EMP and the U.S. Power Grid

An EPRI Update

April 26, 2017

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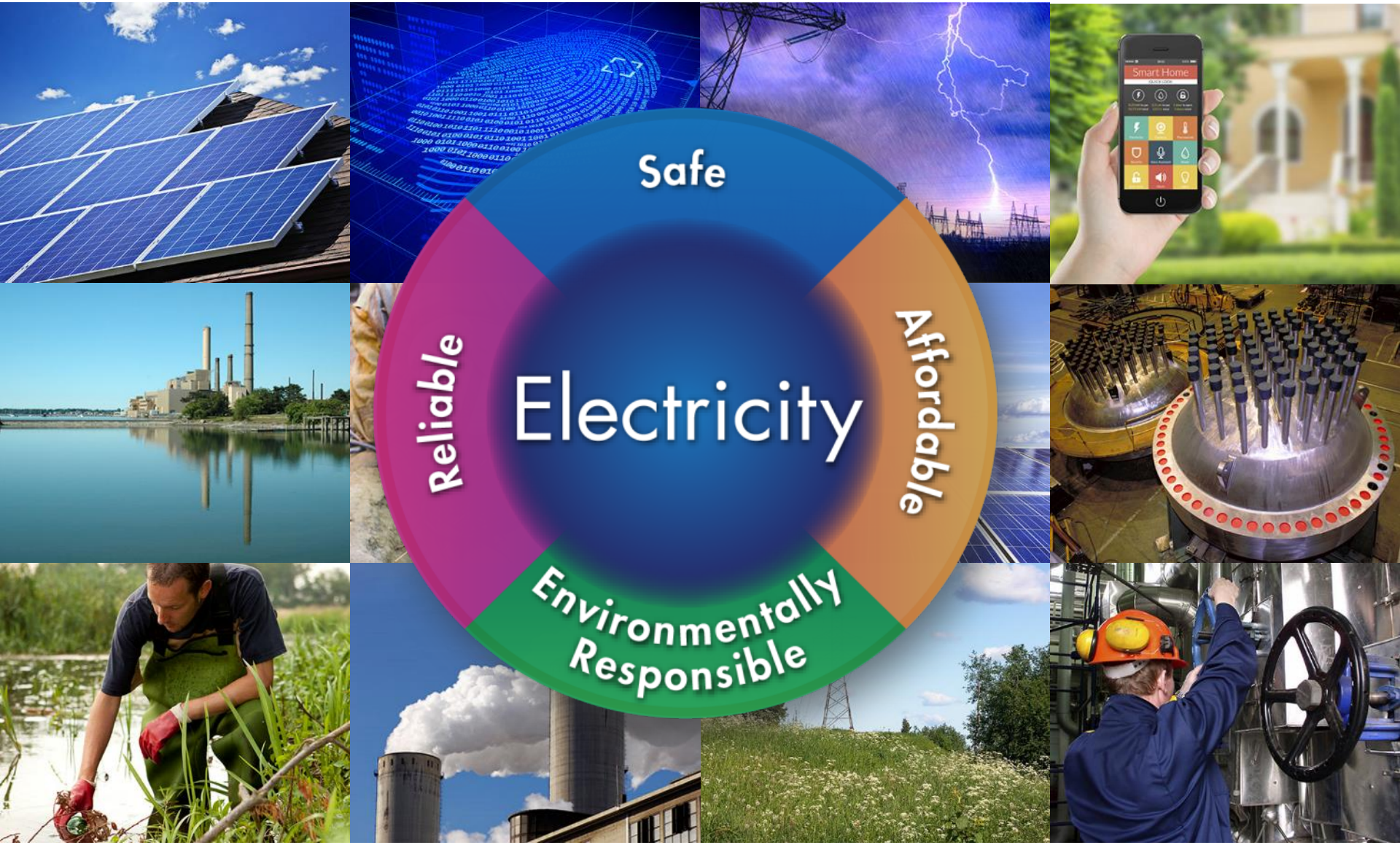
EPRI

Electric Power Research Institute



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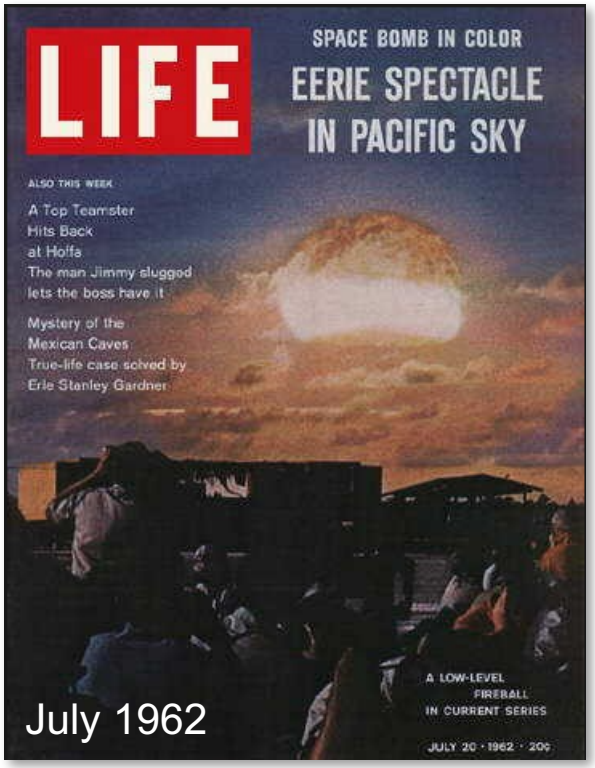
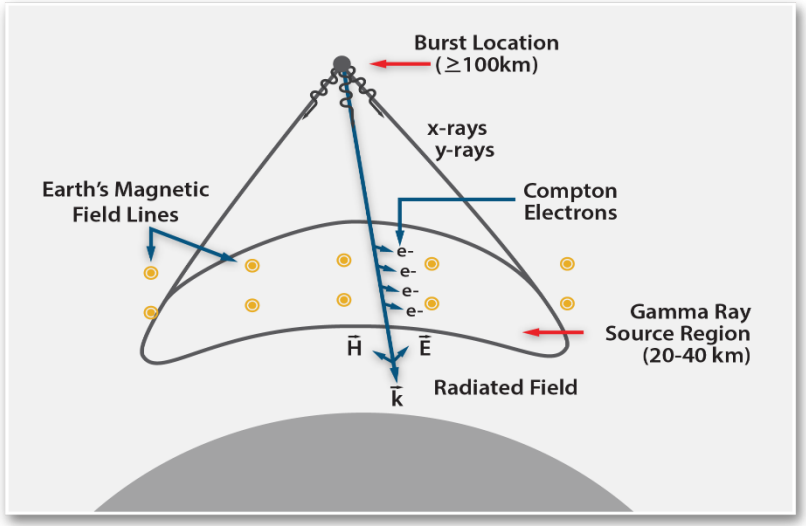
Historical Perspective

