Simulation of Switching Overvoltages and Field Validations

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EMTP

POLYTECHNIQUE MONTRÉAL

Background

November 14, 1994 BPA experience:

A series of flashover during a high-speed reclosing maneuver on the Big Eddy – Chemawa 230 kV line

High speed reclosing on a line with trapped charge

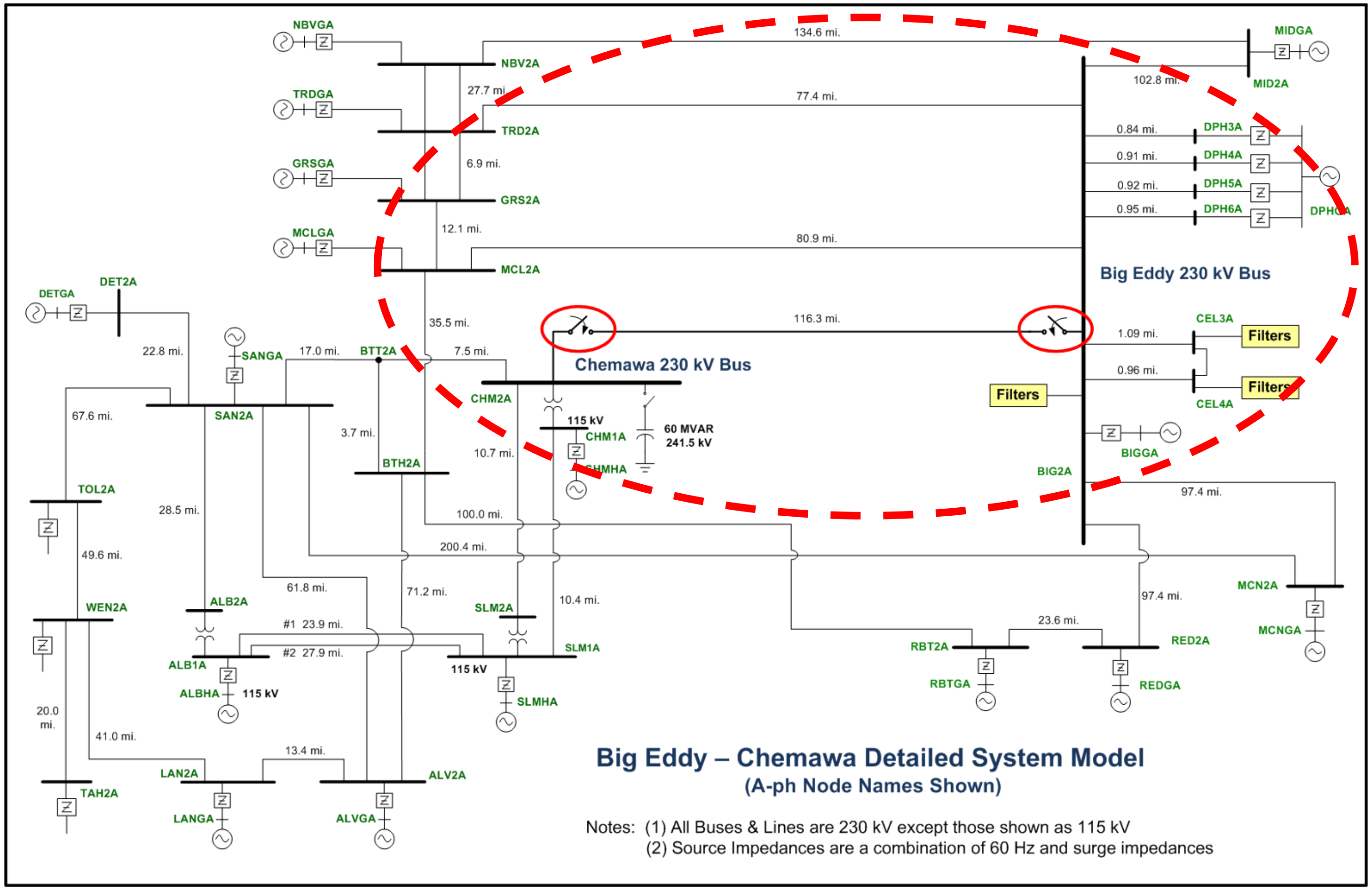
Switching surges not mitigated (no closing resistors and/or surge arrestor)

→ high overvoltages that have been measured above 3 pu

(May trigger flashover on the rod gaps)

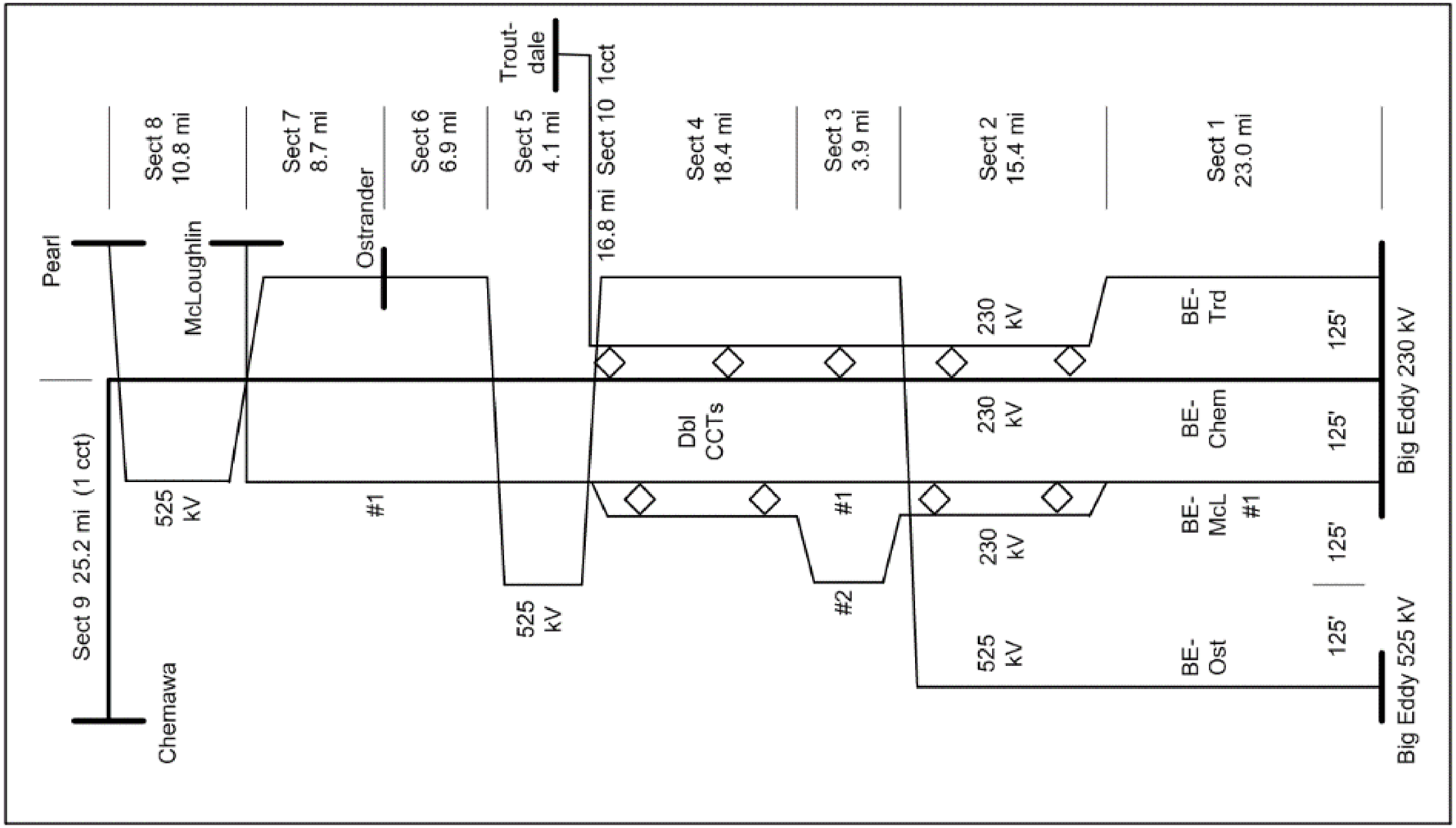
BPA investigation: A series of field tests to record overvoltages and statistical data during high speed reclosing

Test System



<u>Big Eddy Chemawa Line: 230 kV, 116 miles</u>

Big Eddy Chemawa Line



Parallel lines, single and double circuits

Objectives

1. Identify simulation practices to produce the field measurements in EMT simulations
2. Validation of line models – frequency dependence
3. Discussion on modeling approaches, simulation practices, sensitivity to electrical parameters
4. Evaluate maximum overvoltages → used for safety-related purposes: minimum approach distance, clearance practices
5. How to perform statistical simulations, model prestrike and include corona in statistical simulations efficiently?

Initial Observations

1. Variations in
   frequency-dependent line modeling,
   ground resistivity,
   skin effect,
   shunt conductance,
   parallel lines
   source-side detail
   have been tested in an ***unsuccessful attempt*** to decrease the difference between the field measurements and the higher simulation overvoltages.

Conclusions - 1

The pattern of the transient voltage waveforms can be reproduced very well using *frequency-dependent line models* and the inclusion of *prestrike* …

but the magnitude of the maximum overvoltage is significantly overestimated *unless the effect of corona is considered*.

Outline

Validation: the waveforms recorded during the "Three-phase line switching test series", particularly Case 5.03, considered

The three-phase trip and reclose tests approximate high-speed reclosing without creating a staged fault

(once a line model is validated, possible to proceed with statistical simulation phase)

Outline cont.

1. Introduction
2. Description of the test system and study cases
3. Modeling details and (some) parameters of the test system
4. Simulation results
5. Sensitivity of simulation results to line parameters
6. Corona effect using two different corona models
7. Additional study cases
8. Statistical studies, prestrike modeling, worst-case overvoltage
9. Conclusions

Test cases – voltage measurements

1. Three phase Line Switching Cases
2. Field test measurement devices

TABLE I

THREE-PHASE LINE SWITCHING FROM BIG EDDY, PEAK VOLTAGES (KV)

Case	Big Eddy bus			Chemawa bus		
	A-Ph	B-Ph	C-Ph	A-Ph	B-Ph	C-Ph
5-02	442.3	-284.1	-493.8	505.6	445.9	-643.2
5-03	452.1	409.9	-570.6	566.6	561.6	-638.9
5-05	459.7	-284.0	-541.9	536.9	529.2	-622.8

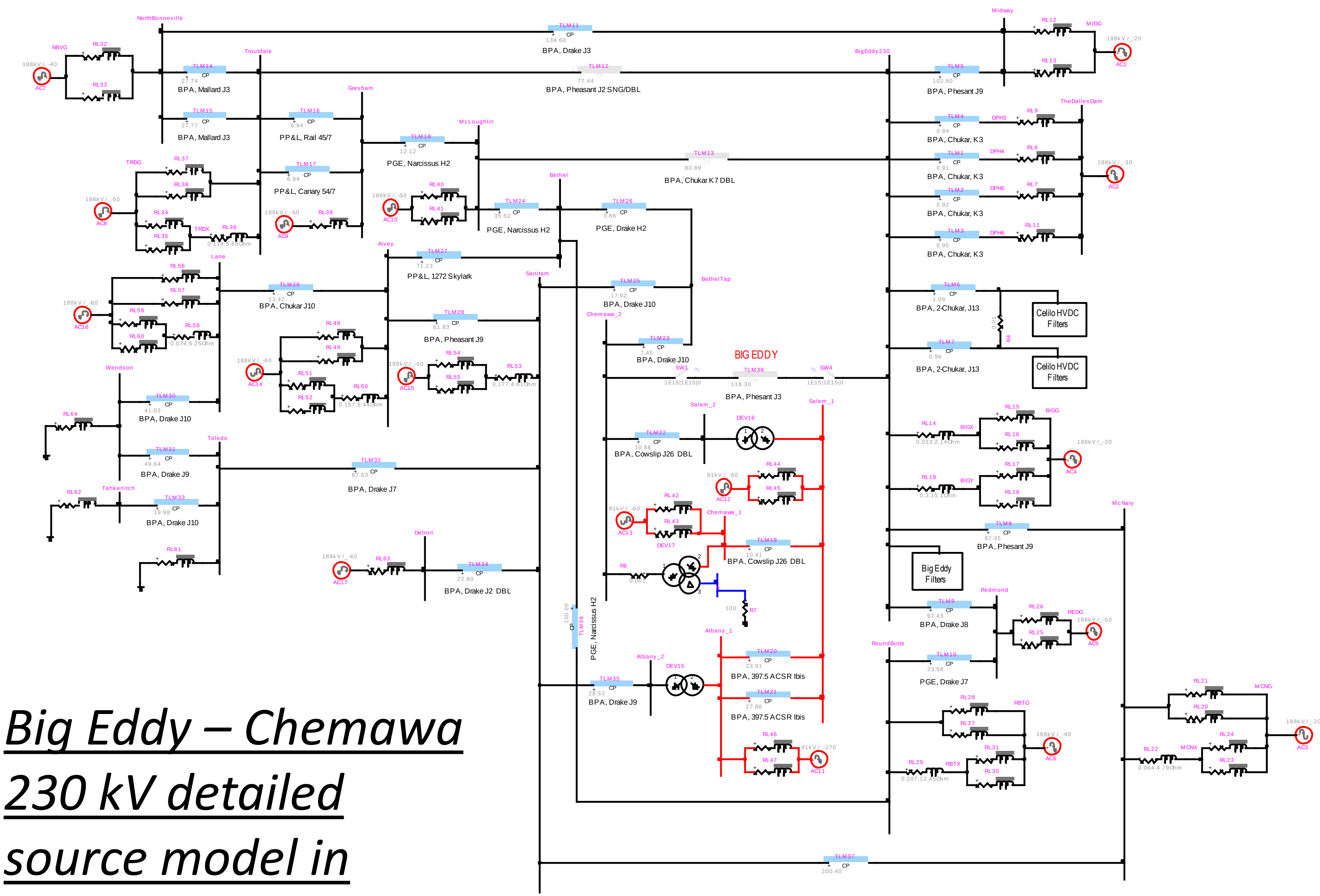
TABLE II

TRAPPED CHARGE VOLTAGES (KV)

Case	Φ^*	A-Ph	B-Ph	C-Ph
5-02	0	-235.36	-176.38	179.56
5-03	18	-230.87	-175.22	179.80
5-05	54	-234.34	-177.41	181.94

*Relative closing angle in degrees.

