EPRI Electromagnetic Pulse Research

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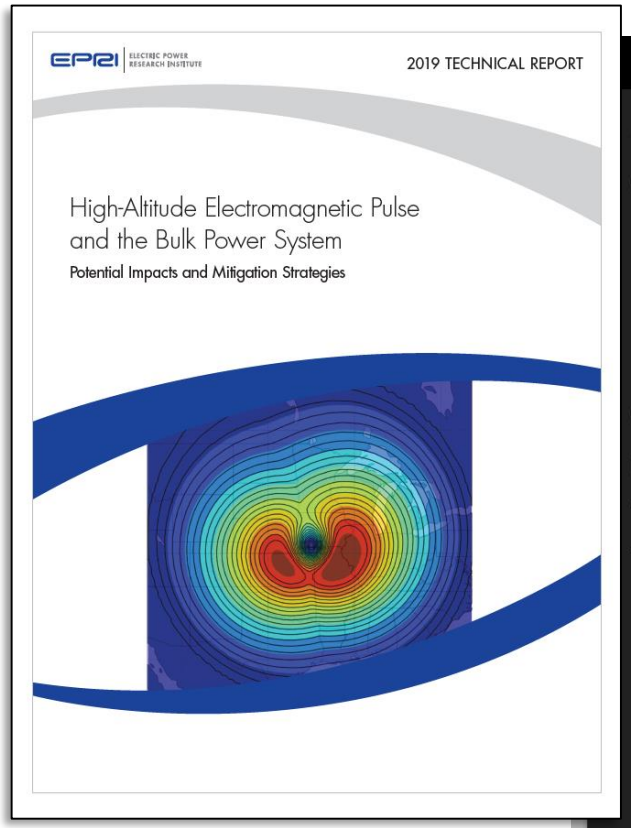
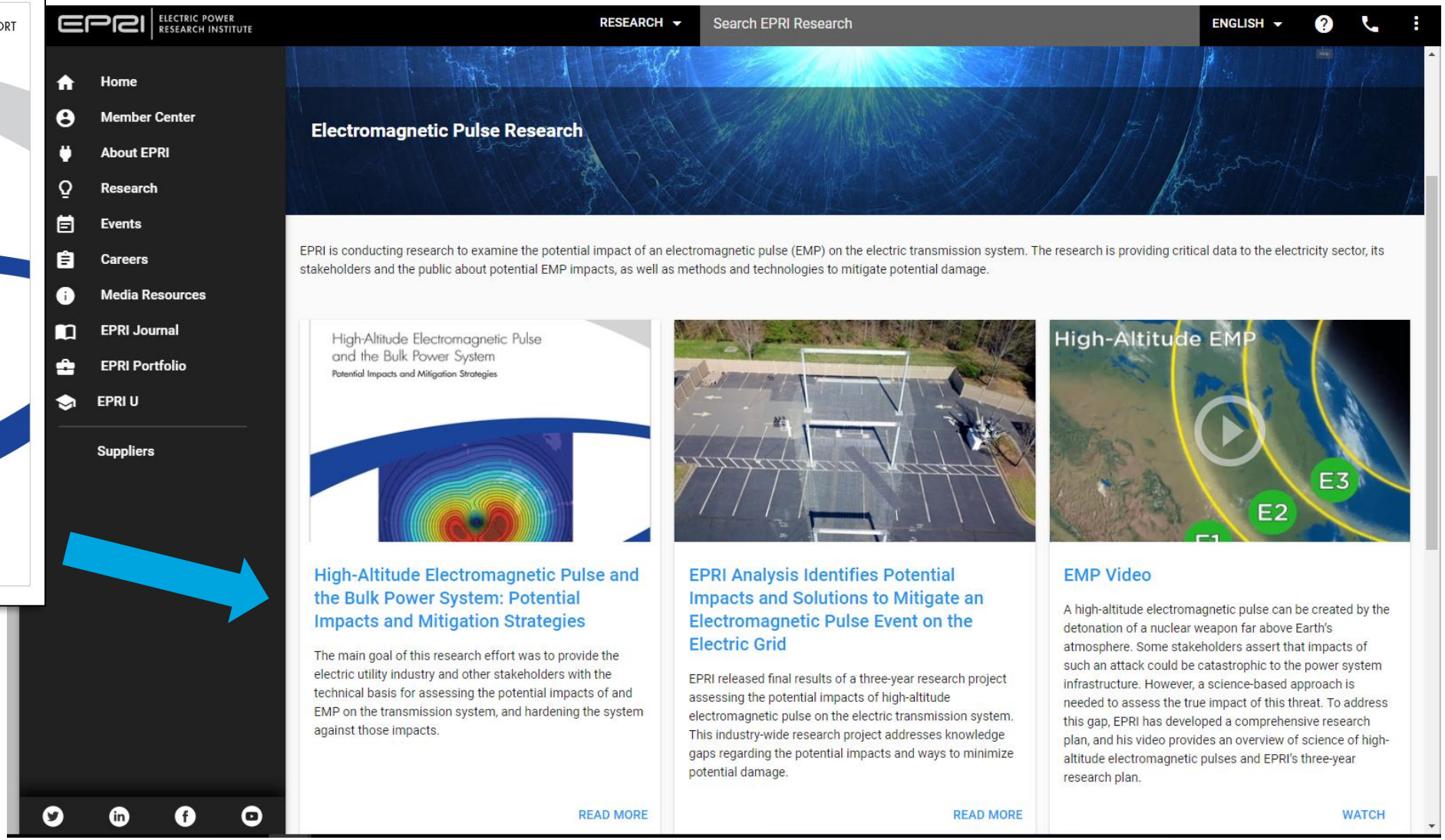
EPRI Final Report

