Geomagnetic Disturbance and High-Altitude EMP in Simulator

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NERC TPL-007-1 Implementation

- Transmission System Planned Performance for Geomagnetic Disturbance Events
- January 1, 2017: start of quarter after FERC 830 became effective
- July 2017: R1, identify responsibilities
- July 2018: R2, maintain system models
- January 2019: R5, provide GIC flow information to transmission and generator owners
- January 2021: R6, transformer thermal impact assessment
- January 2022
  - R3, steady state voltage performance criteria
  - R4, GMD Assessment
  - R7, Corrective Action Plan

Recent Developments in PowerWorld Simulator

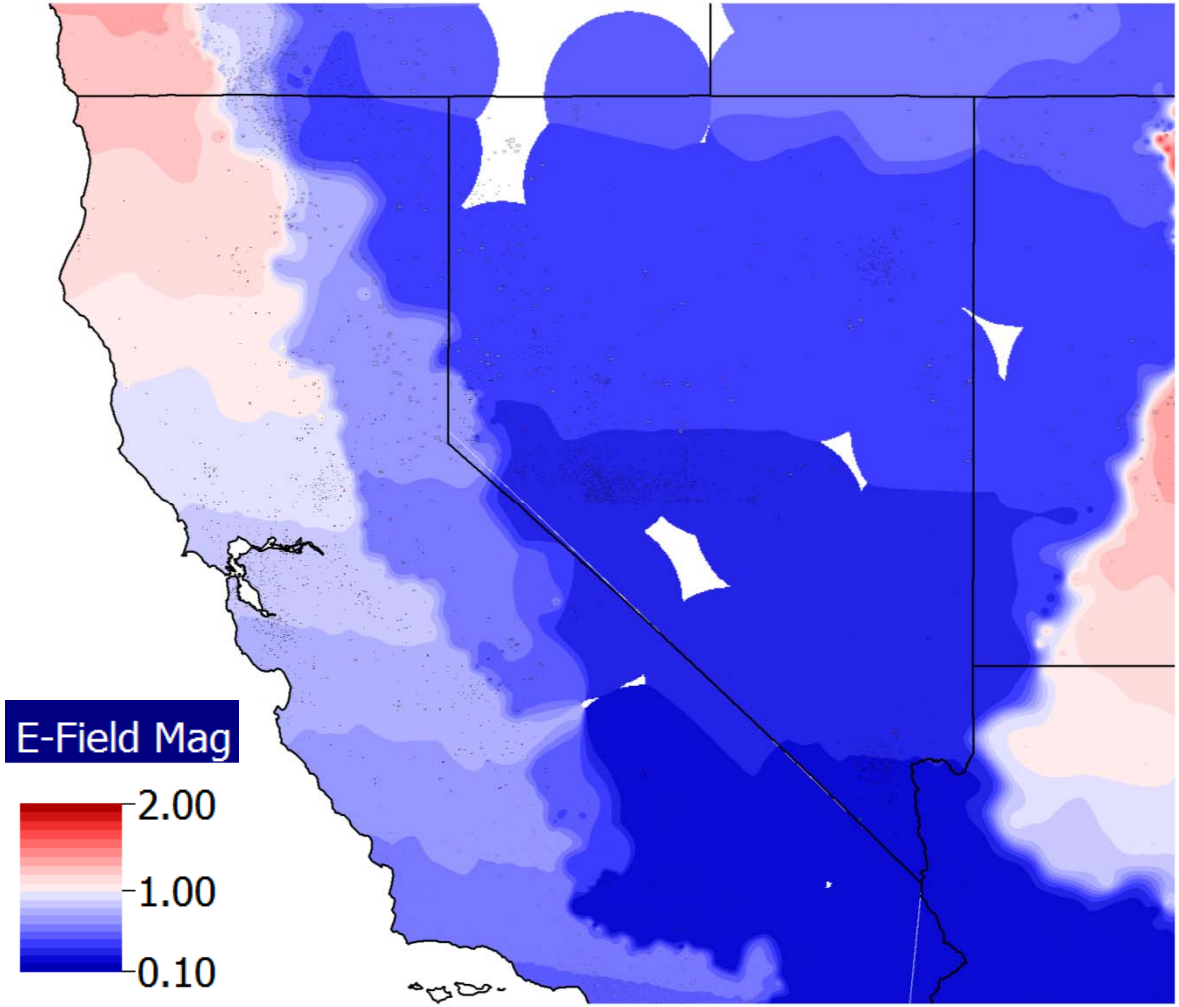
- NERC TPL-007-2
  - Benchmark and Supplemental GMD Events
  - Time-series inputs for transformer thermal modeling
  - FERC Notice of Proposed Rulemaking Issued (comment period through July 23)
- High-Altitude Electromagnetic Pulse (HEMP or EMP) modeling
  - EMP Commission reports made public
  - E3 GIC simulation in PowerWorld Simulator power flow and transient stability

NERC TPL-007-2

- Benchmark Event (TPL-007-1)
  - $E_{peak} = 8 \times \alpha \times \beta_b$ V/km
  - GIC(t) from benchmark event time series
- Supplemental Event
  - $E_{peak} = 12 \times \alpha \times \beta_s$ V/km
  - Planner has flexibility in specifying height and width of "localized peak geoelectric field"
  - GIC(t) from supplemental event time series