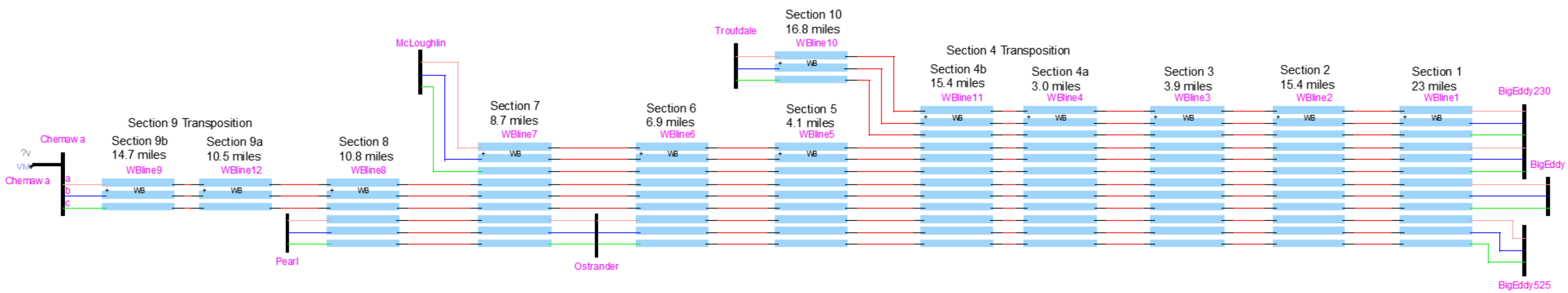
Modeling Details

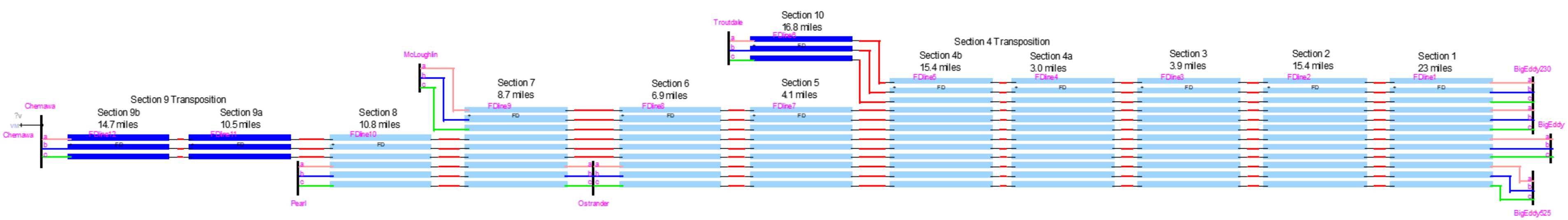


Big Eddy – Chemawa 230 kV detailed source model in EMTP

Modeling Details

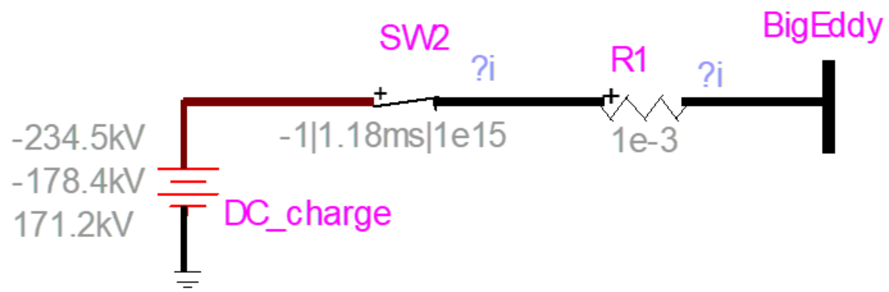
Line models: WB, FD, CP (10 kHz)



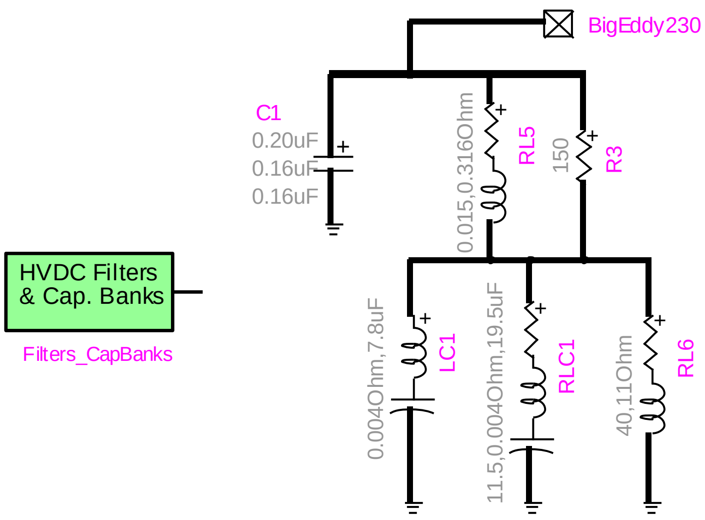


Modeling Details

Trapped Charge

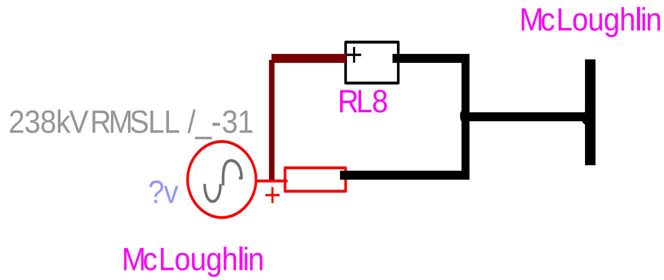


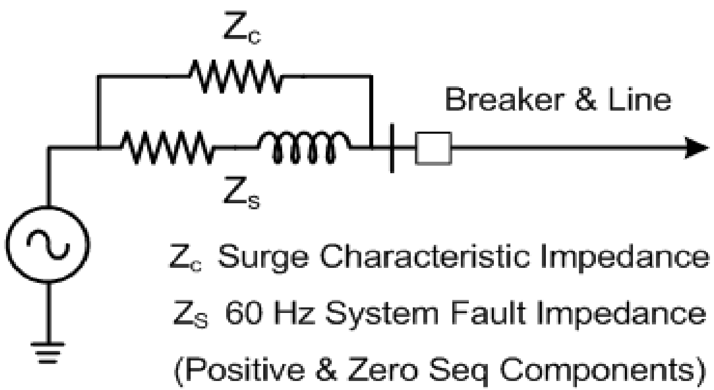
HVDC filters and Capacitor banks



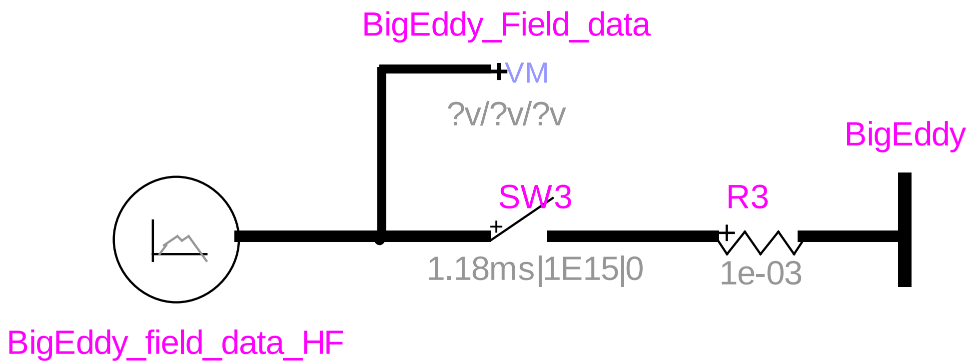
Modeling Details

Simplified source model





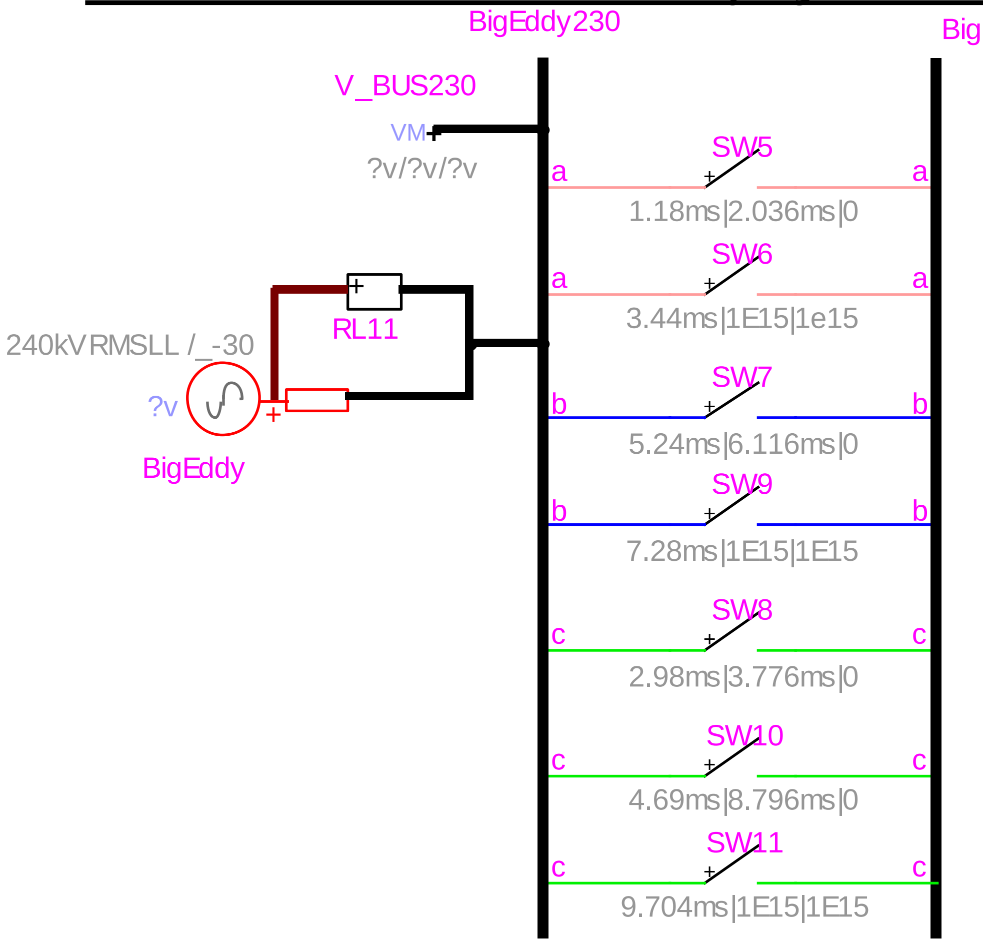
Tabulated source model*



*forcing measurements: intrinsically considers prestrike

Forced Prestrike Model

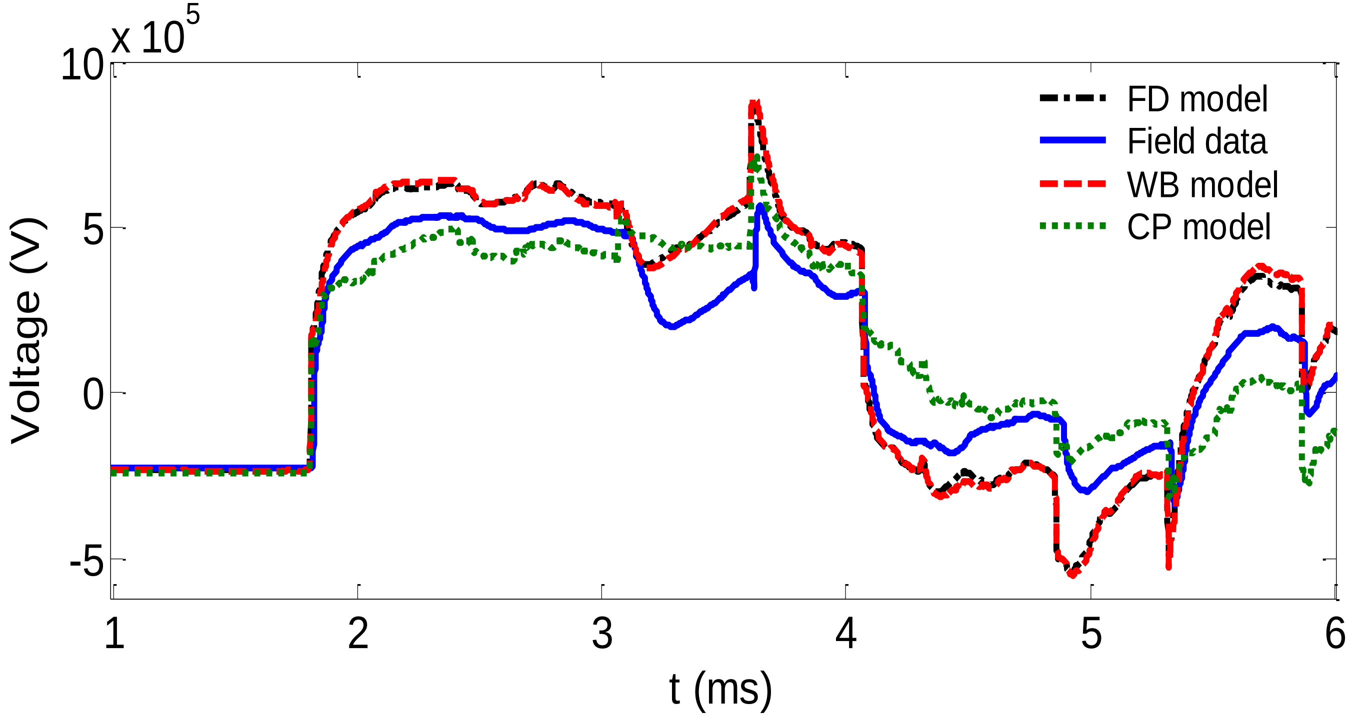
Prestrike model + simplified source



Phase	Condition	Time (ms)
Phase A	Closes	0
	Opens	0.856
	Closes	2.26
Phase B	Closes	4.06
	Opens	4.936
	Closes	6.1
Phase C	Closes	1.8
	Opens	2.596
	Closes	3.51
	Opens	7.616
	Closes	8.51