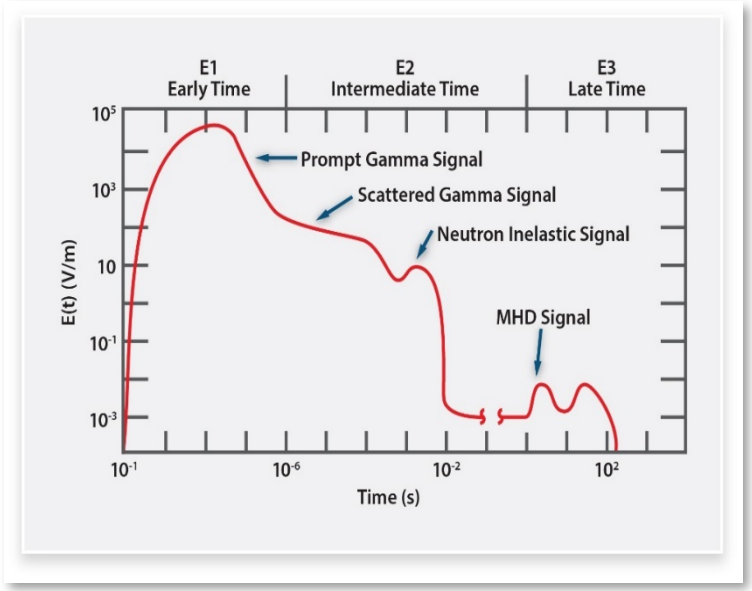
- U.S. government (and others) known about EMP for a long time.
- U.S. performed high-altitude nuclear tests in 50's and 60's to determine impacts to military infrastructure.
- Starfish Prime Test - 1.4 MT weapon detonated approximately 400 km above Johnston Island in the South Pacific (1962).
- Test disrupted communication systems, damaged satellites, and impacted electrical systems in Hawaii (~ 800 mi away).



Technical Characteristics of Electromagnetic Pulse (EMP)

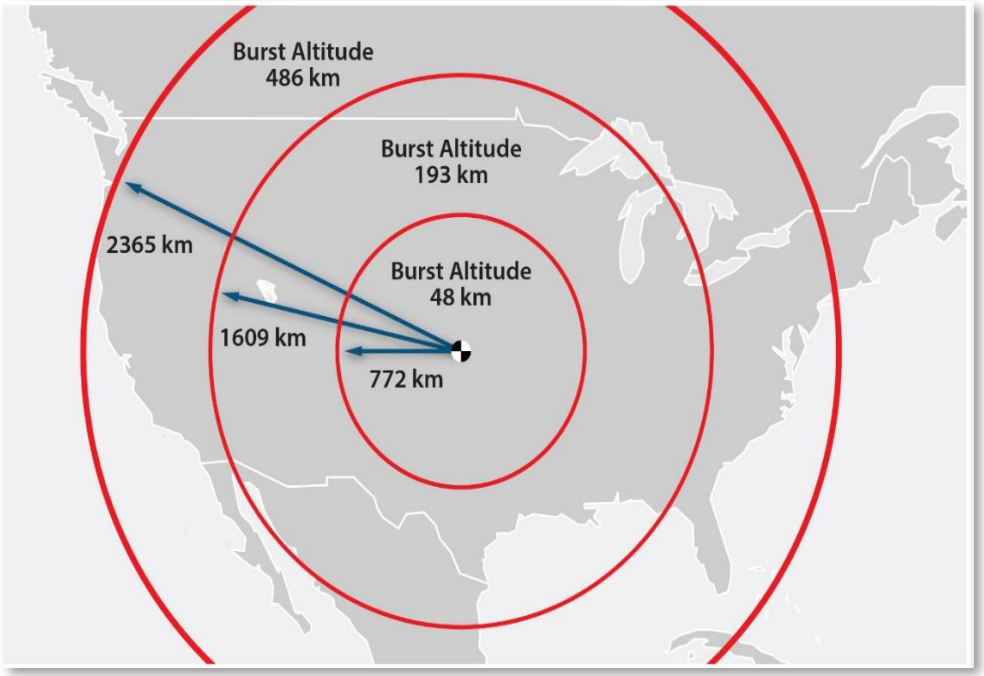
- Intentional, man-made attack
  - **E1 – Very fast rise time**, may result in damage to electronic components either directly, or by coupling into the attached wires.
  - **E2 – Similar to lightning**, can result in damage to electronics and potential flashover of distribution class insulation.
  - **E3 – Long duration and low frequency**, similar to GMD, but EMP (E3) has two potential impacts; increased reactive power consumption and potential protection system misoperation as a result of harmonics.
- EMP can occur with little or no warning, most operational strategies are inapplicable.





