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NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

EMP Task Force Work Plan

Overview of Objectives and Key Deliverables

Soo Jin Kim, NERC / Aaron Shaw, American Electric Power
Electromagnetic Pulse Task Force Workshop
July 25, 2019

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Phased Approach

Phase 1
- Strategic Recommendations

Phase 2
- Technical Committee Work

Phase 3
- Standard Drafting Team (if applicable)

Key Task Force Milestones – Phase 1

June

- Numerous TF calls
- Face-to-face meeting (Washington DC)

July

- Numerous TF calls
- Charter development
- Technical workshop (ATL)

August

- Develop Strategic Recommendations
- Post for industry comment (30 days, end of August)

October

- Review industry comments
- Present recommendations with action items and next steps to appropriate committee

November

- Present recommendations to Board of Trustees

Phase 2

EMP Task Force Purpose

- The task force is an advisory team that collaborates with governmental authorities and industry members to provide front-end, high-level leadership and guidance
- The guidance will address issues resulting from High-Altitude Electromagnetic Pulse (EMP or HEMP) events and the impact to bulk power system (BPS) reliability

EMP Task Force Structure

- **Subgroup 1: System Planning and Modeling**
  - Provide guidance on how the industry might assess the potential impacts of EMP events on BPS reliability using the best available science recognizing the various bulk electric system designs across North America
- **Subgroup 2: Critical Facility Assessment**
  - Provide guidance to BPS owners and applicable NERC committees on how to appropriately identify and prioritize the types of facilities such as, but not limited to, power plants, substations, and control centers, that may have the highest priority with respect to EMP impact assessment and mitigation actions
- **Subgroup 3: Mitigation, Response, and Recovery**
  - The results of work from Subgroups 1 and 2 will be considered to provide guidance to BPS owners and applicable NERC committees on possible mitigation solutions, response plans, and recovery strategies Subgroup 2: Critical Facility Assessment

EMP Task Force Deliverables for 2019

- **Phase 1 Work Plan Schedule:** The Task Force shall develop a schedule for Phase 1 that will be reviewed and updated periodically
- **Phase 1 Meetings:** The Task Force shall convene in-person and/or conference calls to facilitate the discussion required to accomplish its mission and objectives
- **EMP Bibliography/Reference Document:** Publish an EMP bibliography/reference document for the electric sector
- **Phase 1 Strategic Recommendations:** Develop and agree on a set of strategic recommendations that can be shared with the industry for review and comment

EMP Task Force Deliverables for 2019

- **Post Phase 1 Strategic Recommendations for Industry Comments:** Post the strategic recommendations for industry review and comment
- **Review Industry Comments on Phase 1 Strategic Recommendations:** Consider industry comments on the strategic recommendations for inclusion in a Phase 1 report
- **Develop a Report with Recommendations:** Develop a report summarizing the findings of the task force that should include a prioritized list of recommended actions and/or next steps. The Task Force shall develop a resolution requesting endorsement of the report and its recommendations from NERC

Questions and Answers

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EMP Research Efforts

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EPRI Electromagnetic Pulse Research

Randy Horton, Ph.D., P.E.
Senior Program Manager

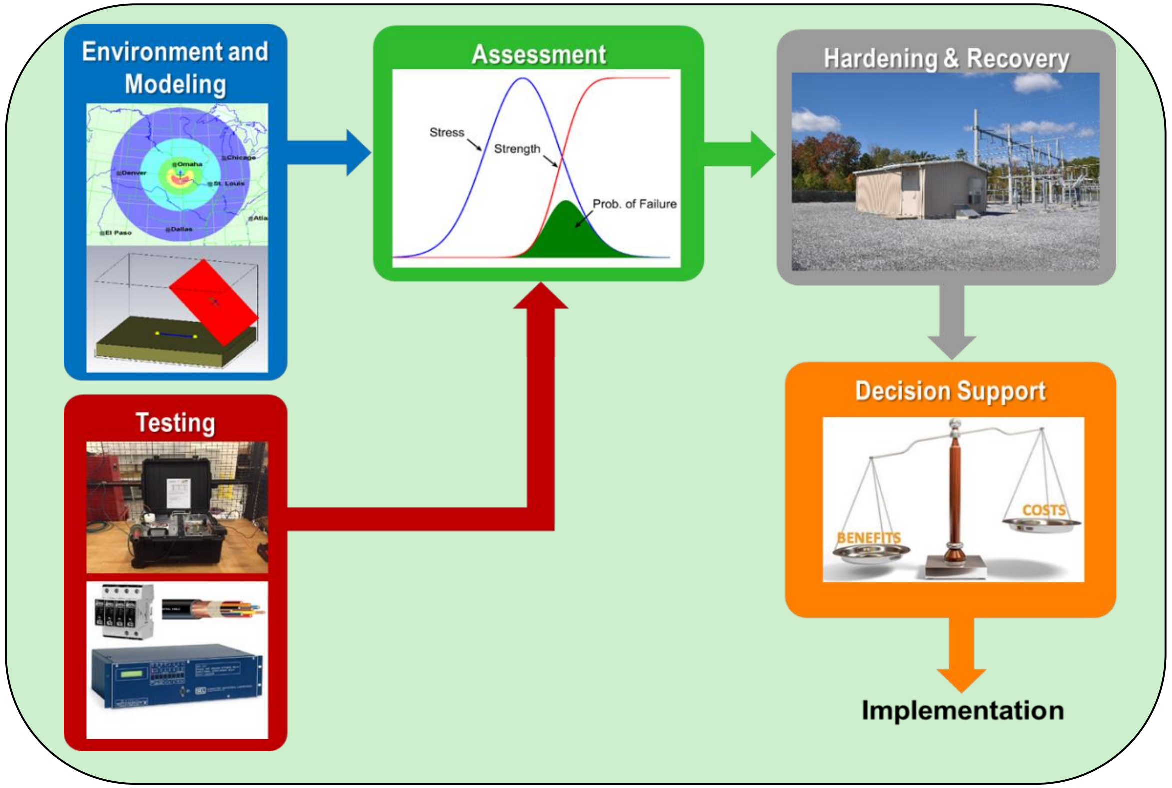
NERC EMP Task Force Meeting
Atlanta, GA
July 25, 2019

www.epri.com

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?

Research Work Flow



Environment and Modeling

Assessment

Hardening & Recovery

Testing

Decision Support

Implementation

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

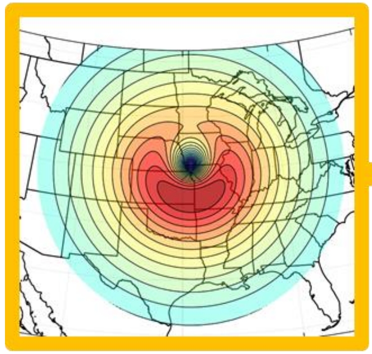
DEFENSE THREAT REDUCTION AGENCY
UNITED STATES OF AMERICA

Lawrence Livermore National Laboratory

E1 EMP Assessment Approach

The E1 EMP environment represents the hazard fields (spatio-temporal electric field) that a bulk power system might be exposed to during a HEMP attack.

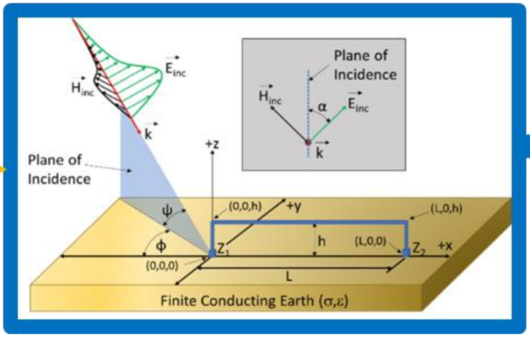
E1 Environment



Component Testing (Strength)

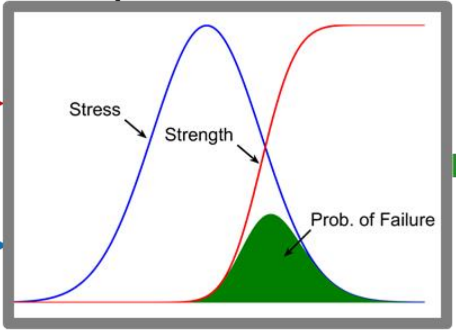
Laboratory testing of critical assets is performed to determine damage thresholds (levels of E1 EMP induced stress that causes upset or damage).

Modeling (Stress)



Modeling is done to estimate the electrical stress that a critical asset could be exposed to during a HEMP attack.

Impact Assessment



A stress vs. strength comparison is made to estimate the probability of failure. Statistical or deterministic methods can be used.

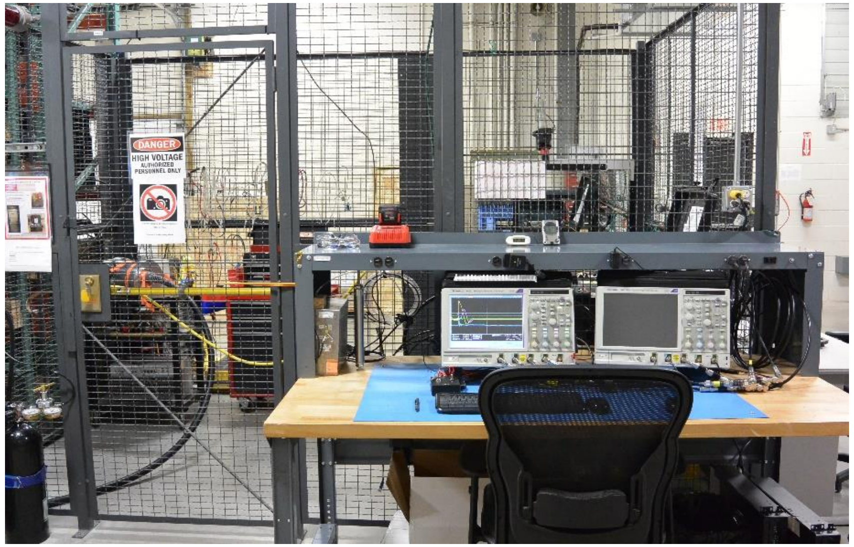
Probability of Failure

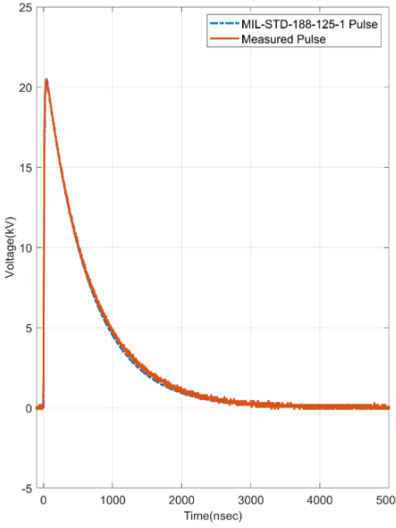
E1 EMP Testing

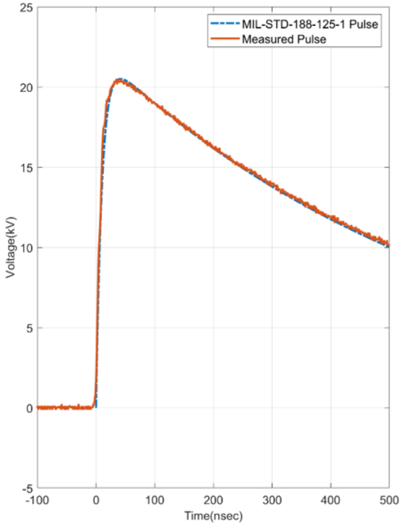
Field Illumination Testing (Radiated Threat) EPRI - Charlotte

Over 50 Digital Protective Relays Tested

Direct Injection Testing (Conducted Threat) EPRI - Knoxville

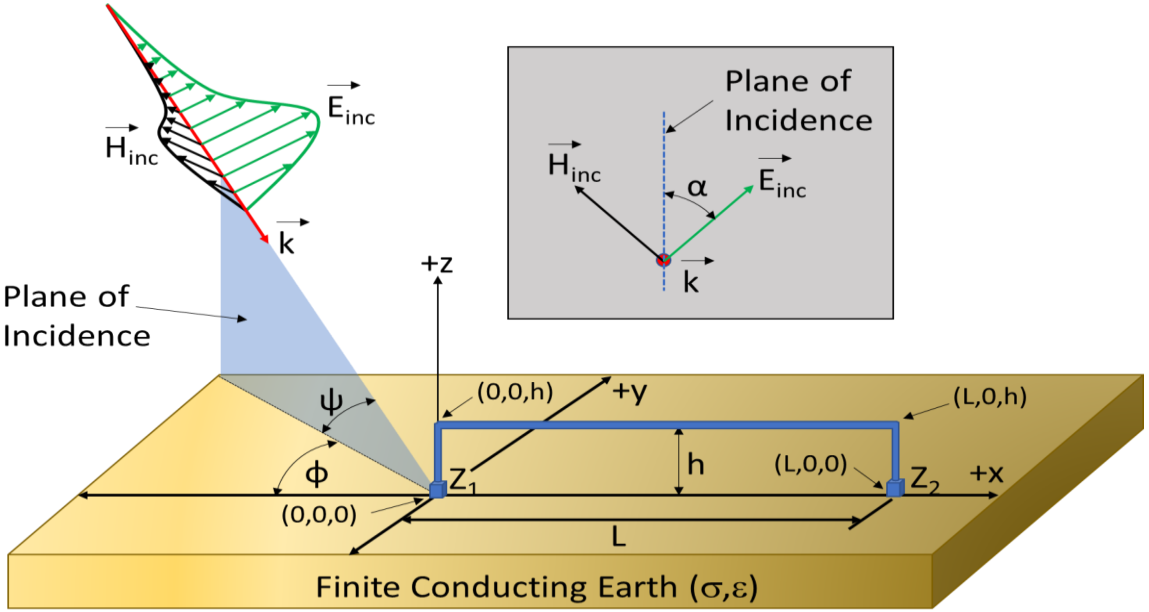




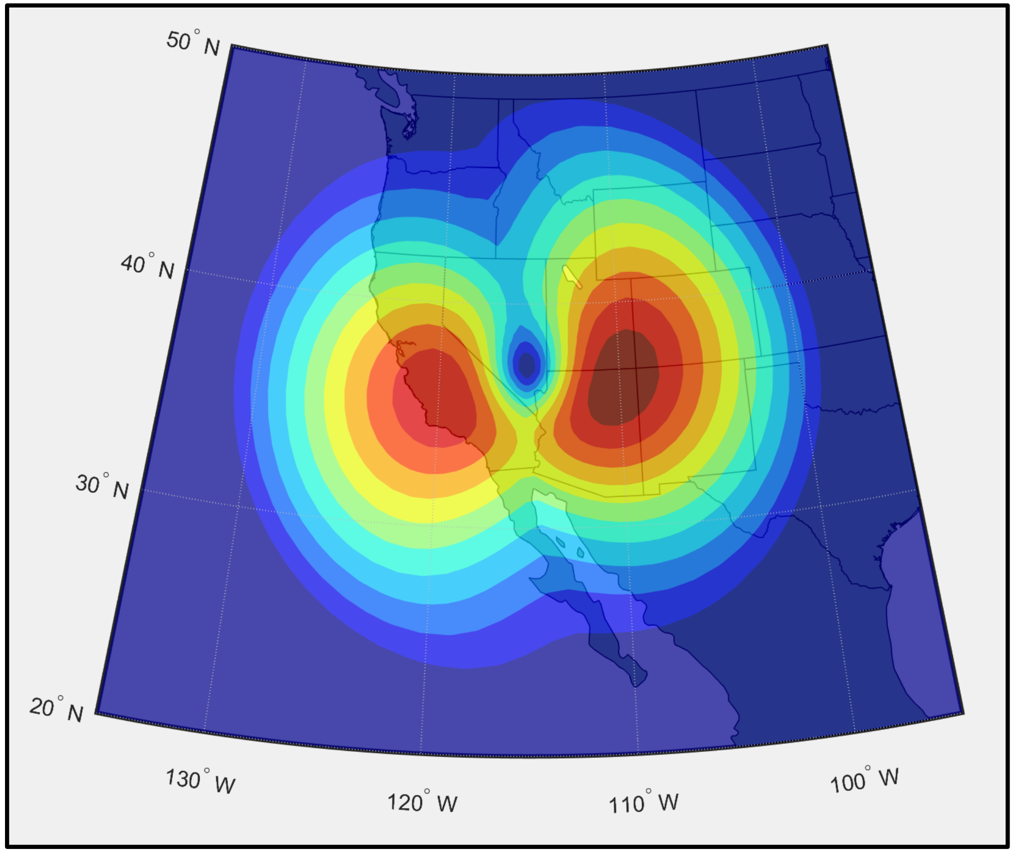


E1 EMP Modeling

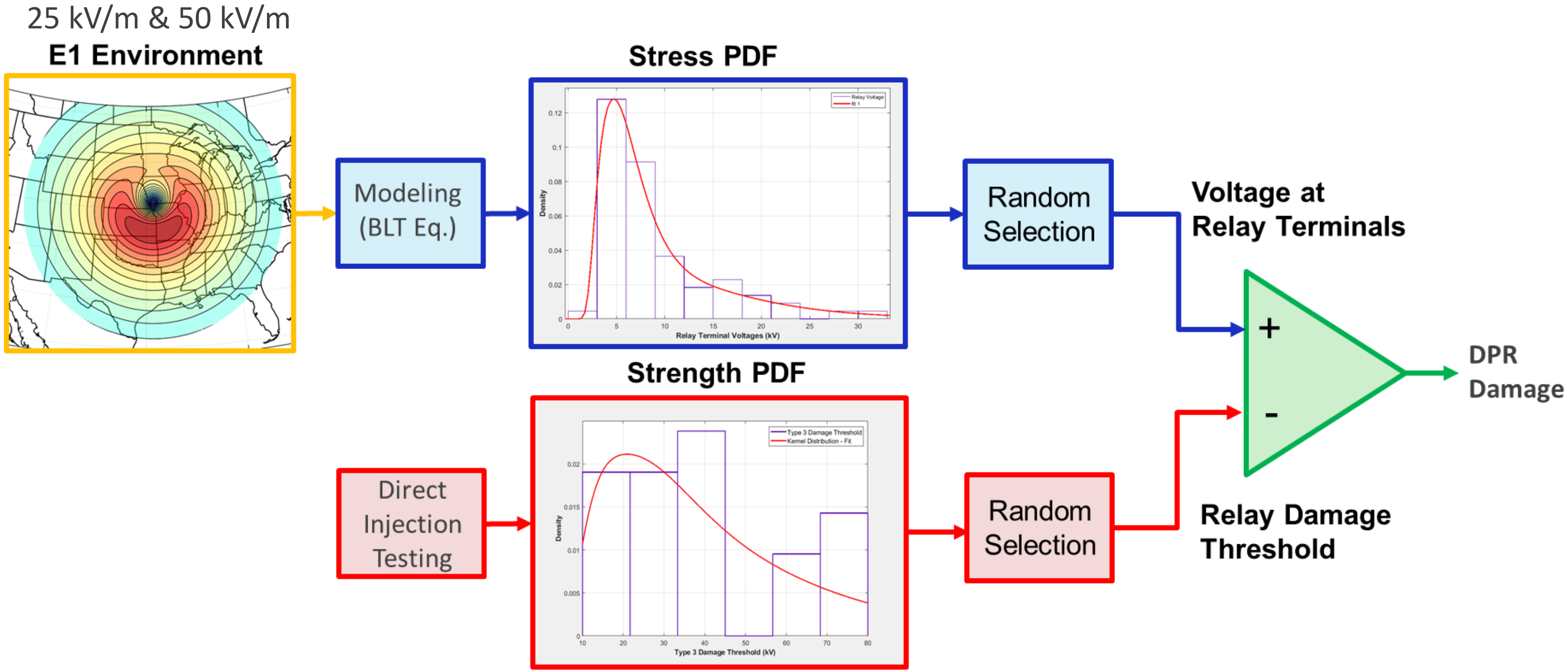
- Modeling was performed to determine the voltage/current surges that equipment might be exposed to during a HEMP event.
- Matlab/EMTP-RV based tools were developed, CST Studio (3D EM solver) also used
- Capability was later expanded to allow for interconnection-scale assessments.



Notional Example for Illustration Purposes



Interconnection-Scale E1 EMP Assessment



25 kV/m & 50 kV/m

E1 Environment

Modeling (BLT Eq.)

