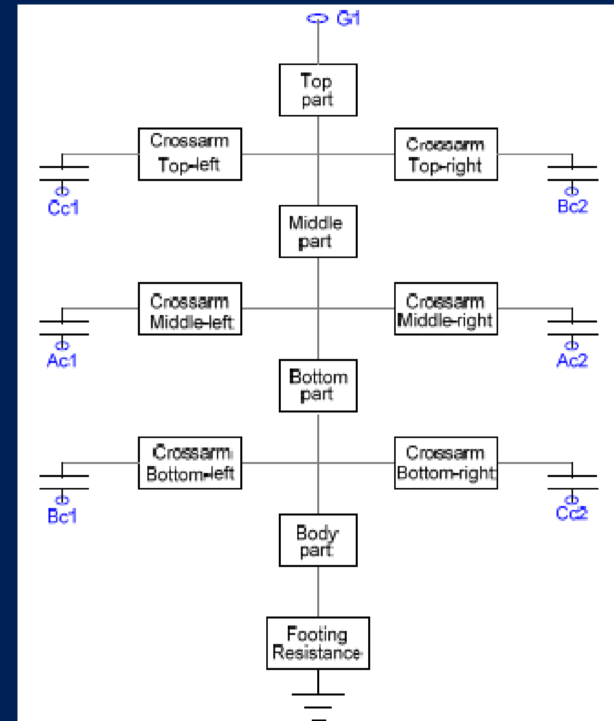


(a) Double circuit with one over head ground wire.

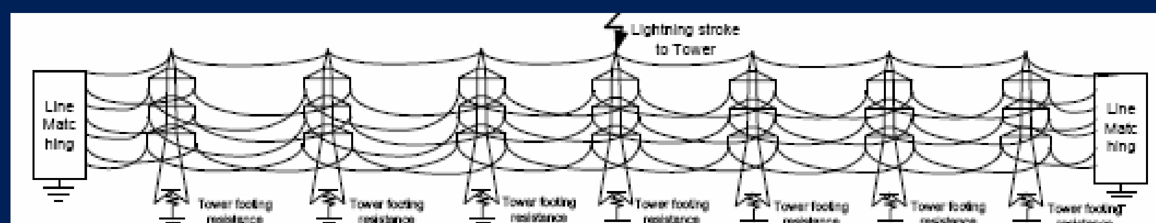
Class 1 Tower

TABLE I : PARAMETER OF TRANSMISSION LINE USED IN THIS STUDY.

Tower type	Member
Normal Span Length	350 m
Conductor	477 MCM. ACSR /Dia. 21.80 mm
Overhead Ground Wire	3/8 GSW(HS) /Dia. 9.144 mm
Sag of Conductor and overhead ground wire	10.62/7.66 m
Insulator type/BIL	Pin type/550kV
Insulator Number of disc/Length of one string	8,9/1500,1900 mm
Tower footing resistance	3,49,48,40,10,21,58 ohm



(b) Tower model using Bergeron model.



(c) The span of towers 8 spans with line matching.

Simulations

- Model Insulators as 80 pF Capacitors with Parallel Switches
- PSCAD & TFlash
  - EPRI HV Lab in Lenox, MA
- Compare Effects of Footing Resistance with Lightning Stroke Front Time, Magnitude of Lightning Stroke, and Tower Structure