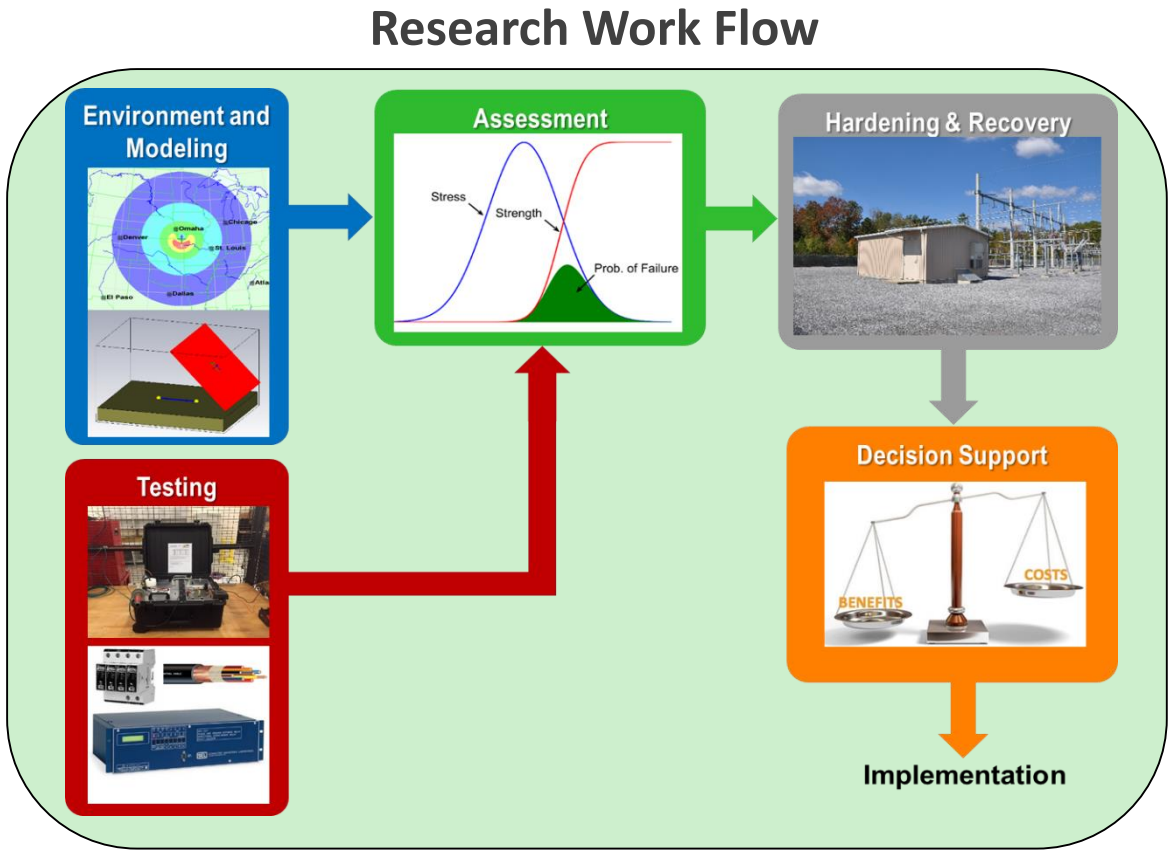
https://www.epri.com/#/pages/sa/emp?lang=en-US





EPRI EMP Research Program

- Initial research project focused on switchyards, lines, and substations (Transmission)
- Assessed impacts of E1, E2, E3 and combined E1 + E3
- Answered two important questions:
  - What are the potential impacts of HEMP on the Transmission system?
  - If impacts are significant concern, can they be mitigated in cost-effective ways?