Stress PDF

Random Selection

Voltage at Relay Terminals

Direct Injection Testing

Strength PDF

Random Selection

Relay Damage Threshold

DPR Damage

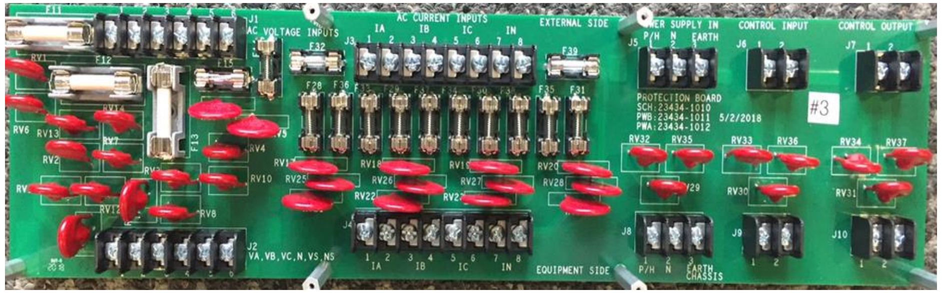
Potential Impacts to Digital Protective Relays Can be Experienced Across an Interconnection

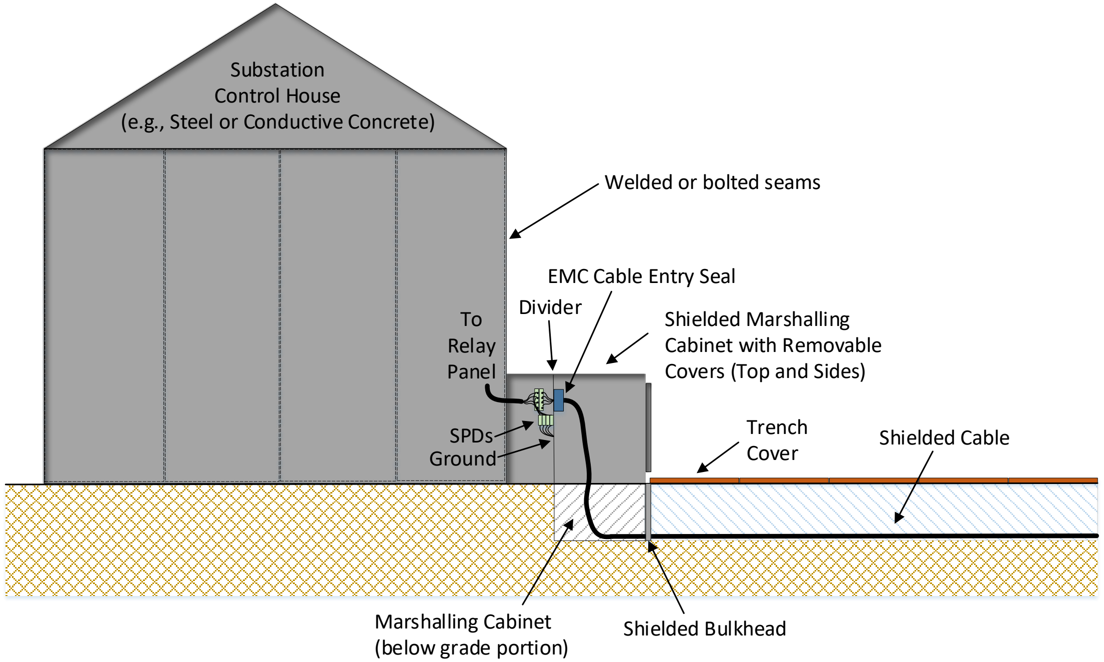
Field Trials of E1 EMP Mitigation Are Needed

- 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 18 U.S. utilities to evaluate E1 EMP mitigations in substations

Example of a Prototype Low-voltage Surge Suppression Device



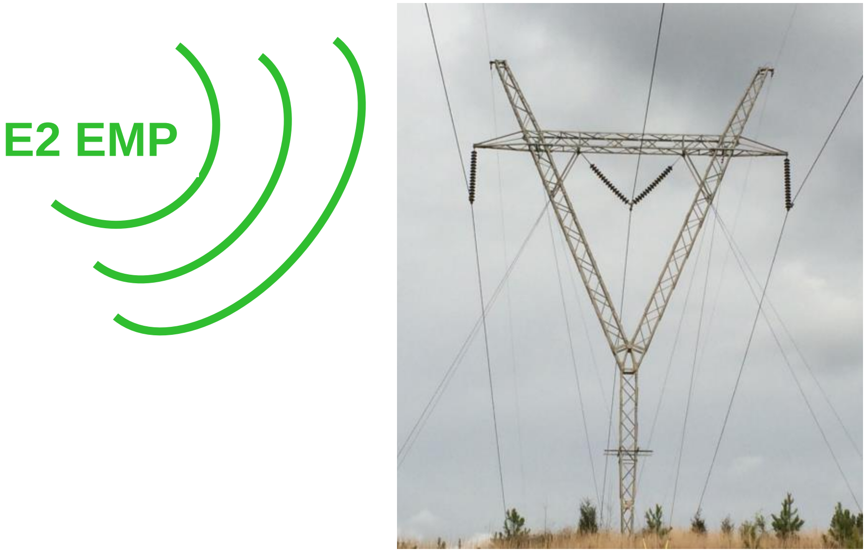


Assessment of E2 Impacts

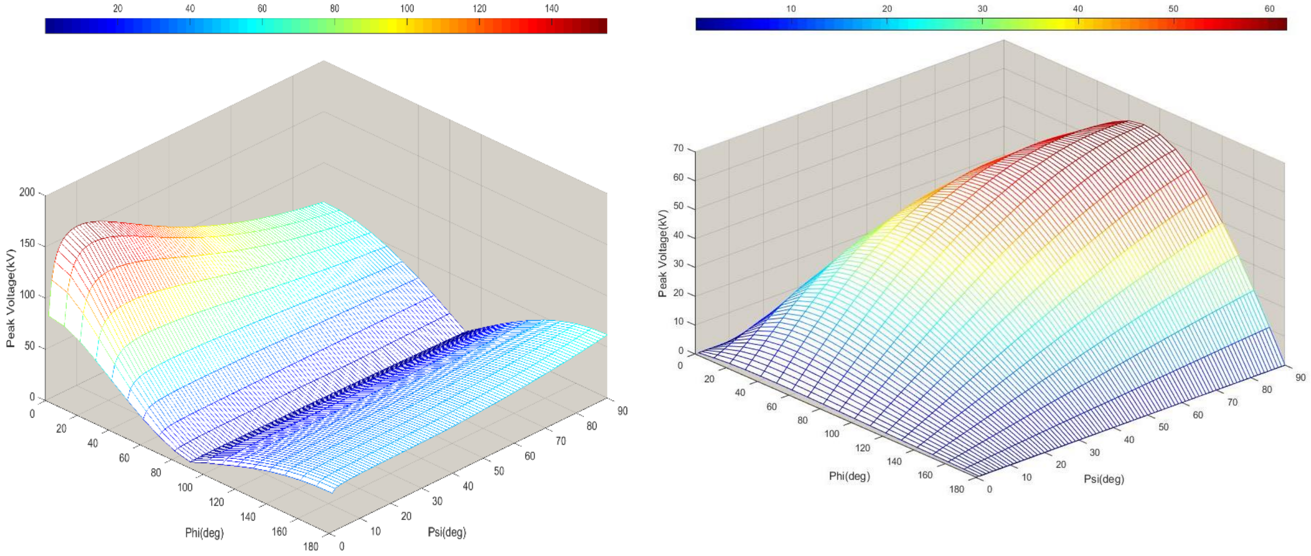
- Assessed potential impacts of E2 EMP on substations using IEC E2 EMP threat environment.

- Results indicate that E2 EMP is not a threat to high-voltage infrastructure or digital protective relays.

- No specific mitigations provided.

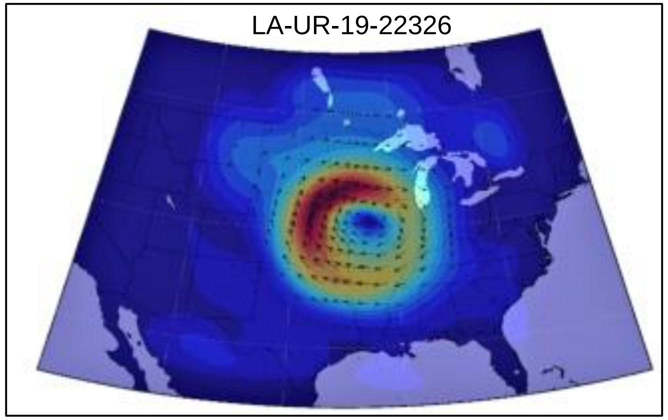


Example Simulation Results

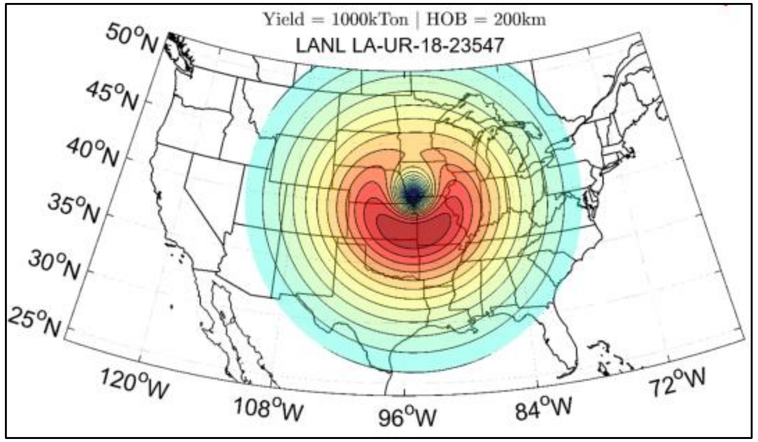


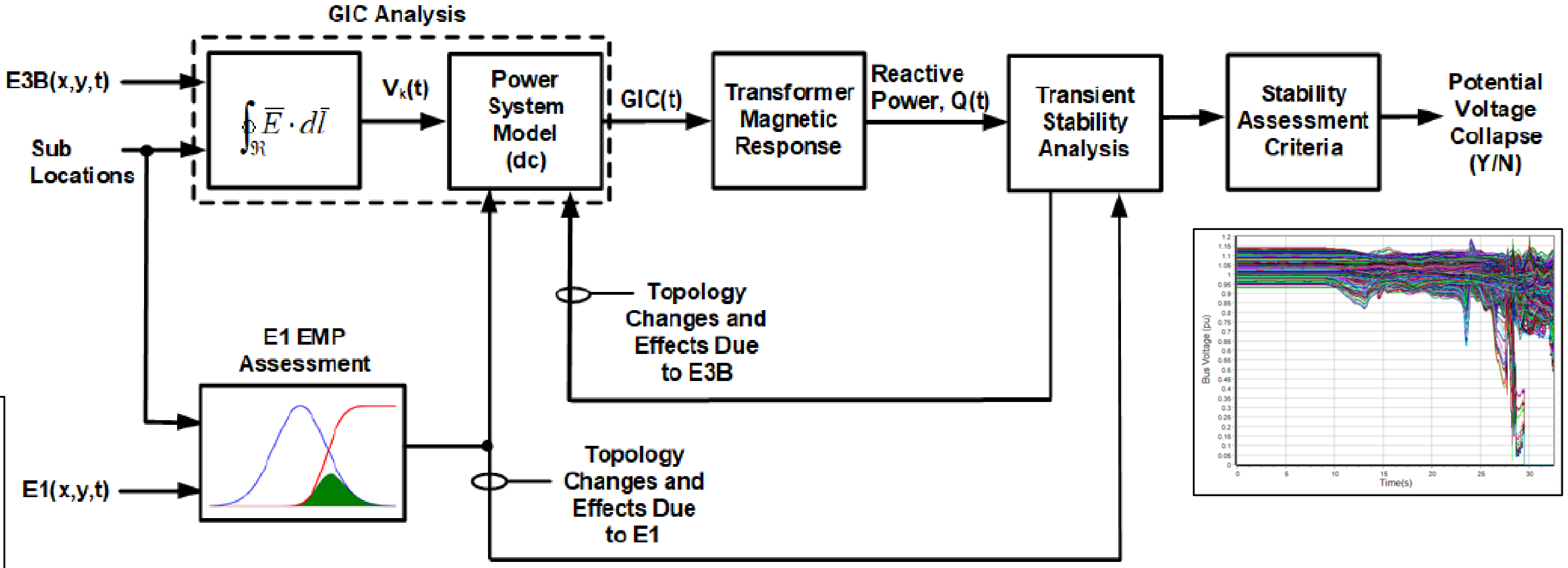
Voltage Stability Assessment With E1 EMP Impacts

E3 Environment (~35 V/km)



E1 Environment (scaled to 50 kV/m)





GIC Analysis

E3B(x,y,t)

Sub Locations

$\int_{\Re} \bar{E} \cdot d\bar{l}$

$V_x(t)$

Power System Model (dc)

GIC(t)

Transformer Magnetic Response

Reactive Power, Q(t)

Transient Stability Analysis

Stability Assessment Criteria

Potential Voltage Collapse (Y/N)

Topology Changes and Effects Due to E3B

E1 EMP Assessment

E1(x,y,t)

Topology Changes and Effects Due to E1

- Regional (multi-state) Voltage Collapse is Possible
- Thermal damage of large power transformers from part-cycle saturation expected to be minimal (3 – 21 depending on the target location evaluated)
- Uncertainty regarding the ability of high-voltage circuit breakers to interrupt high levels of quasi-dc current

Summary of Findings

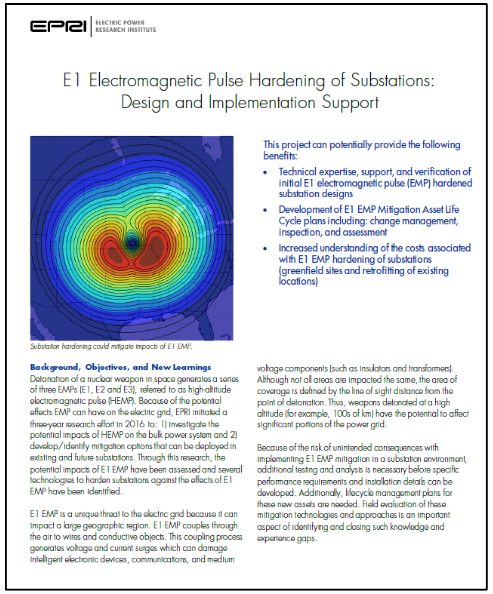
- Extensive modeling, simulation and testing was utilized to assess potential impacts:
  - E1 EMP: Disruption or damage to substation electronics (e.g. digital protective relays) is possible and can be experienced over a large geographic area (electrical interconnection)
  - E2 EMP: Impacts to bulk power 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

- Mitigating E3 EMP impacts is similar to mitigating GMD impacts (reduce/block GIC flows, UVLS, etc.) but the two events should be evaluated separately.

Next Steps

- Technical support and field evaluation of E1 EMP hardening options
  https://www.epri.com/#/pages/product/3002014867/
- Continue E1 EMP investigation to include generating facilities
  https://www.epri.com/#/pages/product/3002015354/
- Work with other Critical Infrastructures to transfer initial results and investigate other technical options



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E1 Electromagnetic Pulse Hardening of Substations: Design and Implementation Support

Substation hardening could mitigate impacts of E1 EMP.

This project can potentially provide the following benefits:

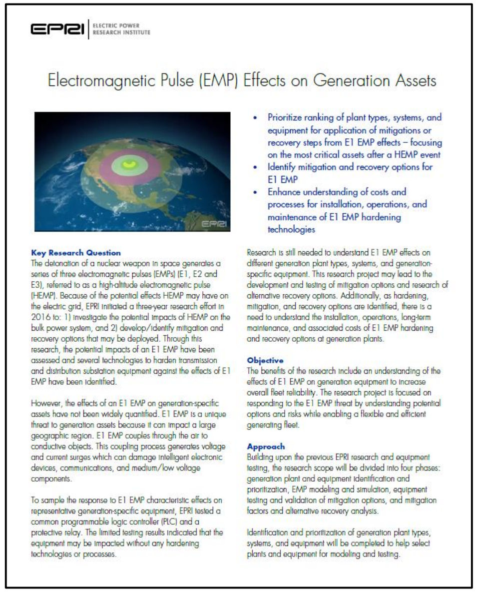
- Technical expertise, support, and verification of initial E1 electromagnetic pulse (EMP) hardened substation designs
- Development of E1 EMP Mitigation Asset Life Cycle plans including: change management, inspection, and assessment
- Increased understanding of the costs associated with E1 EMP hardening of substations (greenfield sites and retrofitting of existing locations)

Background, Objectives, and New Learnings

Detonation of a nuclear weapon in space generates a series of three EMPs (E1, E2 and E3), referred to as high-altitude electromagnetic pulse (HEMP). Because of the potential effects EMP can have on the electric grid, EPRI initiated a three-year research effort in 2016 to: 1) investigate the potential impacts of HEMP on the bulk power system and 2) develop/identify mitigation options that can be deployed in existing and future substations. Through this research, the potential impacts of E1 EMP have been assessed and several technologies to harden substations against the effects of E1 EMP have been identified.

E1 EMP is a unique threat to the electric grid because it can impact a large geographic region. E1 EMP couples through the air to wires and conductive objects. This coupling process generates voltage and current surges which can damage intelligent electronic devices, communications, and medium voltage components (such as insulators and transformers). Although not all areas are impacted the same, the area of coverage is defined by the line of sight distance from the point of detonation. Thus, weapons detonated at a high altitude (for example, 100s of km) have the potential to affect significant portions of the power grid.

Because of the risk of unintended consequences with implementing E1 EMP mitigation in a substation environment, additional testing and analysis is necessary before specific performance requirements and installation details can be developed. Additionally, lifecycle management plans for these new assets are needed. Field evaluation of these mitigation technologies and approaches is an important aspect of identifying and closing such knowledge and experience gaps.



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Electromagnetic Pulse (EMP) Effects on Generation Assets

- Prioritize ranking of plant types, systems, and equipment for application of mitigations or recovery steps from E1 EMP effects – focusing on the most critical assets after a HEMP event
- Identify mitigation and recovery options for E1 EMP
- Enhance understanding of costs and processes for installation, operations, and maintenance of E1 EMP hardening technologies

Key Research Question

The detonation of a nuclear weapon in space generates a series of three electromagnetic pulses (EMPs) (E1, E2 and E3), referred to as a high-altitude electromagnetic pulse (HEMP). Because of the potential effects HEMP may have on the electric grid, EPRI initiated a three-year research effort in 2016 to: 1) investigate the potential impacts of HEMP on the bulk power system, and 2) develop/identify mitigation and recovery options that may be deployed. Through this research, the potential impacts of an E1 EMP have been assessed and several technologies to harden transmission and distribution substation equipment against the effects of E1 EMP have been identified.

However, the effects of an E1 EMP on generation-specific assets have not been widely quantified. E1 EMP is a unique threat to generation assets because it can impact a large geographic region. E1 EMP couples through the air to conductive objects. This coupling process generates voltage and current surges which can damage intelligent electronic devices, communications, and medium/low voltage components.

To sample the response to E1 EMP characteristic effects on representative generation-specific equipment, EPRI tested a common programmable logic controller (PLC) and a protective relay. The limited testing results indicated that the equipment may be impacted without any hardening technologies or processes.

Research is still needed to understand E1 EMP effects on different generation plant types, systems, and generation-specific equipment. This research project may lead to the development and testing of mitigation options and research of alternative recovery options. Additionally, as hardening, mitigation, and recovery options are identified, there is a need to understand the installation, operations, long-term maintenance, and associated costs of E1 EMP hardening and recovery options at generation plants.

Objective

The benefits of the research include an understanding of the effects of E1 EMP on generation equipment to increase overall fleet reliability. The research project is focused on responding to the E1 EMP threat by understanding potential options and risks while enabling a flexible and efficient generating fleet.

Approach

Building upon the previous EPRI research and equipment testing, the research scope will be divided into four phases: generation plant and equipment identification and prioritization, EMP modeling and simulation, equipment testing and validation of mitigation options, and mitigation factors and alternative recovery analysis.

Identification and prioritization of generation plant types, systems, and equipment will be completed to help select plants and equipment for modeling and testing.

Natural Gas

Water

Comm

Others

Together…Shaping the Future of Electricity

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Nuclear Effort Update

Scot Greenlee, Exelon Nuclear
Electromagnetic Pulse Task Force Workshop
July 25, 2019

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Questions and Answers

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Defense Effort Panel

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DHS/CISA EMP ACTIVITY OVERVIEW

JUNE 25, 2019

DHS/CISA Organization Around EMP & GMD

- DHS/CISA/NRMC established the EMP Coordinator position in February 2019. This position is responsible for:
  - Coordination & execution of DHS-internal EMP/GMD work
  - Leading technical interactions with the USG Interagency and industry
- DHS is currently responding to and coordinating work across three different strategies/orders
  - EMP Executive Order
  - National Space Weather Strategy
  - DHS EMP Strategy

There is overlap between these strategies/orders. DHS has put the effort under a single coordinator to leverage work across all three

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Three EMP & GMD Strategies/Orders

- EMP Executive Order—EMP and GMD threats
  - Near-term focus on mitigation and incentives, component test data gaps and additional testing, and demonstration of mitigations
  - Several challenges arising from the sequencing of tasks
- National Space Weather Strategy (NSWS WG-1)—GMD threats
  - Mid-term to long-term focus on R&D to develop space weather forecasting and benchmarking and on infrastructure impact analysis
  - DHS developing work plan—presenting at July 10 SWORM meeting
- DHS EMP Strategy—EMP and GMD threats
  - Encompasses much of the EMP EO and NSWS
  - Additional emphasis on threat communication and response
  - Anticipate projects through DHS S&T

Purpose of the EMP EO

- EMP Executive Order signed on March 26, 2019
- *Section 1. Purpose. An electromagnetic pulse (EMP) has the potential to disrupt, degrade, and damage technology and critical infrastructure systems. Human-made or naturally occurring EMPs can affect large geographic areas, disrupting elements critical to the Nation's security and economic prosperity, and could adversely affect global commerce and stability. <u>The Federal Government must foster sustainable, efficient, and cost-effective approaches to improving the Nation's resilience to the effects of EMPs.</u>*

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Principles of Analysis (For EMP or GMD)

- Use the best available science—Use physics and engineering constraints in analysis to avoid overestimation of risk
- Incorporate the engineered nature of the infrastructures systems—Impacts may already be mitigated by existing control systems, redundancy, backup, hardening, and restoration plans.
- Variable level of analysis sophistication—Each infrastructure has its own level of modeling/simulation maturity → Leverage what is currently available while prioritizing and funding R&D needs
- EMP is one of many threats—Develop best estimate of risk from EMP and GMD to place them in context of other infrastructure threats

U.S. DEPARTMENT OF HOMELAND SECURITY

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For more information:

cisa.gov

Questions?

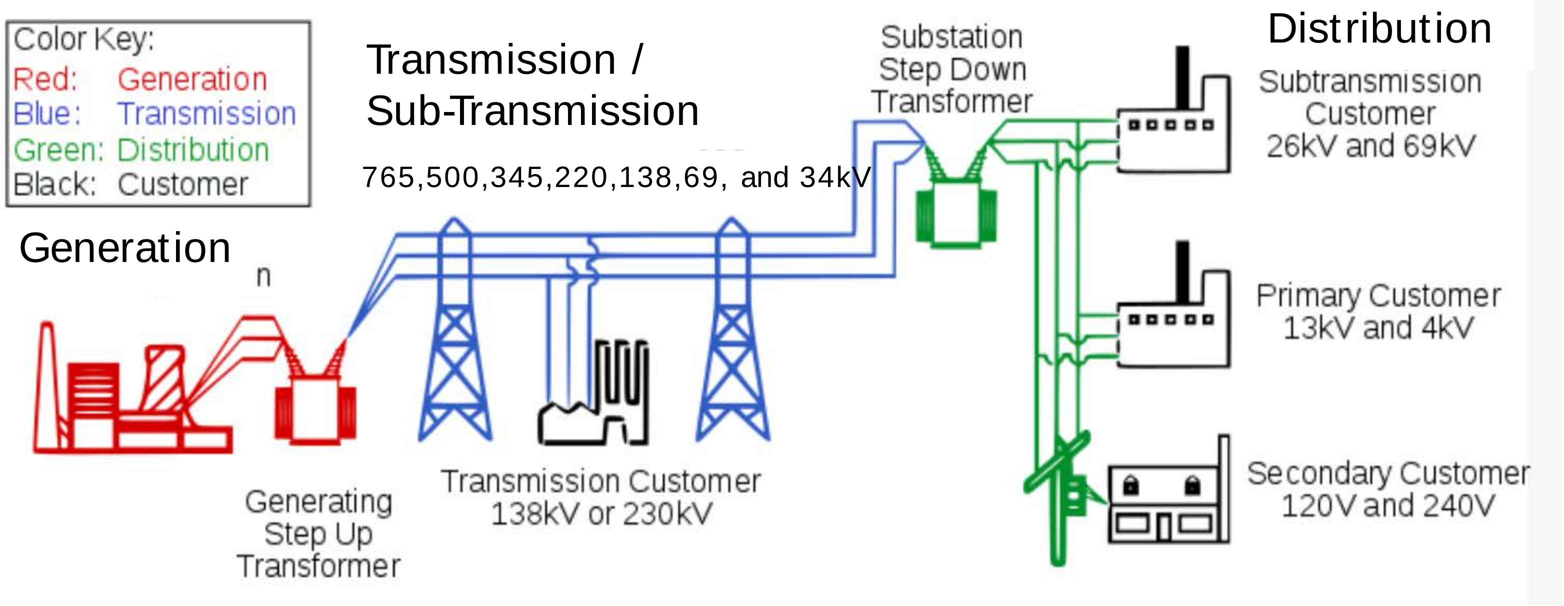
Email: Scott.Backhaus@hq.dhs.gov

Phone:505-551-2607

Ongoing DTRA Power Grid Projects

Michael R. Rooney, DTRA/RD

Electric Power Grid – Simplified Model



- Various levels of the Grid and Equipment are potentially vulnerable to the threats identified in Fixed Ground Base Specification Mil-Std-188-125-1 (performance standard) and the DTRA MIL-HDBK 423 (how to).
- DTRA has conducted tests on selected components within each area to assess the range of responses to the E1 and E3 threats.
- Today: overview of transmission substation digital relay tests (completed)* and power generation plant distributed control system (ongoing).