Simulation Results – Lightning Stroke Front Time

- ↓Is Front Time = ↑V
- ↑V ↑Flashovers

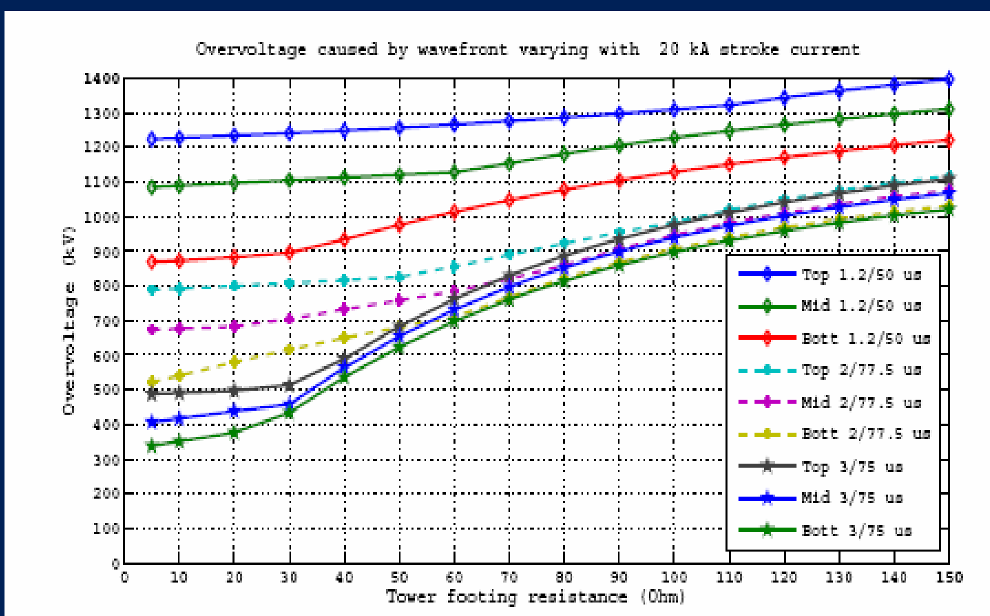


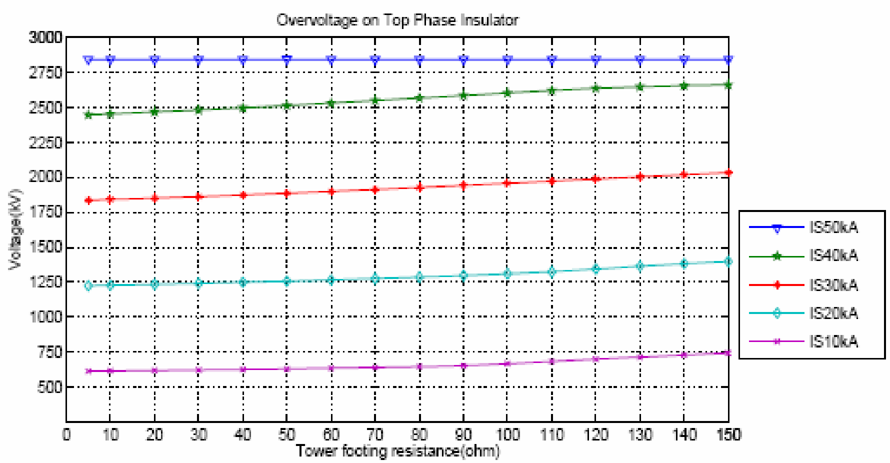
TABLE II : OVERVOLTAGE WITH VARYING FRONT TIME OF STROKE.

Tower footing resistance (ohm)	Wave front 2/77.5 us						Wave front 3/75 us					
	at stroke Is 20 kA			at stroke Is 40 kA			at stroke Is 20 kA			at stroke Is 40 kA		
	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott
5	X	X	X	X	X	X	X	X	X	X	X	X
10	X	X	X	X	X	X	X	X	X	X	X	X
20	X	X	X	X	X	X	X	X	X	X	X	X
30	X	X	X	X	X	X	X	X	X	X	X	X
40	X	X	X	√	X	X	X	X	X	√	X	X
50	X	X	X	√	X	X	X	X	X	√	X	X
60	X	X	X	√	X	X	X	X	X	√	X	X
70	X	X	X	√	X	X	X	X	X	√	X	X
80	X	X	X	√	X	X	X	X	X	√	X	X
90	X	X	X	√	X	X	X	X	X	√	X	X
100	X	X	X	√	X	X	X	X	X	√	X	X
110	X	X	X	√	X	X	√	X	X	√	X	X
120	X	X	X	√	X	X	√	X	X	√	X	X
130	√	X	X	√	X	X	√	X	X	√	X	X
140	√	X	X	√	X	X	√	X	X	√	X	X
150	√	X	X	√	X	X	√	X	X	√	X	X

√: flashover X: no flashover

Simulation Results – Lightning Stroke Magnitude

- ↑Is & ↑R_T = ↑V
- ↑V ↑Flashovers



(a) Top phase insulator

TABLE III : OVERVOLTAGE FLASHOVER AT INSULATOR WITH DIFFERENT MAGNITUDE OF STROKE.