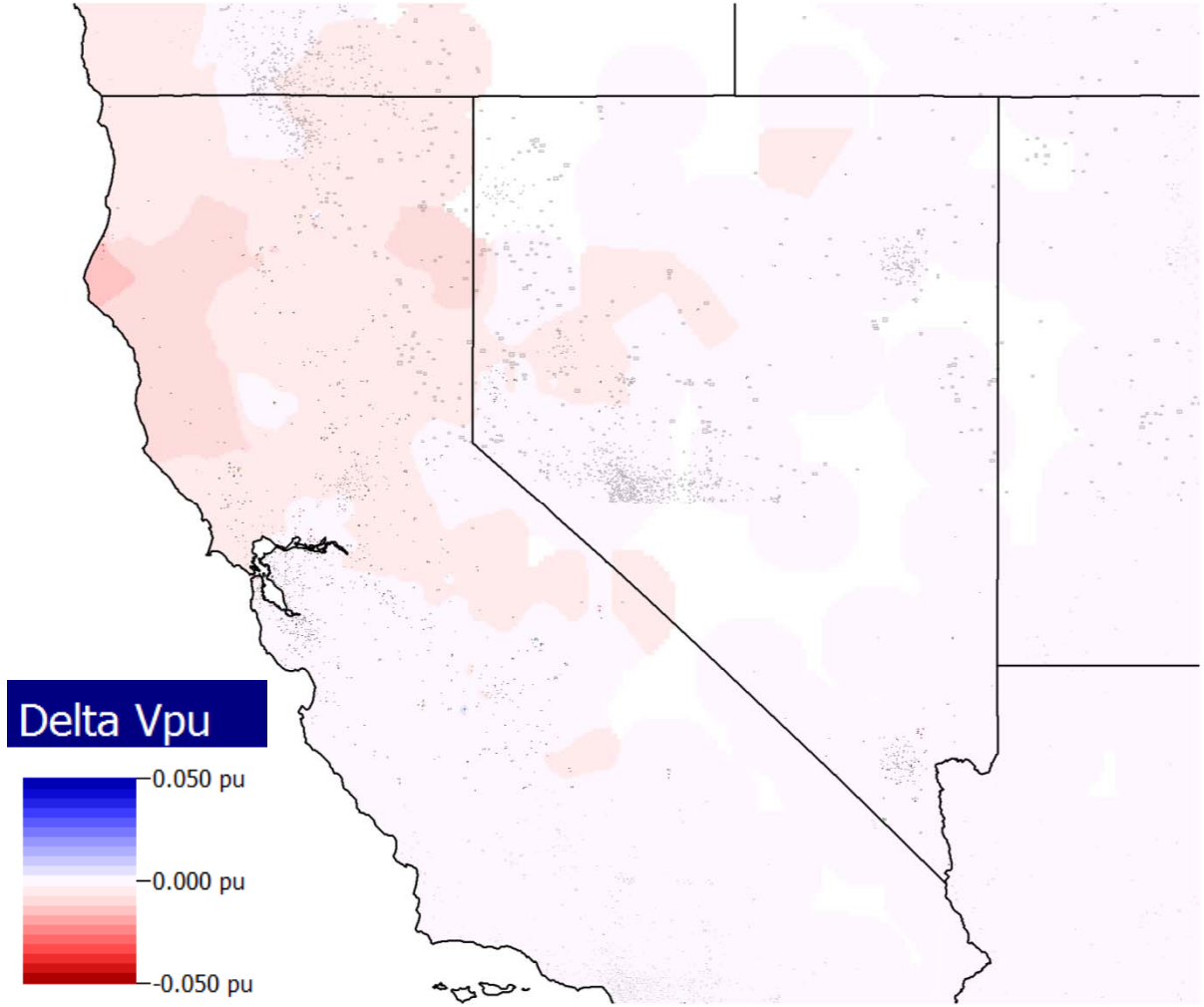
Benchmark Event

- E-field contour, scaled by latitude and resistivity scalars
- $E_{peak} = 8 \times \alpha \times \beta_b$ V/km



Benchmark Event

- Change in AC bus voltages due to GIC reactive power losses in transformers

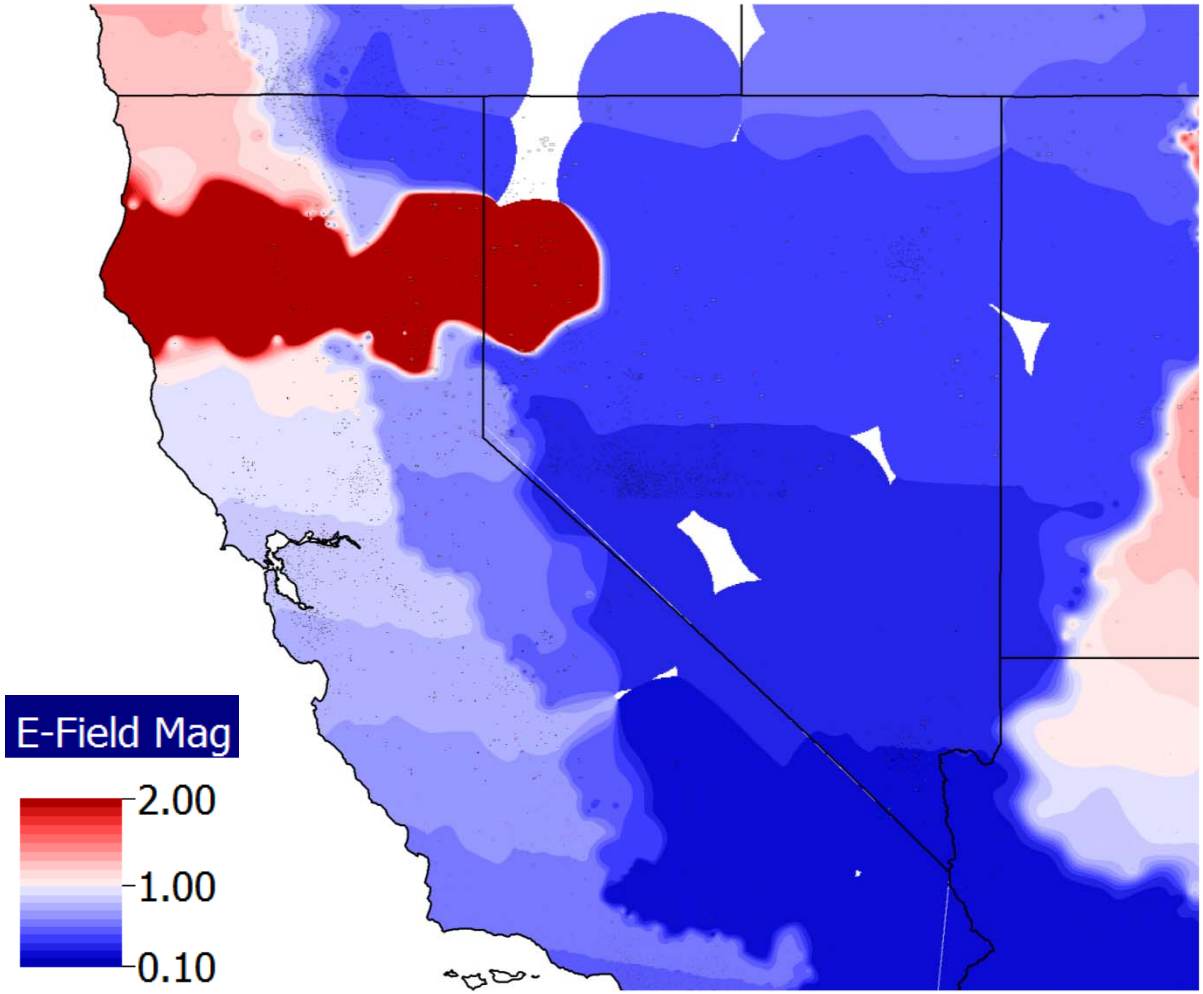


Supplemental Event

- Implemented in Simulator as “Hotspot Modeling”
- Separately specified E-Field strength, optionally scalable with latitude and 1-D Earth Model scalar
- Specify height (N-S), width (E-W), and center coordinates