Why DoD and DTRA Care

- The main charter for protecting the power grid is with DHS and DOE including nuclear electromagnetic pulse (EMP).
- DTRA has extensive experience with EMP and has concern for vulnerabilities to the Defense Critical Power Infrastructure, in addition to …
  - DoD is tasked with publishing all the nuclear weapon effects environment and protection MIL-STDs, and associated handbooks
  - DoDD 3020.04: DoD Policy and Responsibilities for Critical Infrastructure
    - "Identify vulnerabilities in technologies relied upon by DCI [Defense Critical Infrastructure] that are developed, acquired, owned, or operated by the Department of Defense, and develop effective risk response options to emerging vulnerabilities or threats" (2c)
  - Executive Order on Coordinating National Resilience to Electromagnetic Pulses, March 26, 2019
    - "Not later than September 22, 2020, the Secretary of Defense, in consultation with the Secretary of Homeland Security and the Secretary of Energy, shall conduct a pilot program to evaluate engineering approaches for hardening a strategic military installation, including infrastructure that is critical to supporting that installation, against the effects of EMPs and GMDs."
- World nuclear posture is shifting – in the big picture, nuclear warfare is the still the country's biggest threat. Society as we know it today requires AC power.

DTRA Testing: Completed and in Progress

- Control and Protective Equipment
  - Digital Control System (DCS) Substation Protective Relays
    - Protective relays - 3 Manufacturers (complete and published)
  - DCS Power Generation Plant (PGP) Industrial Sensing and Control Equipment
    - Subset of the large number of equipment
    - 4 Manufacturers (1 complete other 3 underway)
- Lightning Arrestors (underway – high current pulser built)
- Large transformer saturation effects
  - Harmonic generation
  - Heating

Strength:
Lab Test

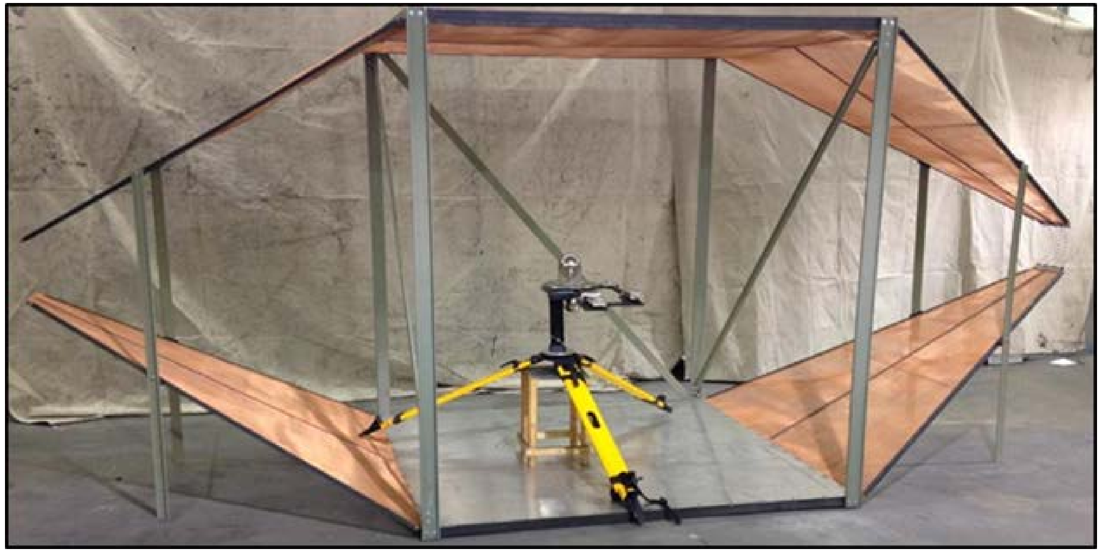
- Power Generation Plant (PGP) Coupling (Test complete and analysis underway)

Stress:
Field Test

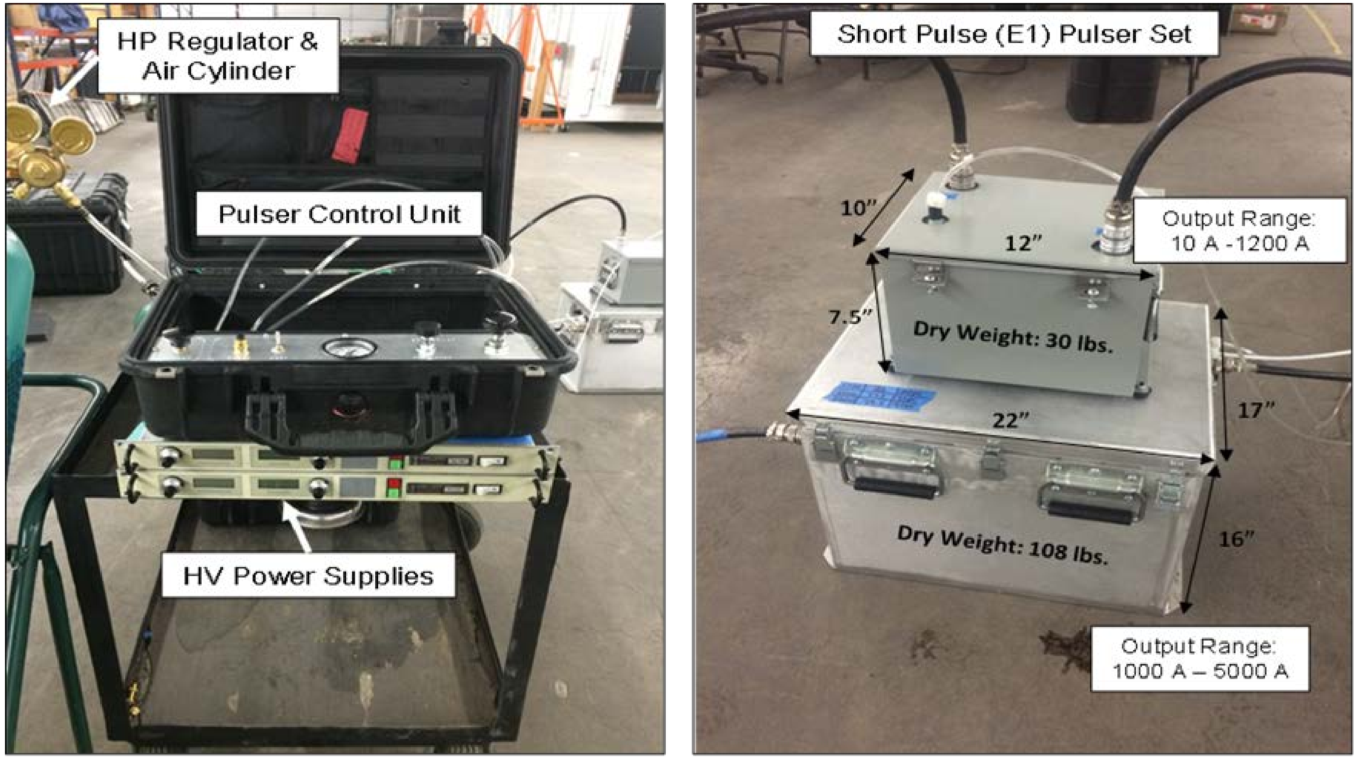
Digital Control System (DCS) Test Overview

- Objective 1: Test a simulated DCS **substation**, rack-level **protective relay** installation using three typical relay Model types from different manufacturers (two test samples/units each)
  - Manufacturer A, Model A (Transmission level)
  - Manufacturer B, Model B (Distribution Level)
  - Manufacturer C, Model C (Distribution Level)
- Objective 2: Test a simulated DCS power generation plant (**PGP**) installation, rack-level protective installation using a sample of four main manufacturers (one-plus test samples/units each)
  - Manufacturer A (same as above) Model PGP-A – testing is complete
  - Three other manufacturer's products are under test
- Perform DCS, protective relay and PGP, equipment testing in both a COTS-**unprotected** (nominal) open-rack and EMP-**protected** open-rack configurations
- DTRA is publishing technical reports which will be Distribution A for both of these tests.
  - "Power System Digital Protective Relay High-Altitude Electromagnetic Pulse Tests," DTRA-TR-18-72, 14 Feb 2016, Distribution A.

Laboratory Test Equipment: Transverse Electromagnetic (TEM) Bounded Wave Transmission Line (BWTL) and Pulsed Current Injection (PCI)



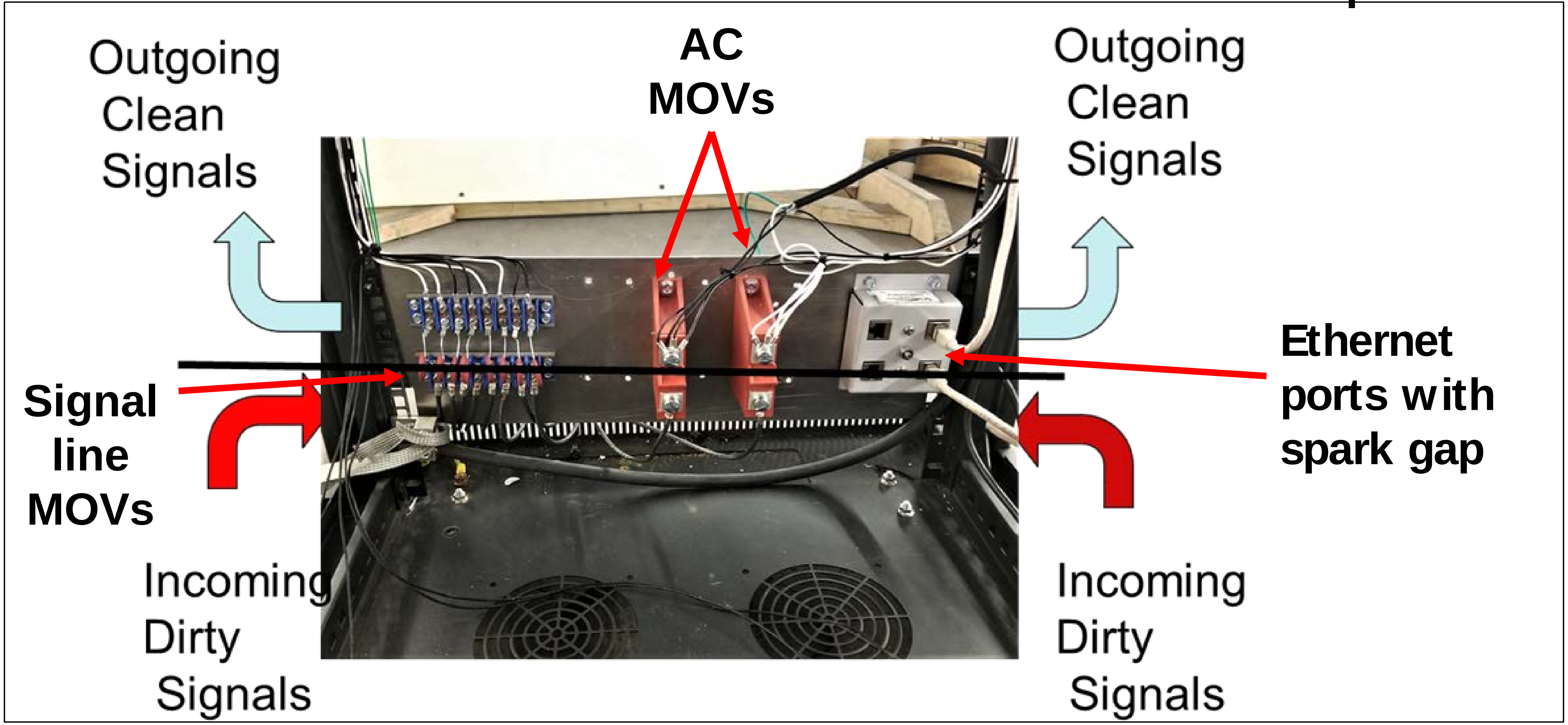
TEM BWTL



PCI

Testing of Both EMP Protected and Unprotected (COTS) Configurations: PGP DCS

Protection for PGP Open Rack



Outgoing Clean Signals

AC MOVs

Outgoing Clean Signals

Signal line MOVs

Ethernet ports with spark gap

Incoming Dirty Signals

Incoming Dirty Signals

TEM BWTL (Radiated) DCS SPE & ISCE Susceptibility Data: Unhardened and EMP Hardened

DCS Substation Protective Relays

Summary of Unprotected TEM Tests - Relays

	Side Illumination				Front Illumination			
Component	6 kV/m	10 kV/m	20 kV/m	32 kV/m	6 kV/m	10 kV/m	20 kV/m	32 kV/m
Manufacturer A	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
Manufacturer B	🟩	🟩	🟩	🟩	🟩	🟩	🟩	NLU - 50%
Manufacturer C	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩

NLU = Non-Latching Upset	🟩 No Response
🟥 PD = Permanent Damage	▨ LU = Latching Upset Due to Paired Component Damage

DCS PGP Equipment

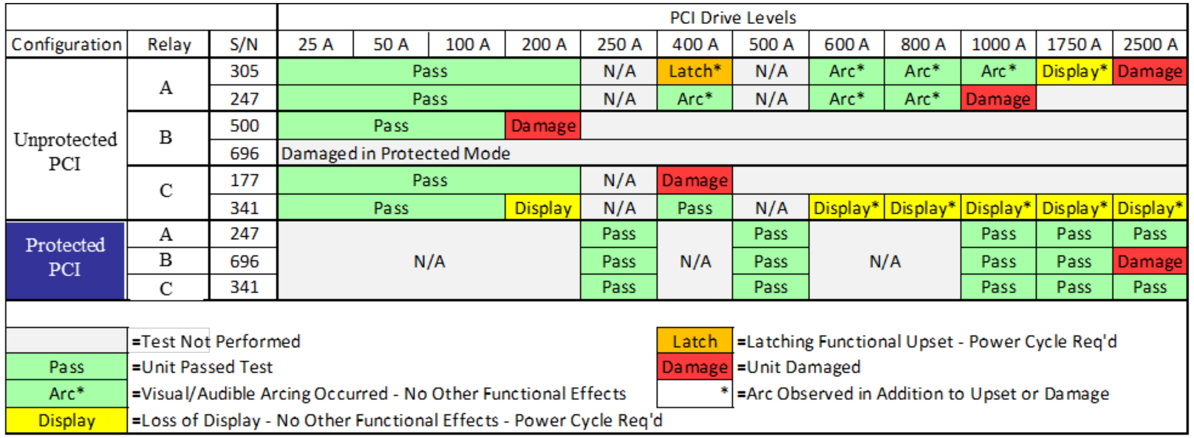
Summary of Unprotected TEM Tests - DCS

	Side Illumination				Front Illumination			
Component	6 kV/m	10 kV/m	20 kV/m	32 kV/m	6 kV/m	10 kV/m	20 kV/m	32 kV/m
Manufacturer A	🟩	🟩	🟩	NLU	🟩	🟩	🟩	NLU
Manufacturer D								
Manufacturer E								
Manufacturer F								

NLU = Non-Latching Upset	🟩 No Response
🟥 PD = Permanent Damage	▨ LU = Latching Upset Due to Paired Component Damage

Pulse Current Injection (PCI) DCS Susceptibility Data: Unhardened and EMP Hardened

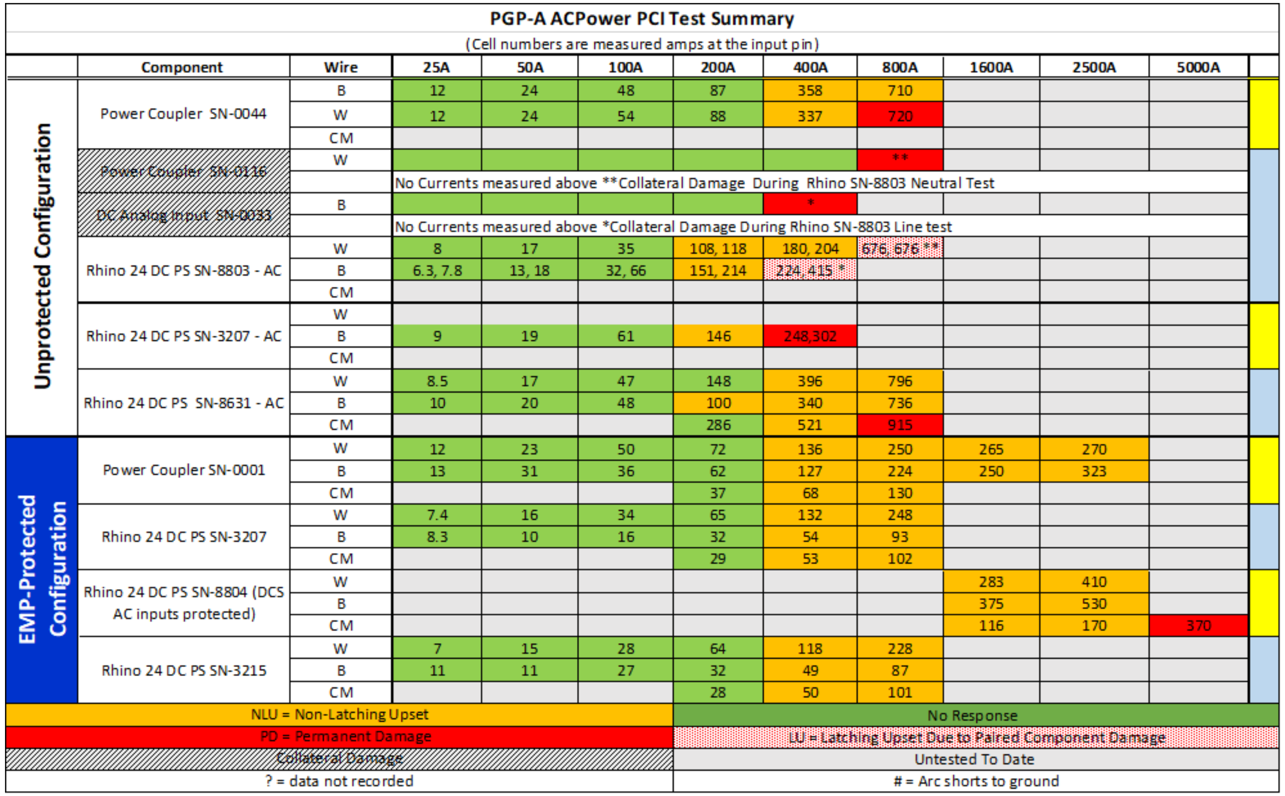
Substation DCS Protective Relays



			PCI Drive Levels											
Configuration	Relay	S/N	25 A	50 A	100 A	200 A	250 A	400 A	500 A	600 A	800 A	1000 A	1750 A	2500 A
Unprotected PCI	A	305	Pass				N/A	Latch*	N/A	Arc*	Arc*	Arc*	Display*	Damage
		247	Pass				N/A	Arc*	N/A	Arc*	Arc*	Damage		
	B	500	Pass			Damage								
		696	Damaged in Protected Mode											
	C	177	Pass				N/A	Damage						
		341	Pass			Display	N/A	Pass	N/A	Display*	Display*	Display*	Display*	Display*
Protected PCI	A	247	N/A				Pass	N/A	Pass	N/A		Pass	Pass	Pass
	B	696					Pass		Pass			Pass	Pass	Damage
	C	341					Pass		Pass			Pass	Pass	Pass

	=Test Not Performed	Latch	=Latching Functional Upset - Power Cycle Req'd
Pass	=Unit Passed Test	Damage	=Unit Damaged
Arc*	=Visual/Audible Arcing Occurred - No Other Functional Effects	*	=Arc Observed in Addition to Upset or Damage
Display	=Loss of Display - No Other Functional Effects - Power Cycle Req'd		

DCS Model-PGP-A



PGP-A ACPower PCI Test Summary

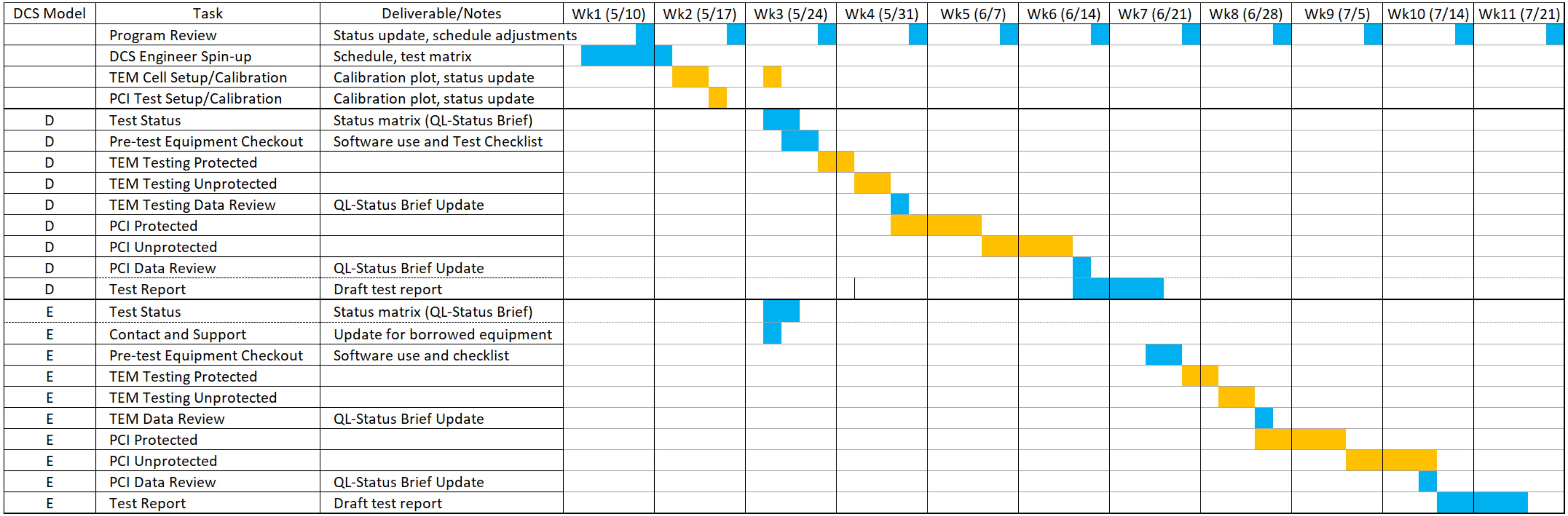
(Cell numbers are measured amps at the input pin)

	Component	Wire	25A	50A	100A	200A	400A	800A	1600A	2500A	5000A
Unprotected Configuration	Power Coupler SN-0044	B	12	24	48	87	358	710			
		W	12	24	54	88	337	720			
		CM									
	Power Coupler SN-0116	W						**			
			No Currents measured above **Collateral Damage During Rhino SN-8803 Neutral Test								
	DC Analog Input SN-0033	B					*				
			No Currents measured above *Collateral Damage During Rhino SN-8803 Line test								
	Rhino 24 DC PS SN-8803 - AC	W	8	17	35	108, 118	180, 204	676, 676 **			
		B	6.3, 7.8	13, 18	32, 66	151, 214	224, 415 *				
		CM									
	Rhino 24 DC PS SN-3207 - AC	W									
		B	9	19	61	146	248,302				
		CM									
	Rhino 24 DC PS SN-8631 - AC	W	8.5	17	47	148	396	796			
		B	10	20	48	100	340	736			
		CM				286	521	915			
EMP-Protected Configuration	Power Coupler SN-0001	W	12	23	50	72	136	250	265	270	
		B	13	31	36	62	127	224	250	323	
		CM				37	68	130			
	Rhino 24 DC PS SN-3207	W	7.4	16	34	65	132	248			
		B	8.3	10	16	32	54	93			
		CM				29	53	102			
	Rhino 24 DC PS SN-8804 (DCS AC inputs protected)	W							283	410	
		B							375	530	
		CM							116	170	370
	Rhino 24 DC PS SN-3215	W	7	15	28	64	118	228			
		B	11	11	27	32	49	87			
		CM				28	50	101			