Collaborative EMP Research

- Transparent, objective EPRI R&D involving numerous energy stakeholders
- Collaboration with 63 U.S. utilities
- Leveraged resources and knowledge from U.S. DOE, National Labs, DoD
- Applied industry-leading expertise to address national security threat

EMP Community Collaboration

Los Alamos NATIONAL LABORATORY EST. 1943

Sandia National Laboratories

Lawrence Livermore National Laboratory

Summary of Findings

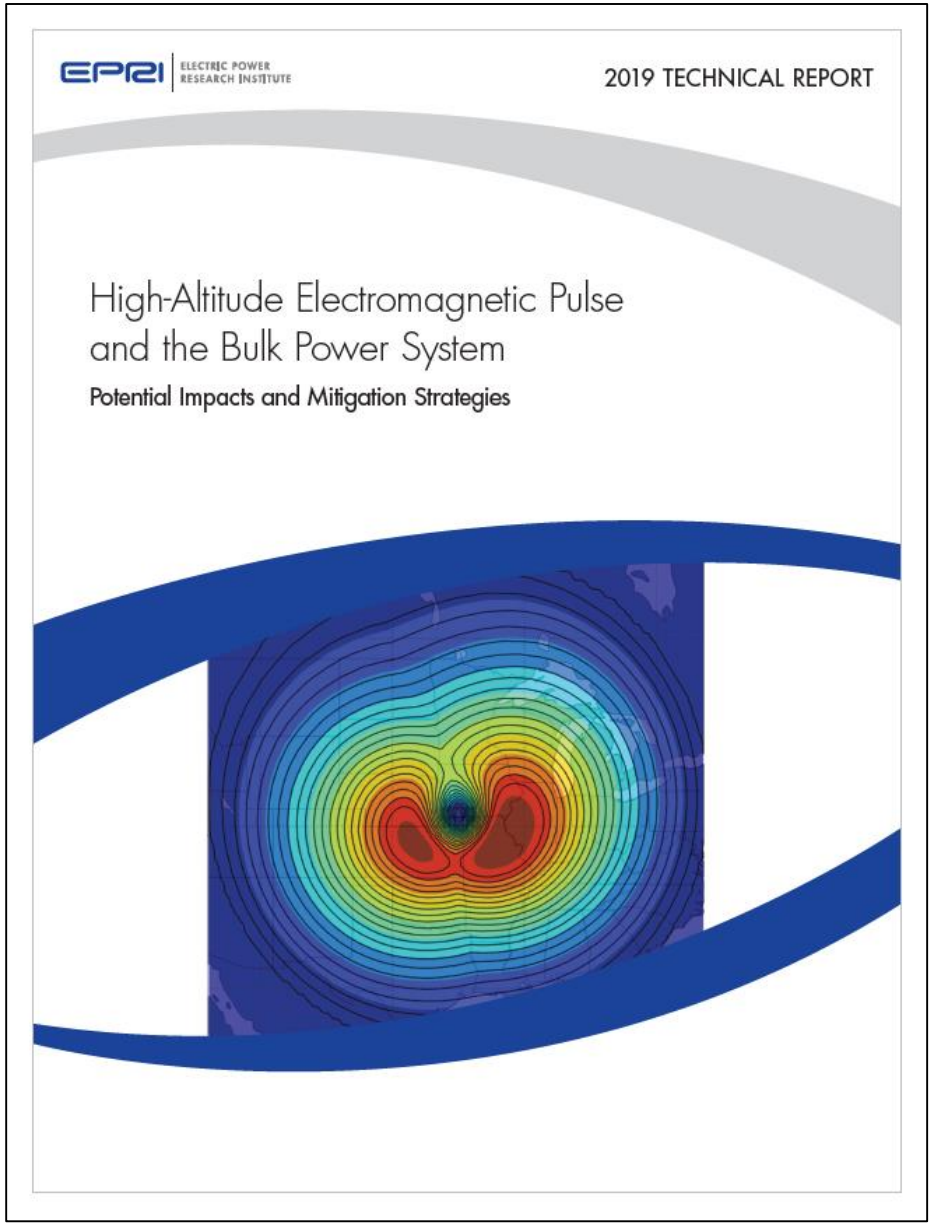
- Extensive modeling, simulation and testing was utilized to assess potential impacts:
  - E1 EMP: Disruption or damage to substation electronics (e.g. digital protective relays) is possible and can be experienced over a large geographic area (electrical interconnection)
  - E2 EMP: Impacts to bulk power system are not expected
  - E3 EMP: Regional voltage collapse is possible; immediate, wide-spread damage to bulk power transformers not expected

- Options for mitigating E1 EMP impacts were tested, but deliberate approach to implementation is recommended to enhance designs, identify/manage potential unintended consequences and improve understanding of cost and long-term asset management

- Two follow-on research efforts are underway:
  - Field trials of E1 EMP hardening at 17+ electric utilities across the U.S.
  - E1 EMP assessment of generation facilities

