Geomagnetic Disturbance and High-Altitude EMP in Simulator

2018 PowerWorld Client Conference
Scott Dahman, P.E.
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)**
  - \( E_{\text{peak}} = 8 \times \alpha \times \beta_b \text{ V/km} \)
  - GIC(t) from benchmark event time series

- **Supplemental Event**
  - \( E_{\text{peak}} = 12 \times \alpha \times \beta_s \text{ V/km} \)
  - 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
- \( E_{\text{peak}} = 8 \times \alpha \times \beta_b \) 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
- \( E_{\text{peak}} = 12 \times \alpha \times \beta_s \) 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

Delta Vpu

-0.050 pu

-0.000 pu

-0.050 pu
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
  - 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)
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
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

E-Field
-24.0 V/km
-12.0 V/km
0.0 V/km
Transient Stability Plots

Frequency: Average by Area

Bus Voltage
Transient Stability:
Voltage Visualization

HEMP Simulation
Voltage Deviation from Initial Conditions
Transient Stability:
Frequency Visualization

HEMA Simulation
Frequency Deviation from Initial Conditions
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
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