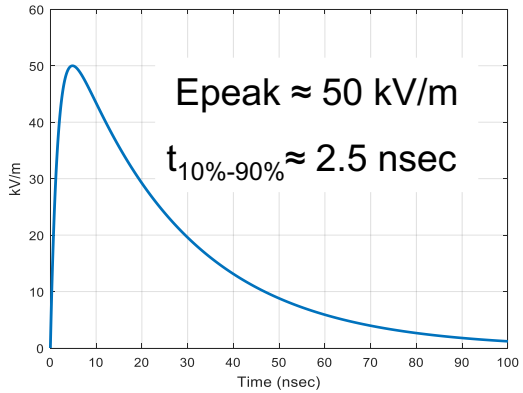
High Altitude Burst Generated EMP (HEMP)

- The HEMP signal extends to the visual horizon as seen from the burst point
- A large device detonated at 400–500 km over central USA would affect all of the continental USA
- Effects depend on: altitude of the detonation, weapon yield, interactions with the earth's magnetic field, and electromagnetic shielding of targets

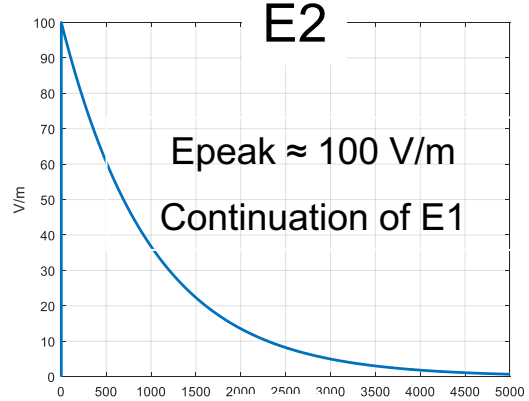


Potential Impacts to the Electric Grid

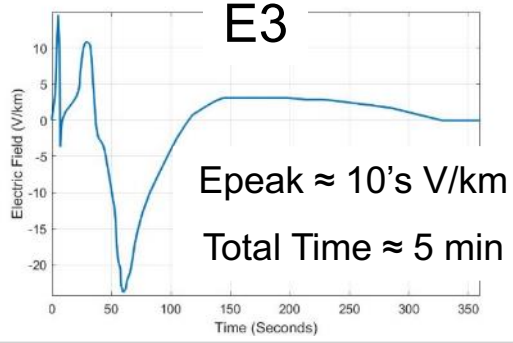
E1



E2

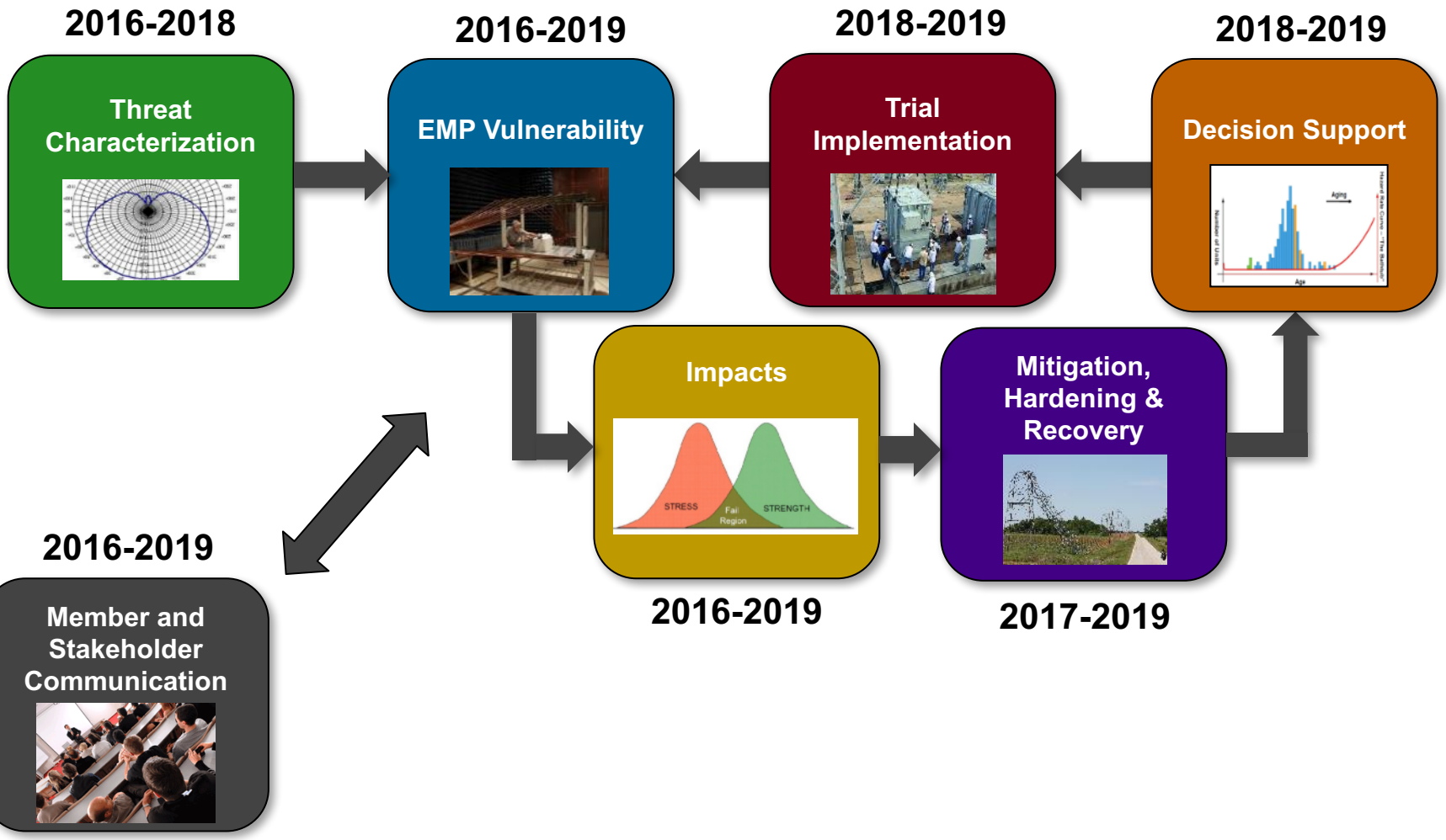


E3

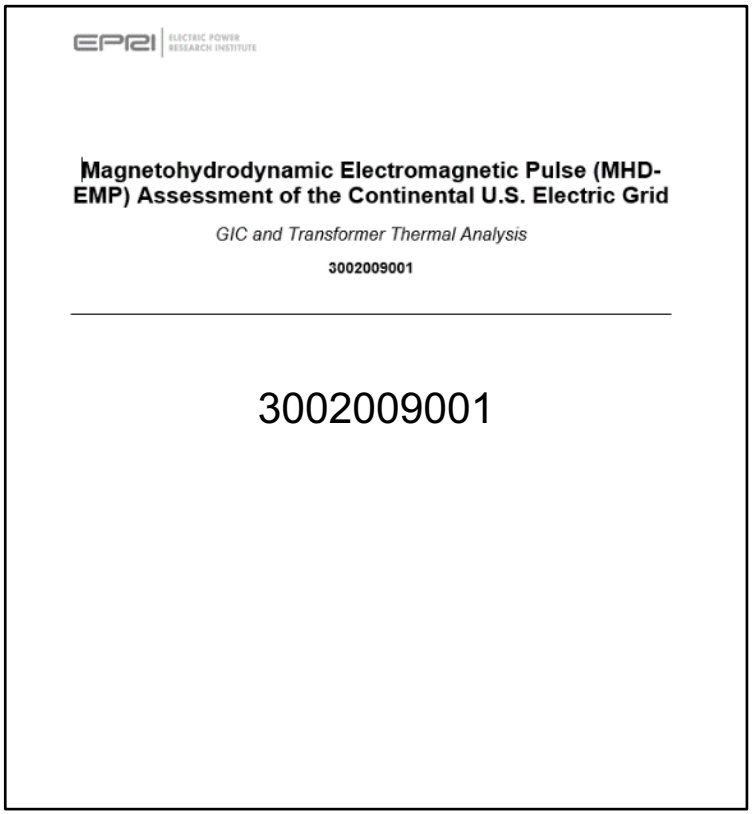


Potential Impact	Unknowns
• Relays, SCADA, Control Centers • Communications • Insulation Flashover • Vehicles	• Resilience of Control Centers? • Radiated vs. Conducted • Strength of Insulation to E1?