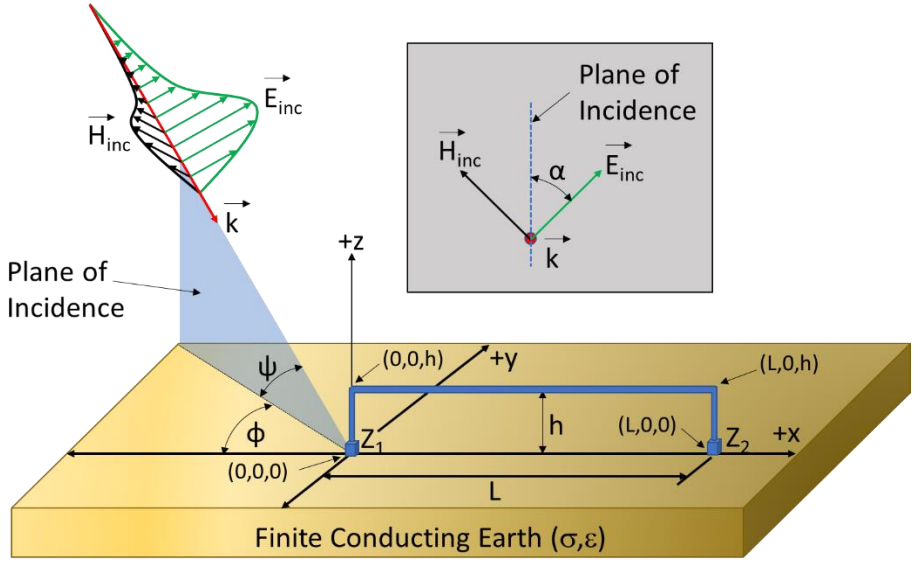
Chapter 8 of Final Report - Research Needs

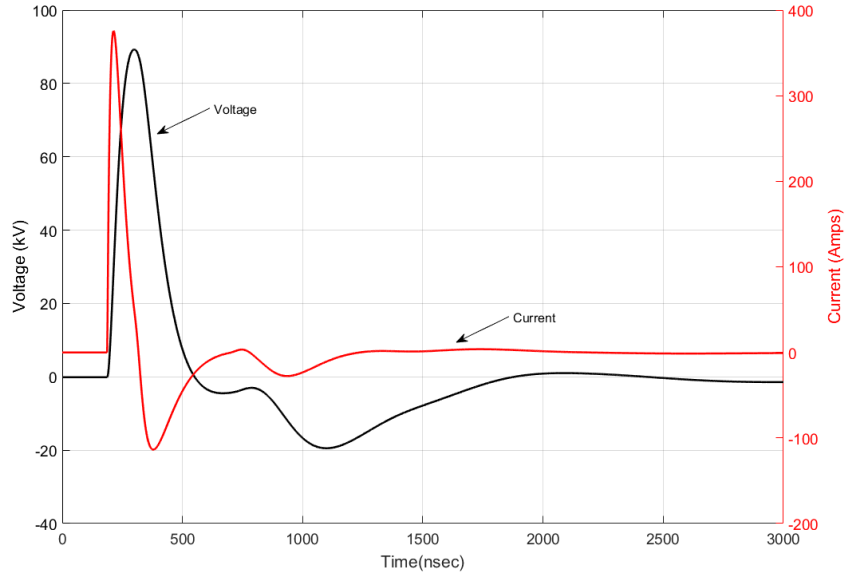
- Integrated Energy Network Assets
- Generation Facilities and End-Use Equipment
- Software Tools and Methods for Performing HEMP Assessments
- Equipment Testing
- HEMP Environments
- Field Trials of E1 EMP Hardening of Substations



E1 EMP Modeling – Individual Substations

- E1 EMP is considered a plane wave so coupling is different than traditional power system transients
- Only aware of commercial tools that are 3D EM solvers
- EPRI developed and used MATLAB/EMTP based-tools and also CST Studio