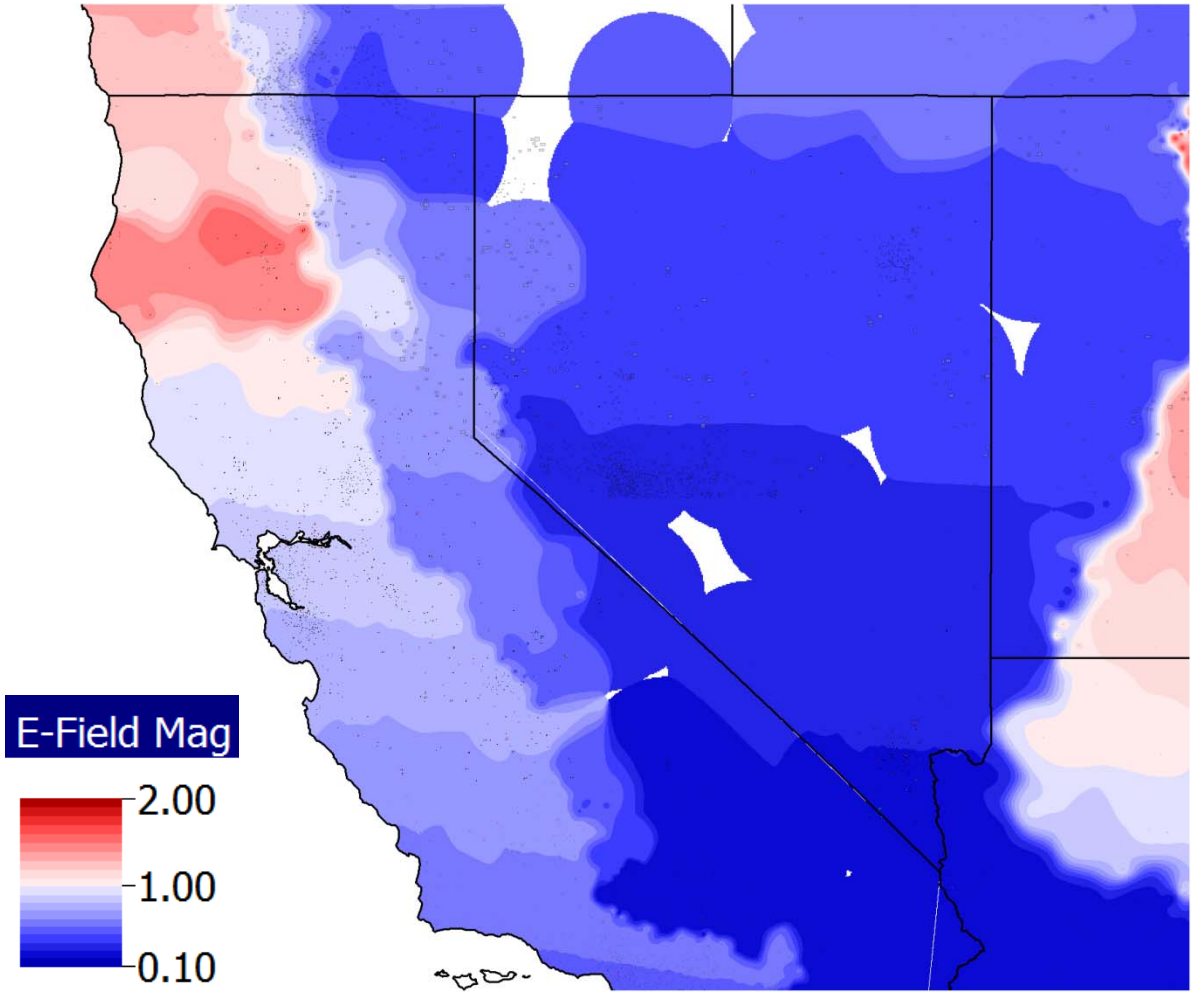
Supplemental Event

- 12 V/km E-field hotspot, unscaled with latitude and earth resistivity
- Centered over Northern CA, with 500 km width and 100 km height



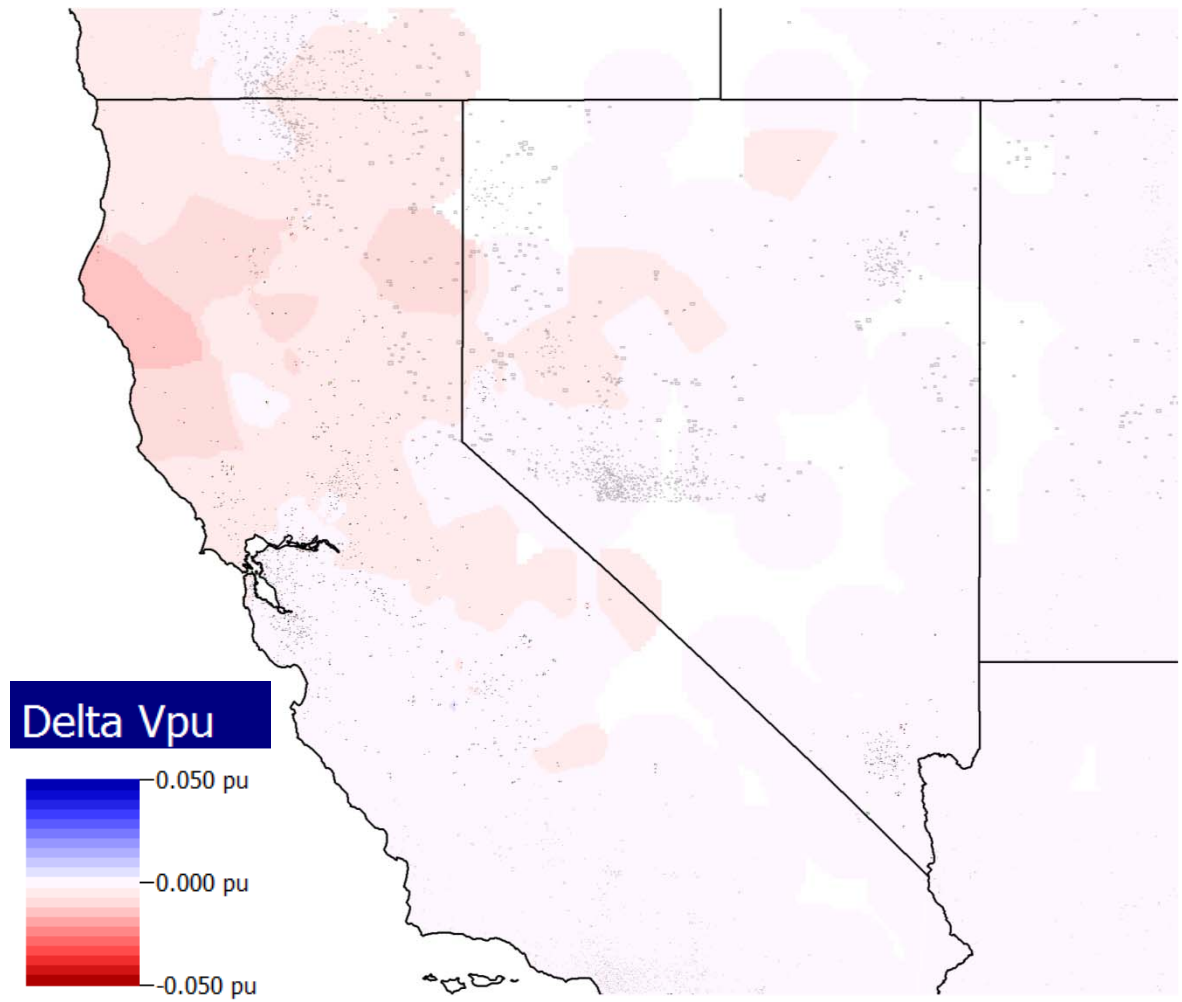
Supplemental Event

- E-field scaled with latitude and supplemental event earth resistivity scalars
- $E_{peak} = 12 \times \alpha \times \beta_s$ V/km

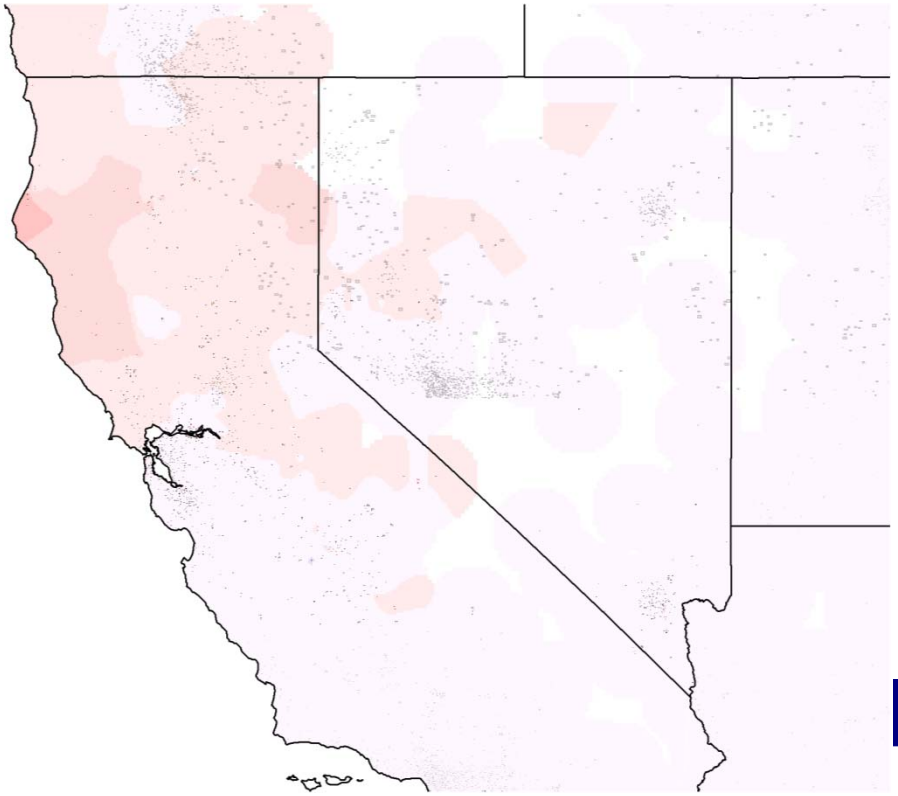


Supplemental Event

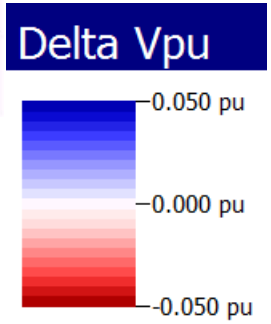
- Change in AC bus voltages due to GIC reactive power losses in transformers
- Voltages slightly more depressed in affected region vs. benchmark event