• Distribution Insulation Flashover	• Reliability Impacts
• Voltage Collapse due to ➢ increased reactive power consumption ➢ protection mis-operation due to harmonics • Overheating of Power Transformers	• Blackout Potential • Extent of Bulk System Transformer Failures Scope of initial EPRI report

Three year Research Plan
April 2016 – April 2019



Magnetohydrodynamic Electromagnetic Pulse (MHD-EMP) Assessment of the Continental U.S. Electric Grid



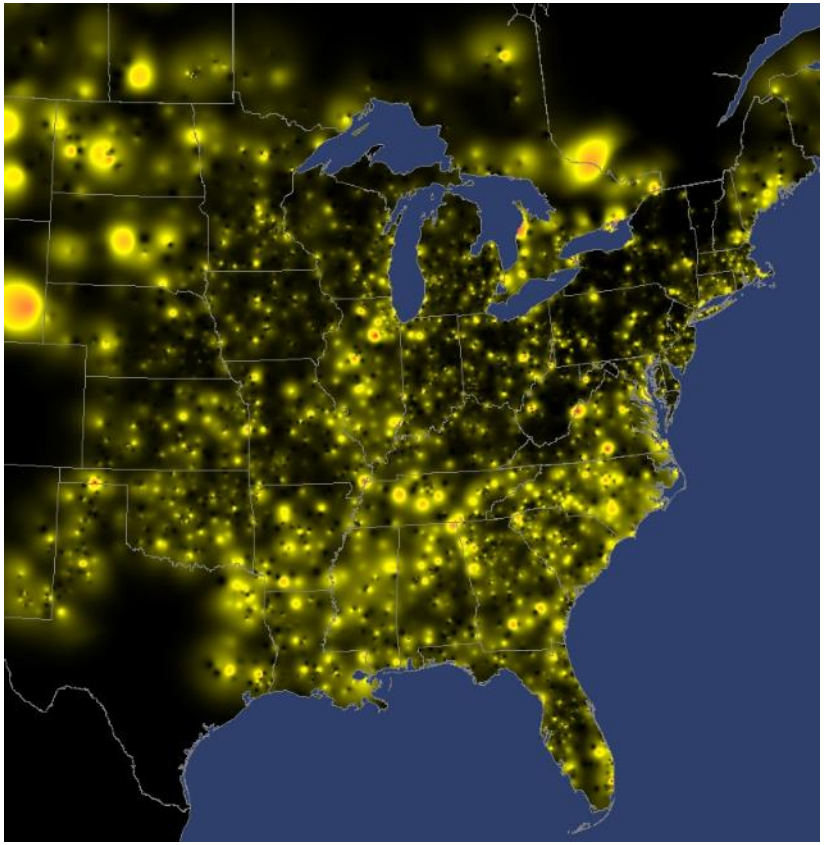
- Introduction
- GIC Model and MHD-EMP(E3) Environment
- Transformer Thermal Assessment
- Conclusions
- References
- Appendix A: Transformer Thermal Model
- Appendix B: Comparison of MHD-EMP Waveshape on Transformer Hotspot Heating
- Appendix C: Analysis of GIC Impacts on Autotransformer Delta Tertiary Windings