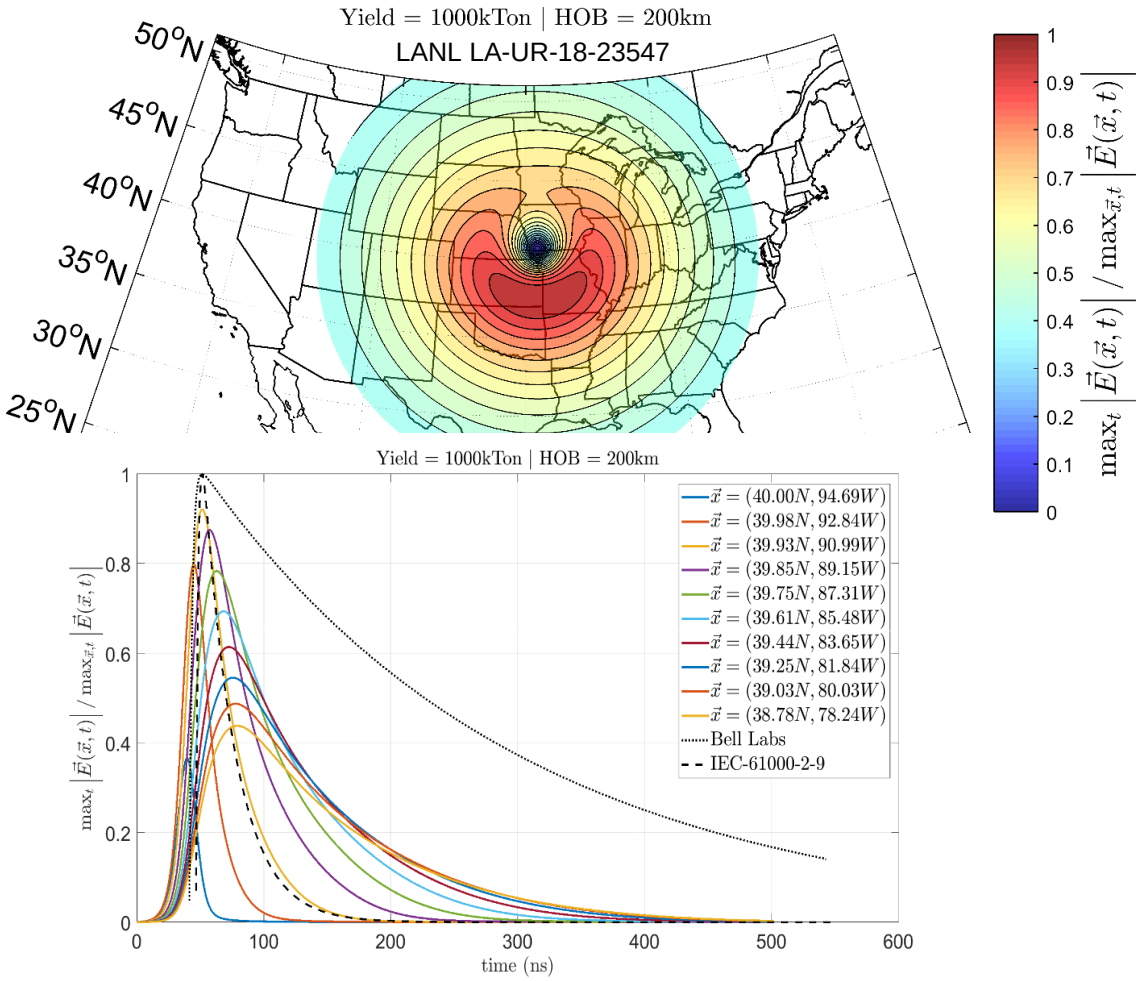




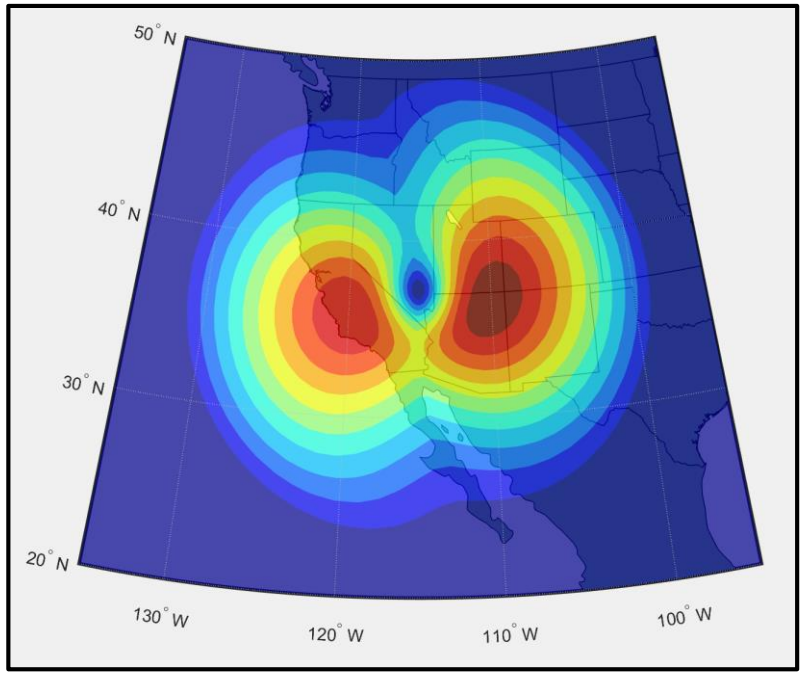
E1 EMP Modeling – Interconnection Scale

- Requires high-fidelity E1 EMP environment (not publicly available) and ability to perform coupling calculations on 1000's of substations simultaneously