NLU = Non-Latching Upset	No Response
PD = Permanent Damage	LU = Latching Upset Due to Paired Component Damage
Collateral Damage	Untested To Date
? = data not recorded	# = Arc shorts to ground

DCS PGP Test Schedule

- Model-PGP-A testing complete
- Model-PGP-F testing TBD
- Model-PGP-D and Model-PGP-E test schedule (underway)



DCS Model	Task	Deliverable/Notes	Wk1 (5/10)	Wk2 (5/17)	Wk3 (5/24)	Wk4 (5/31)	Wk5 (6/7)	Wk6 (6/14)	Wk7 (6/21)	Wk8 (6/28)	Wk9 (7/5)	Wk10 (7/14)	Wk11 (7/21)
	Program Review	Status update, schedule adjustments	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦
	DCS Engineer Spin-up	Schedule, test matrix	🟦	🟦									
	TEM Cell Setup/Calibration	Calibration plot, status update		🟨	🟨								
	PCI Test Setup/Calibration	Calibration plot, status update		🟨									
D	Test Status	Status matrix (QL-Status Brief)			🟦								
D	Pre-test Equipment Checkout	Software use and Test Checklist			🟦								
D	TEM Testing Protected				🟨	🟨							
D	TEM Testing Unprotected					🟨							
D	TEM Testing Data Review	QL-Status Brief Update				🟦							
D	PCI Protected					🟨	🟨						
D	PCI Unprotected						🟨	🟨					
D	PCI Data Review	QL-Status Brief Update						🟦					
D	Test Report	Draft test report						🟦	🟦				
E	Test Status	Status matrix (QL-Status Brief)			🟦								
E	Contact and Support	Update for borrowed equipment			🟦								
E	Pre-test Equipment Checkout	Software use and checklist							🟦				
E	TEM Testing Protected								🟨	🟨			
E	TEM Testing Unprotected									🟨			
E	TEM Data Review	QL-Status Brief Update								🟦			
E	PCI Protected									🟨	🟨		
E	PCI Unprotected										🟨	🟨	
E	PCI Data Review	QL-Status Brief Update										🟦	
E	Test Report	Draft test report										🟦	🟦

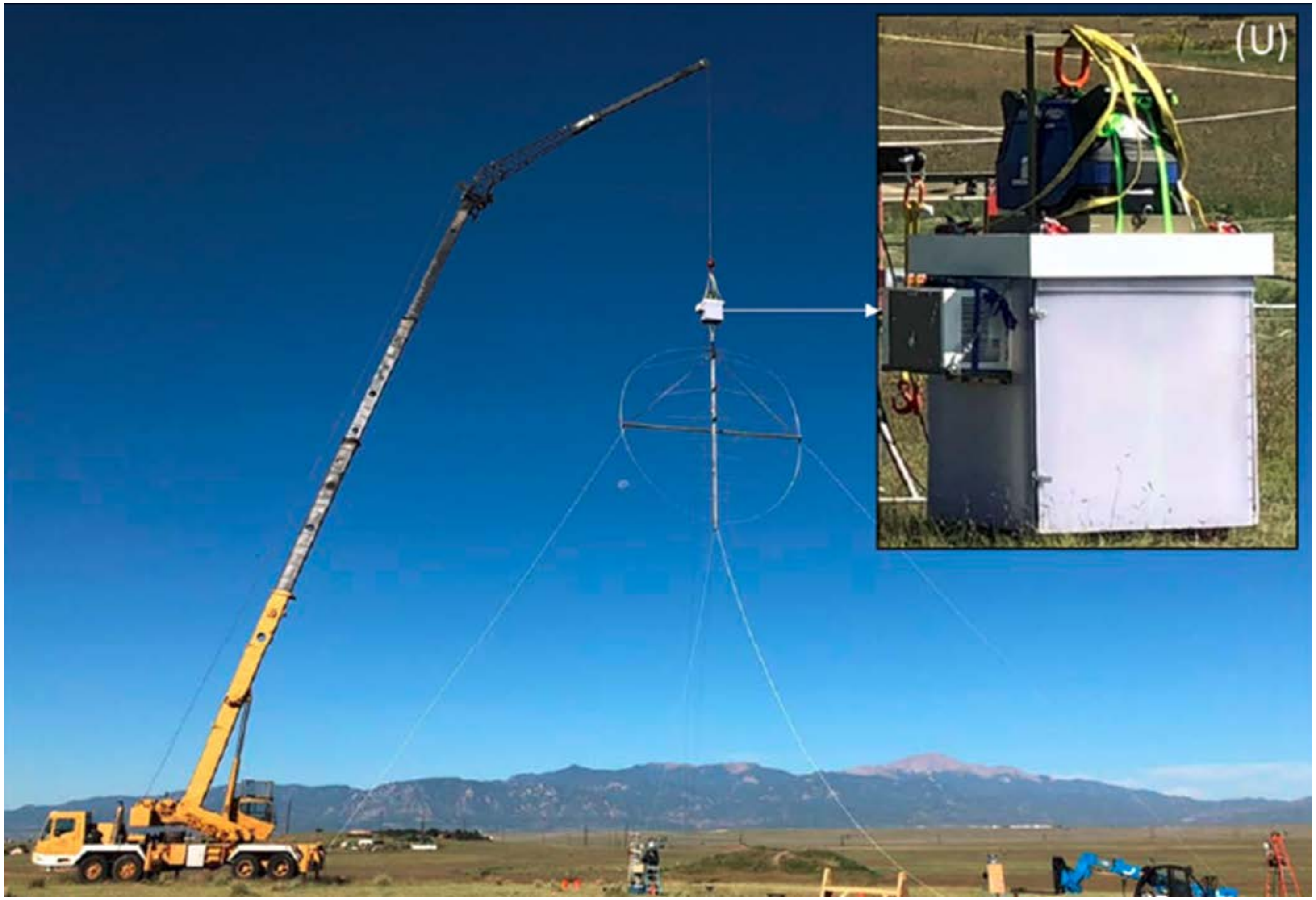
Power Generation Plant (PGP) Continuous Wave Immersion (CWI) Testing Scope

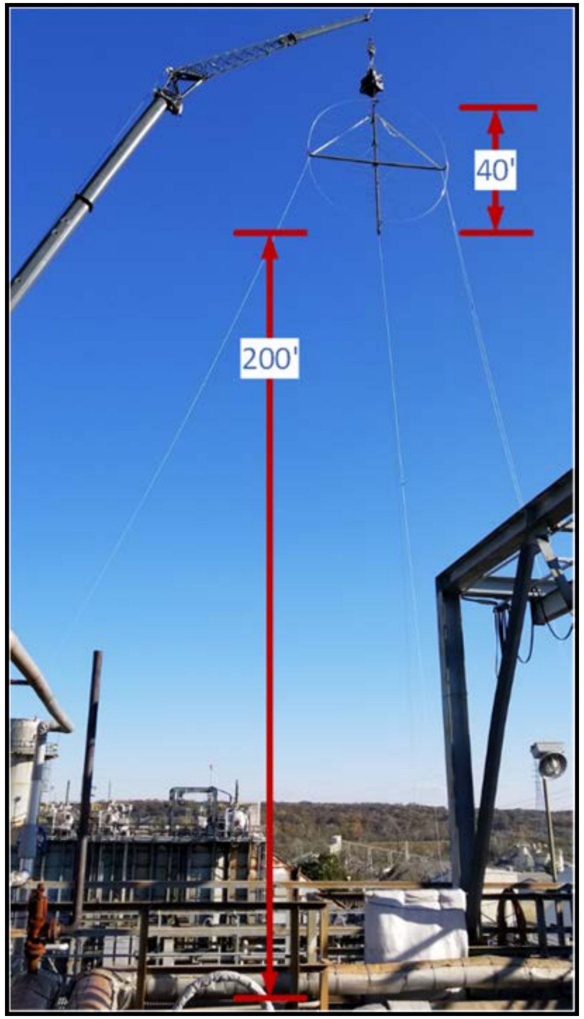
- Perform a CWI Field Map prior to the execution of the PGP facility test
- Evaluate the PGP facility IAW MIL-STD-188-125-1
  - Appendix A Shield Effectiveness (SE)
  - Appendix C Continuous Wave Immersion (CWI)
  - Gather empirical data during the CWI test to quantify coupling mechanisms to the power generating infrastructure
  - The coupled current data obtained will be used to benchmark DTRA's modeling methodologies for applications to more distributed systems
    - The models will provide data for an evaluation of the inherent hardness of as-built PGP facilities to a HEMP threat
    - We measured current at both the field sensor location and at the end point in the control room on short, medium, and long cables. Analysis will be done to correct for the non-uniform CWI on the cables.

Power Generation Plant (PGP) CWI Testing Objectives

- Perform a low-level RF Illumination of a power generation plant from 100 kHz to 1 GHz (stepped)
- Acquire coupled current measurements at both ends of approximately 33 priority circuits in the PGP
- Acquire electric and magnetic field measurements at various locations throughout the PGP
- Measure shielding effectiveness of normal PGP construction at a minimum of 4 locations from 10 kHz to 1 GHz
- Benchmark DTRA modeling efforts with empirically gathered data

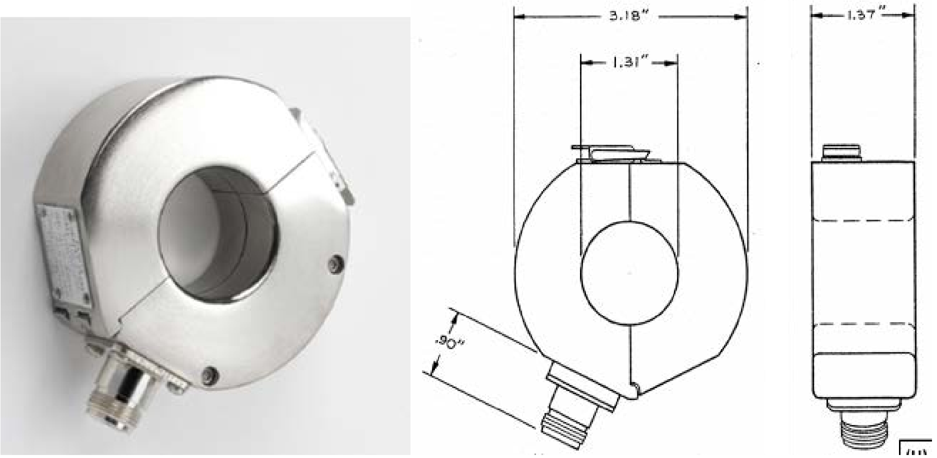
Field Test Equipment: Continuous Wave Immersion (CWI) during Field Mapping

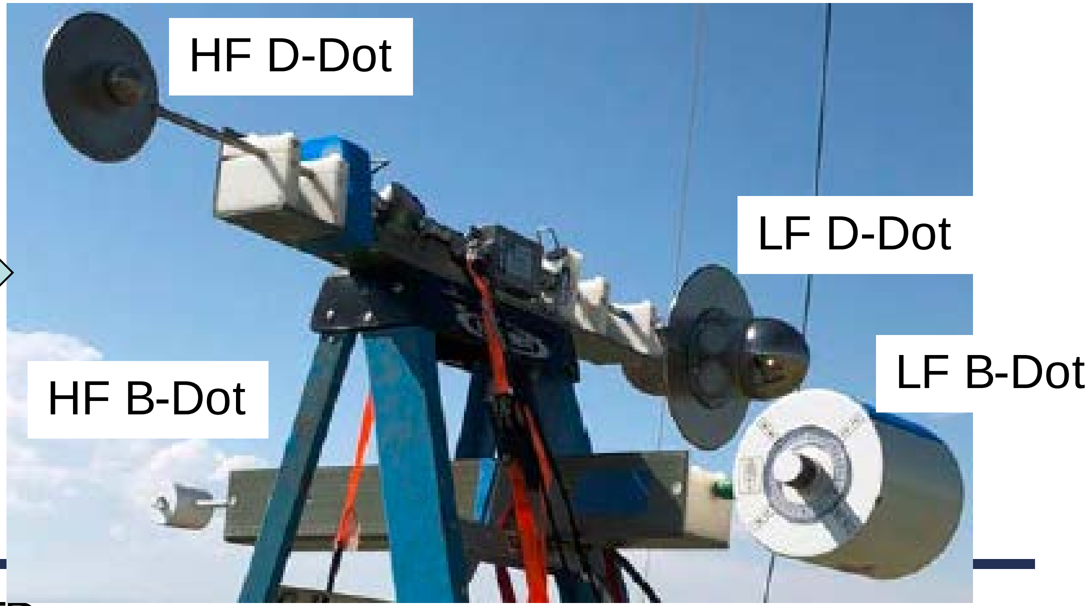




Field Test equipment: Current and EM Field Sensors

- Utilizes several types of sensors for multiple applications
    - Clamp-on Current Transformers (CT) such as Prodyn I-125-1/2HF (Top)
    - Magnetic Field Sensors such as Prodyn LF and HF B-Dot Sensors and Baluns (Bottom)
    - Electric Field Sensors such as Prodyn LF and HF D-Dot Sensors and Baluns (Similar to B-Dot)





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PGP CWI Test Results Status

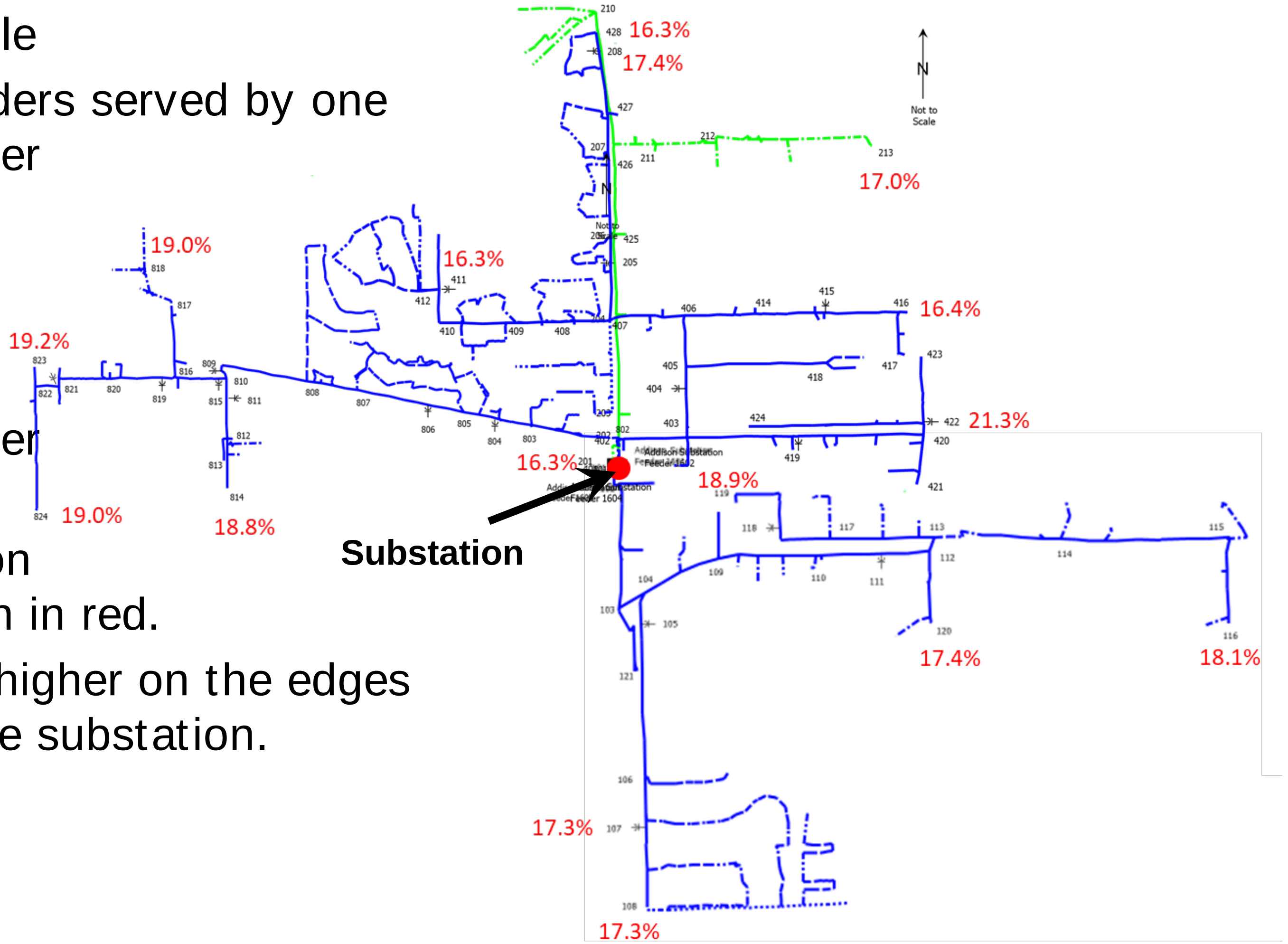
- Testing complete
- Analysis and modeling underway

MHD-E3 Harmonic Threat to the Grid and its Loads from Over-Voltage: Baylor University

- The objective of this research is to investigate the impact of an MHD-E3 “perfect storm” caused by deeply saturated grid transformers resonating with power factor correction capacitors on distribution feeders.
- The phenomenon was first discovered during DTRA’s Albuquerque tests in 2008 and, because the phenomenon is driven by severe saturation which does not occur in practice, the effect is relatively unknown in public literature.
- Distribution feeder capacitors cause feeder circuits to resonate in the 3rd to 13th harmonic (of 60 Hz) range, which is usually not a problem. But as noticed in Albuquerque, large transformers become a large source of low-frequency harmonics as they transition into deep saturation, producing serious harmonic resonance on distribution feeders and customer loads.
- The resonance amplifies the harmonic voltages to create overvoltages on sensitive power electronics equipment such as computers, uninterruptable power supplies, and motor drives.

Dallas Distribution Grid Harmonic Example

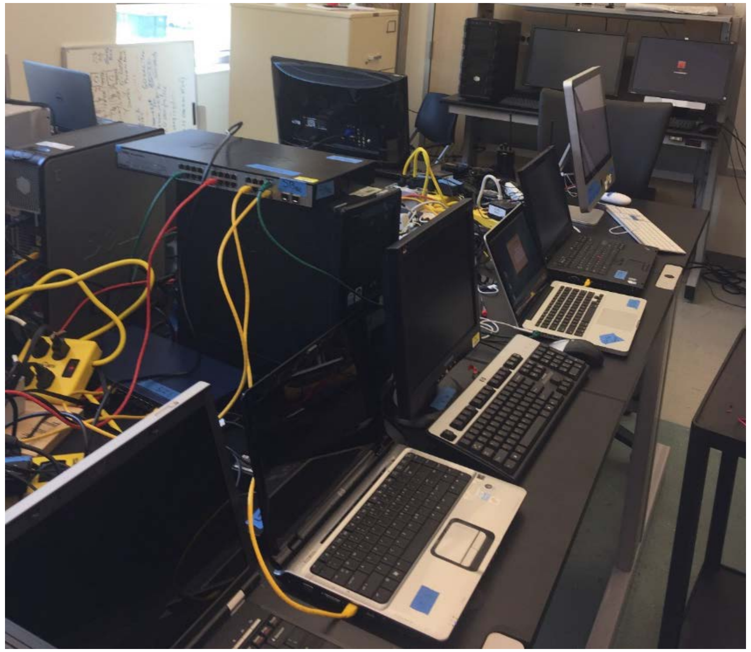
- Dallas suburb example
- Four distribution feeders served by one substation transformer
- Model it in PCFLO, using the INL-WEST distorted voltage on the low-side of the substation transformer
- The calculated THDs across the distribution are the values shown in red.
- Distortion is usually higher on the edges of feeders than at the substation.



Harmonic Effects on COTS Equipment is Underway

- Harmonic waveforms based on DTRA-INL testing
- Programmable harmonic generator will drive test equipment

Harmonic Test Bed



COTS Equipment to Test for Harmonic Effects

Equipment	# to be tested
Computers	12
Routers	6
Ethernet Switches	6
Handheld Radios	7
Cell Phones	11
Satellite Phones	2
Variable Frequency Drive (VFD)	~3
EMP Filters	~3
DCS Protective Relays	3
DCS PGP	4

Summary

- The overall goal of Team DTRA is to provide unclassified empirical data on the EMP vulnerability of critical grid components.
- Get unclassified empirical data to utilities:
  - Inherent toughness (strength) of equipment against HEMP radiated energy and coupled currents (stresses)
  - Shielding effectiveness empirical data of buildings and enclosures
  - Empirical data on HEMP induced currents in control and power cables
- Early results indicate that the HEMP induced currents are the largest vulnerability for control equipment.
- Continue to support the Presidential Executive Order as directed.

Questions?