http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002009001

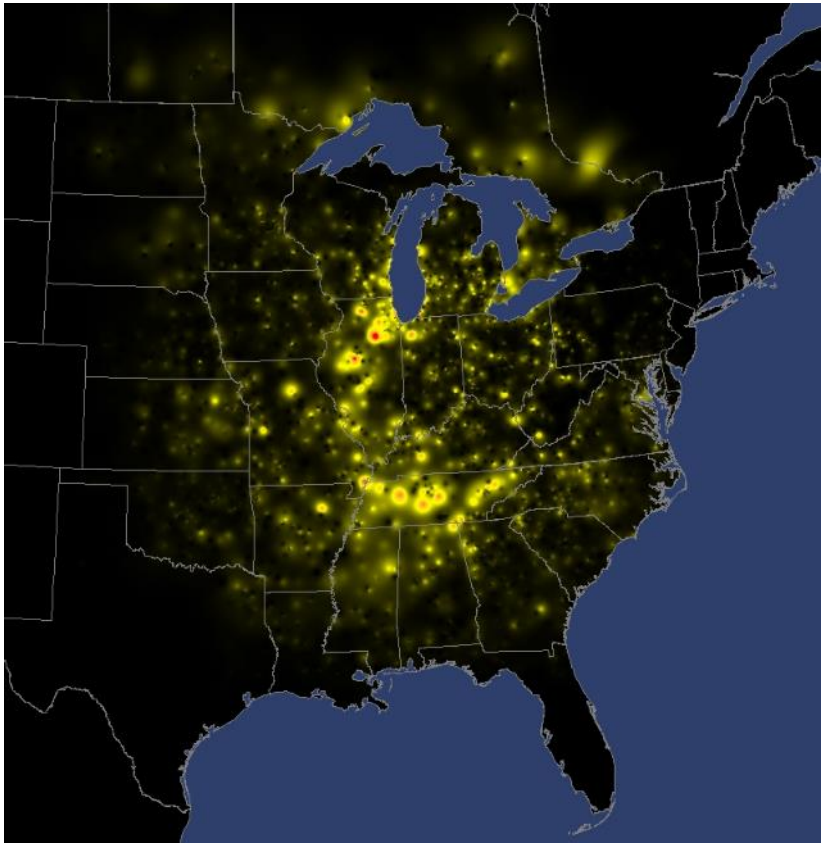
Example GIC Calculation (Snapshot)