High-Fidelity E1 EMP Environment

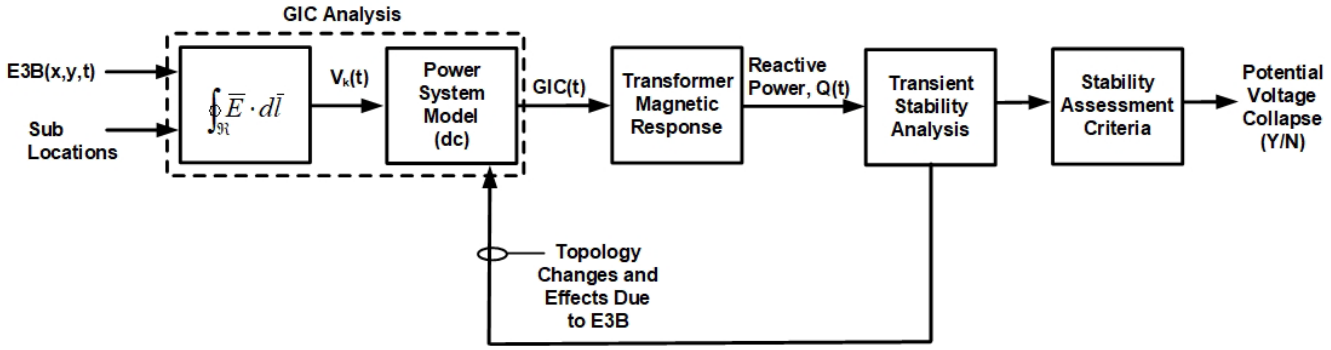


Notional Coupling Results

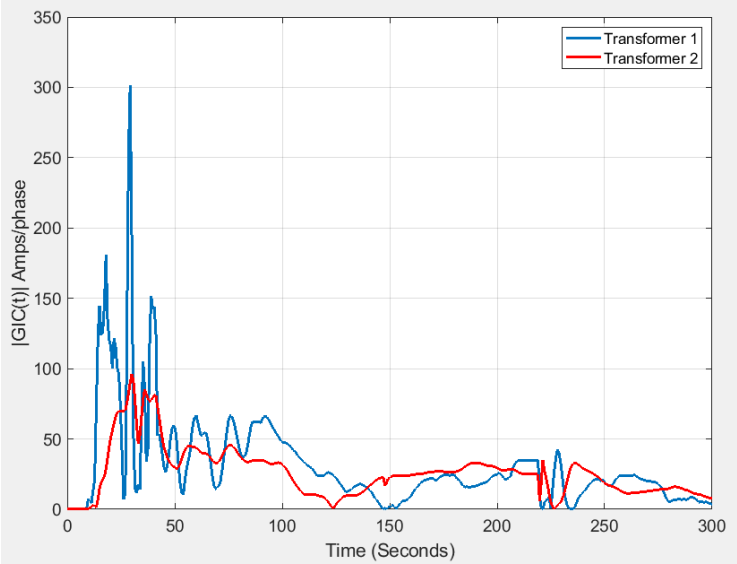


Voltage Stability Analysis (E3 Only)

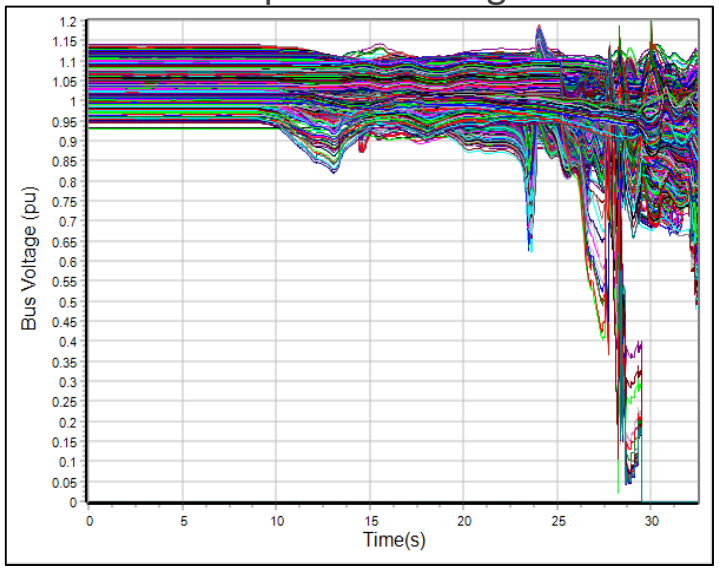
- Because of the nature and duration of the event, transient stability tools are necessary for determining voltage collapse
- Key modeling features include:
  - Dynamic load models
  - Overexcitation limiters
  - Protective relays
  - UV/OV and UF/OF tripping of generators
- GIC analysis requires the use of highly non-uniform E-field that varies spatially and temporally
  - Additional off-line tool in addition to transient stability tool required for higher fidelity environments