Studies

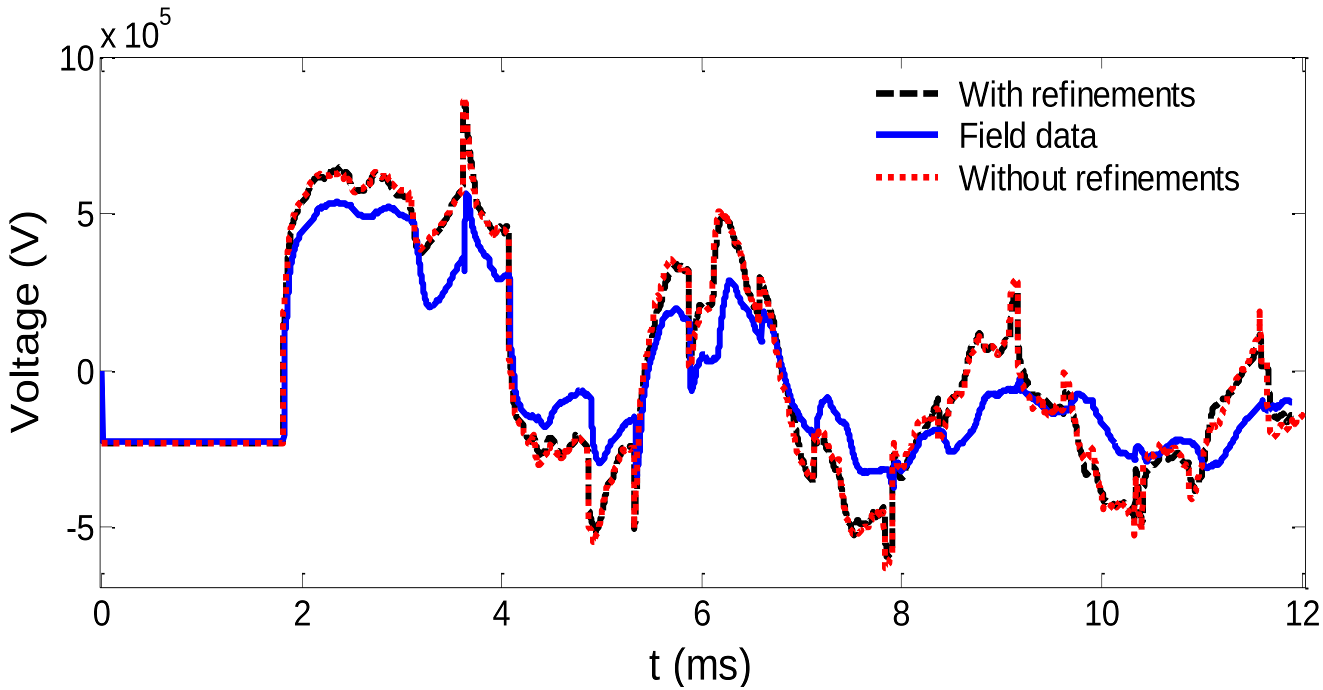
Simplified source, all parallel lines considered, prestrike



Voltage of phase A at Chemawa end, comparison of different line models

Refinements in Line Parameters

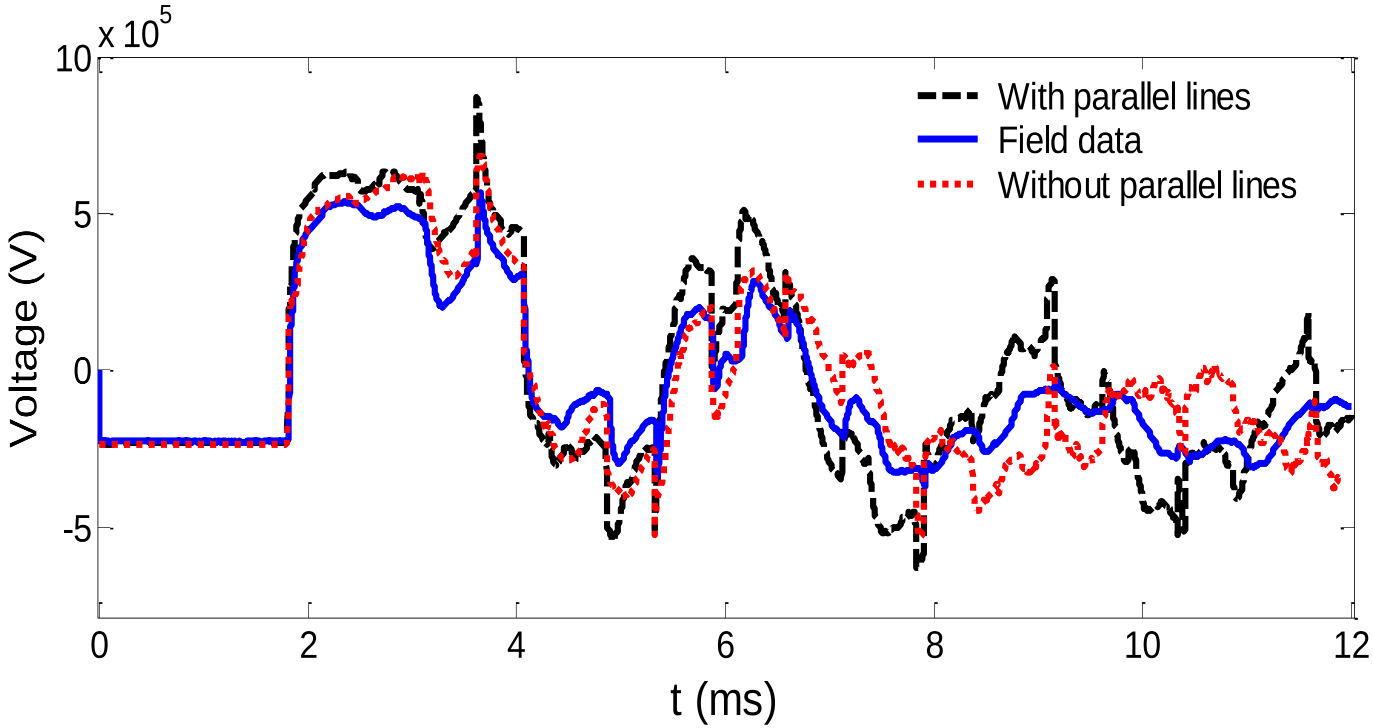
Skin effect correction, phase-to-ground conductance (2e-10 to 6e-8 S/mile), ground resistivity (50 – 200 instead of 100 Ω/mile)



Voltage of phase A at Chemawa end

Impact of parallel lines

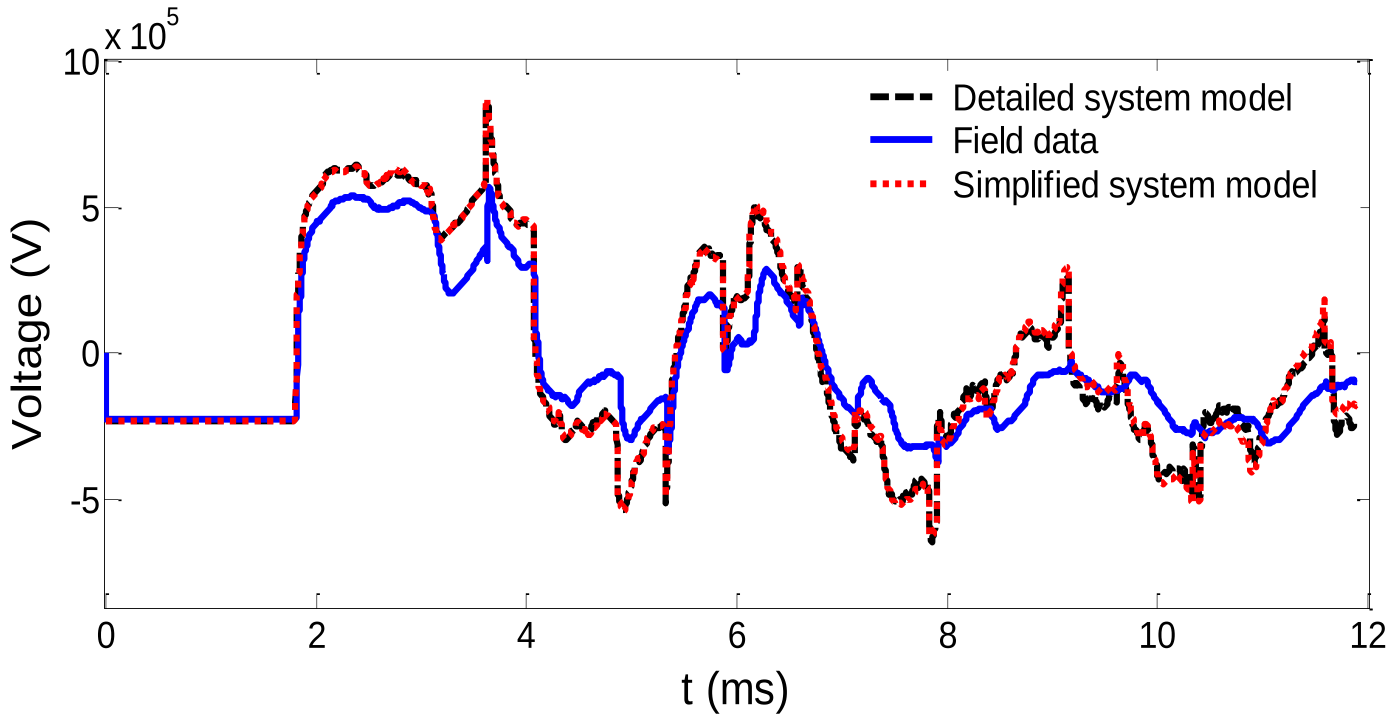
Important variation in waveforms, ***keep parallel lines***



Voltage of phase A at Chemawa end

Detailed vs simplified source

Not significant

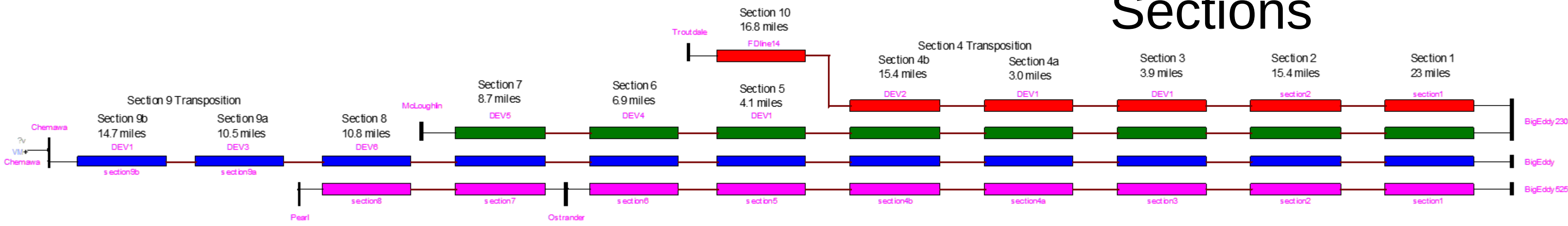


Voltage of phase A at Chemawa end

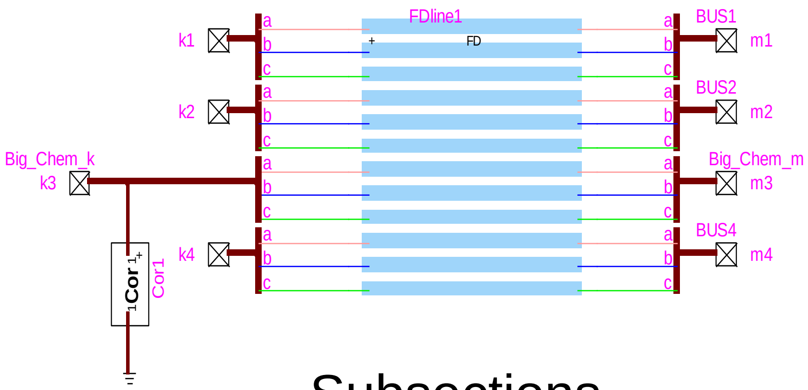
Corona Suliciu Model

Subdivision (0.1 – 0.6 - 1 miles long tested)

Sections



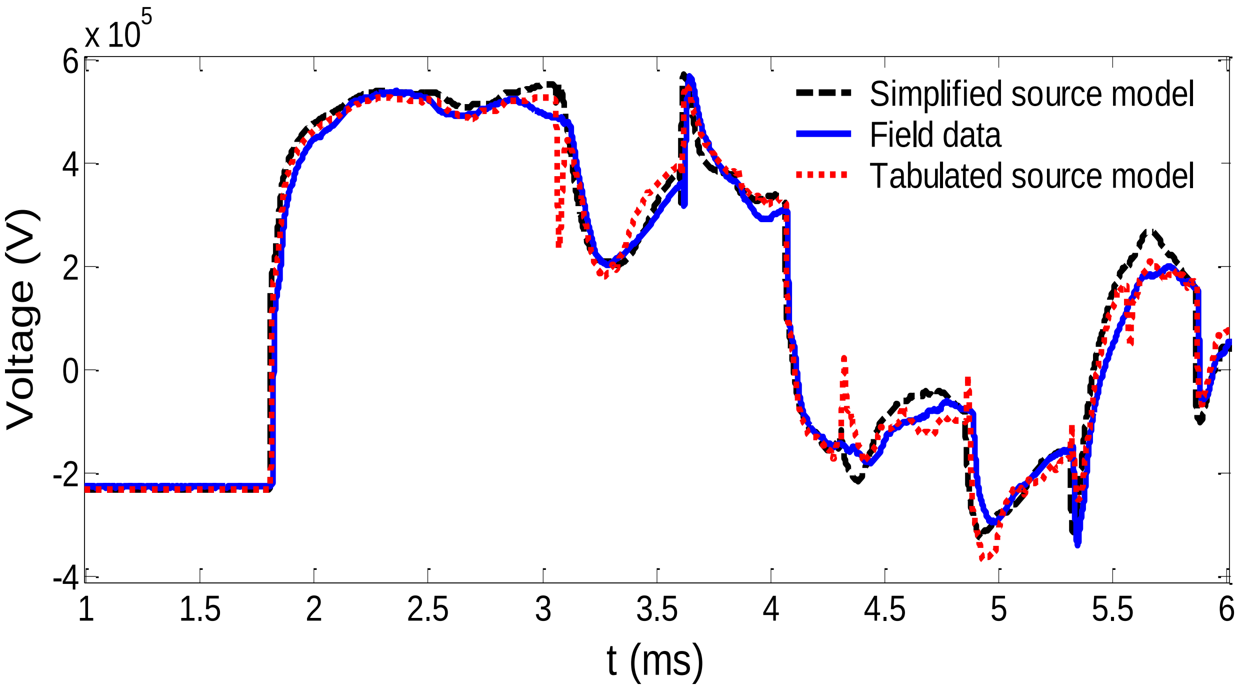
Suliciu corona model at each subsection on the Big Eddy – Chemawa line only