Tower footing resistance (ohms)	Overvoltage Flashover											
	at stroke Is 20 kA			at stroke Is 30 kA			at stroke Is 40 kA			at stroke Is 50 kA		
	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott
5	X	X	X	X	X	X	X	X	X	√	X	X
10	X	X	X	X	X	X	X	X	X	√	X	X
20	X	X	X	X	X	X	X	X	X	√	X	X
30	X	X	X	X	X	X	√	X	X	√	X	X
40	X	X	X	X	X	X	√	X	X	√	X	X
50	X	X	X	√	X	X	√	X	X	√	X	X
60	X	X	X	√	X	X	√	X	X	√	X	X
70	X	X	X	√	X	X	√	X	X	√	X	X
80	X	X	X	√	X	X	√	X	X	√	X	X
90	X	X	X	√	X	X	√	X	X	√	X	X
100	√	X	X	√	X	X	√	X	X	√	X	X
110	√	X	X	√	X	X	√	X	X	√	X	√
120	√	X	X	√	X	X	√	X	X	√	X	√
130	√	X	X	√	X	X	√	X	X	√	X	√
140	√	X	X	√	X	X	√	X	X	√	X	√
150	√	X	X	√	X	X	√	X	X	√	X	√

√: flashover X: no flashover

Simulation Results – Structure of Tower

- 1 GW vs. 2 GW
- Flashover Dependent

On: I, R_T, & # of GW

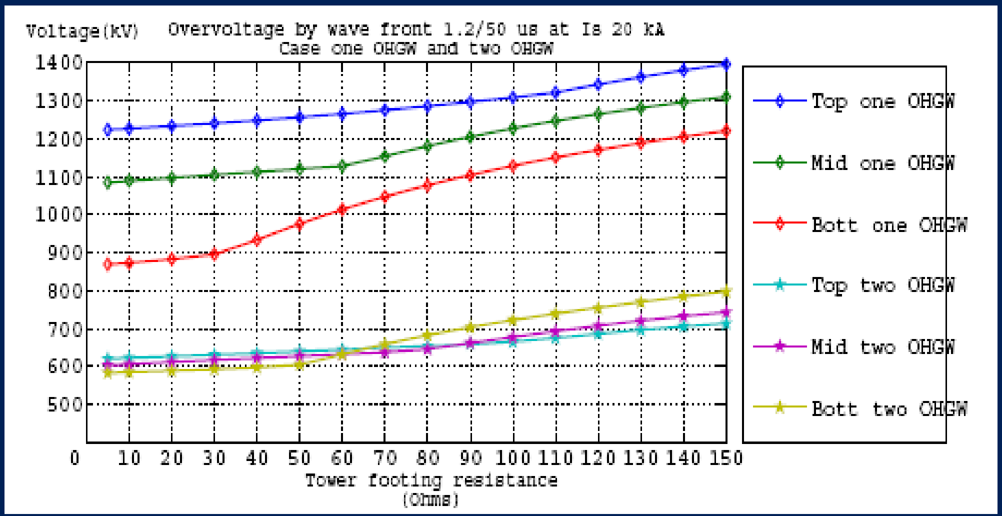
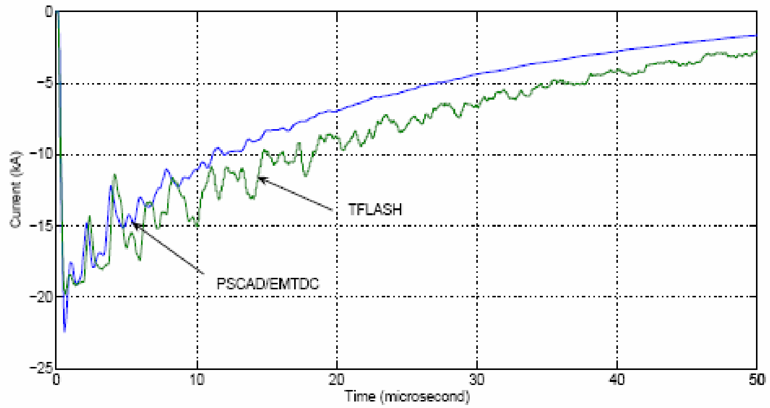


TABLE IV : OVERVOLTAGE FLASHOVER AT INSULATOR WITH ONE OHGW AND TWO OHGW.