Example GIC Waveforms



Example Bus Voltages



Voltage Stability Assessment With E1 Impacts

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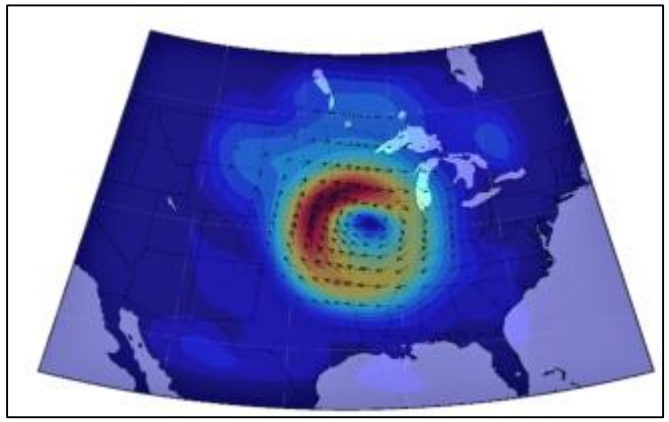
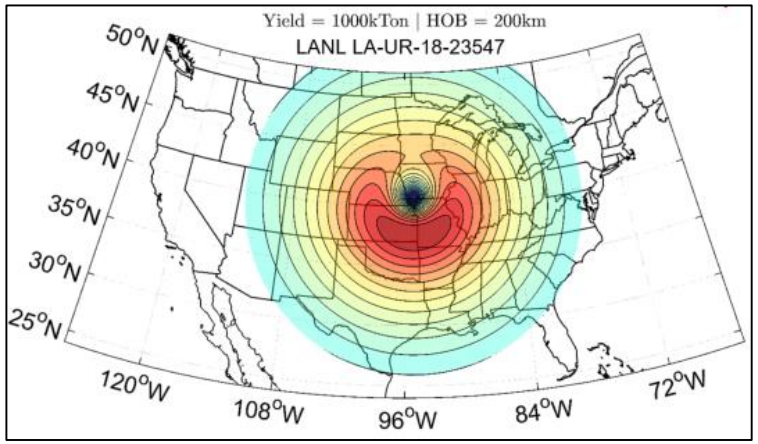
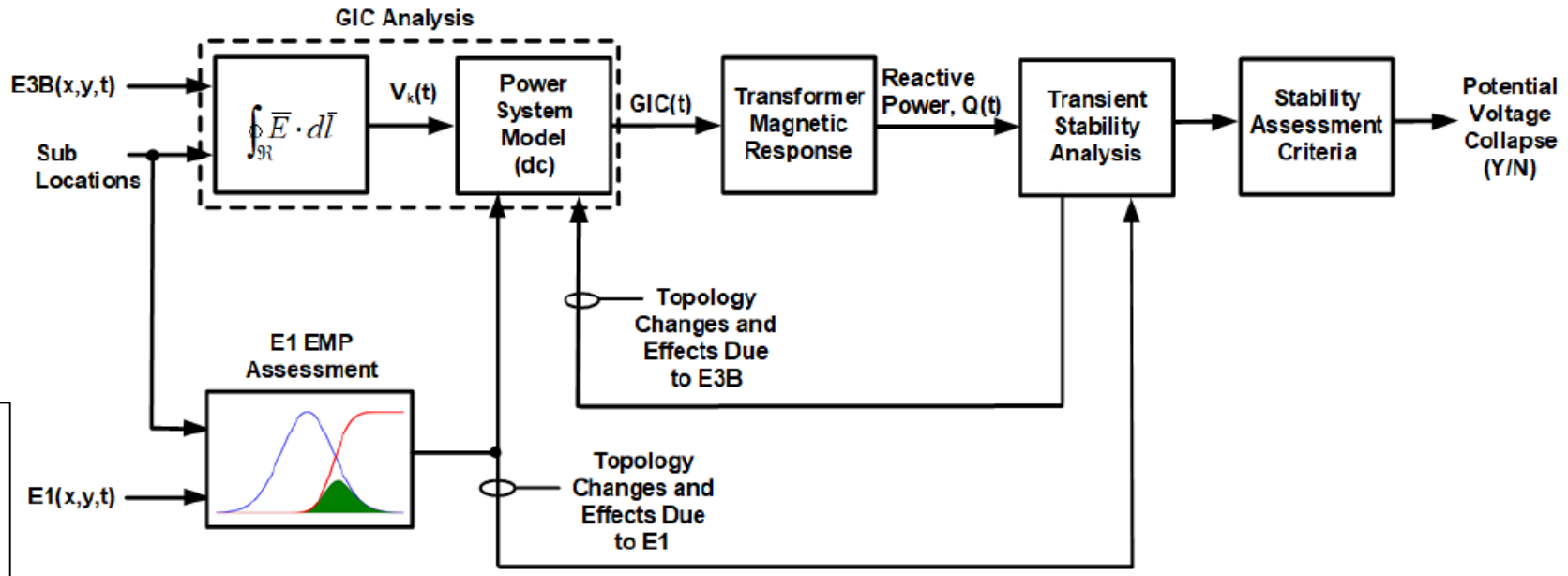