Subsections

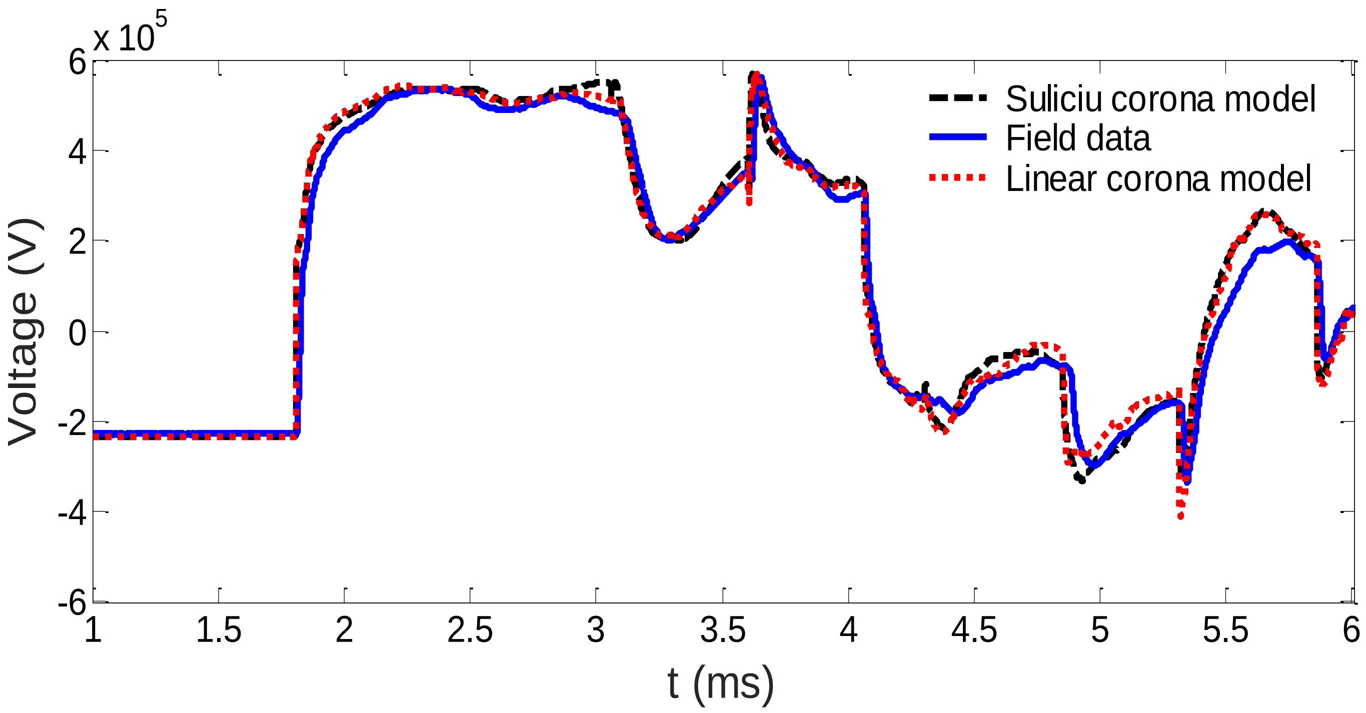
Corona Suliciu Model

Subdivision (0.1 – 0.6 - 1 miles long tested)



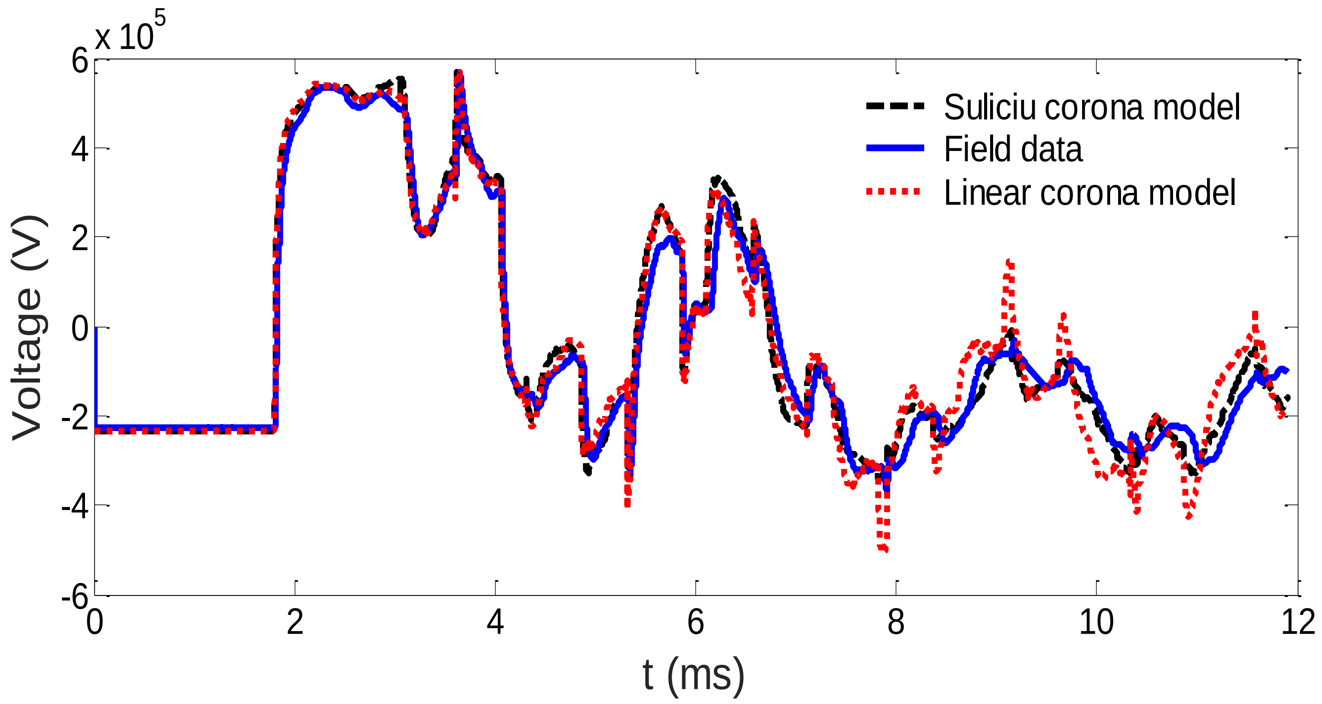
Linear Corona Model - 1

Linear : 3 straight lines to approximate the nonlinear characteristics



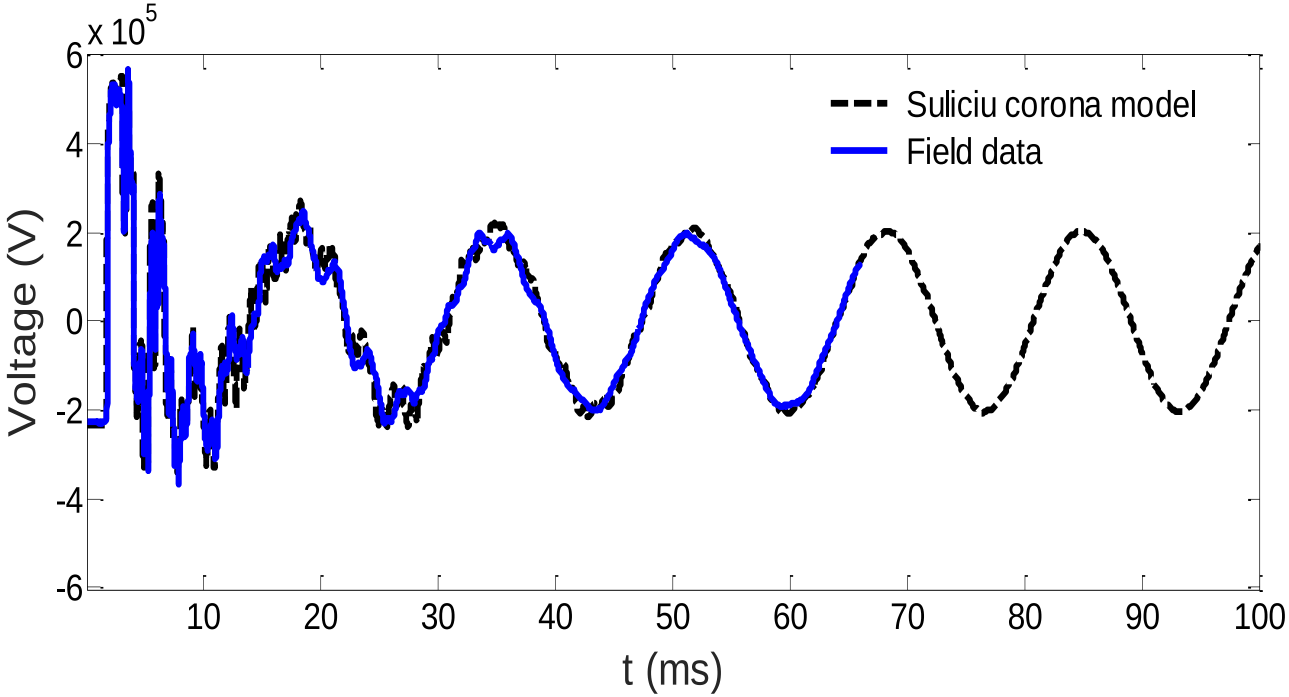
Linear Corona Model - 2

Linear : Damping problem, tuning is important to match



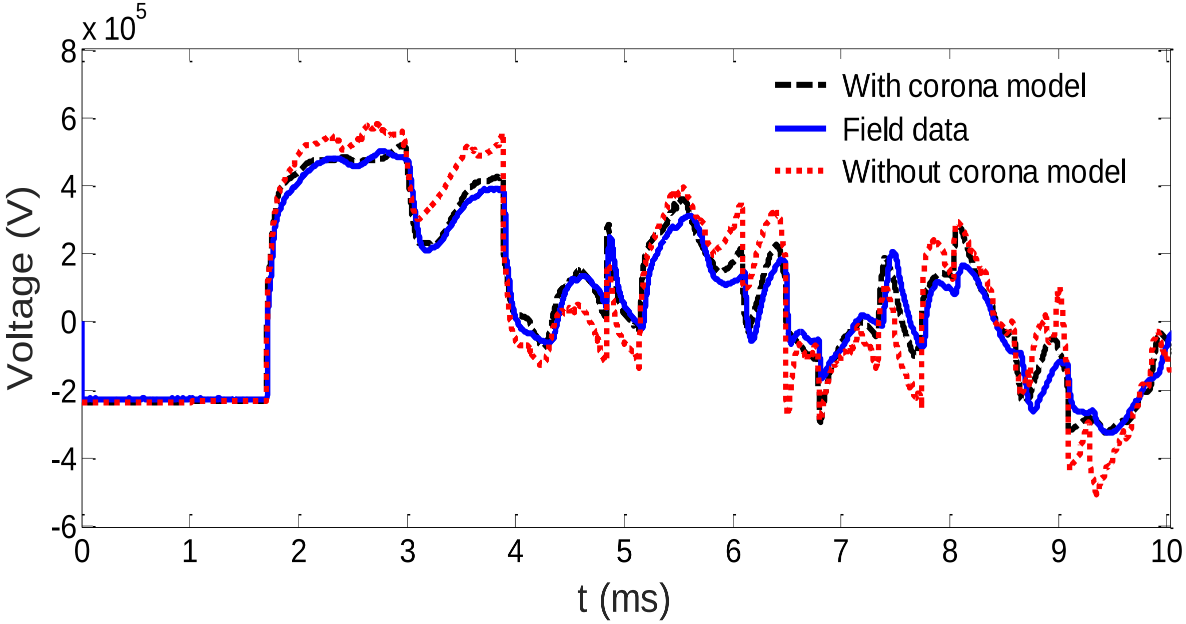
Longer Simulation Times

Data available for 66 ms of simulation time



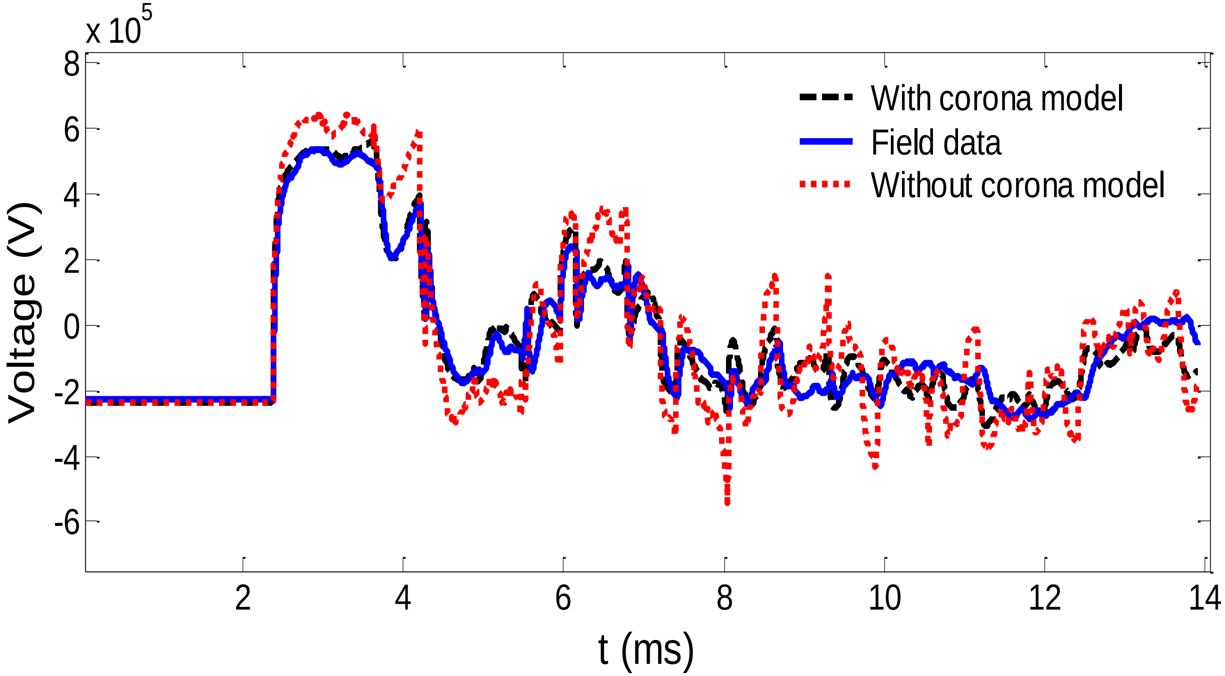
Other cases

Case 5-02



Other cases

Case 5-05



Conclusions - 2

Pattern of the transient waveforms

Frequency dependence

Prestrike (simple model)