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LeMay Center for Doctrine

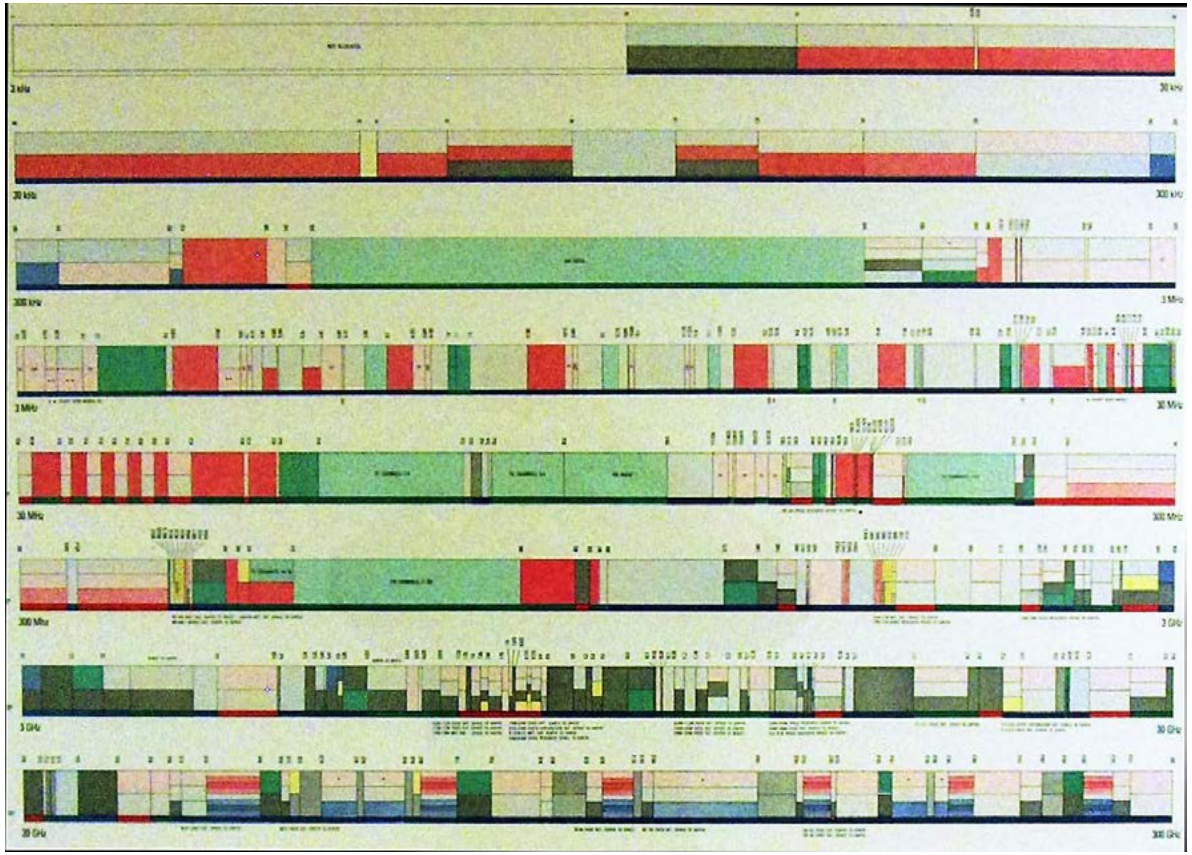
"At the Heart of Warfare Lies Doctrine"

USAF Multi-Domain Operations

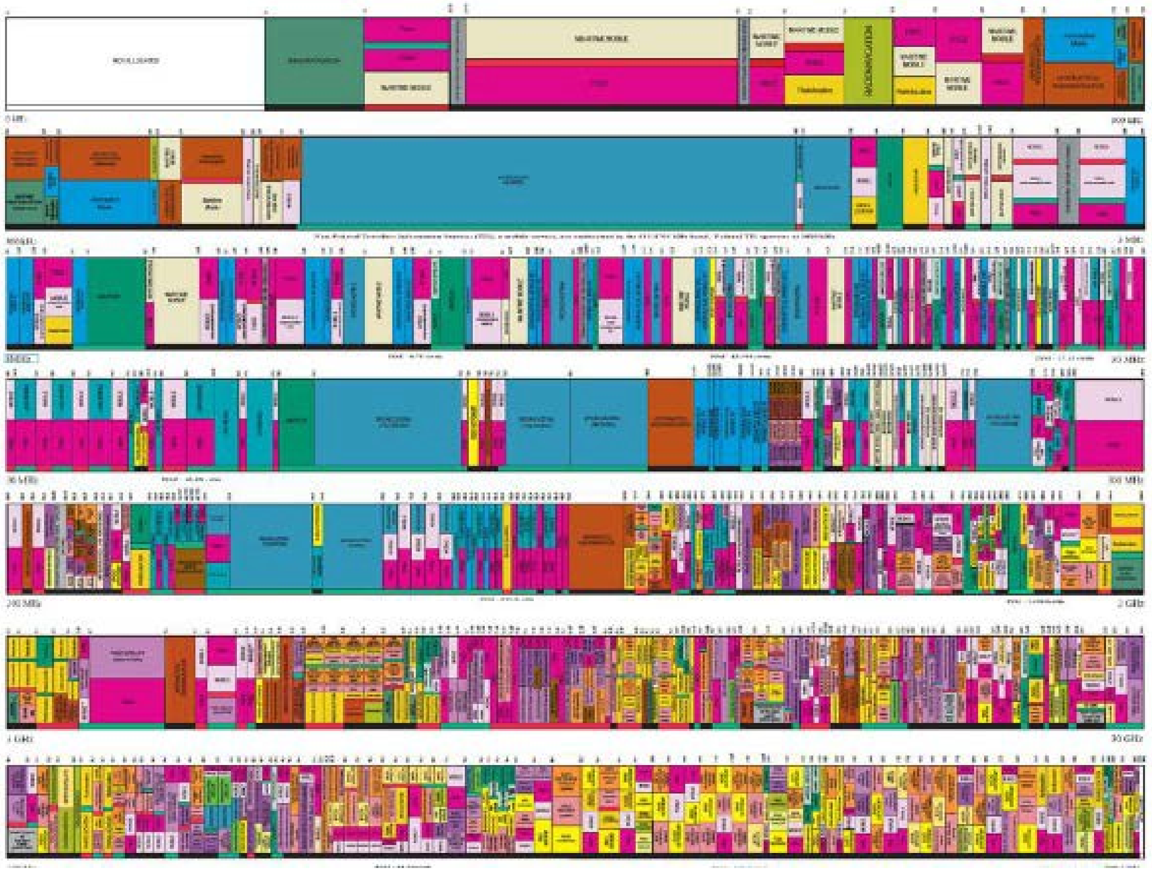
Colonel Doug "Cinco" DeMaio
LeMay Center Vice Commander
25 July 2019

Space & Cyber Added

Competition in the EMS



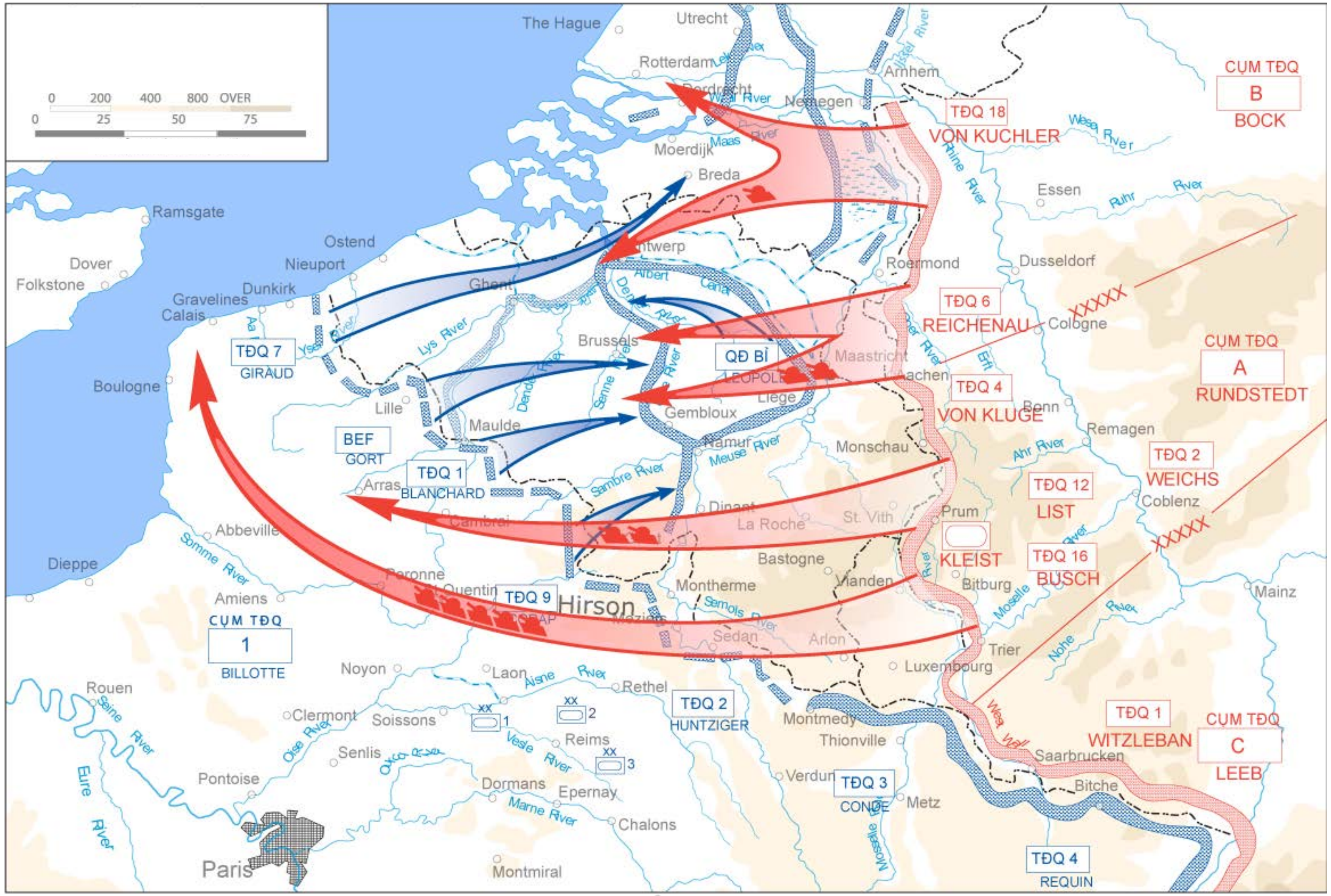
EMS 1970



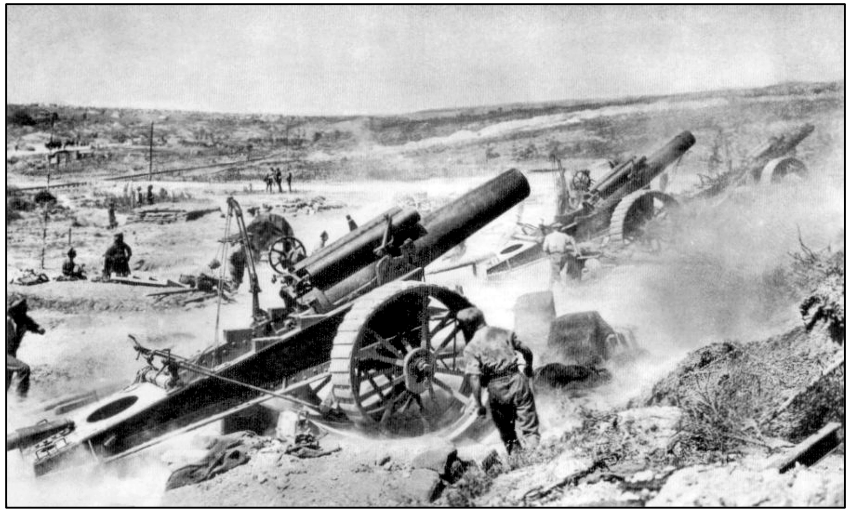
EMS 2016

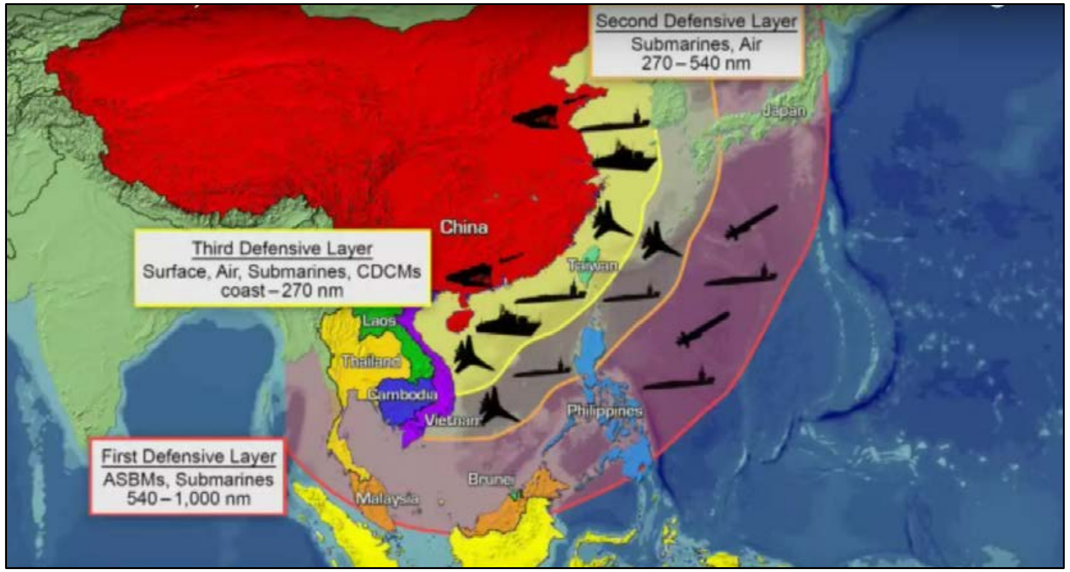
Continued EMS competition and adversary exploitation are a national center of gravity.

Battle of France 1940



Trench Warfare at 70,000 Feet





The New Joint Operations Area

LeMay Center for Doctrine

“At the Heart of Warfare Lies Doctrine”

Questions?

Colonel Doug “Cinco” DeMaio
LeMay Center Vice Commander
25 July 2019

High-Altitude EMP in PowerWorld Simulator

NERC EMP Task Force Workshop

July 25, 2019

Scott Dahman, P.E.

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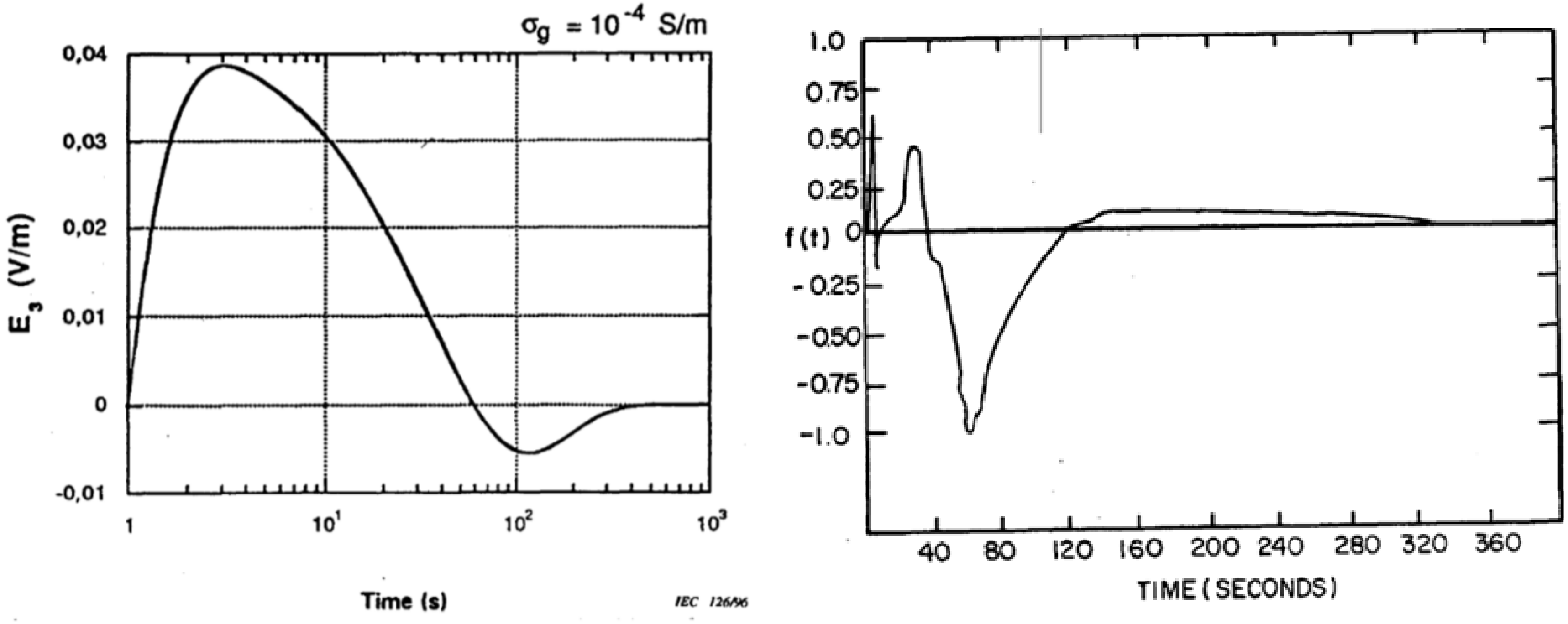
High-Altitude Electromagnetic Pulse (EMP)

- 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

EMP 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 EMP Environment – Radiated Disturbance. Basic EMC Publication,” International Electrotechnical Commission. Feb. 19, 1996.

EMP 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

EMP E3A

- For a uniform earth conductivity model, the E3A Blast wave can be modeled as a fairly uniform east-west electric field; hence it is very similar to a standard GMD

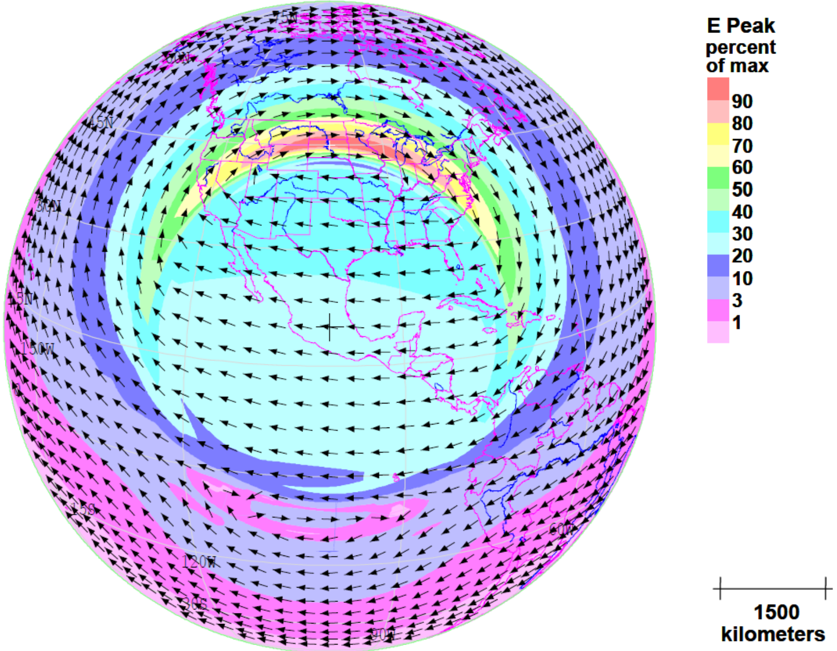


Image Source: Metatech R-321, Figure 2-4

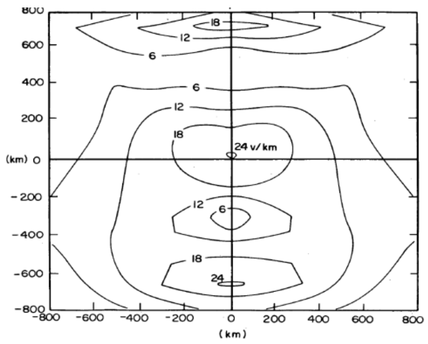
Because of the relatively large, uniform electric field area, the results are somewhat insensitive to location

1985 ORNL Report Time-Varying Model

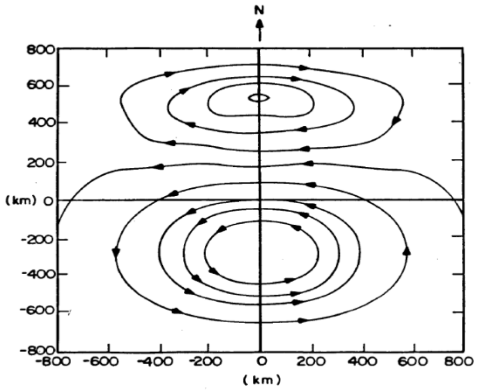
- The 1985 ORNL report models the electric field during the E3B as the product of a spatially independent time function (fig 8), and time independent spatial magnitude and directions (fig 9 and 10)

$$\bar{E}\left(x,\mathrm{y},\mathrm{t}\right)=\varepsilon(x,y)\,\bar{e}(\mathrm{x},\mathrm{y})\;f\,(t)$$

=



X



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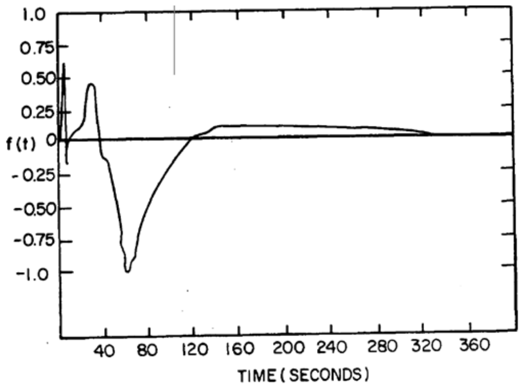


Values were calculated assuming a uniform conductivity of 0.001 S/m

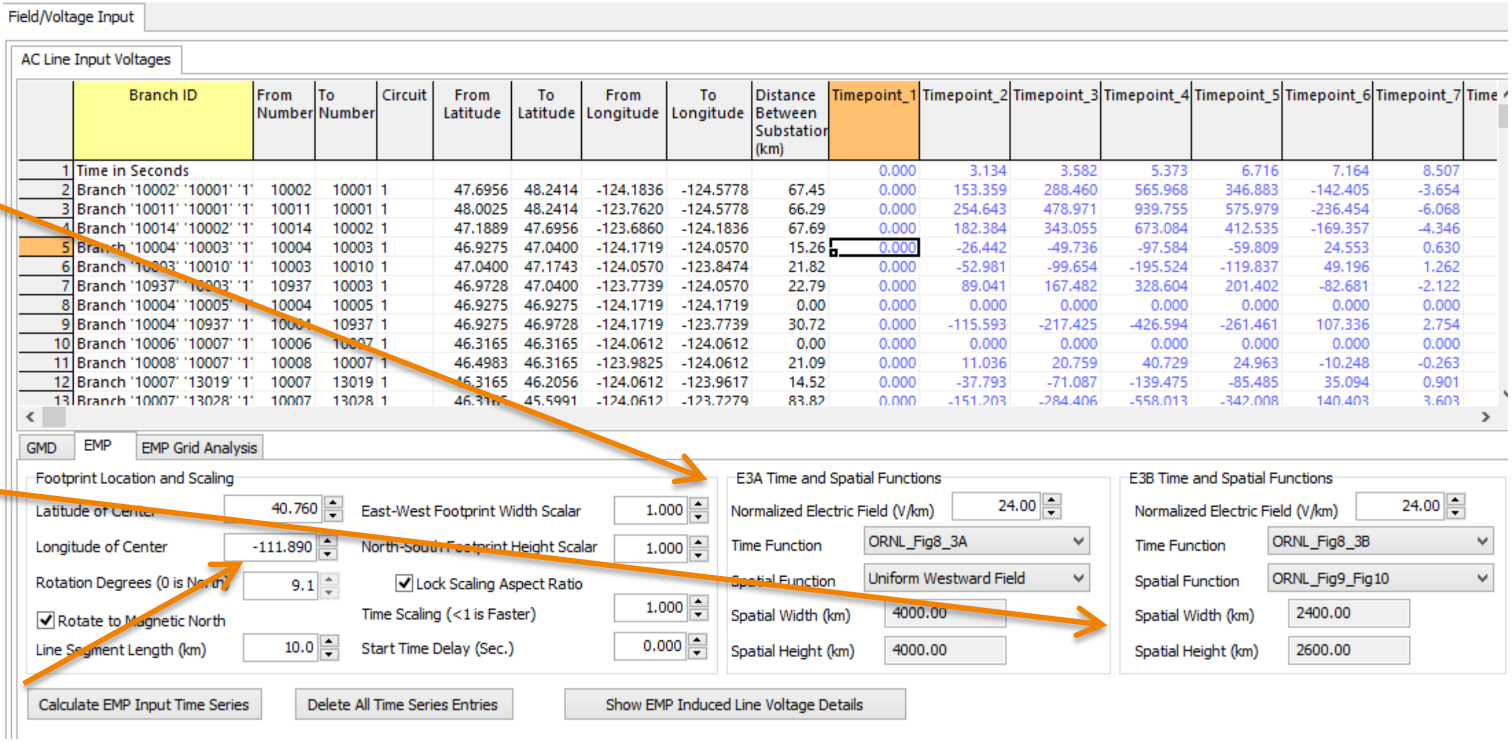
Time and Spatially-Varying Electric Fields

- PowerWorld Simulator can auto-create time-varying electric fields associated with public EMP waveforms (e.g. ORNL, IEC)