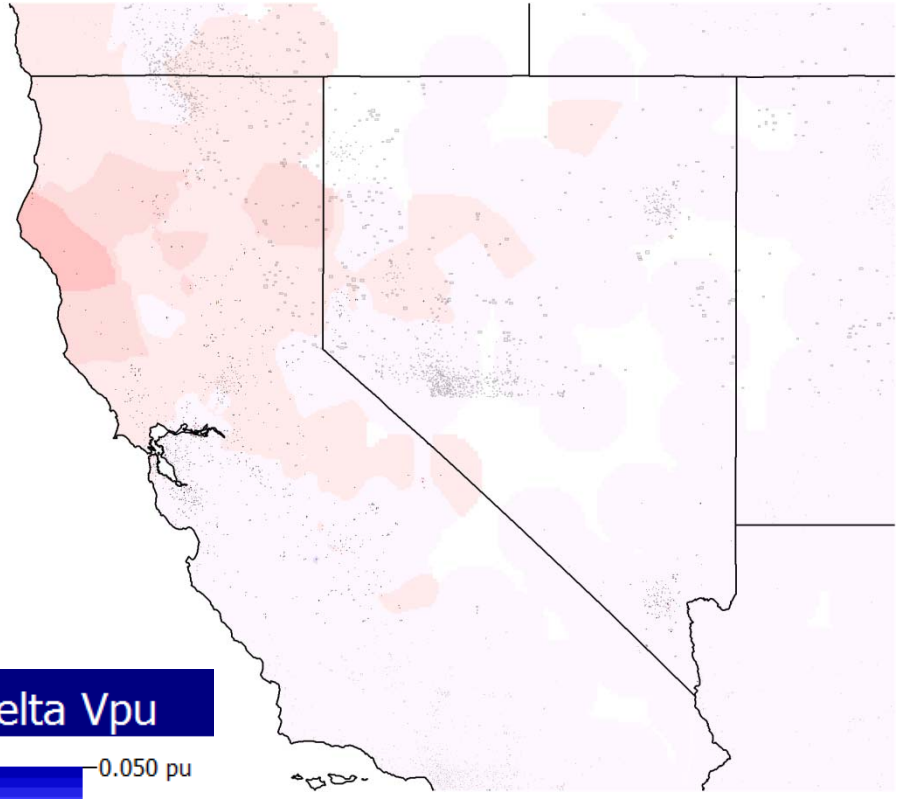


Hotspot Impact on AC Voltage



Benchmark Event





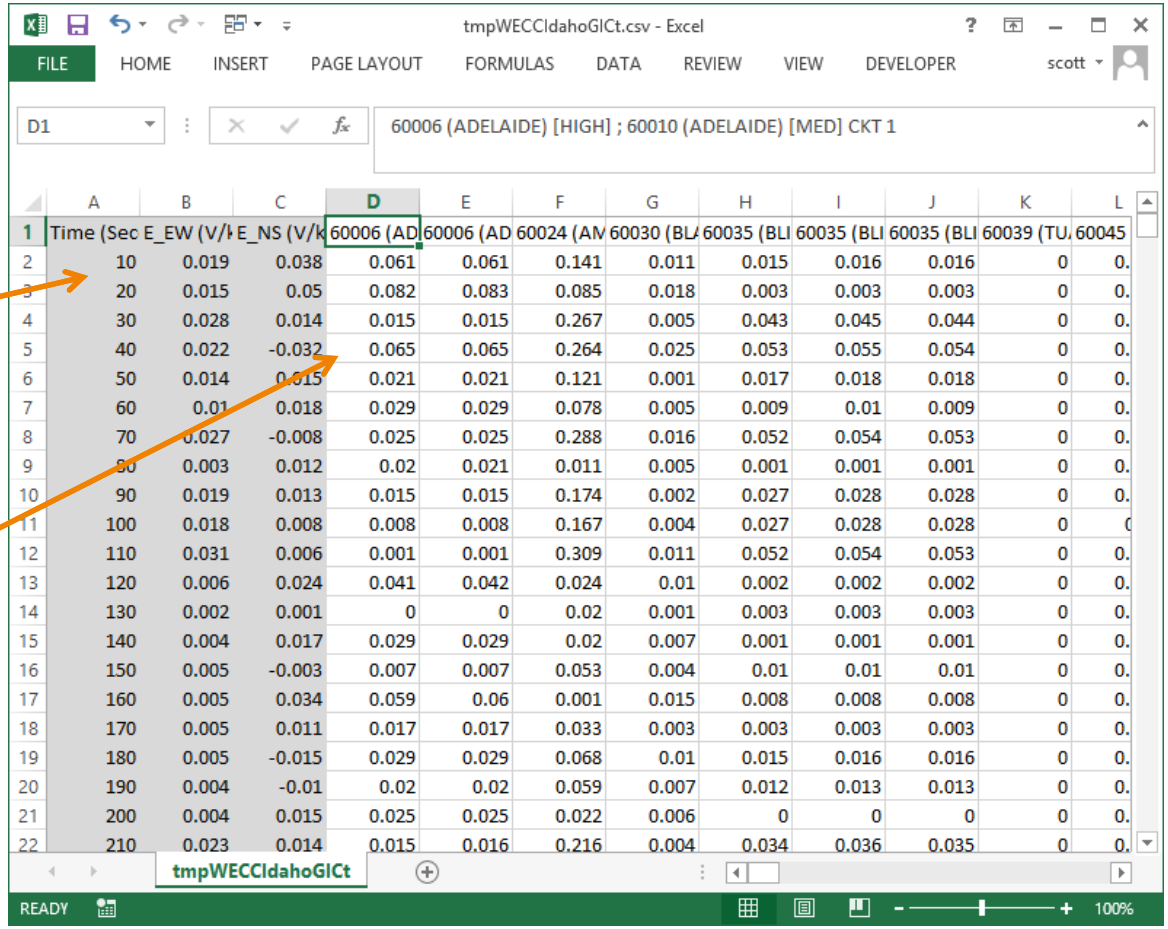
Supplemental Event

Benchmark and Supplemental Event Time Series

- Automatically generate a csv file of GIC(t) time series for a uniform time-varying E(t) field
- Input in CSV format
  - fields are time, eastward E(t), and northward E(t) in V/km
  - Sample input files at https://www.powerworld.com/knowledge-base/transformer-time-series-for-nerc-benchmark-gmd-event
  - 10-second samples matching **Figures 2 and 3** in the NERC *Benchmark Geomagnetic Disturbance Event Description*
- Output CSV is GIC(t) for all transformers on the GIC Transformers display
  - it usually makes sense to filter this list (e.g. transformers with Maximum per-phase Effective GIC >= 75A)
  - May be used as input to thermal analysis

NERC Benchmark Event Time Series

- Sample output file shown
- Input time series
- Transformer GIC(t)