Simplified source or detailed source model

Parallel lines

Peak overvoltage

CORONA

Challenge

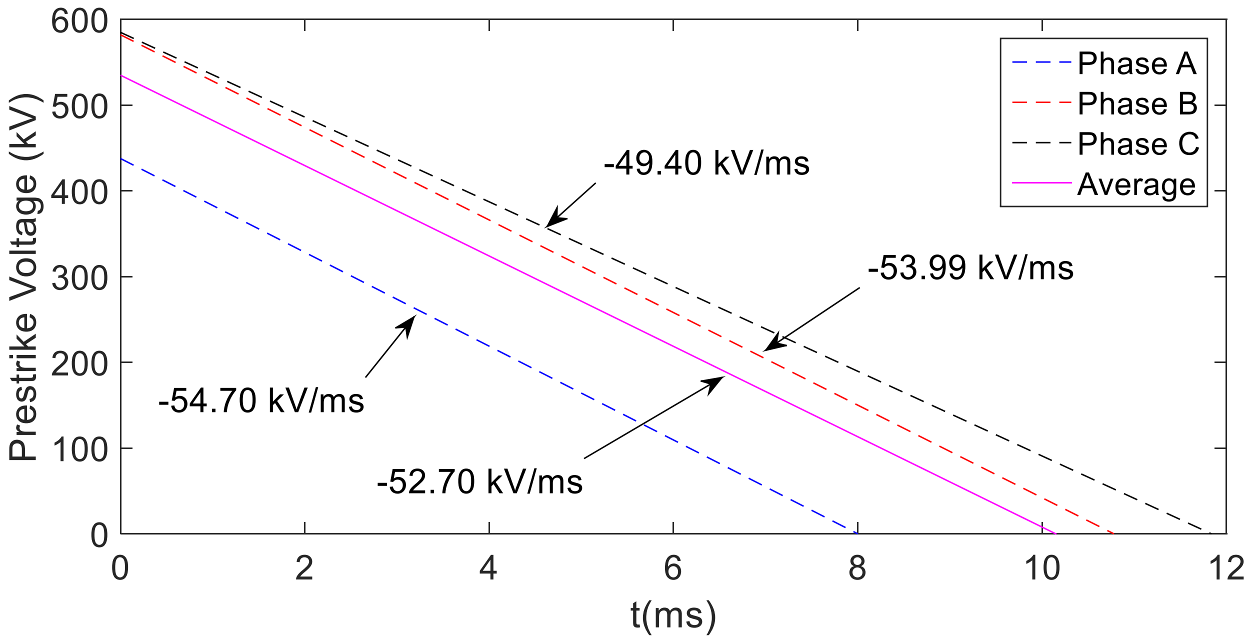
How to identify nonlinear corona parameters

Prestrike Modeling

Prestrike data

Prestrike data for each phase of the Big-Eddy breaker

Pole span is determined by taking the difference in time when the prestrike characteristic of each phase crosses zero voltage



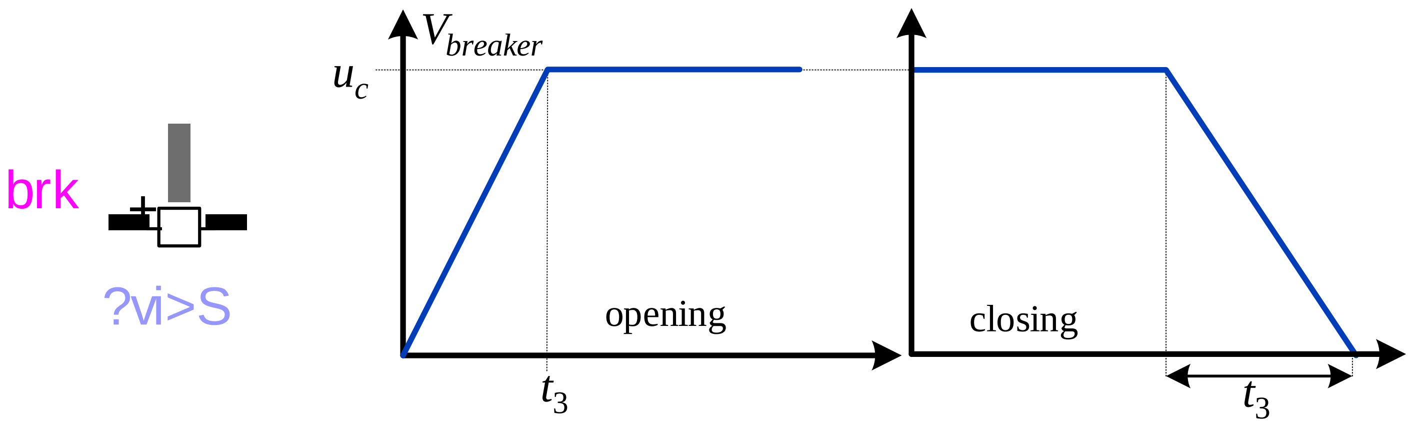
Big Eddy breaker dielectric slopes

Modeling details

Prestrike model

Model enables the breaker conduction when its voltage withstand is reached

When the breaker is closing, if the voltage at the terminal of the breaker reaches the envelope of the voltage withstand, the gap is closed and opened again when the current crosses zero



Prestrike modeling in EMTP

Simulation tests

1. Single simulation with fixed closing times

The breaker closing times of the three phases are fixed

Prestrike conditions are represented using the dielectric slope model

2. Simulations with systematic closing times

Set of 360 simulations

The breaker closing times of the three phases are varied uniformly over a complete 60 Hz cycle

Prestrike conditions are represented using the dielectric slope model

Simulation tests

3. Simulations with random closing times

Set of 300 simulations

The breaker closing times of the three phases are estimated by the Gaussian law

Prestrike conditions are represented using the dielectric slope model

4. Simulations with random prestrike times

Set of 300 simulations

The breaker closing times of the three phases are calculated by the Gaussian law

Prestrikes times are estimated by the Gaussian law

Simulation tests

For running the statistical simulations, the corona model is not included…

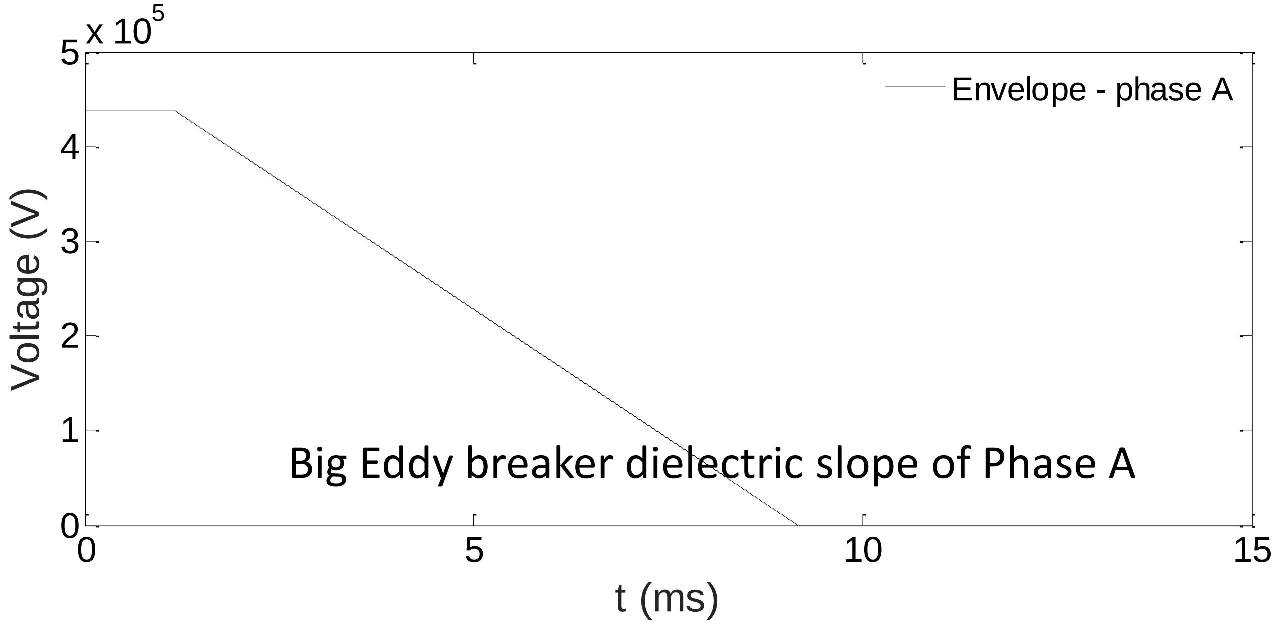
…The simulation with the highest overvoltage is compared afterwards with the one obtained by including corona

Simulation results

1. Single simulation with fixed closing times

The Big Eddy-Chemawa line is energized from the Big Eddy bus at 1.18 ms

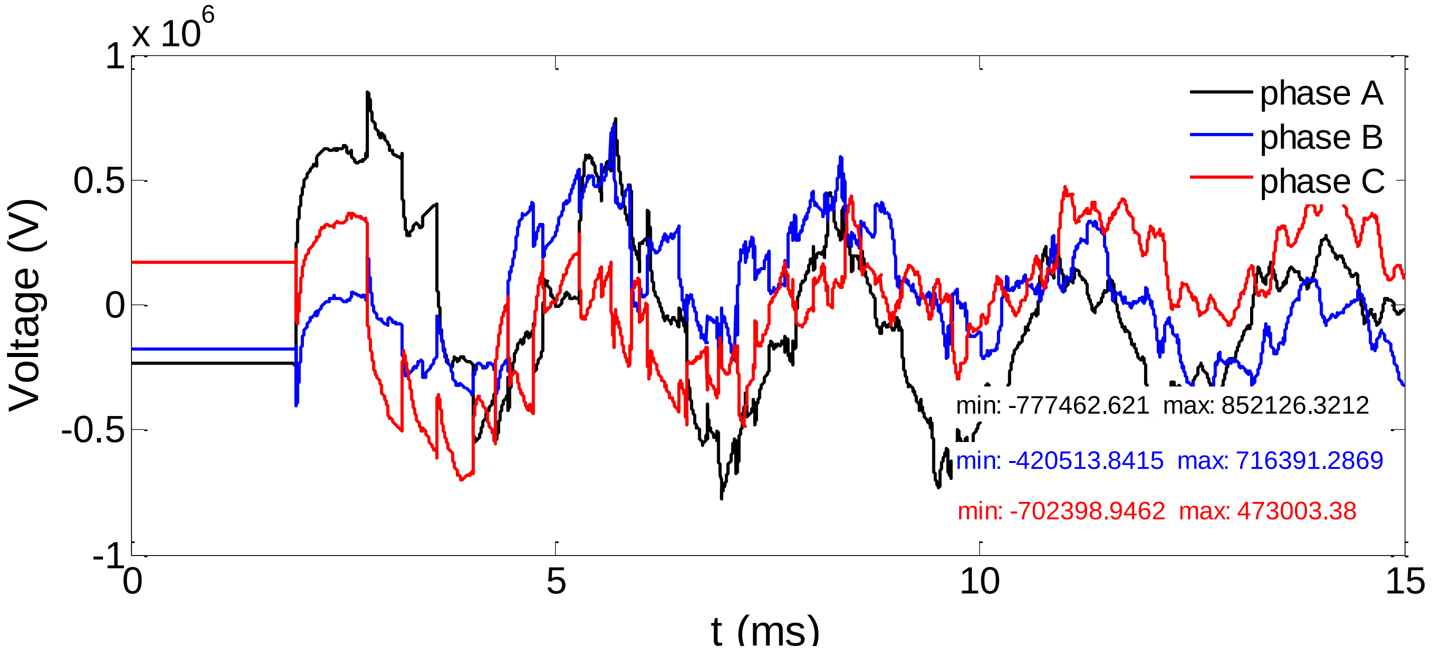
Prestrike conditions: Linear slope of phase A, t_3 = 8 ms and u_c = 437 kV



Simulation results

1. Single simulation with fixed closing times

The maximum overvoltage occurs on phase A, i.e. 852.126 kV or 4.53 pu

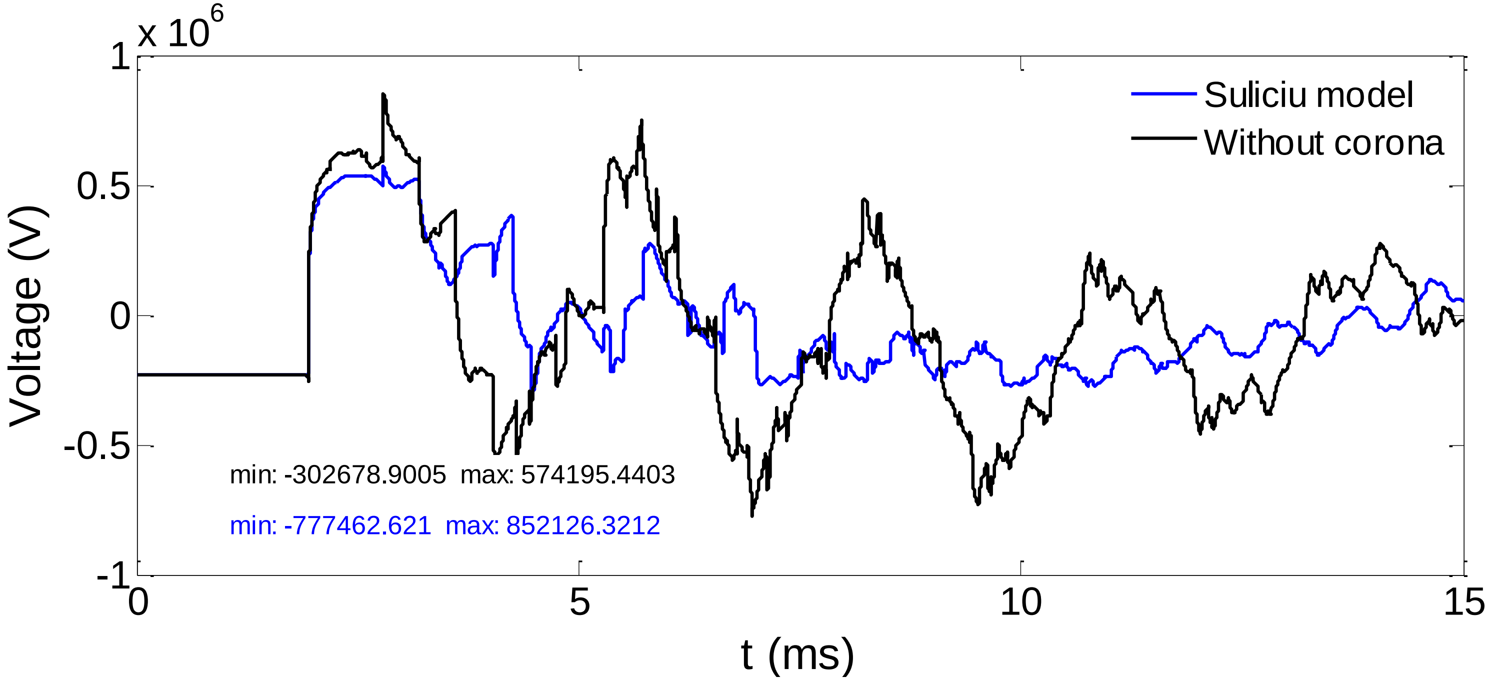


Voltages at Chemawa end

Simulation results

1. Single simulation with fixed closing times

The maximum overvoltage obtained **with corona** is of 3.05 pu.