E3A Functions and Peak Magnitude

E3B Functions and Peak Magnitude

Target Location



Field/Voltage Input

AC Line Input Voltages

	Branch ID	From Number	To Number	Circuit	From Latitude	To Latitude	From Longitude	To Longitude	Distance Between Substation (km)	Timepoint_1	Timepoint_2	Timepoint_3	Timepoint_4	Timepoint_5	Timepoint_6	Timepoint_7
1	Time in Seconds									0.000	3.134	3.582	5.373	6.716	7.164	8.507
2	Branch '10002' '10001' '1'	10002	10001	1	47.6956	48.2414	-124.1836	-124.5778	67.45	0.000	153.359	288.460	565.968	346.883	-142.405	-3.654
3	Branch '10011' '10001' '1'	10011	10001	1	48.0025	48.2414	-123.7620	-124.5778	66.29	0.000	254.643	478.971	939.755	575.979	-236.454	-6.068
4	Branch '10014' '10002' '1'	10014	10002	1	47.1889	47.6956	-123.6860	-124.1836	67.69	0.000	182.384	343.055	673.084	412.535	-169.357	-4.346
5	Branch '10004' '10003' '1'	10004	10003	1	46.9275	47.0400	-124.1719	-124.0570	15.26	0.000	-26.442	-49.736	-97.584	-59.809	24.553	0.630
6	Branch '10003' '10010' '1'	10003	10010	1	47.0400	47.1743	-124.0570	-123.8474	21.82	0.000	-52.981	-99.654	-195.524	-119.837	49.196	1.262
7	Branch '10937' '10003' '1'	10937	10003	1	46.9728	47.0400	-123.7739	-124.0570	22.79	0.000	89.041	167.482	328.604	201.402	-82.681	-2.122
8	Branch '10004' '10005' '1'	10004	10005	1	46.9275	46.9275	-124.1719	-124.1719	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	Branch '10004' '10937' '1'	10004	10937	1	46.9275	46.9728	-124.1719	-123.7739	30.72	0.000	-115.593	-217.425	-426.594	-261.461	107.336	2.754
10	Branch '10006' '10007' '1'	10006	10007	1	46.3165	46.3165	-124.0612	-124.0612	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	Branch '10008' '10007' '1'	10008	10007	1	46.4983	46.3165	-123.9825	-124.0612	21.09	0.000	11.036	20.759	40.729	24.963	-10.248	-0.263
12	Branch '10007' '13019' '1'	10007	13019	1	46.3165	46.2056	-124.0612	-123.9617	14.52	0.000	-37.793	-71.087	-139.475	-85.485	35.094	0.901
13	Branch '10007' '13028' '1'	10007	13028	1	46.31[illegible]	45.5991	-124.0612	-123.7279	83.82	0.000	-151.203	-284.406	-558.013	-342.008	140.403	3.603

GMD | EMP | EMP Grid Analysis

Footprint Location and Scaling

Latitude of Center: 40.760

Longitude of Center: -111.890

Rotation Degrees (0 is North): 9.1

☑ Rotate to Magnetic North

Line Segment Length (km): 10.0

East-West Footprint Width Scalar: 1.000

North-South Footprint Height Scalar: 1.000

☑ Lock Scaling Aspect Ratio

Time Scaling (<1 is Faster): 1.000

Start Time Delay (Sec.): 0.000

E3A Time and Spatial Functions

Normalized Electric Field (V/km): 24.00

Time Function: ORNL_Fig8_3A

Spatial Function: Uniform Westward Field

Spatial Width (km): 4000.00

Spatial Height (km): 4000.00

E3B Time and Spatial Functions

Normalized Electric Field (V/km): 24.00

Time Function: ORNL_Fig8_3B

Spatial Function: ORNL_Fig9_Fig10

Spatial Width (km): 2400.00

Spatial Height (km): 2600.00

EMP Modeling

- Appropriate power system models depend on the timeframe of the underlying problems

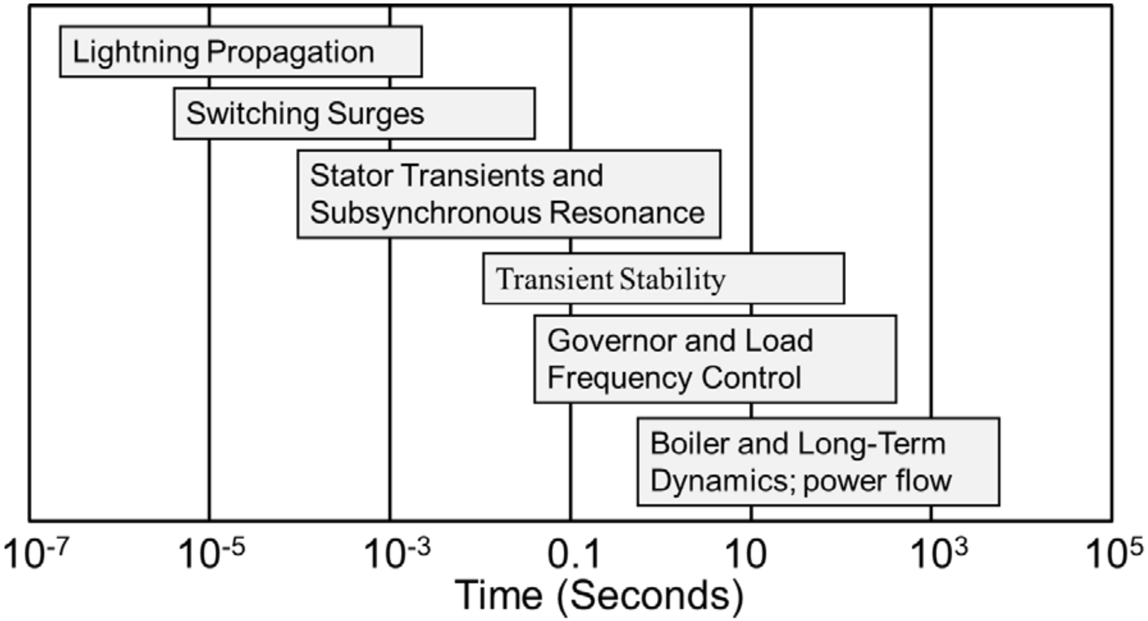


Image: Sauer, P.W., M. A. Pai, *Power System Dynamics and Stability*, Stripes Publishing, 2007

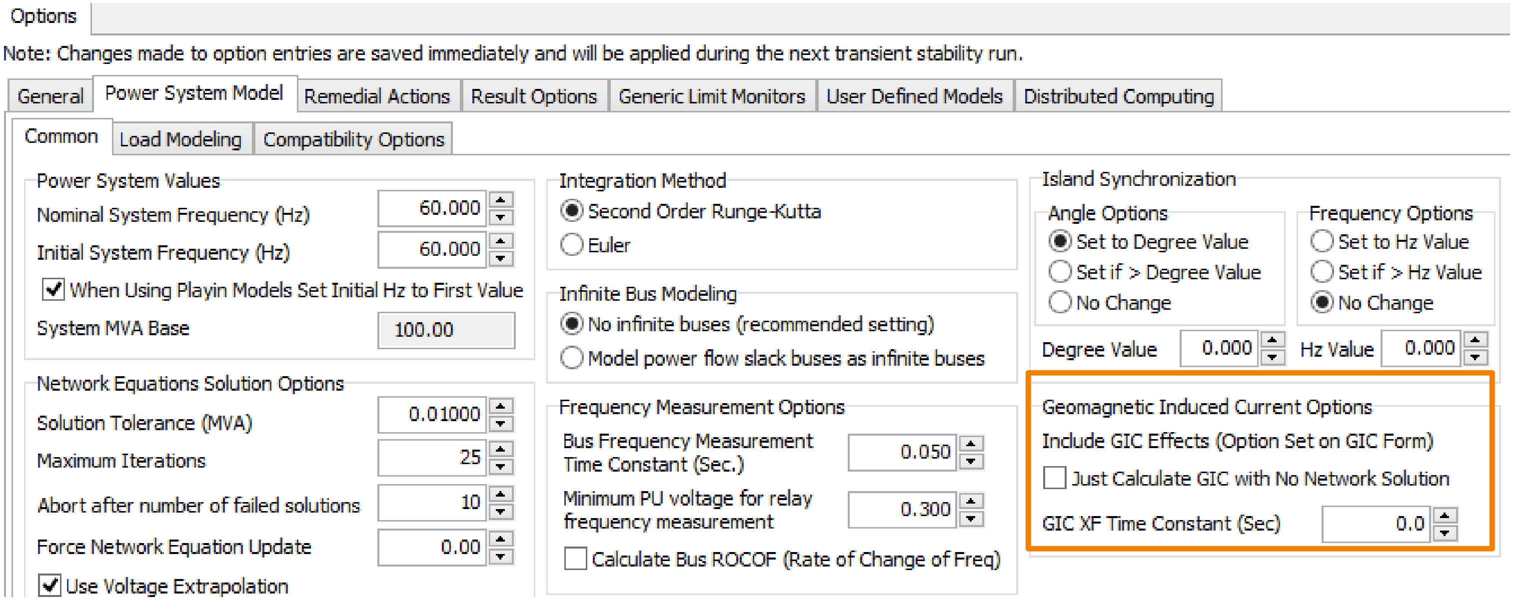
GMDs caused by solar corona mass ejections (CMEs) mostly fall in the power flow timeframe; EMP-induced GMDs move towards transient stability

EMP Modeling

- EMP 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, relays, generator exciters, excitation limiters, and other characteristics not modeled in power flow
- Detailed modeling of relaying and limiters over 10s to 100s of seconds would be useful
  - e.g. generator over-excitation limiters, low/high voltage/frequency ride through
  - Common transient stability models in use are incomplete in these time scales

Integration with Transient Stability

- Transient Stability interface may be used to calculate GIC time series and store large quantities of results with OR without dynamic network solution



Note: Changes made to option entries are saved immediately and will be applied during the next transient stability run.

Power System Values

Nominal System Frequency (Hz) 60.000

Initial System Frequency (Hz) 60.000

☑ When Using Playin Models Set Initial Hz to First Value

System MVA Base 100.00

Network Equations Solution Options

Solution Tolerance (MVA) 0.01000

Maximum Iterations 25

Abort after number of failed solutions 10

Force Network Equation Update 0.00

☑ Use Voltage Extrapolation

Integration Method

● Second Order Runge-Kutta

○ Euler

Infinite Bus Modeling

● No infinite buses (recommended setting)

○ Model power flow slack buses as infinite buses

Frequency Measurement Options

Bus Frequency Measurement Time Constant (Sec.) 0.050

Minimum PU voltage for relay frequency measurement 0.300

☐ Calculate Bus ROCOF (Rate of Change of Freq)

Island Synchronization

Angle Options

● Set to Degree Value

○ Set if > Degree Value

○ No Change

Frequency Options

○ Set to Hz Value

○ Set if > Hz Value

● No Change

Degree Value 0.000

Hz Value 0.000

Geomagnetic Induced Current Options

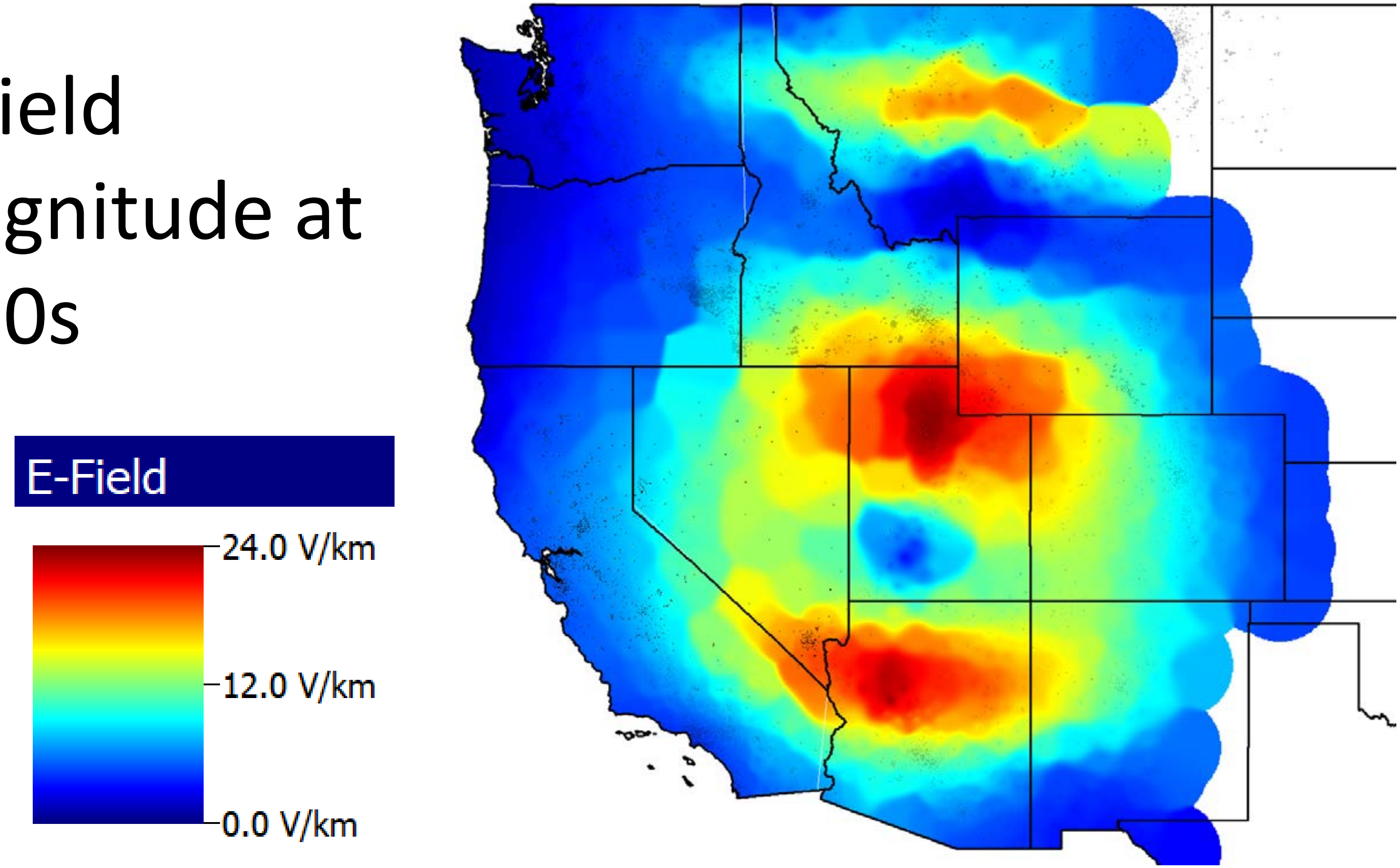
Include GIC Effects (Option Set on GIC Form)

☐ Just Calculate GIC with No Network Solution

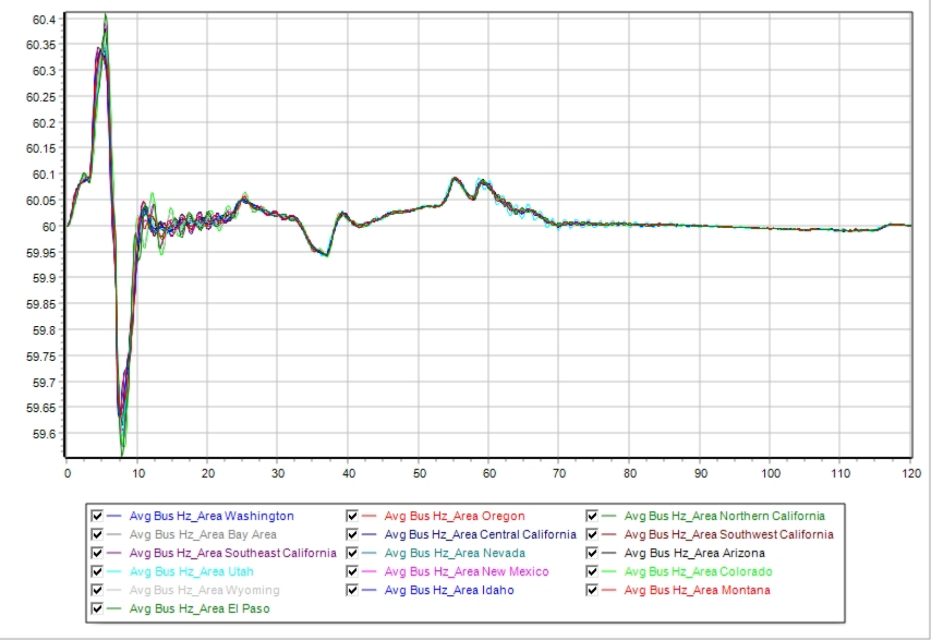
GIC XF Time Constant (Sec) 0.0

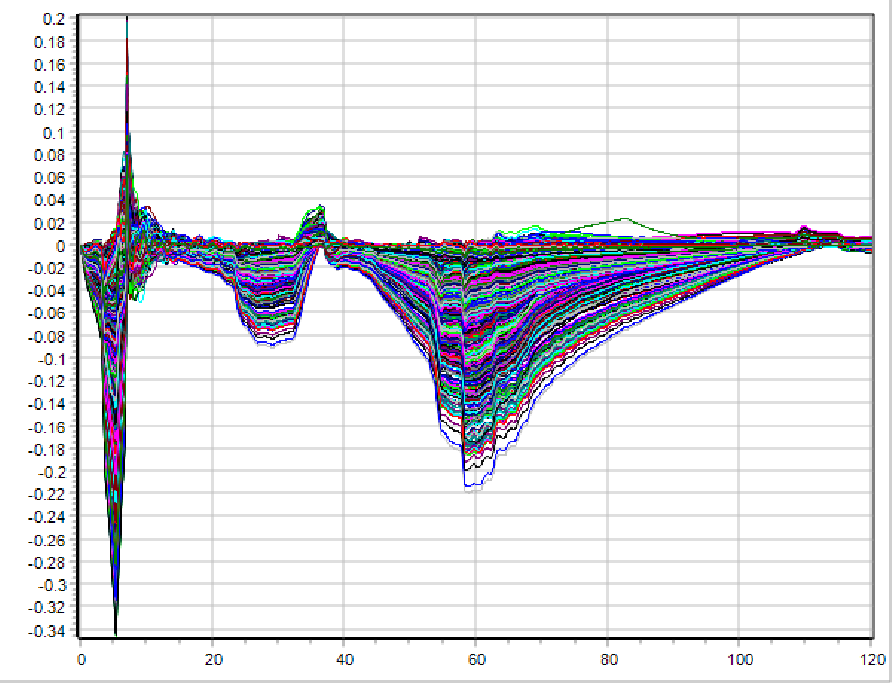
ORNL E3B Example

E-Field Magnitude at t=60s



Transient Stability Plots



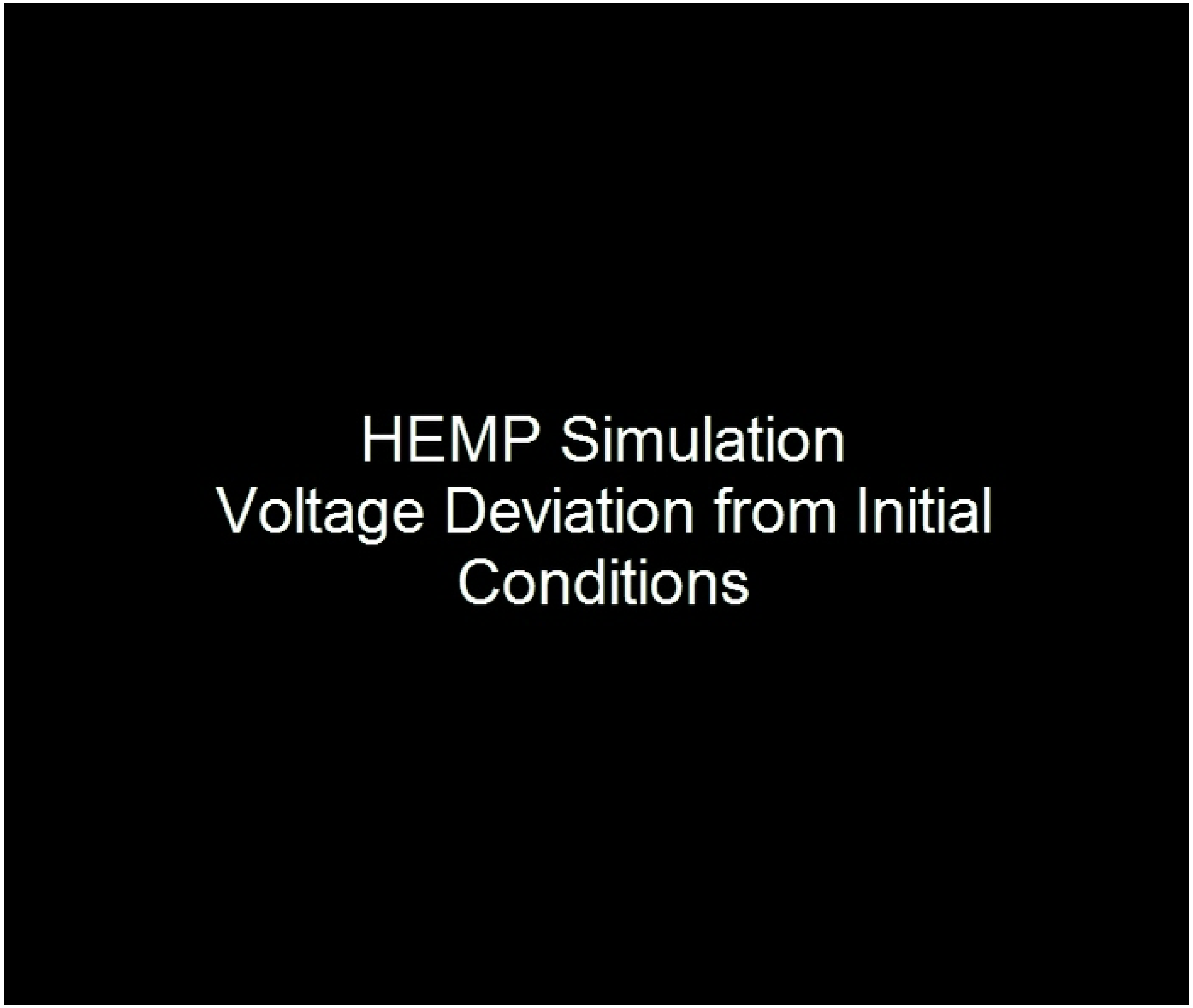


Frequency:
Average by Area

Bus Voltage: deviation
from initial value

Transient Stability:

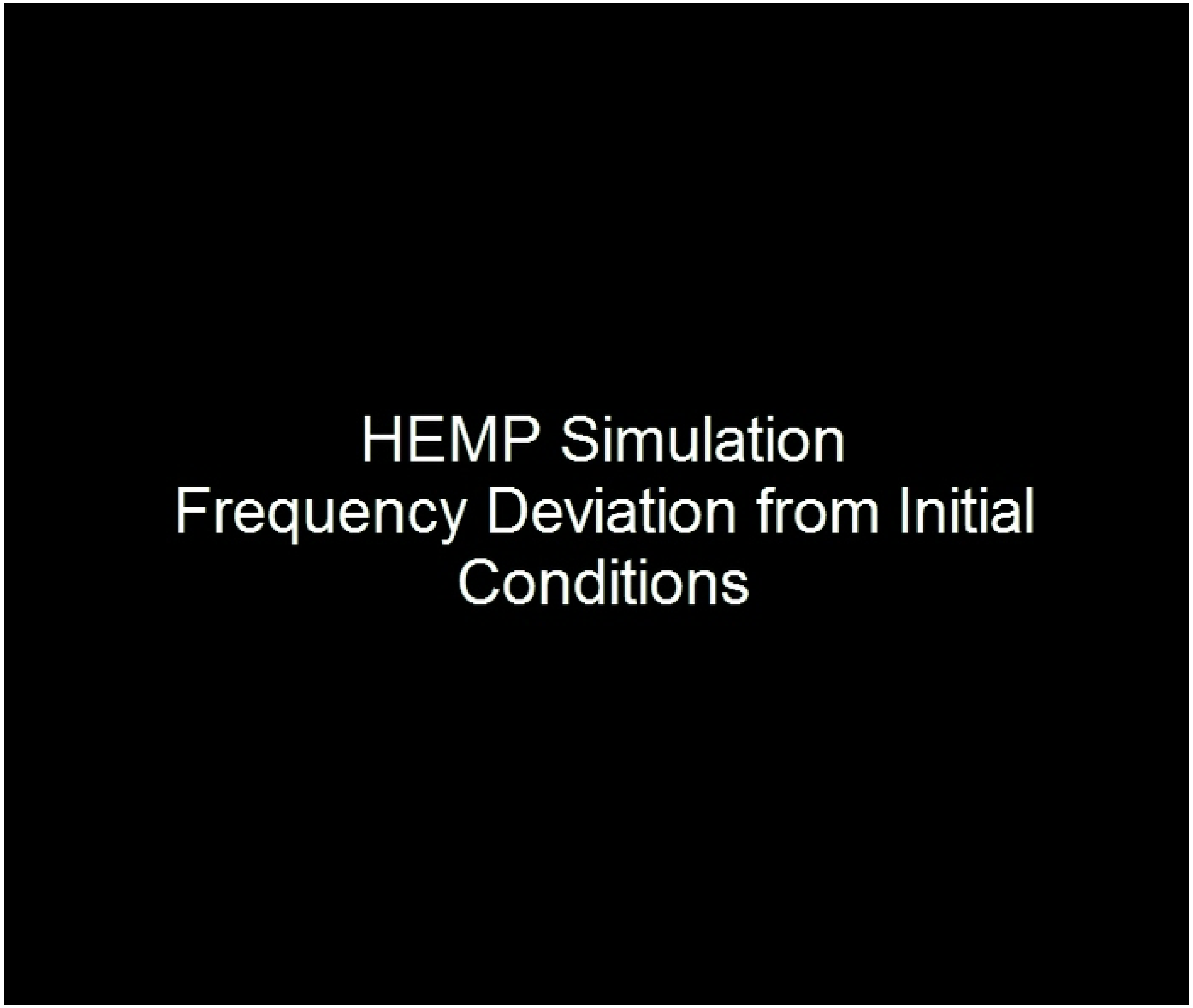
Voltage Visualization



HEMP Simulation
Voltage Deviation from Initial Conditions

Transient Stability:

Frequency Visualization



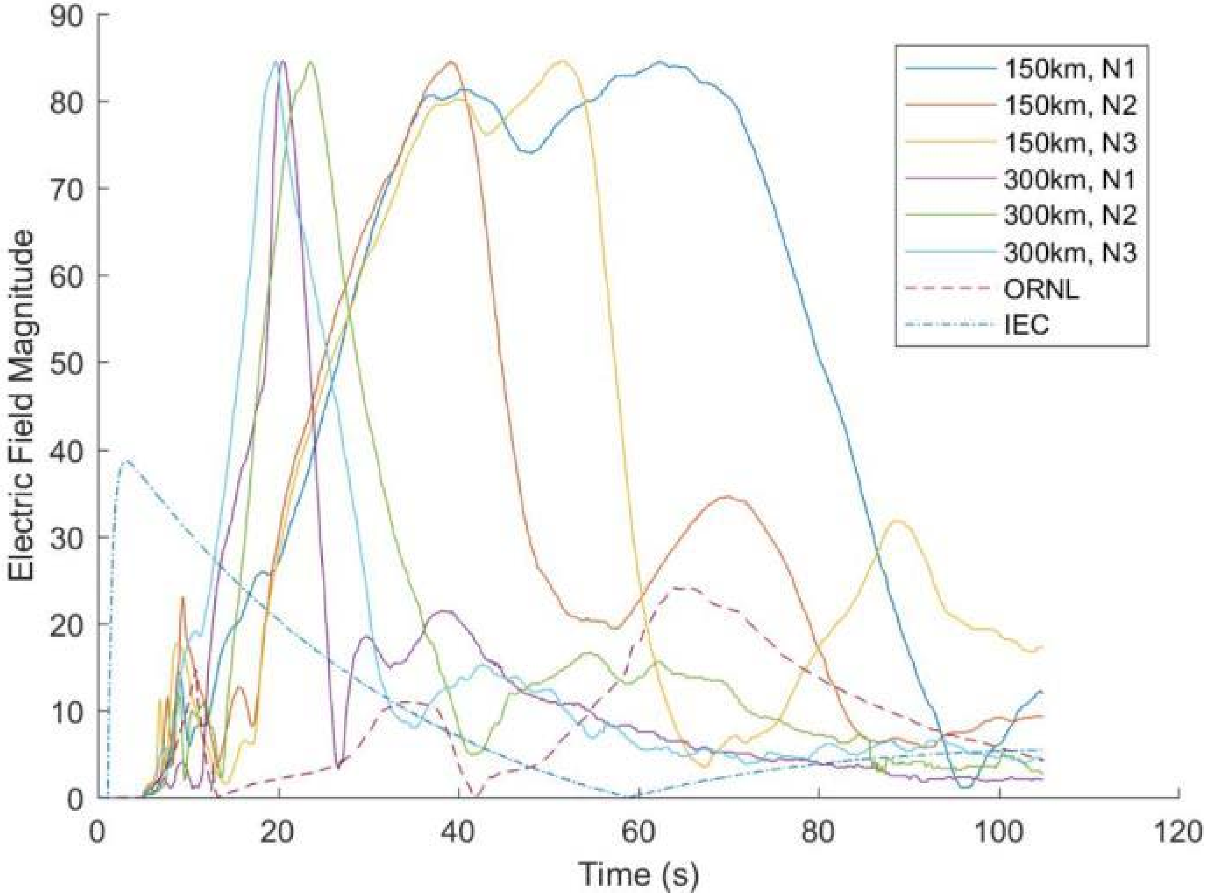
HEMP Simulation
Frequency Deviation from Initial Conditions

Future Direction

- Report of the “Commission to Assess the Threat to the United States from EMP Attack” (EMP Commission) was released to public in 2018
- “A realistic unclassified peak level for E3 EMP would be 85 V/km for CONUS as described in this report”

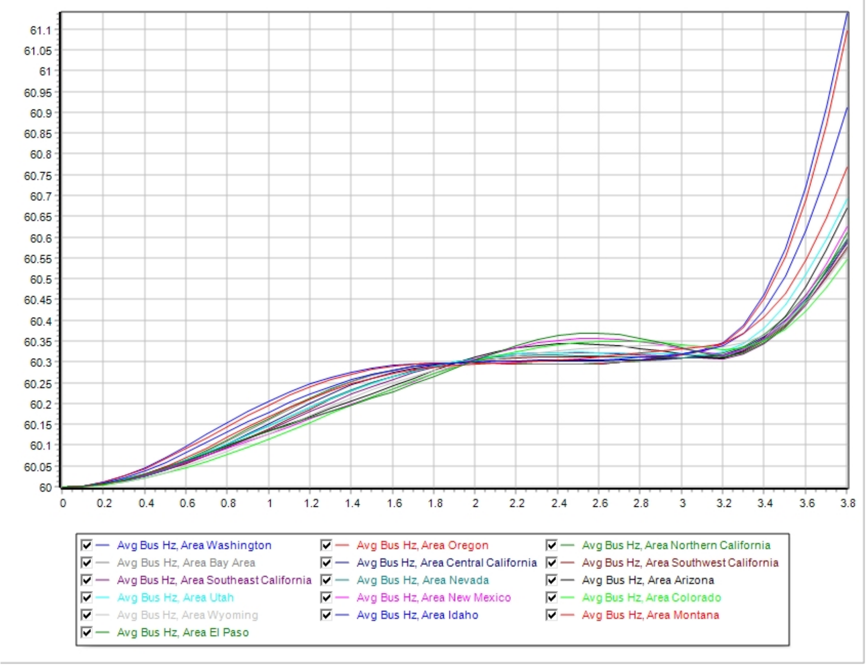
EMP Waveform Comparison

- 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 EMP Electric Field Waveforms on a Synthetic Grid”, submitted to *North American Power Symposium*, 2018.

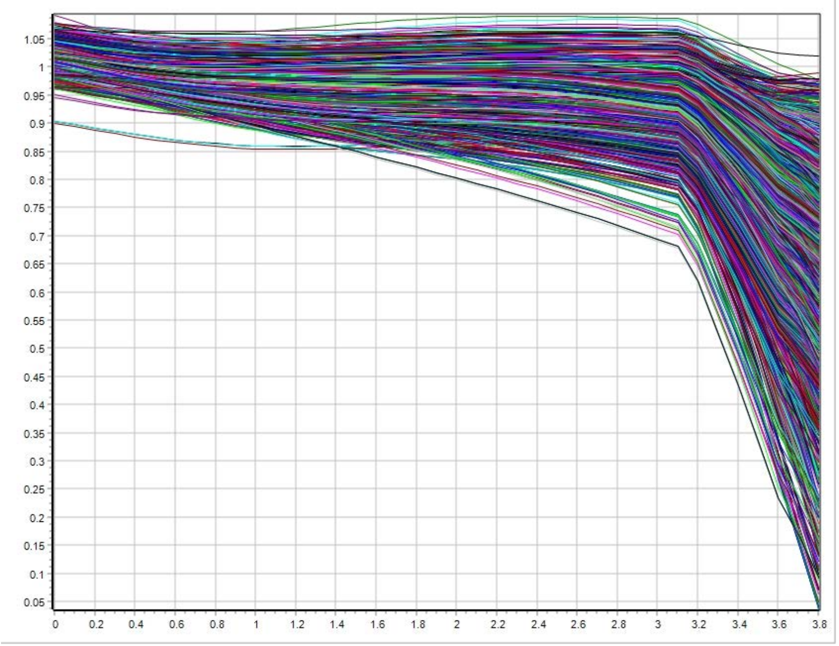


Transient Stability Plots:

ORNL with 85 V/km Peak



Frequency:
Average by Area



Bus Voltage:
Collapse at t=3.9s!

Conclusions

- EMP E3 threats are severe in magnitude, rise time, and geographic breadth
- Initial modeling strongly suggests that interconnected grid would be vulnerable to wide-area collapse from an attack from a modern weapon without remedial actions
- Loss of some load due to E1 could impact the system's E3 response as well

HEMP Vulnerability Assessment and Modeling Tools

Knowledge Gaps Discussion

Rey Ramos, Southern Company Services
EMP Task Force Technical Workshop
July 25, 2019

RELIABILITY | ACCOUNTABILITY

Discussion Objectives

- Provide an opportunity for industry, and government partners, to participate in the conversation
- Discuss how the industry might approach the task of performing a HEMP Vulnerability Assessment
    1. **Identify** issues, modeling requirements, information gaps
    2. **Inform** future conversations and efforts (Phase 2 and Phase 3)
- Obtain feedback and recommendations for the EMP Task Force

Emphasis on:

Phase 1

- Strategic Recommendations

Strategic Recommendations (Phase 1)

***** DRAFT – Your input is needed *****

Recommendation 1

- Provide Direction for Computing HEMP-Induced Surges in the BPS

Recommendation 2

- Provide Direction for Assessing HEMP Impacts on the BPS

Recommendation 3

- Develop Tools for Industry Planners to Assess EMP Mitigation Strategies

Recommendation 4

- Develop HEMP Environment(s) to be Used in HEMP Assessments

Recommendation 5

- Develop Educational Material

Strategic Recommendations (Continued)

*** DRAFT – Your input is needed ***

1) **Provide direction to the industry on how to compute HEMP-induced surges in the BPS**
Objective: provide technical (and practical) tools for computing voltages and currents that result from coupling plane wave into infrastructure. These could include theoretical background, modeling methodology, data considerations, necessary assumptions, limitations.

2) **Provide direction to the industry on how to assess HEMP impacts on the BPS**
Objective: provide practical information (e.g., technical references, guides) to the industry on how to assess HEMP impacts on the BPS.

3) **Develop tools for industry planners to assess and develop EMP mitigation strategies**
Objective: support development of practical equipment vulnerability assessment tools (open source software modeling tools), and methods to enhance industry response to HEMP threats.

4) **Develop suite of HEMP environment(s) to be used in HEMP vulnerability assessments**
Objective: support development of HEMP environments "benchmark event(s)" needed to inform HEMP vulnerability assessments. Note: **DHS** is currently working on developing catalog of EMP waveforms, and working on downgrading classification so that is usable by industry – March 2020.

5) **Develop Educational Material**
Objective: provide list of references to the industry, conduct training and public webinars, facilitate venue to exchange ideas and collaboration between researchers and industry.

Questions and Answers

OVERVIEW OF EMP MITIGATION

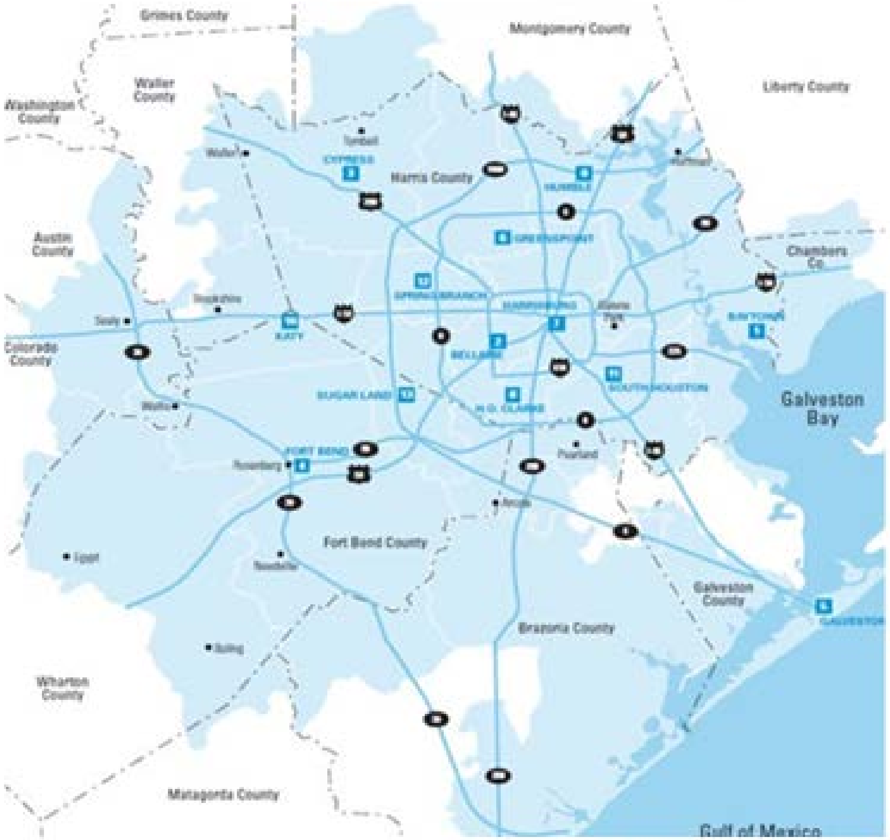
OVERVIEW

- Background
- Regulatory Activity
- Maturity Model
- Control Center
- Control House
- Installation and Application
- Challenges to Mitigation
- EMP Module
- System Operation

BACKGROUND

- 2+ Million Customers
- 230+ Substations (Transmission & Distribution)
- Serves 5,000 square miles that includes Houston

CNP Service Area Map

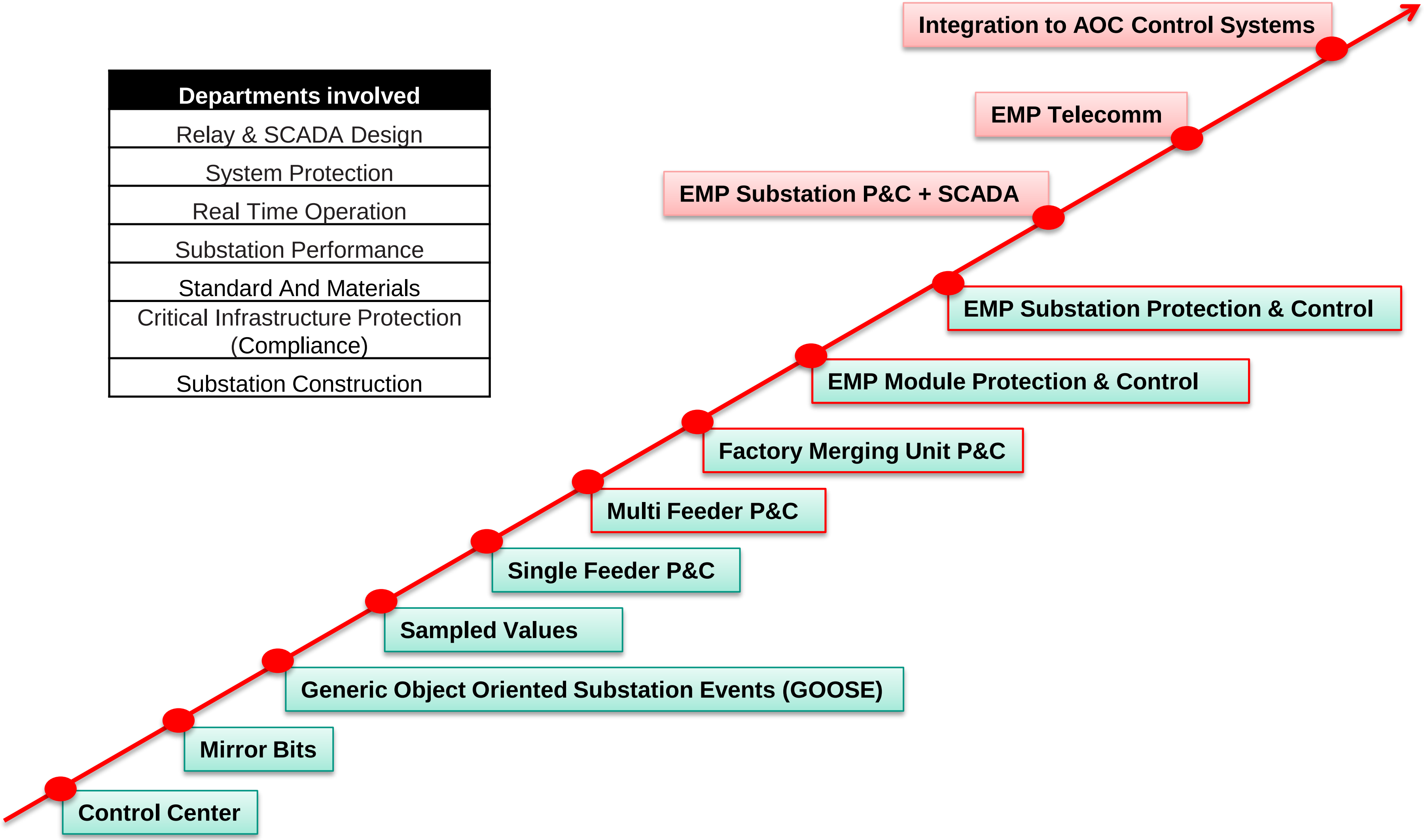


REGULATORY ACTIVITY

- 2010 CenterPoint started to investigate EMP resiliency to its system.
- 2011 FERC Order issued approving Standard EOP-008-1
- 2012 CenterPoint built an EMP hardened backup control center.
- 2015 CenterPoint & other utilities were called to testify in the Texas Legislature regarding EMP.
- 2016 CenterPoint began designing a substation solution.
- 2017 EMP related bills proposed in Texas Legislature
- 2019 EMP related bills proposed in Texas Legislature
- 2019 Executive Order pertaining to EMP Resiliency

MATURITY MODEL

Departments involved
Relay & SCADA Design
System Protection
Real Time Operation
Substation Performance
Standard And Materials
Critical Infrastructure Protection (Compliance)
Substation Construction



CNP BACKUP CONTROL CENTER

- On April 2011 FERC Order issued approving **Standard EOP-008-1**

- New CNP Backup Control Center Built in 2015

- Meets Military EMP standard (**MIL-STD-188-125**)
    - **Facility Shield**
    - **Shielded Points of Entry** (POEs)
    - Minimum Attenuation is **80 dB** across wide frequency range
    - **Tested on an annual basis**
    - **43,300 sq. ft**. EMP shielded area

CNP BACKUP CONTROL CENTER

EMP CONTROL CUBICLE BASED DESIGN

Multi-departmental effort to develop EMP hardened Substation which resulted in a **Multi-hazard conceptual design**:

EMP – Hardened Control Cubicle (House) design

Additional mitigations:

- Wind
- Flooding
- Ballistics
- Fire

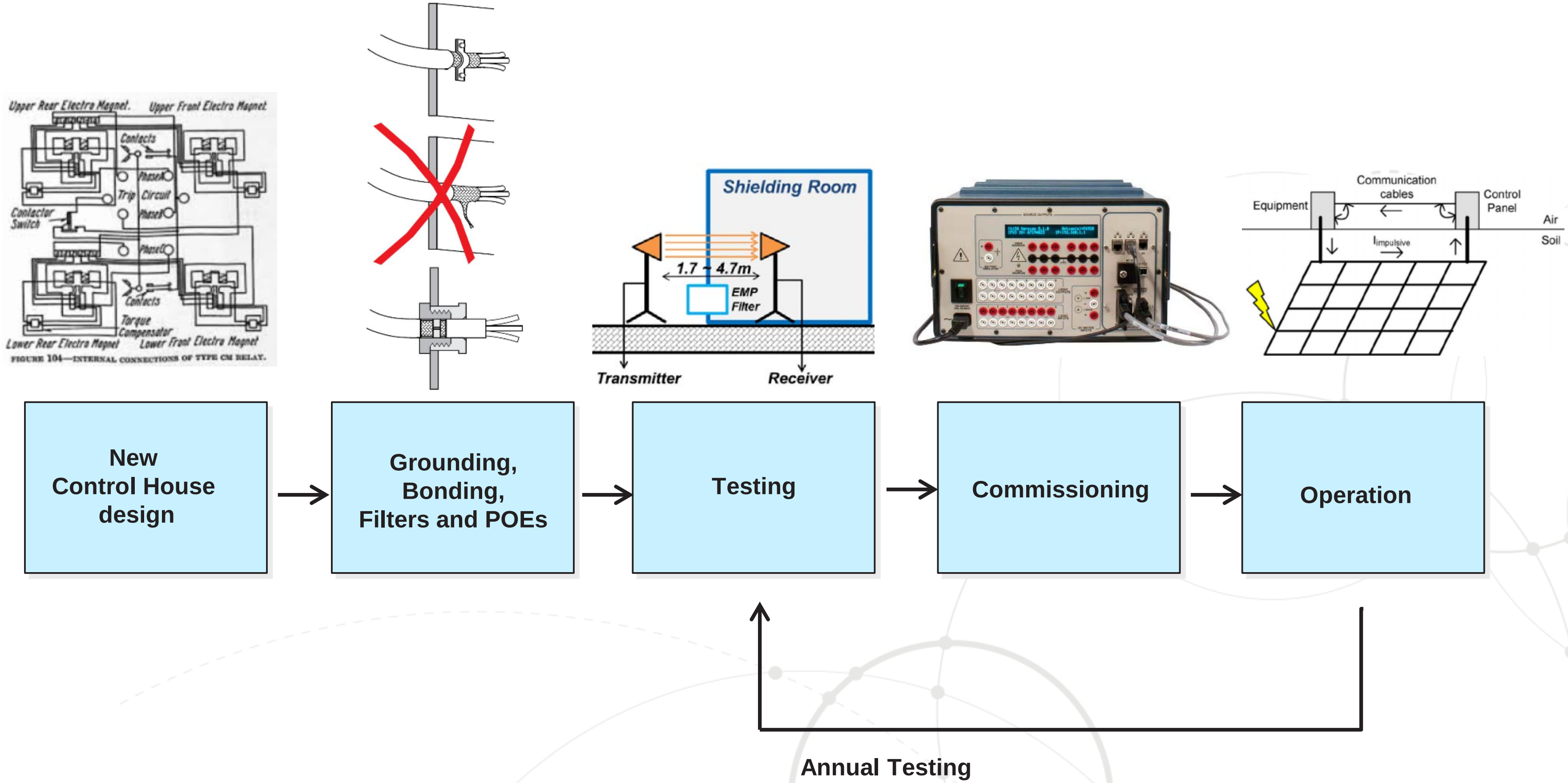
POTENTIAL SUBSTATION SOLUTIONS

Metallic Enclosure

Conductive Concrete

Shielded Cables

CONTROL HOUSE LIFE CYCLE



New Control House design → Grounding, Bonding, Filters and POEs → Testing → Commissioning → Operation