- Instantaneous effective GIC flows in tens of thousands of transformers

t = 5.4 seconds



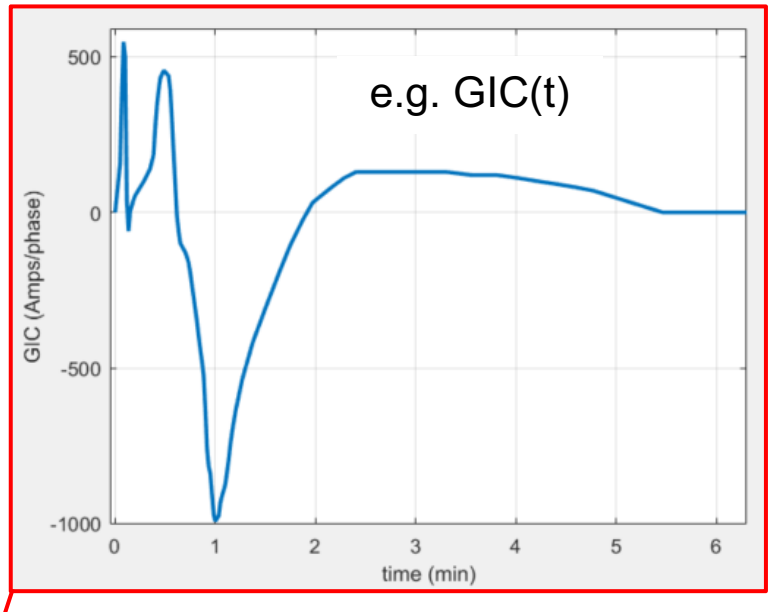
t = 60 seconds

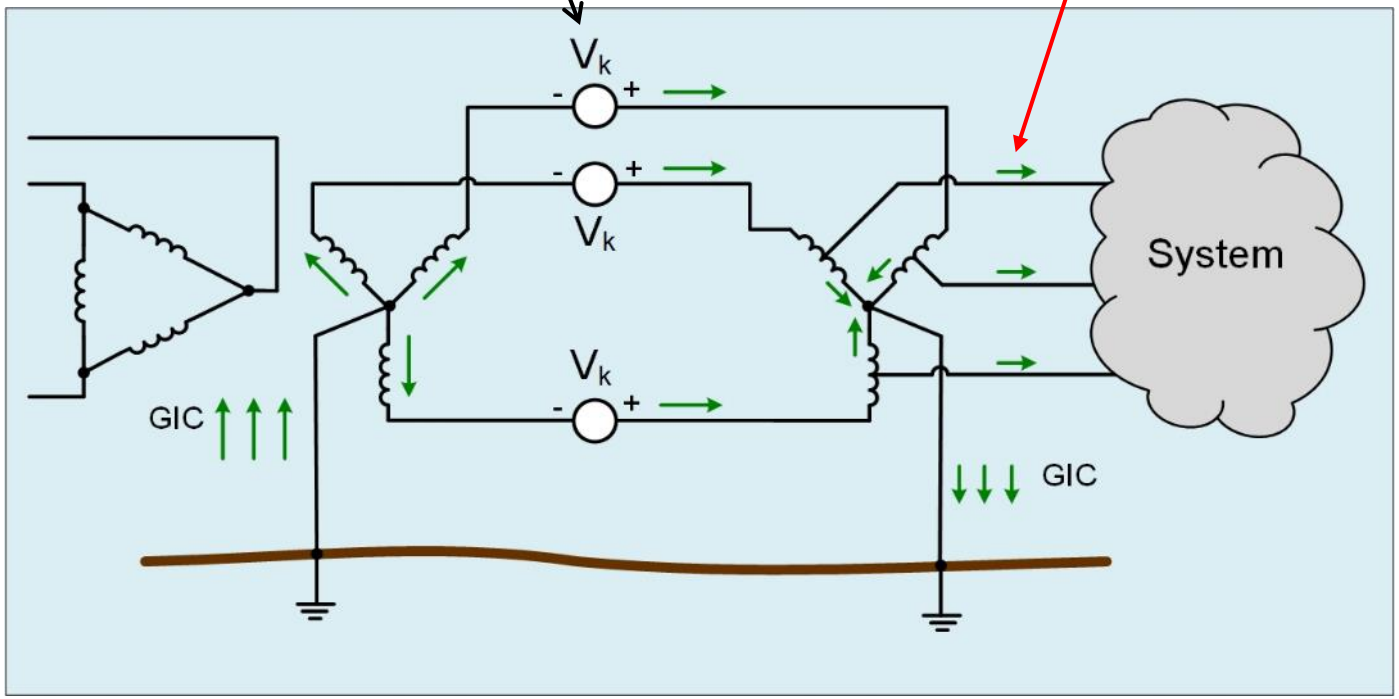


GIC Calculations

- Induced voltage is computed at each time step using the geoelectric field which is a function of location (x,y) and time.
- Induced voltage and dc system model are used to compute GIC(t)

$$V_k = \oint_{\Re} \left(\varepsilon(x,y)\bar{e}(x,y)f(t)\right) \circ d\vec{l}$$





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Condition-Based GIC Susceptibility

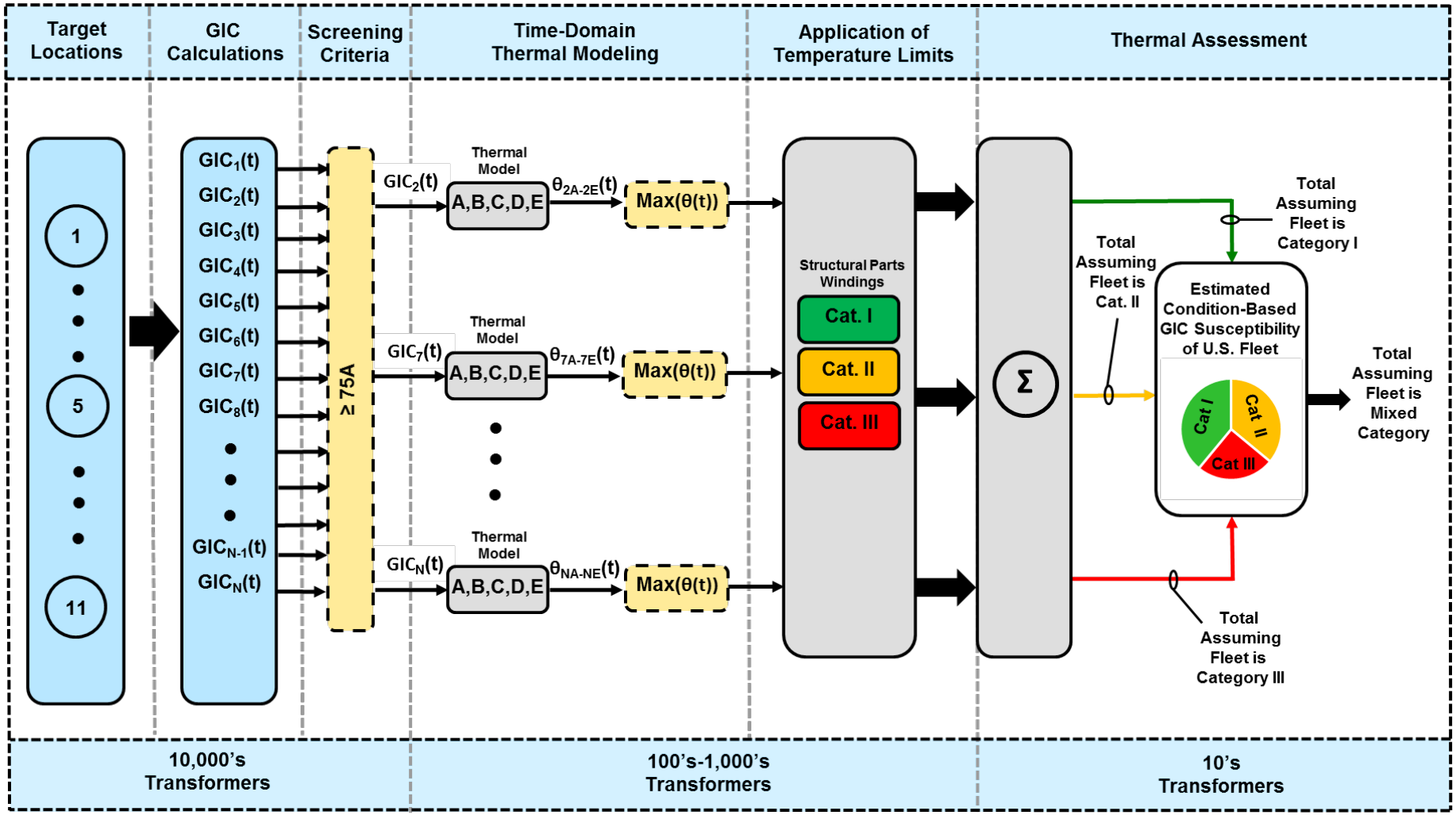
- IEEE C57.163 Temp limits assumes transformers in new
- Temp limits that account for all transformer conditions needed.
- Concept of “Condition-Based” GIC Susceptibility developed
- “GIC susceptibility” is related to potential vulnerabilities that may be exacerbated by a sudden increase in component temperatures which can occur during these events.