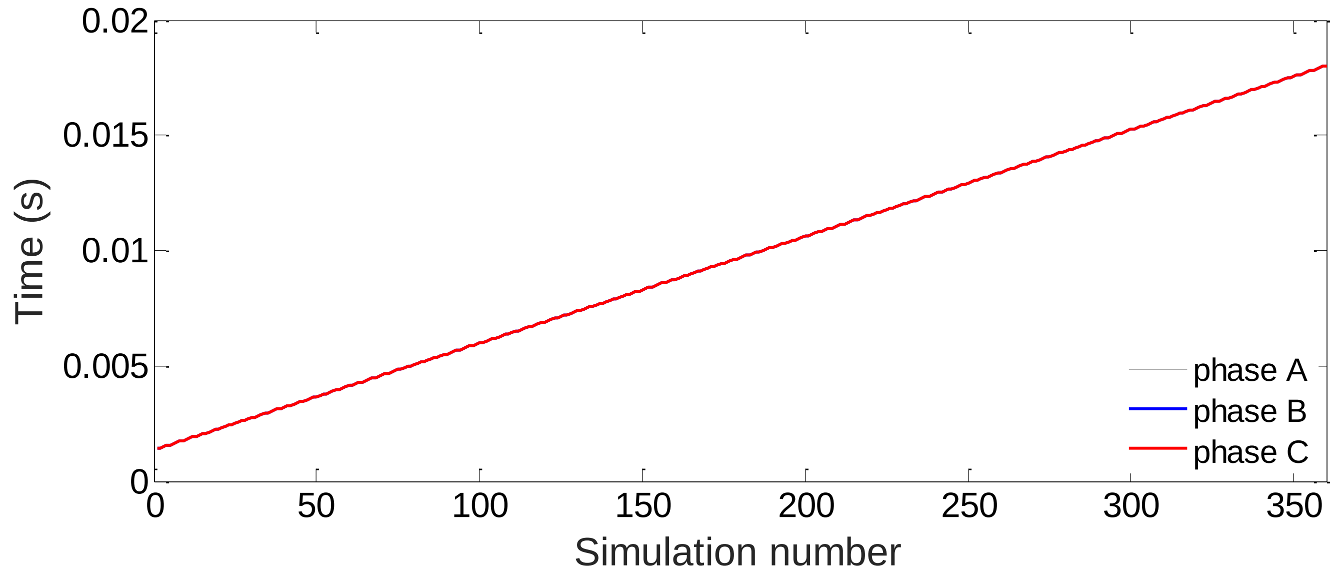
Voltages at Chemawa end

Simulation results

2. Simulations with systematic closing times

Closing times of the three phases are uniformly varied over a complete 60 Hz cycle by increments of 1 electrical degree

Prestrike conditions: Linear slope (ph-A), t_3 = 8 ms, u_c = 437 kV

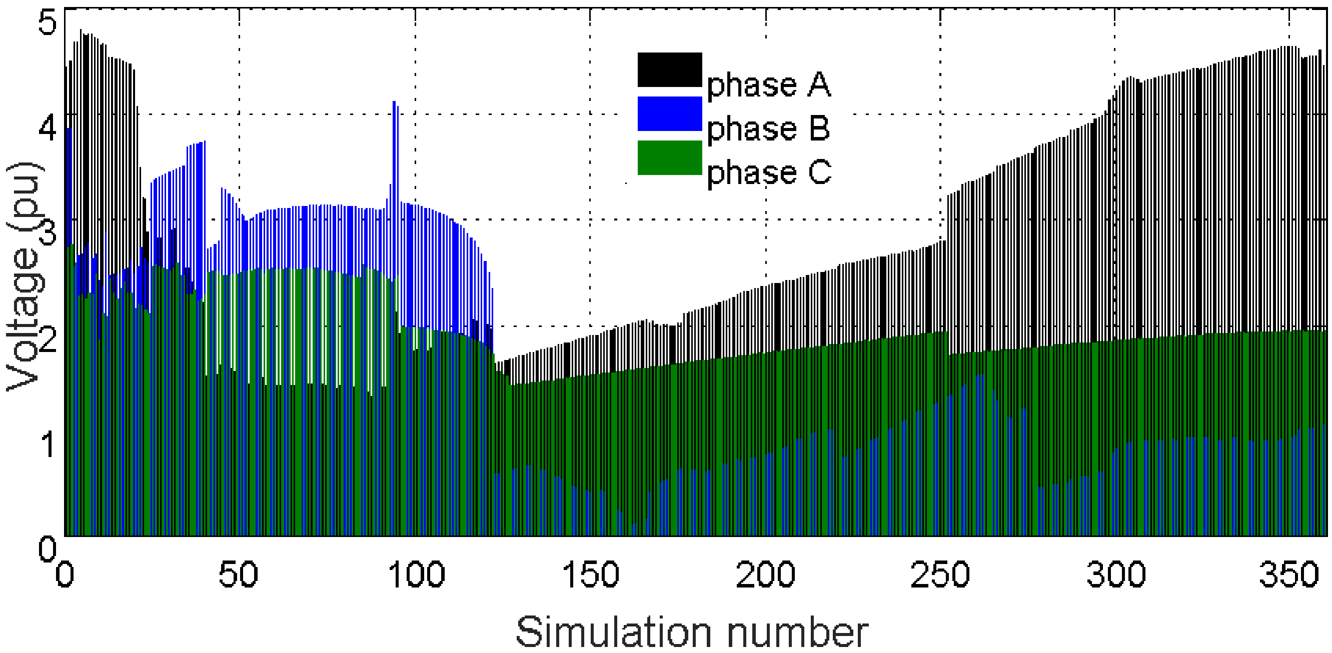


Switching times

Simulation results

2. Simulations with systematic closing times

The maximum overvoltage: Simulation 5, 4.79 pu, at 1.585 ms

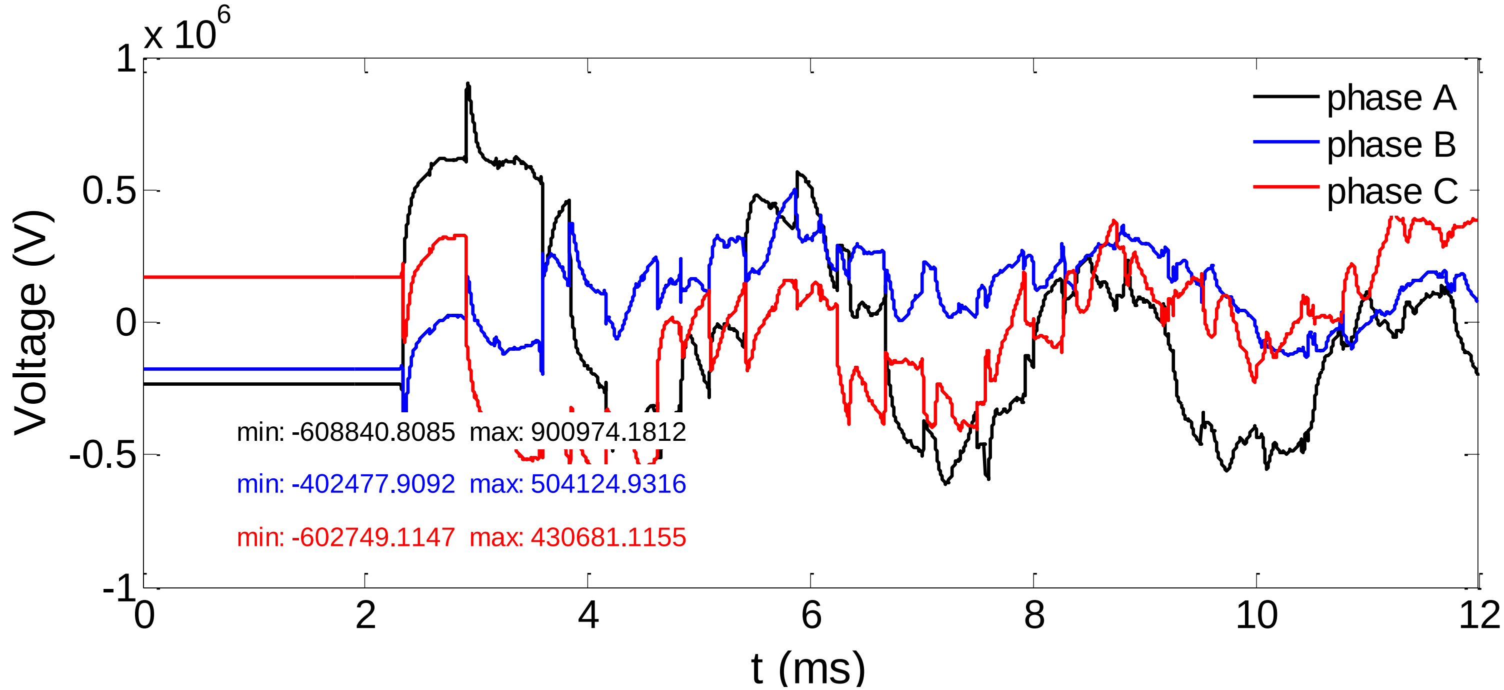


Maximum overvoltages values obtained in the 360 simulations

Simulation results

2. Simulations with systematic closing times

The maximum overvoltage: Simulation 5, 4.79 pu, at 1.585 ms

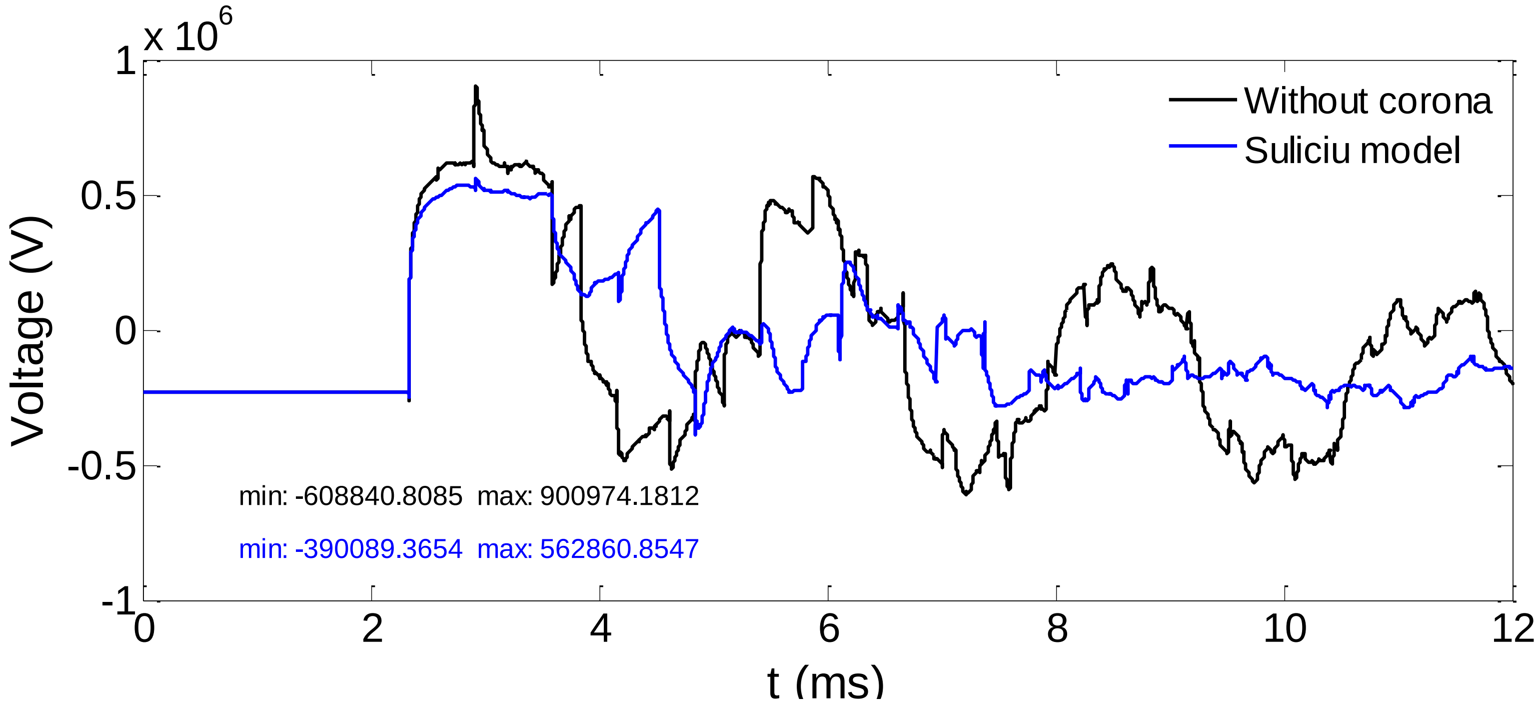


Voltage at Chemawa of the simulation 5

Simulation results

2. Simulations with systematic closing times

The maximum overvoltage obtained with corona is of 2.99 pu.