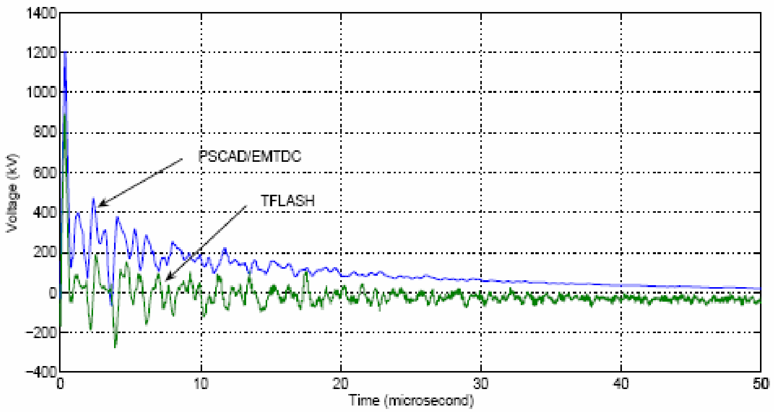
Tower footing resistance (ohm)	Over Voltage Flashover											
	Case one OHGW at stroke Is 20 kA			Case one OHGW at stroke Is 40 kA			Case two OHGW at stroke Is 20 kA			Case two OHGW at stroke Is 40 kA		
	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott
5	X	X	X	X	X	X	X	X	X	X	X	X
10	X	X	X	X	X	X	X	X	X	X	X	X
20	X	X	X	X	X	X	X	X	X	X	X	X
30	X	X	X	√	X	X	X	X	X	X	X	X
40	X	X	X	√	X	X	X	X	X	X	X	X
50	X	X	X	√	X	X	X	X	X	X	X	X
60	X	X	X	√	X	X	X	X	X	X	X	X
70	X	X	X	√	X	X	X	X	X	X	X	X
80	X	X	X	√	X	X	X	X	X	X	X	√
90	X	X	X	√	X	X	X	X	X	X	X	√
100	√	X	X	√	X	X	X	X	X	X	X	√
110	√	X	X	√	X	X	X	X	X	X	X	√
120	√	X	X	√	X	X	X	X	X	X	X	√
130	√	X	X	√	X	X	X	X	X	X	X	√
140	√	X	X	√	X	X	X	X	X	X	X	√
150	√	X	X	√	X	X	X	X	X	X	X	√

√: flashover X: no flashover

PLSCAD vs. TFLASH



(a) Surge current into ground.



(b) Voltage across insulator

Table V : Comparison simulation results between PSCAD and TFlash.

Tower footing resistance (ohm)	Over Voltage Flashover											
	Case PSCAD at stroke Is 20 kA			Case PSCAD at stroke Is 60 kA			Case TFlash at stroke Is 20 kA			Case TFlash at stroke Is 60 kA		
	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott	Top	Mid	Bott
5	X	X	X	√	X	X	X	X	X	√	X	X
10	X	X	X	√	X	X	X	X	X	√	X	X
20	X	X	X	√	X	X	X	X	X	√	X	X
30	X	X	X	√	X	X	X	X	X	√	X	X
40	X	X	X	√	X	X	X	X	X	√	X	X
50	X	X	X	√	X	X	X	X	X	√	X	X
60	X	X	X	√	X	X	X	X	X	√	X	X
70	X	X	X	√	X	X	X	X	X	√	X	X
80	X	X	X	√	X	√	X	X	X	√	X	X
90	X	X	X	√	X	√	X	X	X	√	X	X
100	√	X	X	√	X	√	X	X	X	√	X	X
110	√	X	X	√	X	√	X	X	X	√	X	X
120	√	X	X	√	X	√	X	X	X	√	X	X
130	√	X	X	√	X	√	X	X	X	√	X	√
140	√	X	X	√	X	√	√	X	X	√	X	√
150	√	X	X	√	X	√	√	X	X	√	X	√

√: flashover X: no flashover

Conclusions

- R_T Can Affect Insulator Failure
  - ↓Is Front Time = ↑Failures
  - ↑Is Magnitude = ↑Failures
  - ↑# of GW = ↓Failures
- Software Results

References

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