Conservative Temperature Limits

Condition-based GIC Susceptibility Category	Hotspot Temperature Limit	
	Structural Parts (°C)	Windings (°C)
I	180	160
II	160	140
III	140	120

For comparison, IEEE C57.163 limits are 200°C for structural parts and 180°C cellulose insulation (windings).

Transformer Thermal Assessment Process



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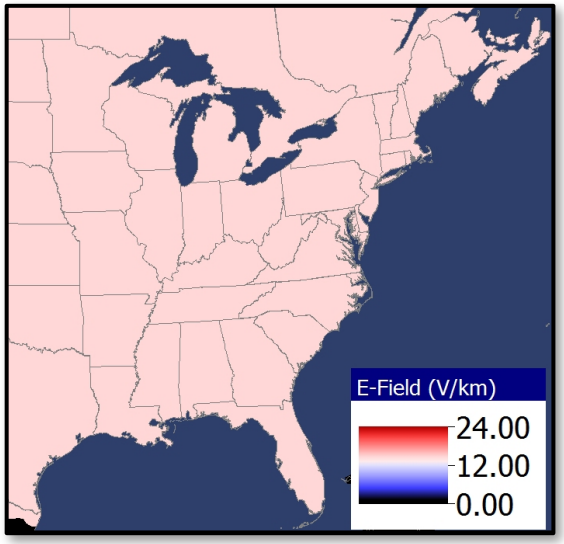
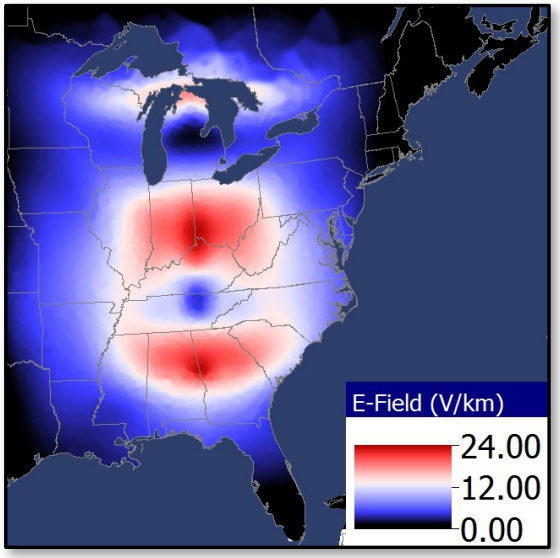
Results

- 1st of several studies is complete: Assessing potential impact of late-time EMP (E3) on bulk-power transformers.
- Study uses detailed thermal models to evaluate impacts of Geomagnetically Induced Currents (GIC) on transformers on an interconnection-wide basis.
- Significant number of transformers (100's to 1,000's) could experience effective GIC flows greater than or equal to 75 Amps/phase.
- Failure of a large number (hundreds) of bulk-power transformers from E3 is unlikely.
- Assessments that account for the synergistic impacts of E1, E2 and E3 are necessary to inform appropriate future courses of action.