Voltage at Chemawa of the simulation 5

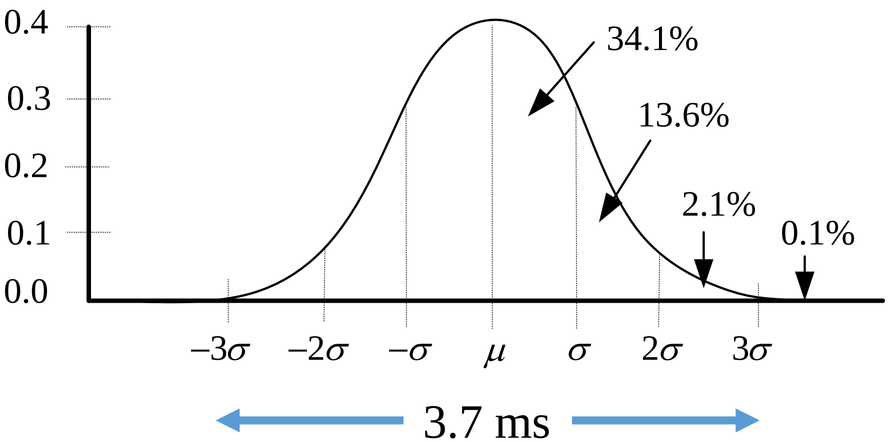
Simulation results

3. Simulations with random closing times

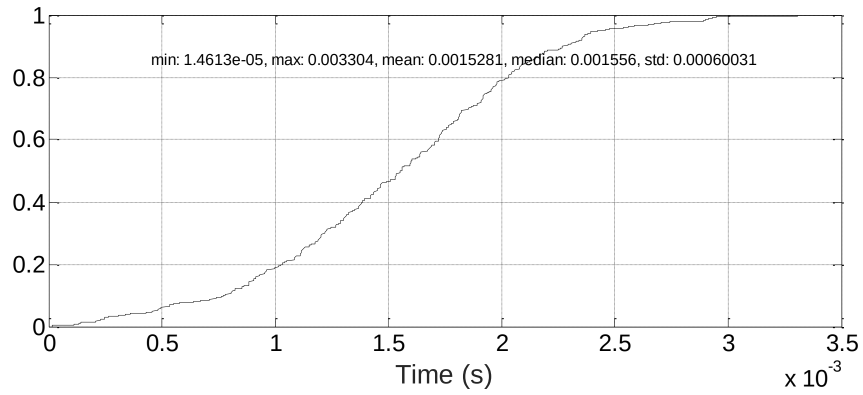
Closing times of the three phases are found by a Gaussian law

Standard deviation: σ = 0.6 ms, mean time value: μ = 1.585 ms

Prestrike conditions: Linear slope (ph-A), t_3 = 8 ms, u_c = 437 kV



Maximum closing time difference between the phases in the Big Eddy breaker



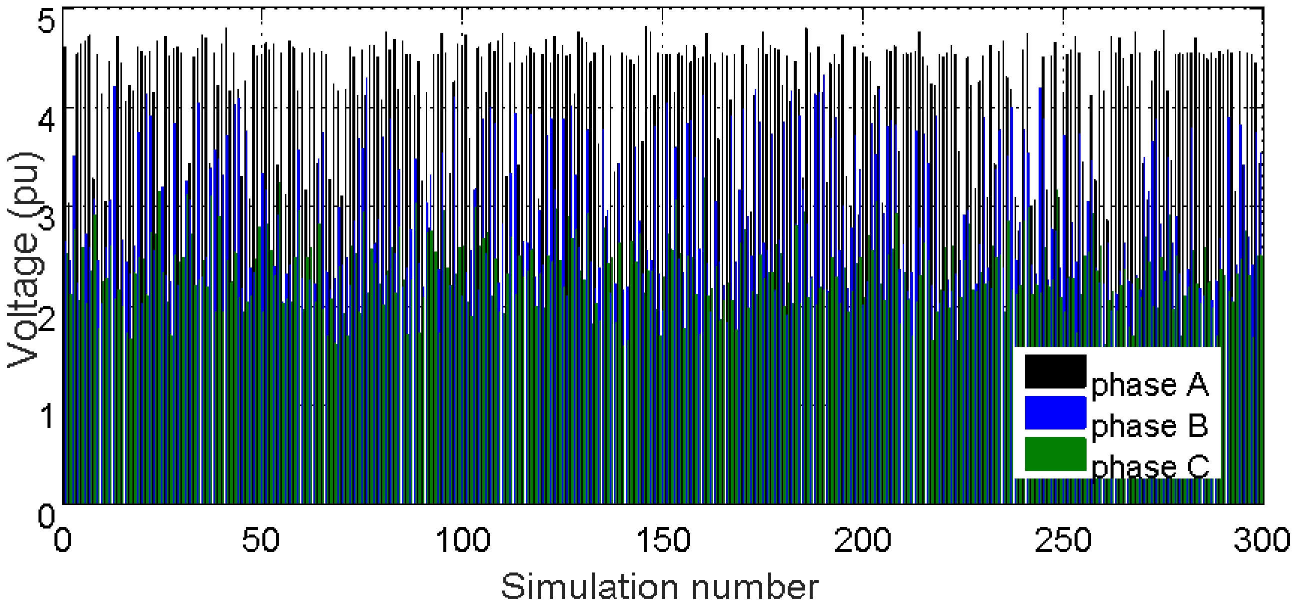
Cumulative distribution function

Simulation results

3. Simulations with random closing times

The maximum overvoltage: Simulation 146, 4.79 pu

Switching times: phase A = 1.446 ms, phase B = 2.286 ms, phase C = 1.311 ms

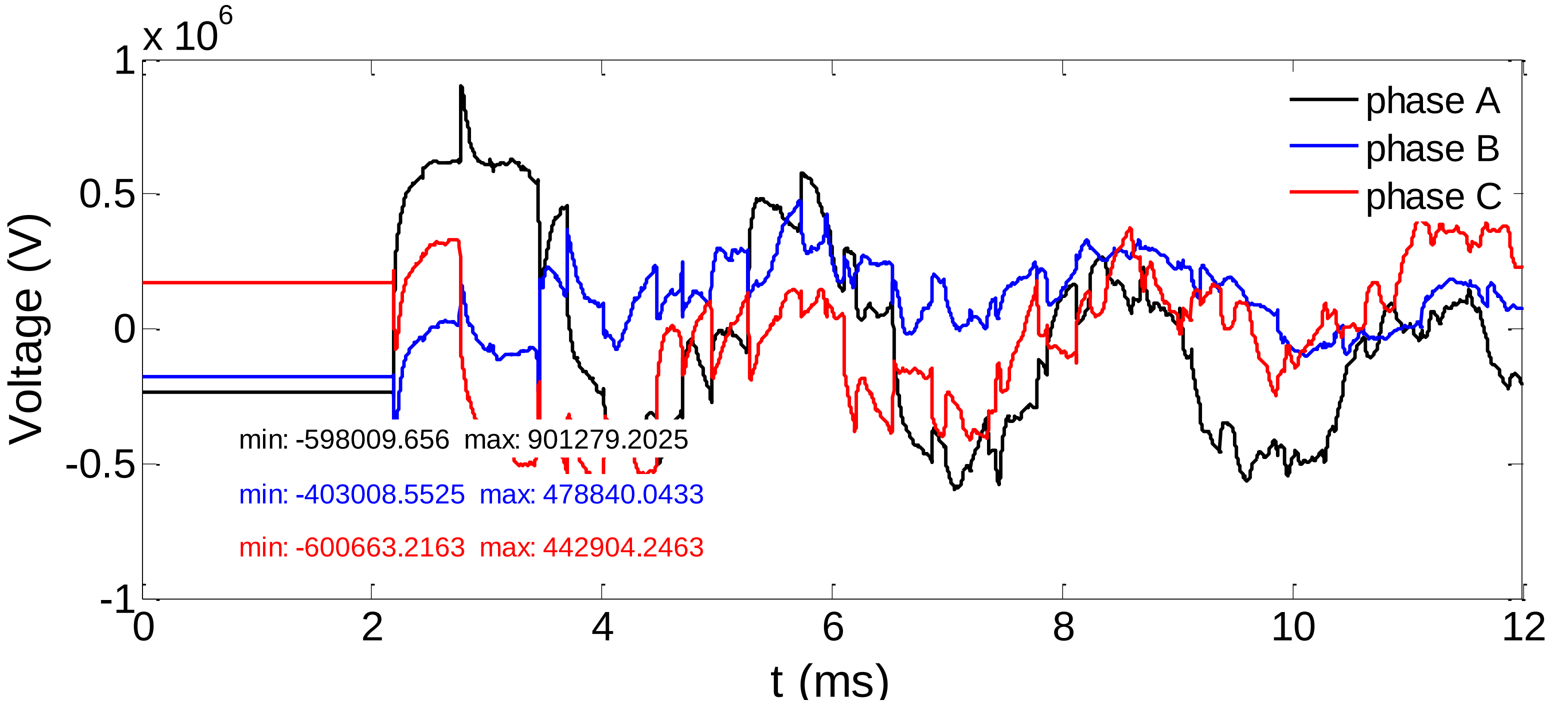


Maximum overvoltages values obtained in 300 simulations

Simulation results

3. Simulations with random closing times

The maximum overvoltage: Simulation 146, 4.79 pu

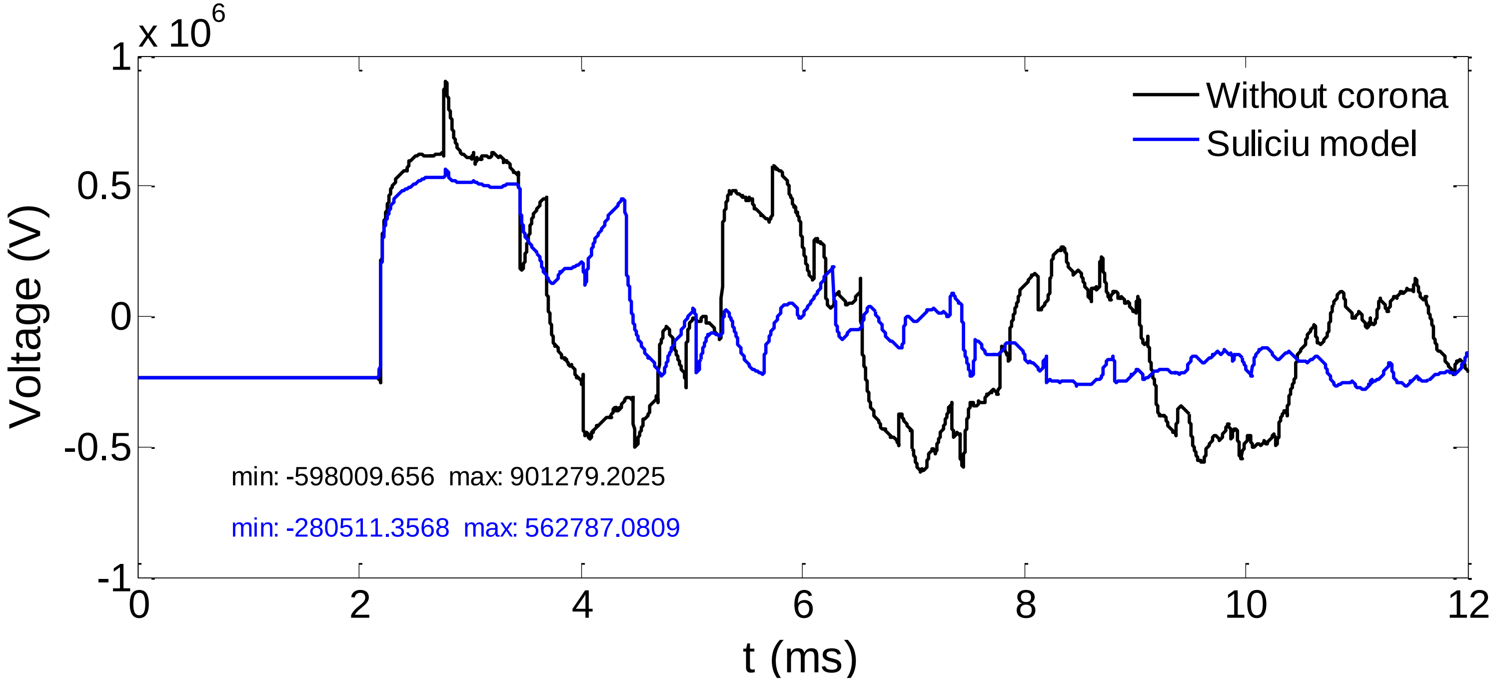


Voltage at Chemawa of the simulation 146

Simulation results

3. Simulations with random closing times

The maximum overvoltage obtained with corona is of 2.99 pu



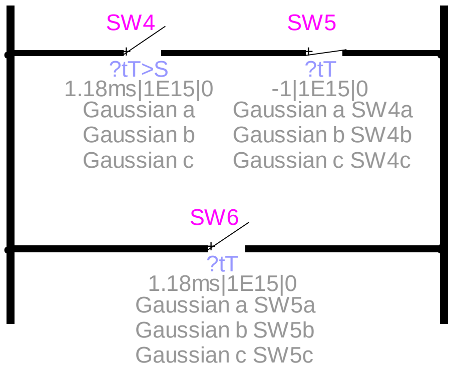
Voltage at Chemawa of the simulation 146

Simulation results

4. Simulations with random prestrike times

Closing times and prestrike conditions → Gaussian law

Mean and standard deviation values are selected based on available prestrike data