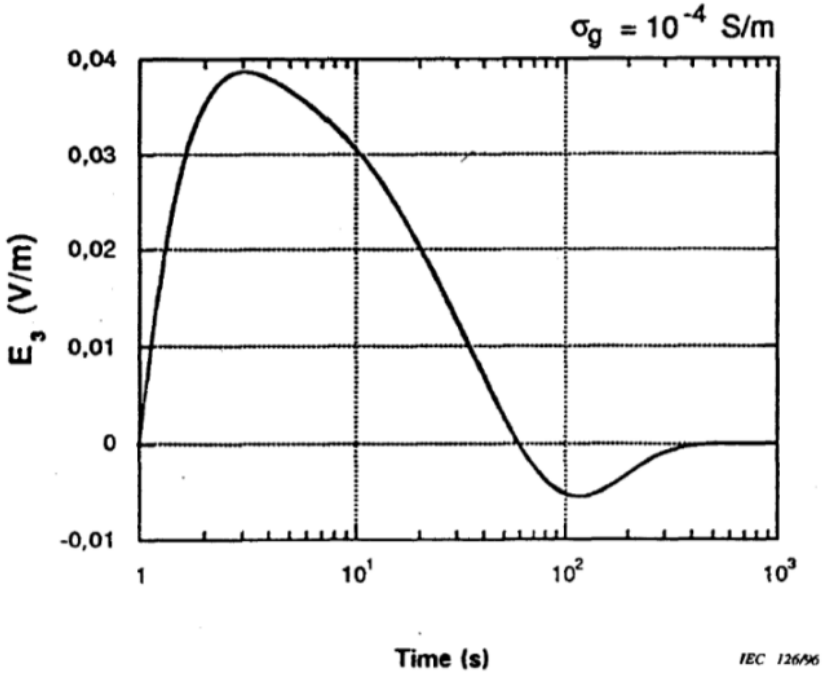


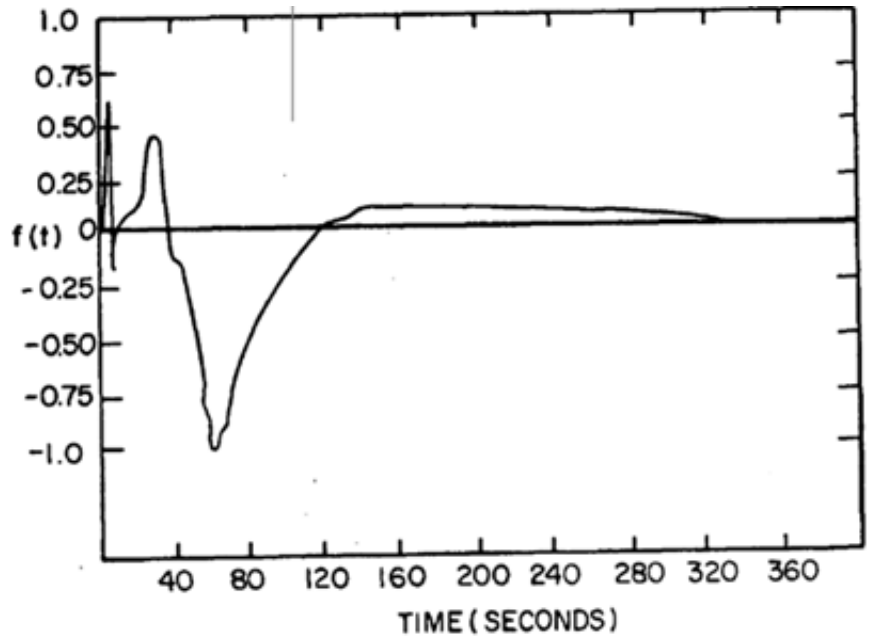
	A	B	C	D	E	F	G	H	I	J	K	L
1	Time (Sec	E_EW (V/k	E_NS (V/k	60006 (AD	60006 (AD	60024 (AN	60030 (BL	60035 (BL	60035 (BL	60035 (BL	60039 (TU	60045
2	10	0.019	0.038	0.061	0.061	0.141	0.011	0.015	0.016	0.016	0	0.
3	20	0.015	0.05	0.082	0.083	0.085	0.018	0.003	0.003	0.003	0	0.
4	30	0.028	0.014	0.015	0.015	0.267	0.005	0.043	0.045	0.044	0	0.
5	40	0.022	-0.032	0.065	0.065	0.264	0.025	0.053	0.055	0.054	0	0.
6	50	0.014	0.015	0.021	0.021	0.121	0.001	0.017	0.018	0.018	0	0.
7	60	0.01	0.018	0.029	0.029	0.078	0.005	0.009	0.01	0.009	0	0.
8	70	0.027	-0.008	0.025	0.025	0.288	0.016	0.052	0.054	0.053	0	0.
9	80	0.003	0.012	0.02	0.021	0.011	0.005	0.001	0.001	0.001	0	0.
10	90	0.019	0.013	0.015	0.015	0.174	0.002	0.027	0.028	0.028	0	0.
11	100	0.018	0.008	0.008	0.008	0.167	0.004	0.027	0.028	0.028	0	0
12	110	0.031	0.006	0.001	0.001	0.309	0.011	0.052	0.054	0.053	0	0.
13	120	0.006	0.024	0.041	0.042	0.024	0.01	0.002	0.002	0.002	0	0.
14	130	0.002	0.001	0	0	0.02	0.001	0.003	0.003	0.003	0	0.
15	140	0.004	0.017	0.029	0.029	0.02	0.007	0.001	0.001	0.001	0	0.
16	150	0.005	-0.003	0.007	0.007	0.053	0.004	0.01	0.01	0.01	0	0.
17	160	0.005	0.034	0.059	0.06	0.001	0.015	0.008	0.008	0.008	0	0.
18	170	0.005	0.011	0.017	0.017	0.033	0.003	0.003	0.003	0.003	0	0.
19	180	0.005	-0.015	0.029	0.029	0.068	0.01	0.015	0.016	0.016	0	0.
20	190	0.004	-0.01	0.02	0.02	0.059	0.007	0.012	0.013	0.013	0	0.
21	200	0.004	0.015	0.025	0.025	0.022	0.006	0	0	0	0	0.
22	210	0.023	0.014	0.015	0.016	0.216	0.004	0.034	0.036	0.035	0	0.

High-Altitude Electromagnetic Pulse (HEMP)

- The late-time (E3) effects of a nuclear detonation tens-hundreds of km over the surface of the Earth gives rise to geomagnetic disturbances (GMD) similar to a coronal mass ejection from the sun
- The E3 is usually broken into two components
  - E3A “Blast Wave” caused by the expansion of the nuclear fireball, expelling the Earth’s magnetic field
  - E3B “Heave” as bomb debris and air ions follow geomagnetic lines at about 130 km, making the air rise, which gives rise to a current and an induced electric field

HEMP E3A and E3B





Left Image: IEC 1000-2-9, Figure 9, Right Image: ORNL "Study to Assess the Effects of Magnetohydrodynamic Electromagnetic Pulse on Electric Power Systems Phase I Final Report," May 1985, Figure 8