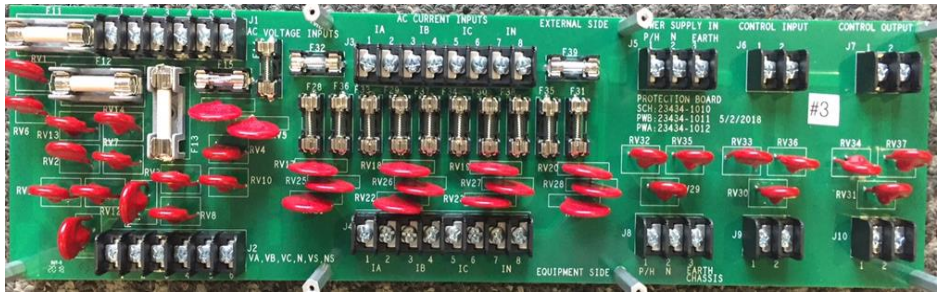
- Interconnection-scale E1 EMP impacts are used to initialize the transient stability tool prior to the E3 EMP event
- High-fidelity E1 EMP and E3 EMP environments are not publicly available
- Currently, no commercial tool(s) exist to perform this analysis

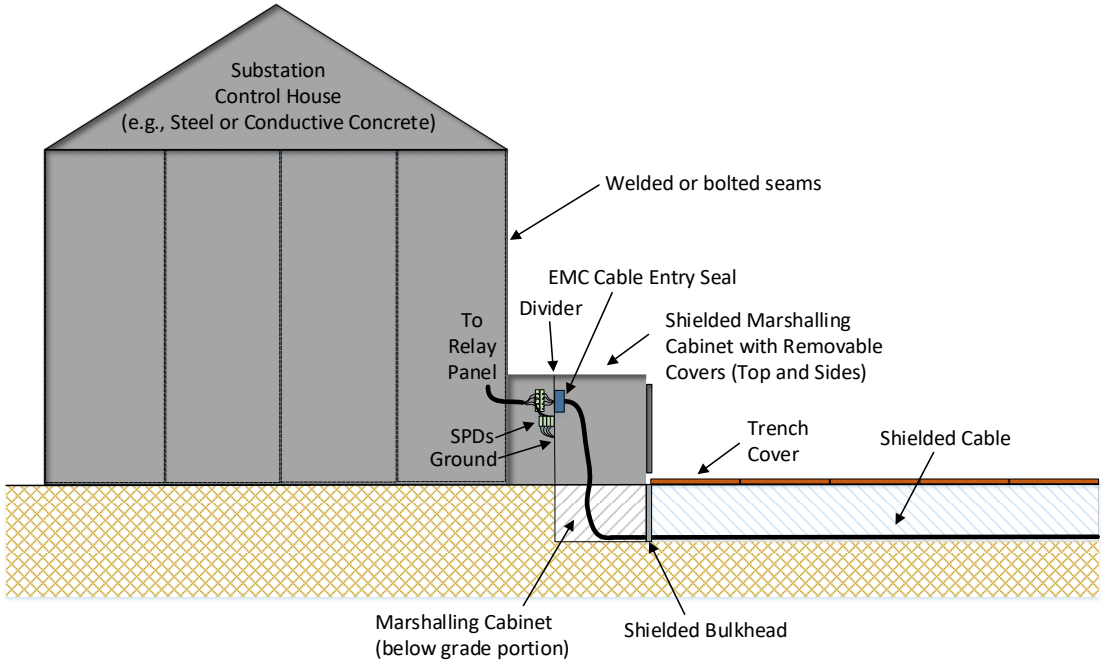
Field Trials of E1 EMP Mitigation Are Needed

- Potential mitigation options include:
  - Low-voltage surge suppression devices and filters
  - Shielded or fiber optic cables
  - Substation control house design modifications
  - Grounding/bonding enhancements
- Identifying and managing unintended consequences is critical
- Improving designs and understanding cost and long-term asset management also very important

Currently working with 17 U.S. utilities to evaluate E1 EMP mitigations in substations

Example of a Prototype Low-voltage Surge Suppression Device





Together...Shaping the Future of Electricity