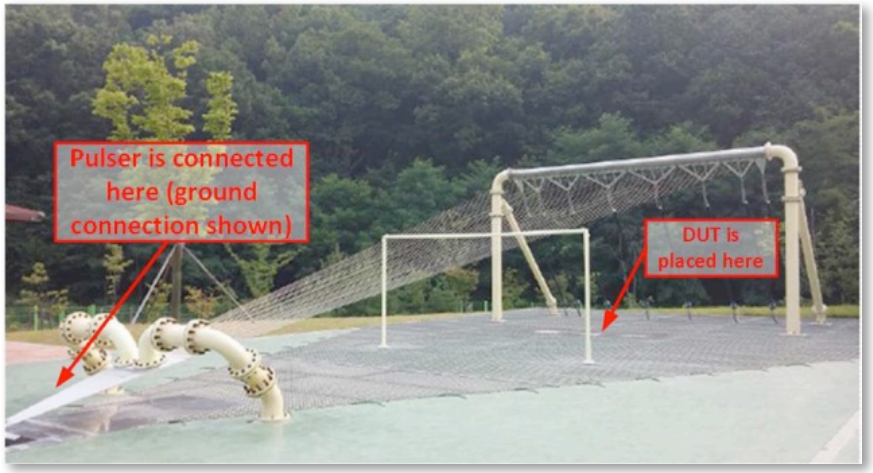
Spatial Variation of E3A at t = 5 seconds



Spatial Variation of E3B at t = 60 seconds



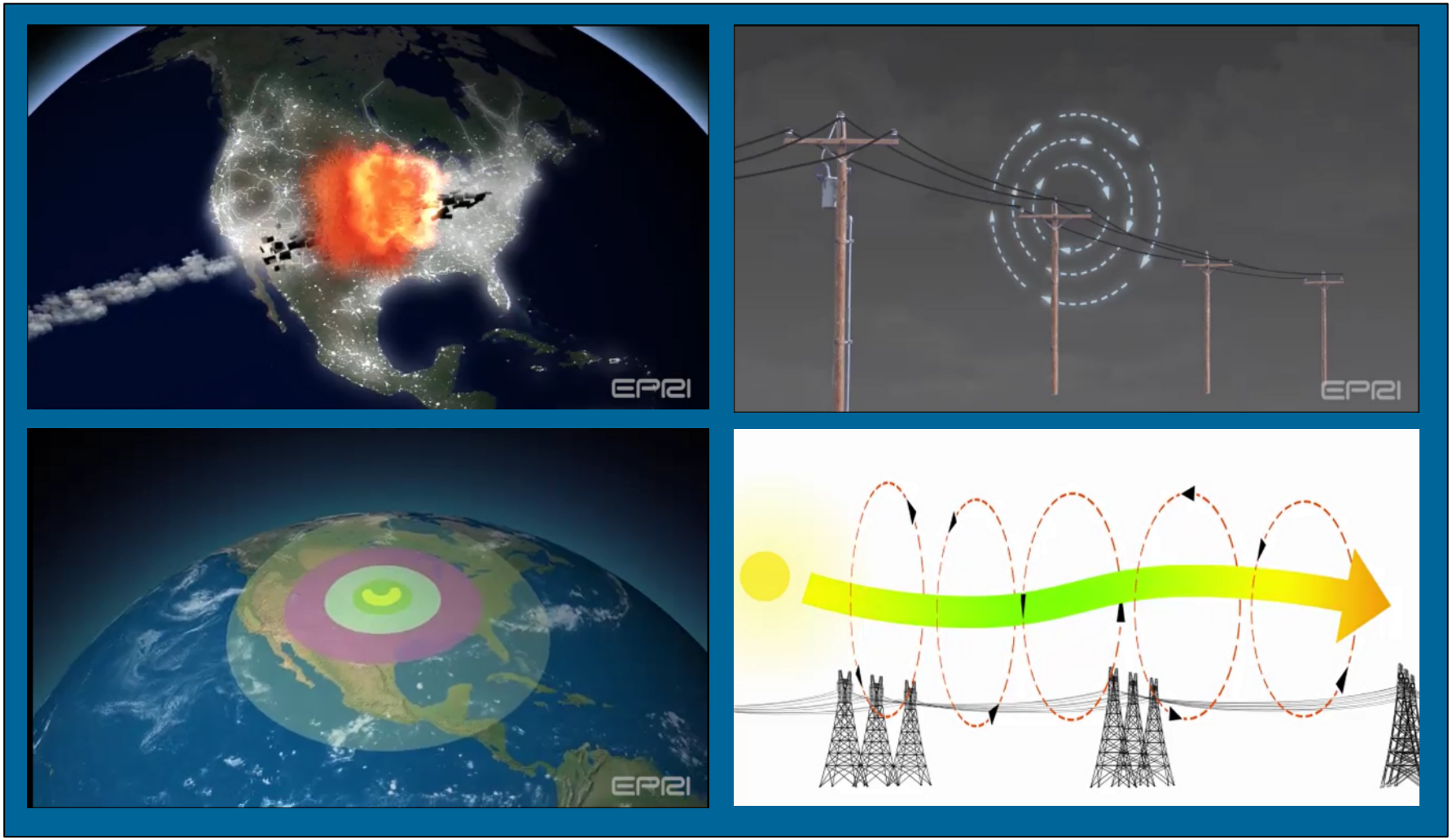
What's Next?



- Developing interim guidance on hardening substations using the guidance provided in IEC and MIL standards. (complete Q2 – 2017)
- Building EMP test labs to test systems and components. Testing of protection and control systems is initial priority. (begin Q2 2017)
- Developing models to simulate coupling of E1/E2 into transmission infrastructure to determine impacts on equipment. (Q4 2017)
- Developing specifications for an EMP-hardened mobile transmission control center. (complete Q3 2017)
- Collaborate regularly with DOE, national labs and the DoD (Defense Threat Reduction Agency).

EMP Video

- Now Available:
- https://media.epri.com/public/pdu/HEMP-Research.mp4



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