HEMP Modeling

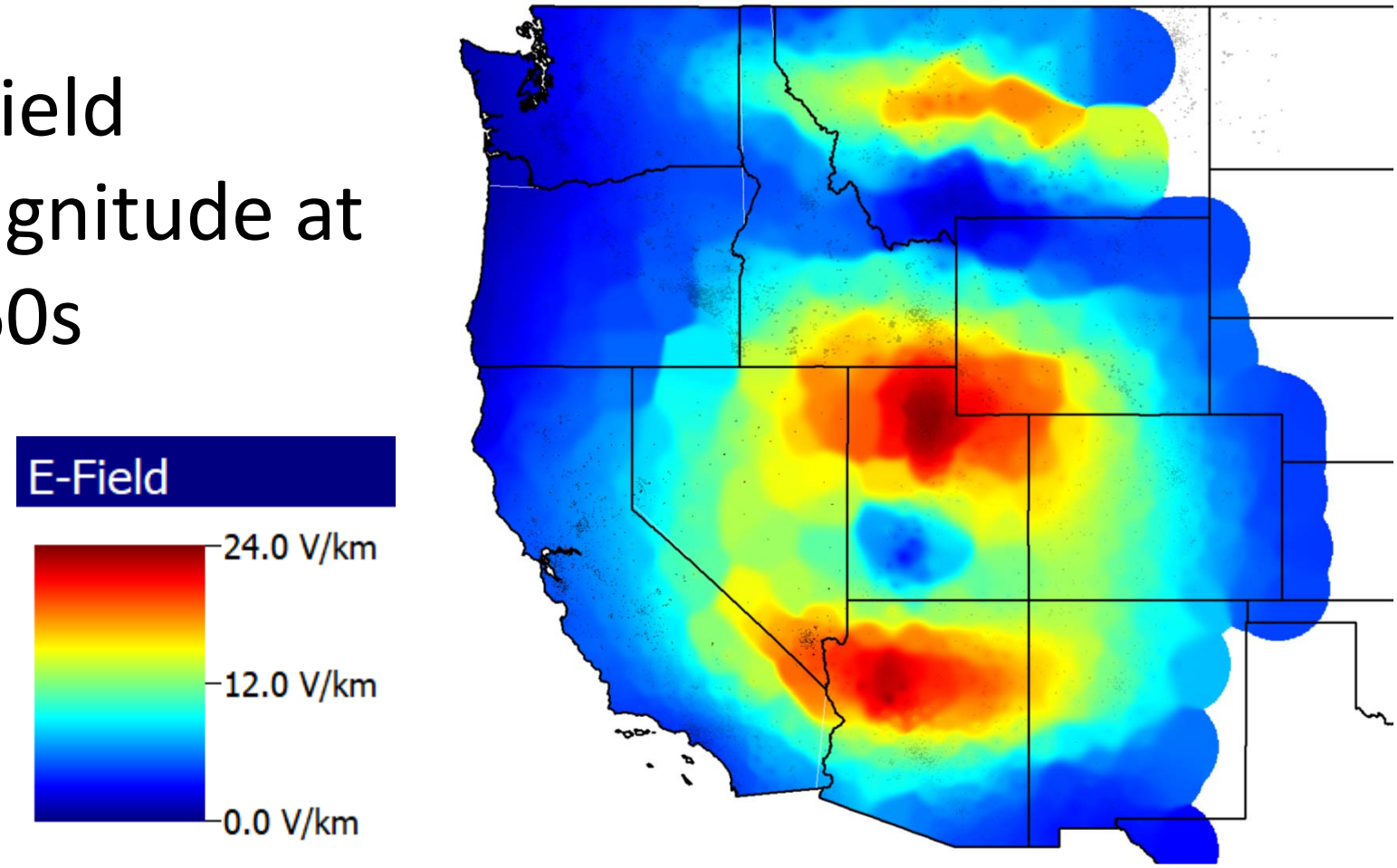
- Sources of initial time and spatial waveforms implemented in PowerWorld Simulator
  - "Study to Assess the effects of Magnetohydrodynamic Electromagnetic Pulse on Electric Power System, Phase 1, Final Report," Martin Marietta Energy Systems Inc. Oak Ridge National Labs. 1985.
  - "IEC 61000-2-9 – Electromagnetic Compatibility (EMC) – Part 2: Environment – Section 9: Description of HEMP Environment – Radiated Disturbance. Basic EMC Publication," International Electrotechnical Commission. Feb. 19, 1996.

HEMP Modeling

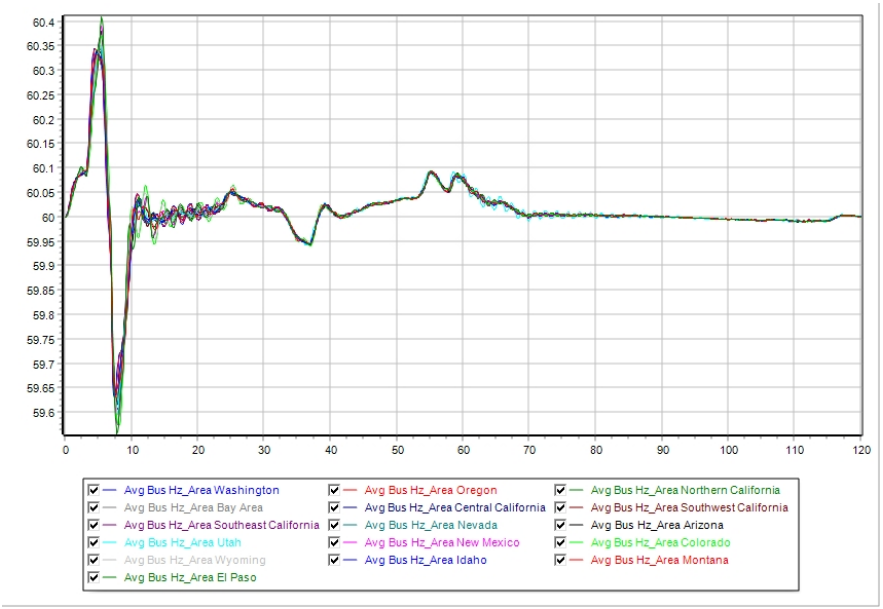
- HEMP disturbances have faster rise times than solar GMD, but may last only several minutes
- It often makes sense to analyze EMP in the transient stability domain
  - Incorporate load shedding, generator exciters, excitation limiters, and other characteristics not modeled in power flow