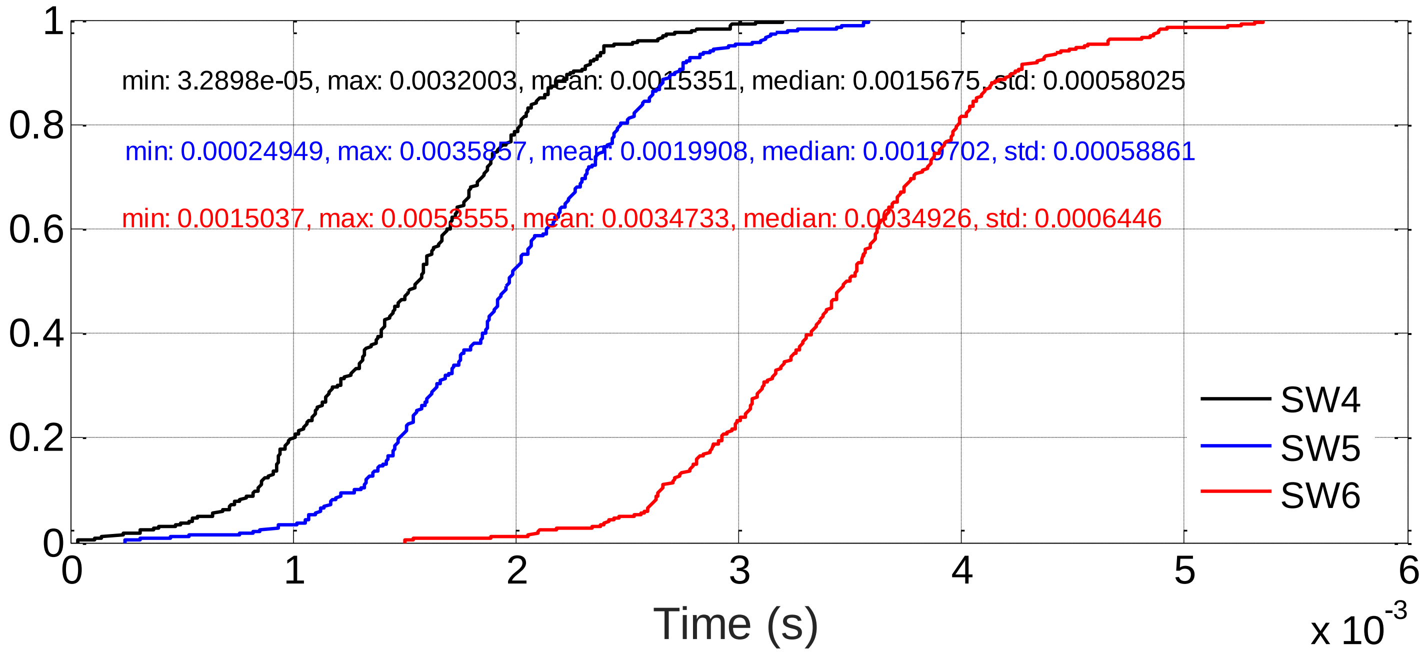
Switch	Condition	Dependency	Mean value μ (ms)	Standard deviation σ (ms)
SW4	Closing	Master	1.585	0.60
SW5	Opening	Slave SW4	0.450	0.10
SW6	Closing	Slave SW5	0.700	0.23

Prestrike model with random times

Simulation results

4. Simulations with random prestrike times

Cumulative distribution for the switches SW4, SW5 and SW6

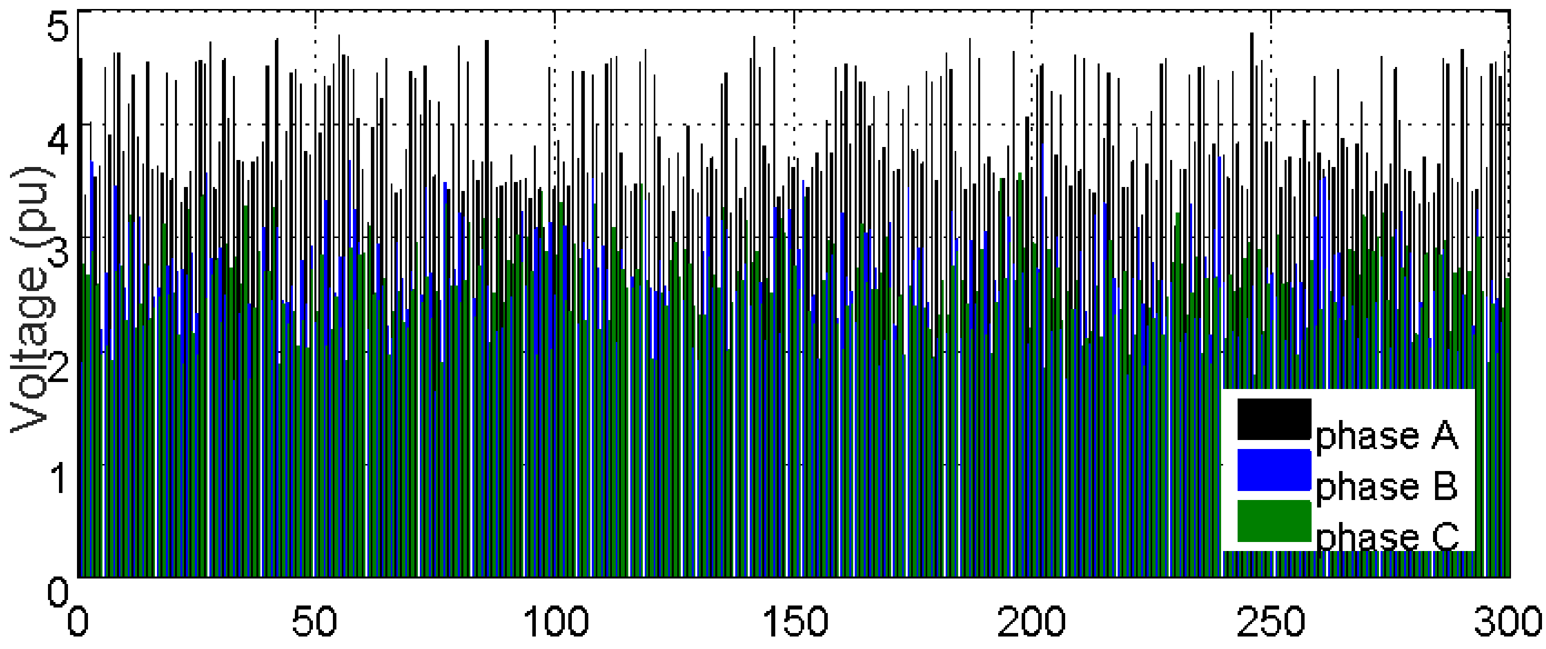


Cumulative distribution function

Simulation results

4. Simulations with random prestrike times

The maximum overvoltage: Simulation 246, 4.78 pu



Maximum overvoltages values obtained in 300 simulations

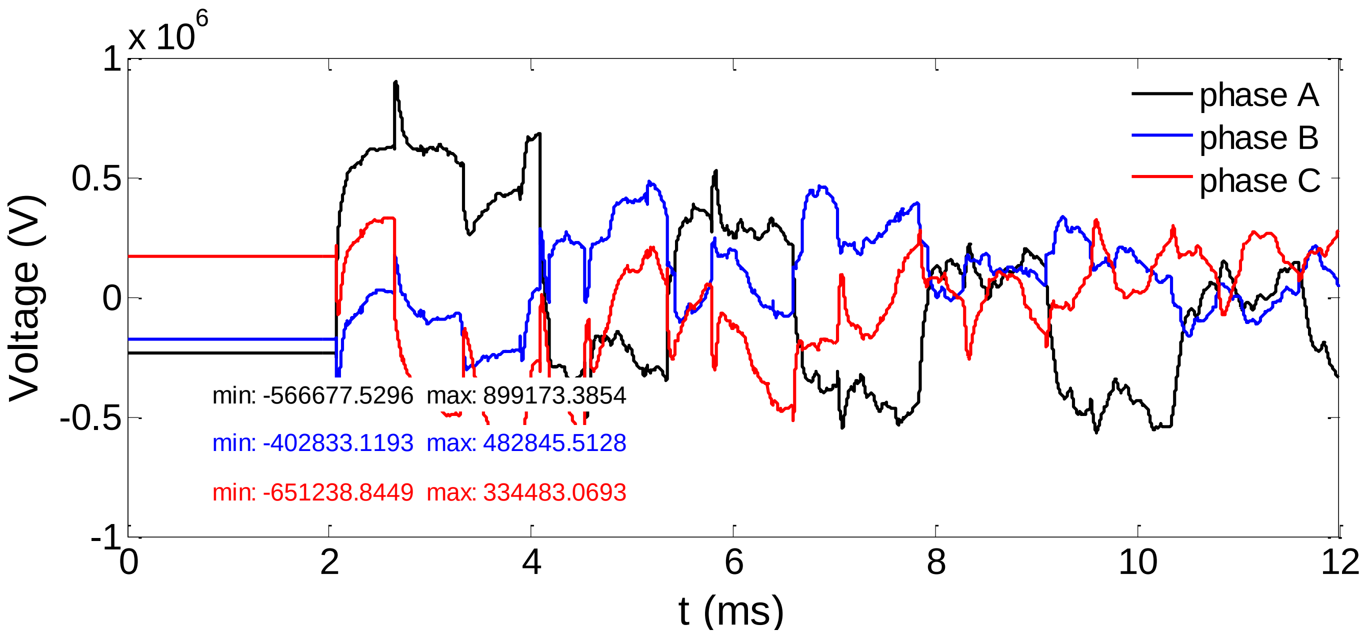
Simulation results

4. Simulations with random prestrike times

The maximum overvoltage:

Simulation 246, 4.78 pu

Phase	Closes (ms)	Opens (ms)	Closes (ms)
A	1.442	2.711	3.466
B	1.555	1.897	3.551
C	2.017	3.383	3.906

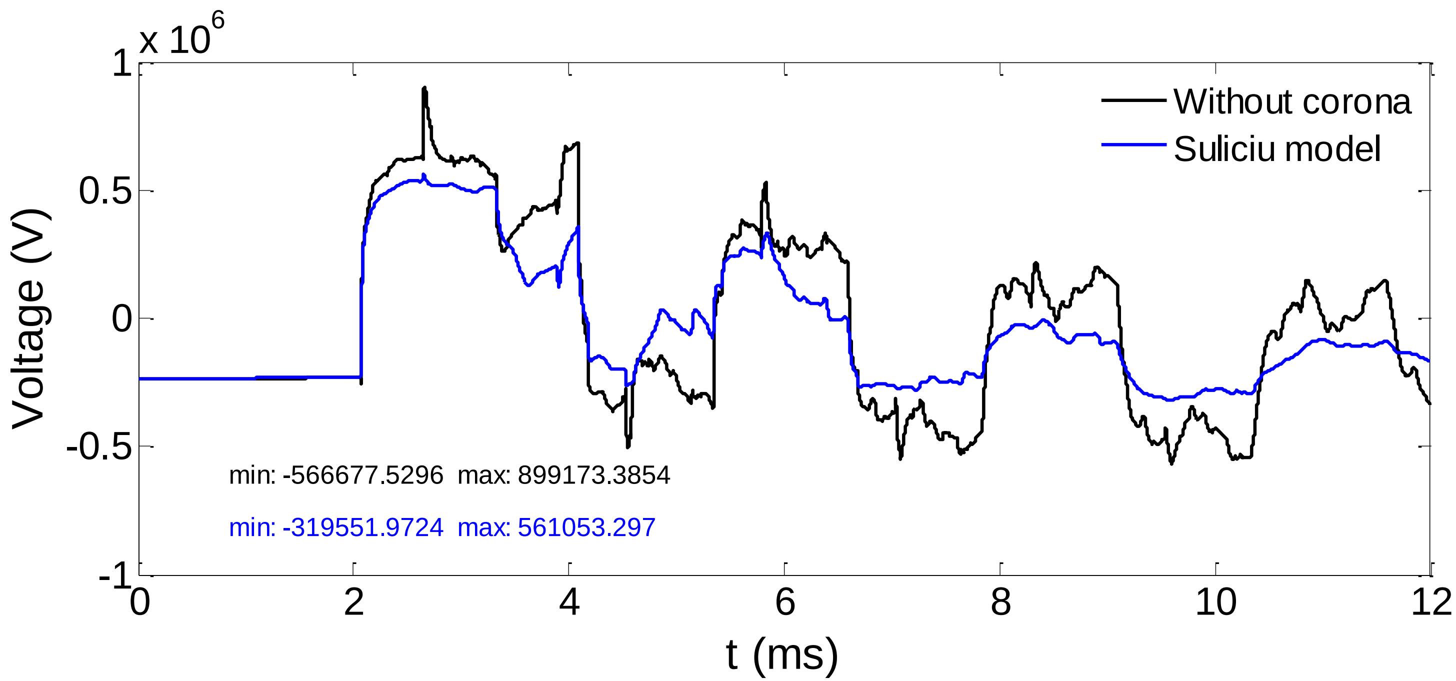


Voltage at Chemawa of the simulation 246

Simulation results

4. Simulations with random prestrike times

The maximum overvoltage obtained with corona is of 2.98 pu.



Voltage at Chemawa of the simulation 246

Simulation results

5. Summary of results

Maximum overvoltage recorded in the field data: 3.01 pu

Test	Closing times	Prestrike model	Number of simulations	Maximum overvoltage (pu)	
				Without corona	With corona
1	Varied uniformly over a complete cycle	Deterministic (linear slope)	360	4.79	2.99
2	Varied randomly (Gaussian law)	Deterministic (linear slope)	300	4.79	2.99
3	Varied randomly (Gaussian law)	Random (Gaussian law)	300	4.78	2.98
4	Varied randomly (Gaussian law)	Random (Gaussian law)	500	4.78	2.98

Conclusions - 3

Simulation tests

1. Single simulation with fixed closing times
2. Simulations with systematic closing times
3. Simulations with random closing times
4. Simulations with random prestrike times

Simplified source or detailed source model

The estimated maximum overvoltage shows a good agreement with the one recorded in the field tests (0.02 pu)

Recapitulation

- High speed reclosing on trapped charge results in overvoltages. Accurate evaluation in simulations require considering corona.
- Prestrike and frequency dependent line models are necessary for precise transient waveform reproduction in EMTP
- Statistical studies are performed to find the peak overvoltage, corona is applied to the worst case