ORNL E3B Example

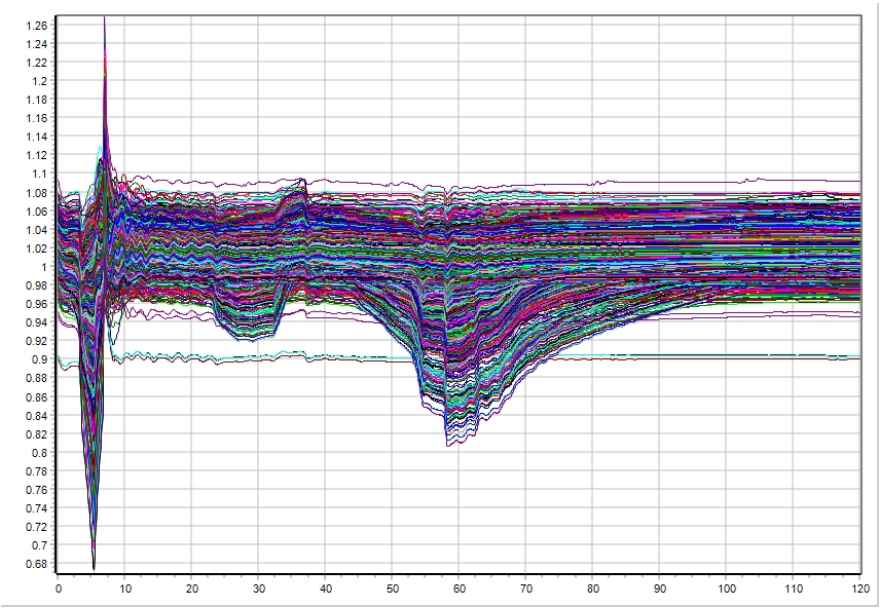
E-Field Magnitude at t=60s



Transient Stability Plots



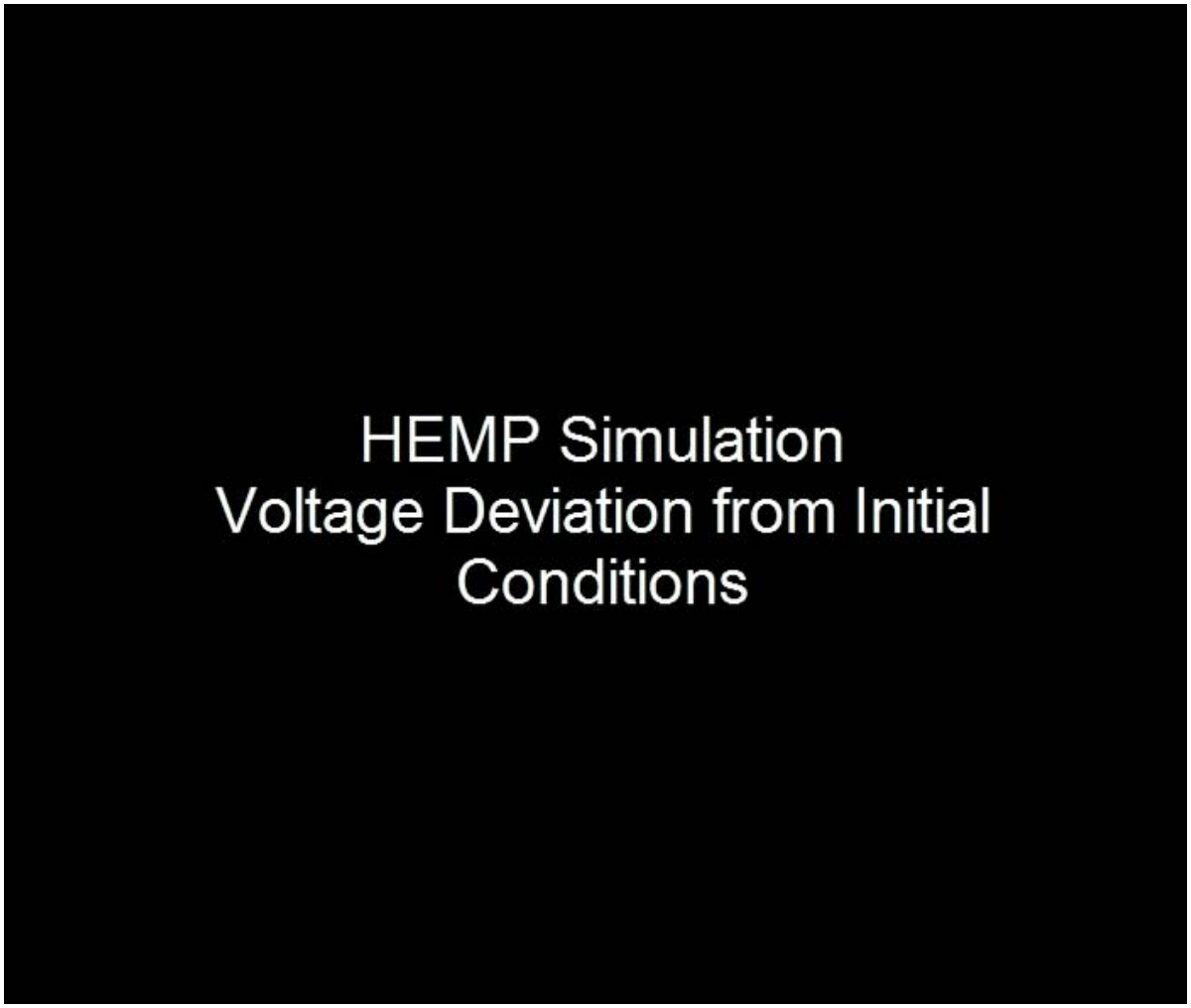
Frequency:
Average by Area



Bus Voltage

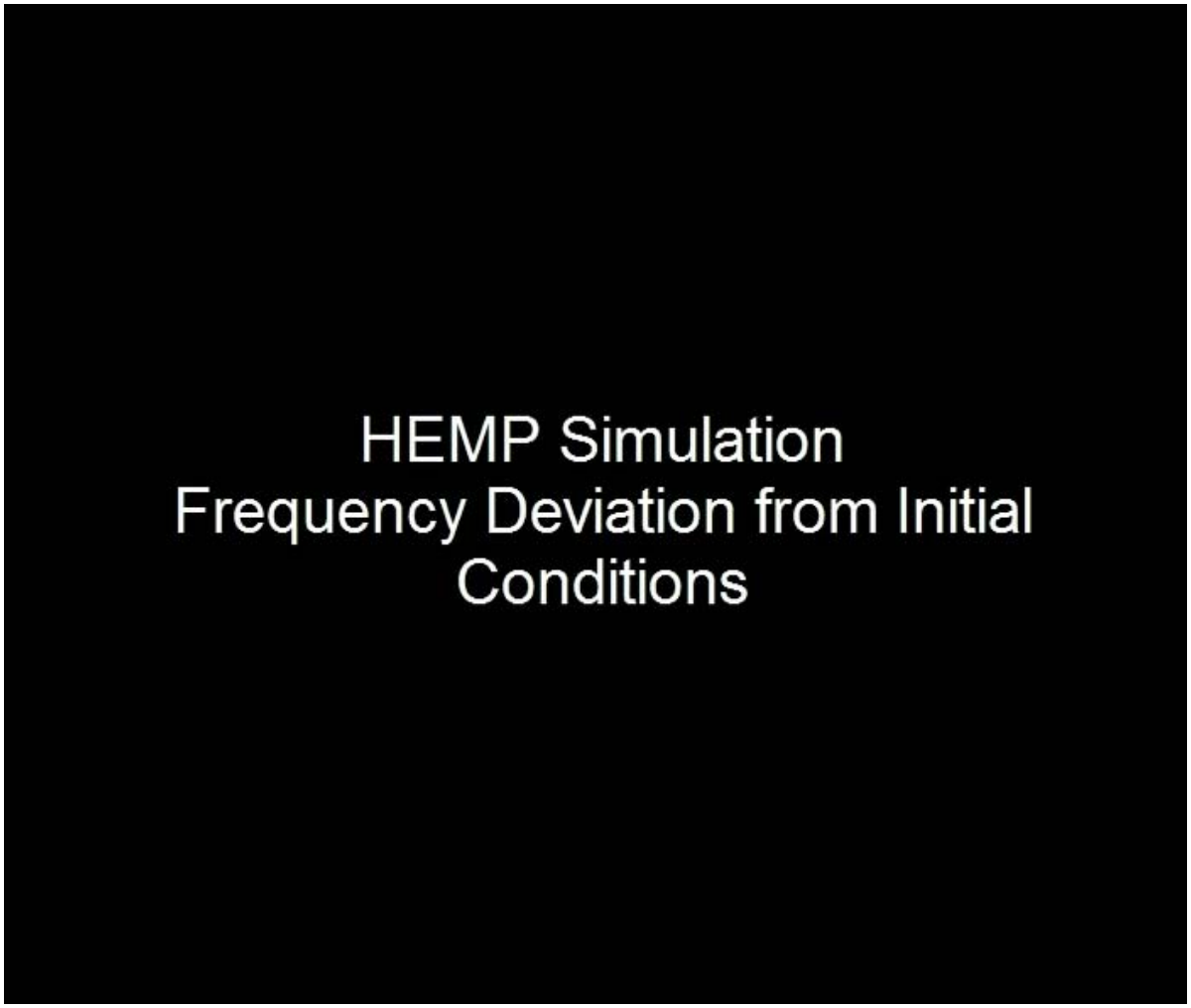
Transient Stability:

Voltage Visualization



Transient Stability:

Frequency Visualization

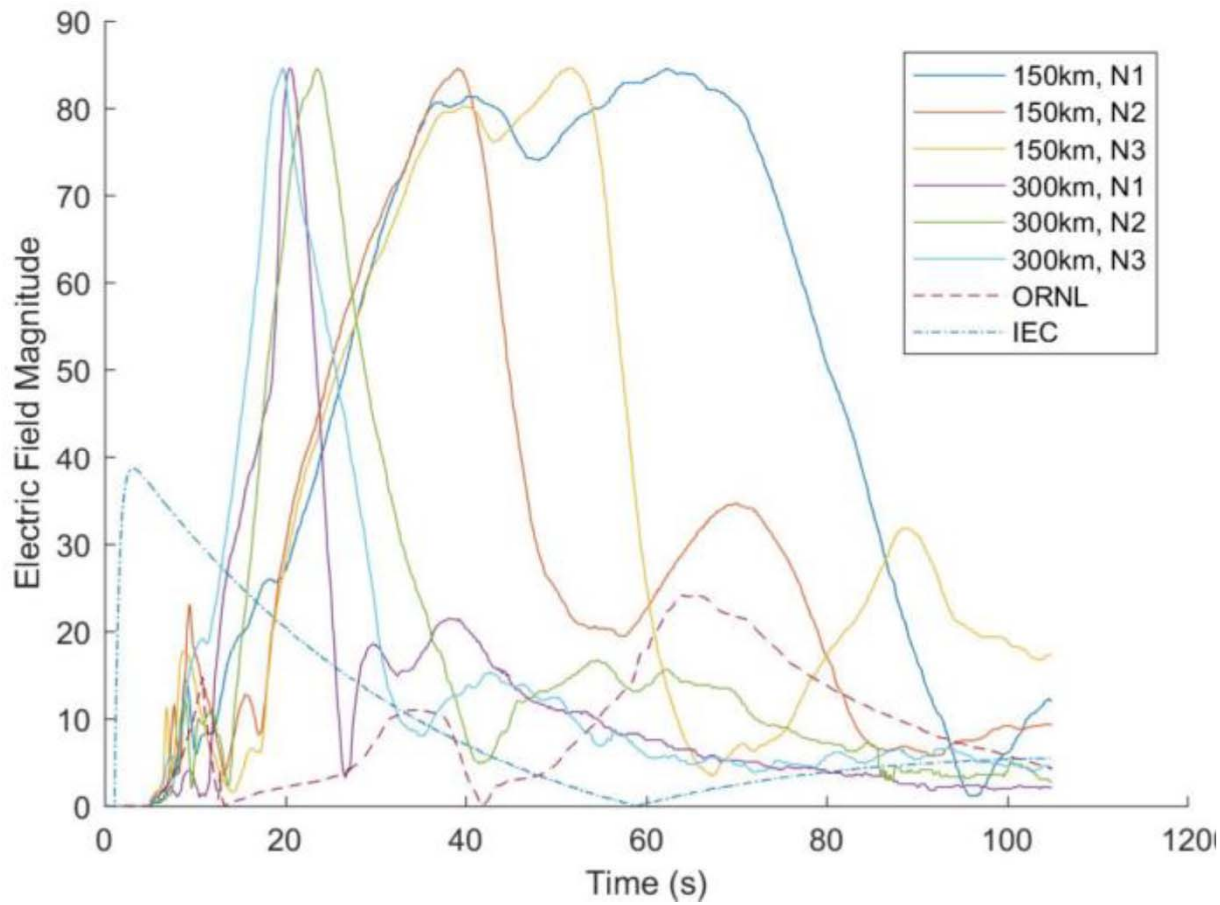


HEMP Future Studies

- Report of the "Commission to Assess the Threat to the United States from EMP Attack" (EMP Commission) has recently been released to public
- "A realistic unclassified peak level for E3 HEMP would be 85 V/km for CONUS as described in this report"

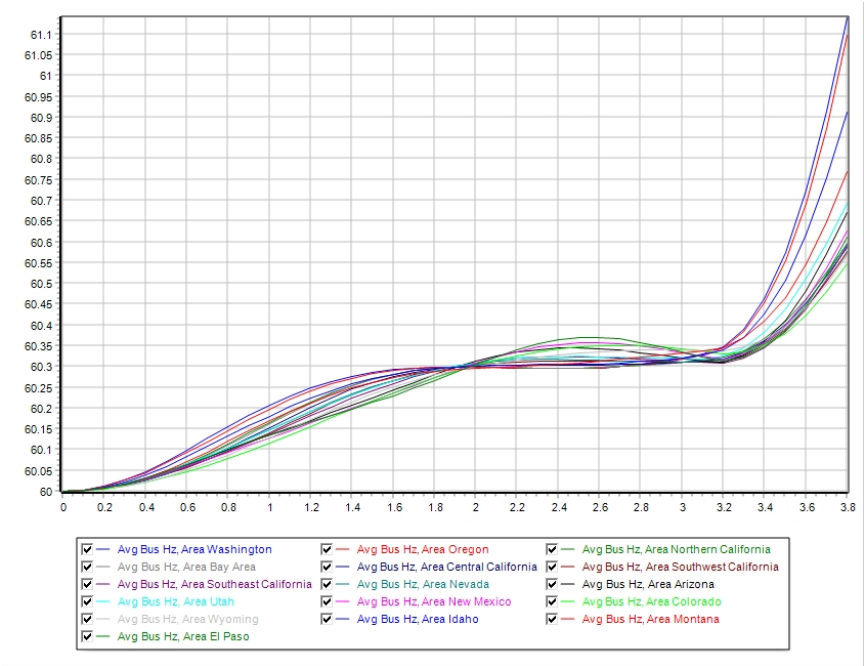
HEMP Waveform Comparison

- Plot of newly-released electric field waveforms, the ORNL 1985 waveform, and the IEC 1996 waveform
- Source: Lee, R. and Overbye, T. J.; "Comparing the Impact of HEMP Electric Field Waveforms on a Synthetic Grid", submitted to *North American Power Symposium*, 2018.

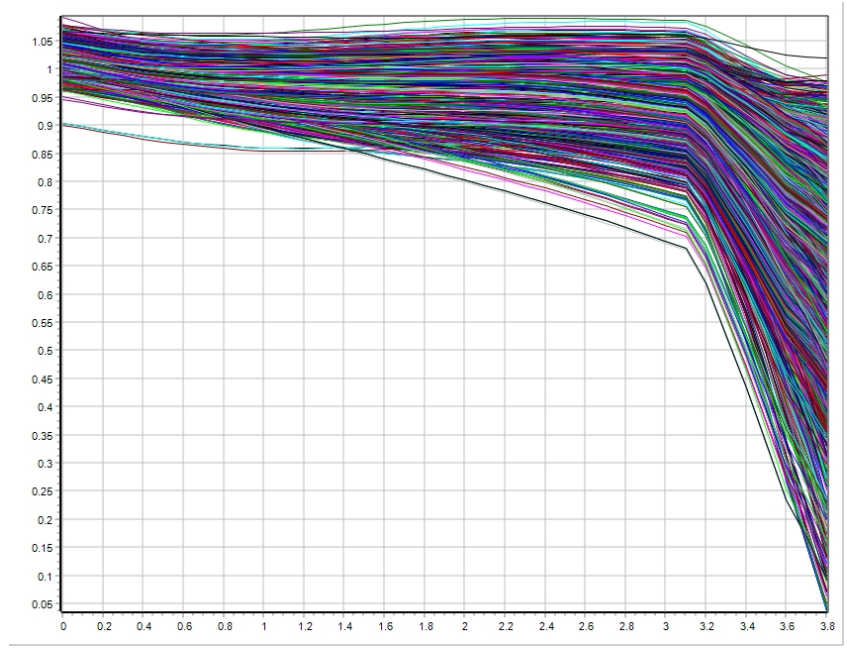


Transient Stability Plots:

85 V/km Peak



Frequency:
Average by Area



Bus Voltage:
Collapse at t=3.9s!

Conclusions

- Much ongoing development in TPL-007 standards
  - Supplemental Event
  - 3D Earth Models on the horizon
- HEMP threats could be much more severe in magnitude, rise time, and geographic breadth