Annual Testing

CHALLENGES TO EM MITIGATION

- Additional Property required for new control houses
- Increased construction outages
- New skills for High-frequency Grounding/Maintenance
- Increased in construction time and cost per control house
- Potential protective relay operational challenges
- Shielded control house maintenance cost

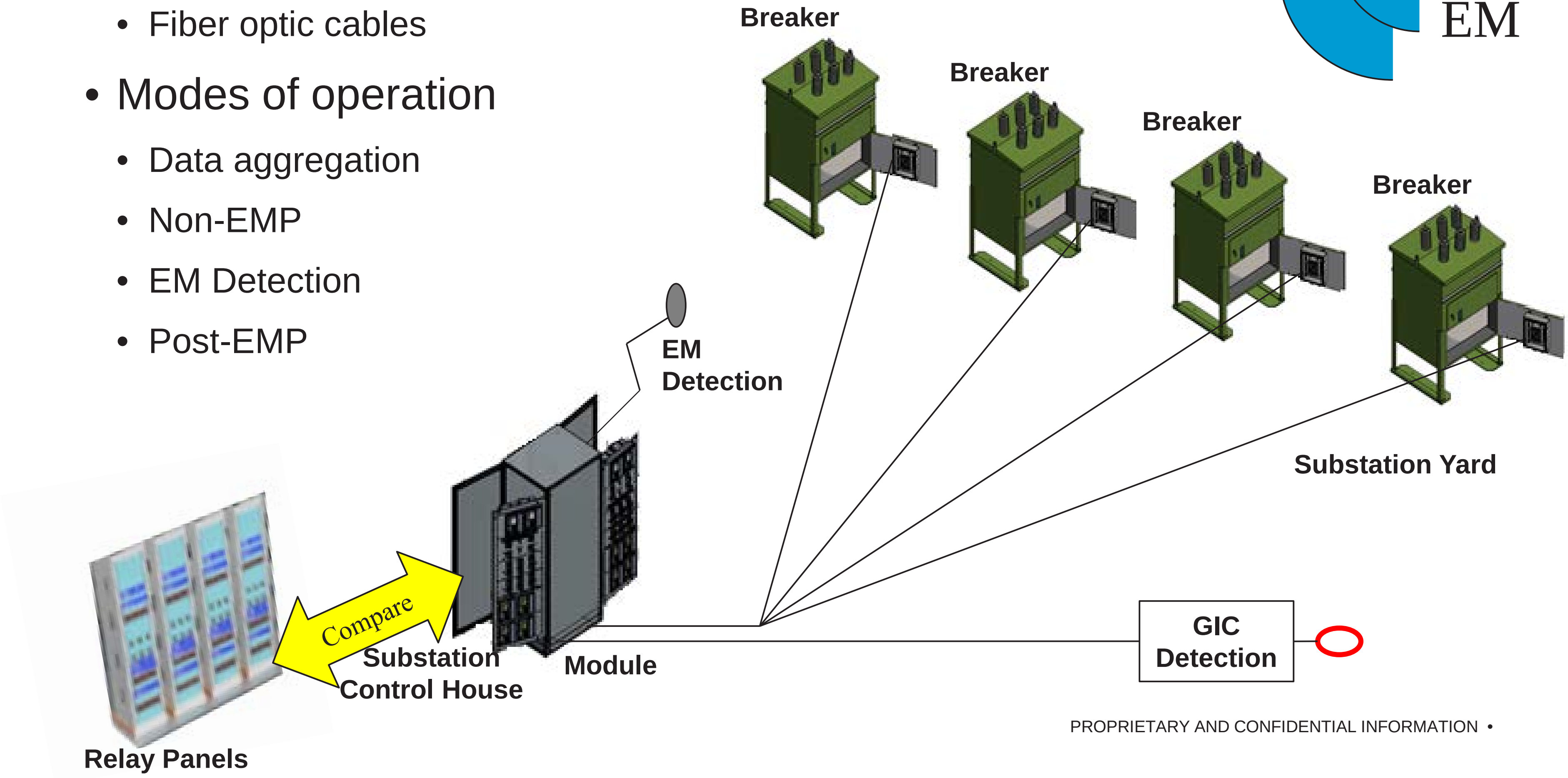
IEC 61850 PROOF OF CONCEPT

Single and Multi Feeder

Factory Merging Unit

INSTALLATION AND APPLICATION

- Mitigation System Construction
  - Merging Units
  - Module
  - Fiber optic cables
- Modes of operation
  - Data aggregation
  - Non-EMP
  - EM Detection
  - Post-EMP



EMP/IEMI/ ELECTRONIC ATTACK (EA) DETECTION SYSTEM

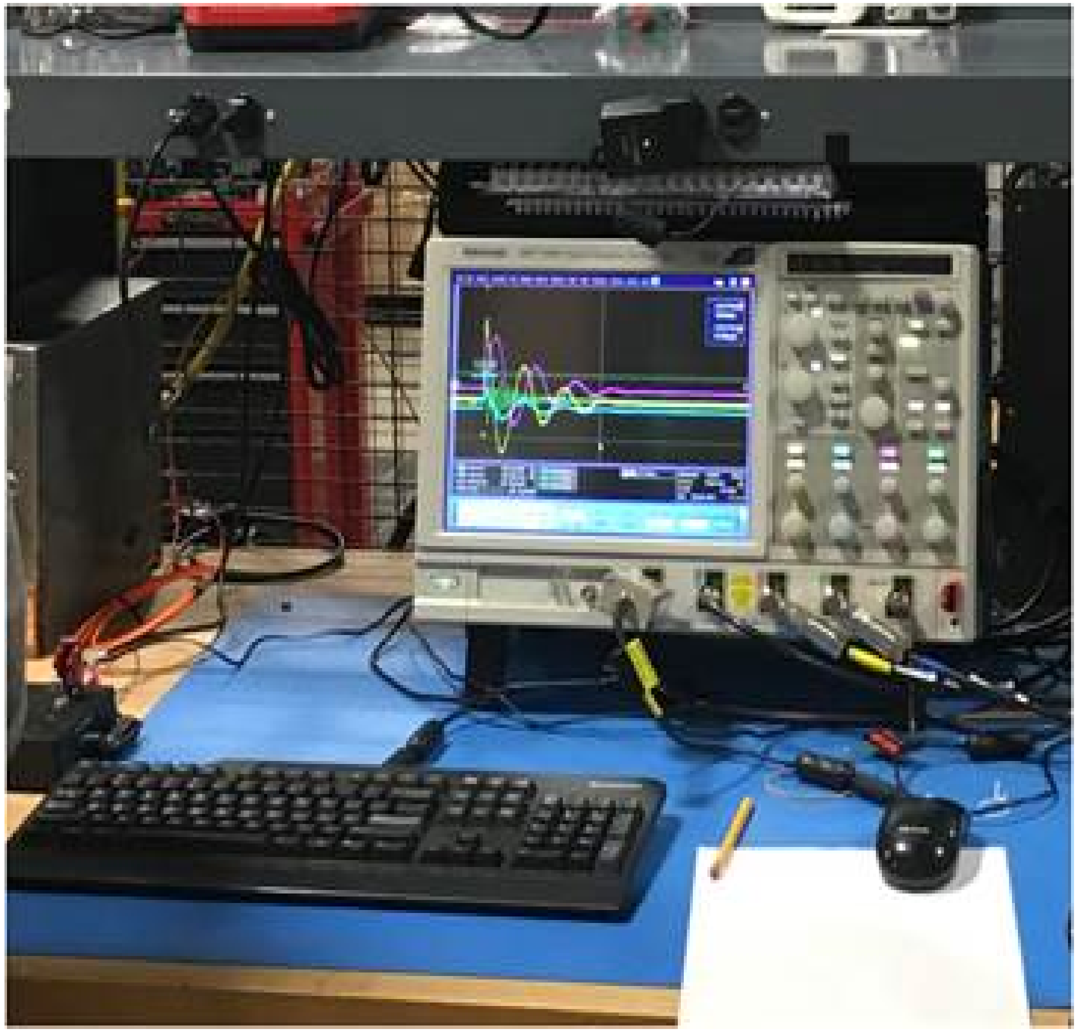
- CE marked and FCC Compliant
- Provides Peak IEMI and instantaneous Average IEMI detection / discrimination
    - 30 MHz to 6 GHz instantaneous IEMI detection bandwidth
- Incorporates an IEMI hardened Event Logger
    - Stores time, date and IEMI event threshold data in non-volatile removable flash memory
- Remote control and data download available via:
    - Re-configurable fiber optic interface - Serial Tx only for IEC 61850/NERC CIP/ISO 27001 compliance and/or IP addressable for less sensitive applications
- 24/7 Operation & reporting by managed service (if required)

MODULE FABRICATION

- Enclosure fabricated with EMP mitigations
- IEEE 299 Shielding effectiveness testing
- Relay and SCADA equipment tested for noise emissions
- Thermal modeling based on expected conditions

TESTING – DIRECT INJECTION

- Unclassified E1 pulse
- 80kV direct injection
- Common mode
- Differential mode



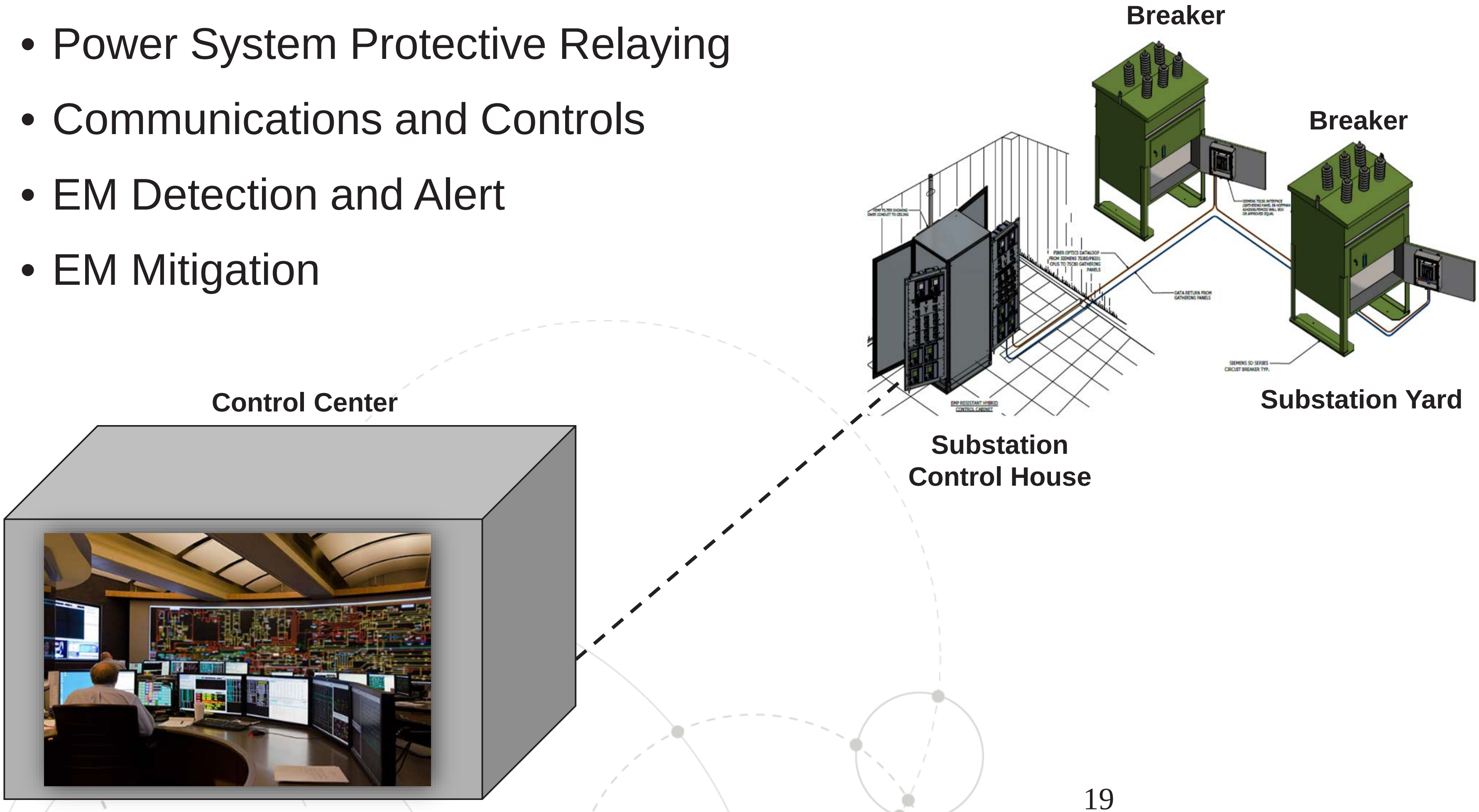
TESTING – FIELD ILLUMINATION

SUBSTATION INSTALLATION

- Capability to protect and control entire substation (4 trf/16 feeders)
- Initially 1 trf/4 feeders
- Placed inside existing substation
- Installation time of approximately 7 days.
- Revisions to design to eliminate outages for installation

SYSTEM OPERATION

- Power System Protective Relaying
- Communications and Controls
- EM Detection and Alert
- EM Mitigation



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THANK YOU!

AMERICAN TRANSMISSION COMPANY®

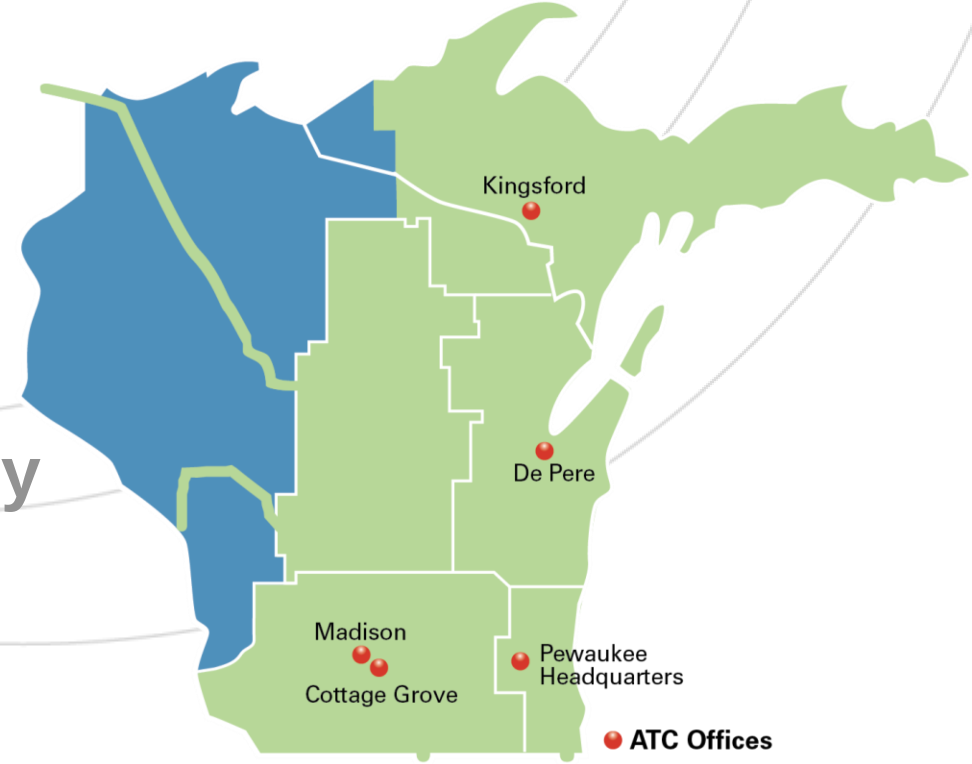
Helping to keep the lights on,
businesses running
and communities strong®

High Altitude Electromagnetic Pulse (HEMP) Preliminary Risk Analysis

July 2019

Introducing American Transmission Co.

- **Began in 2001**
- **First multi-state, transmission only utility in U.S.**



Introducing American Transmission Co.

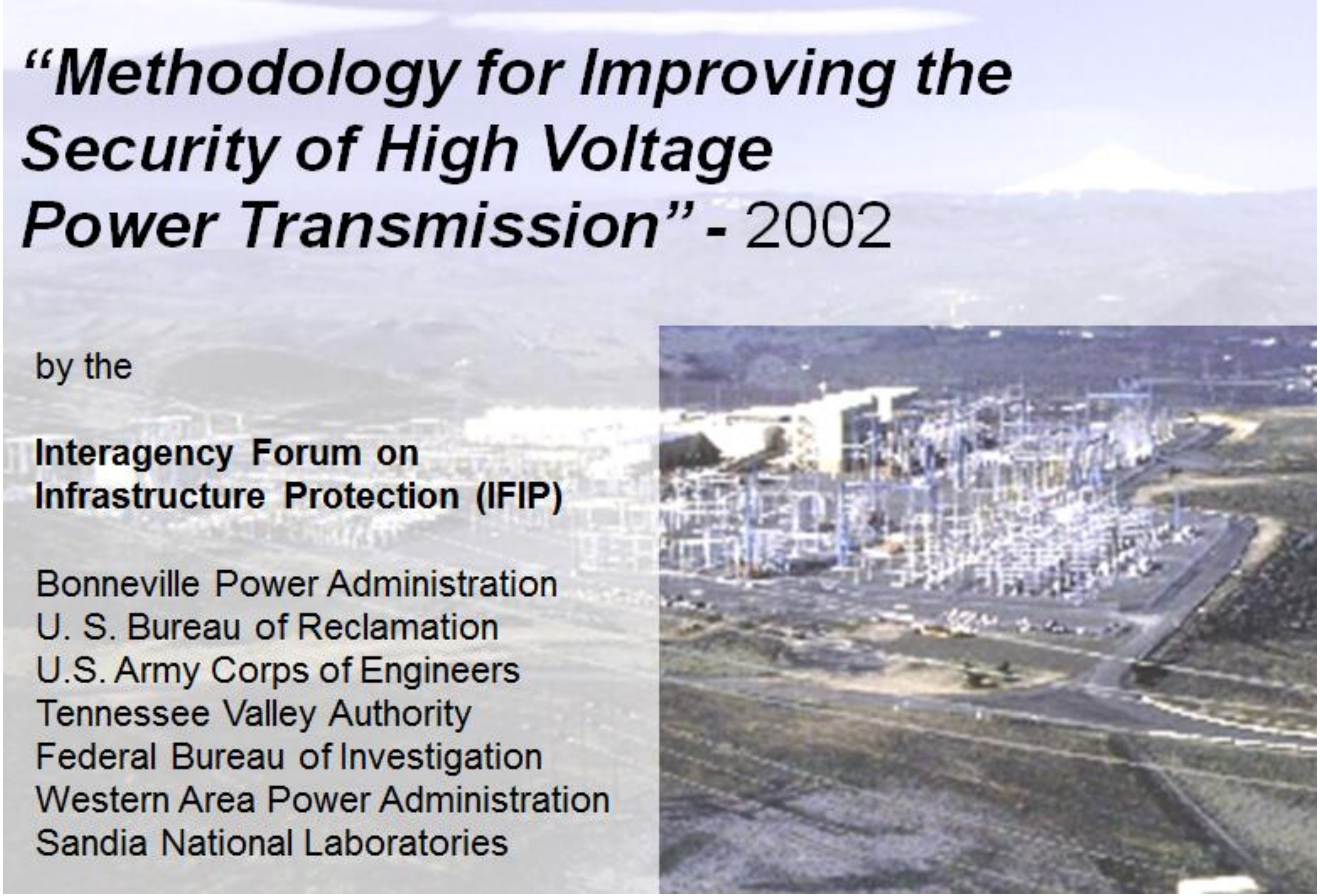
WE OPERATE

9,890+ miles of lines & 568 substations in

Wisconsin
Michigan
Minnesota
Illinois

Risk Assessment Methodology – Transmission (RAM-T)

- RAM-T was developed in the 1990s to protect high-value military targets from physical attack
- Demonstrable effectiveness through lab testing and experience (Sandia National Labs developed tool)
- After 9/11, was significantly modified and adapted for use on:
  - Dams (Army Corp of Engineers)
  - Electric transmission – substations, lines, control centers, IT, fiber
  - Buildings
  - Water systems (EPA)
  - Bridges
  - Military facilities
  - Pipelines
  - IT infrastructure



"Methodology for Improving the Security of High Voltage Power Transmission" - 2002

by the

Interagency Forum on Infrastructure Protection (IFIP)

Bonneville Power Administration
U. S. Bureau of Reclamation
U.S. Army Corps of Engineers
Tennessee Valley Authority
Federal Bureau of Investigation
Western Area Power Administration
Sandia National Laboratories

Interest: NSC, CIAO, FEMA, FERC, NERC, DOE/DOD, Canadian (CIP), Municipalities

What is RAM-T?

Provides a **relative** security risk by gauging:

- **Threats**: Who and what capabilities/interest?
- **Vulnerabilities**: How can they hurt us?
- **Consequences**: What is important?

$$\textbf{Risk} = P_A \times (1-P_E) \times C$$

P_A = Likelihood of attack

$(1-P_E)$ = Security system ineffectiveness

C = Consequences

Note: High = 0.9 Medium = 0.5 Low = 0.1

Source: Sandia National Labs

Likelihood is not the same as probability
The tool calculates a relative risk

- Adversary capability, including:
  - Access to region
  - Technical skills
  - Material resources, financing
- Adversary history, including:
  - Historical interest or attacks
  - Current interest or surveillance
  - Documented threats
- Relative attractiveness of asset to adversary, including:
  - Desired level of consequence
  - Ideology
  - Ease of attack

Department of Homeland Security publicly considers the **threat** and **likelihood** of a HEMP attack **low**

Consequences: gauging bad outcomes

- Outage: People in the dark
- Reliability: Load loss
- Market: Commerce
- Repair: Ratepayer impacts
- Public safety: Loss of essential societal services
- Worker safety: Employees and contractors at risk
- Public confidence: Government oversight and public perception

High = 0.9
Medium = 0.5
Low = 0.1

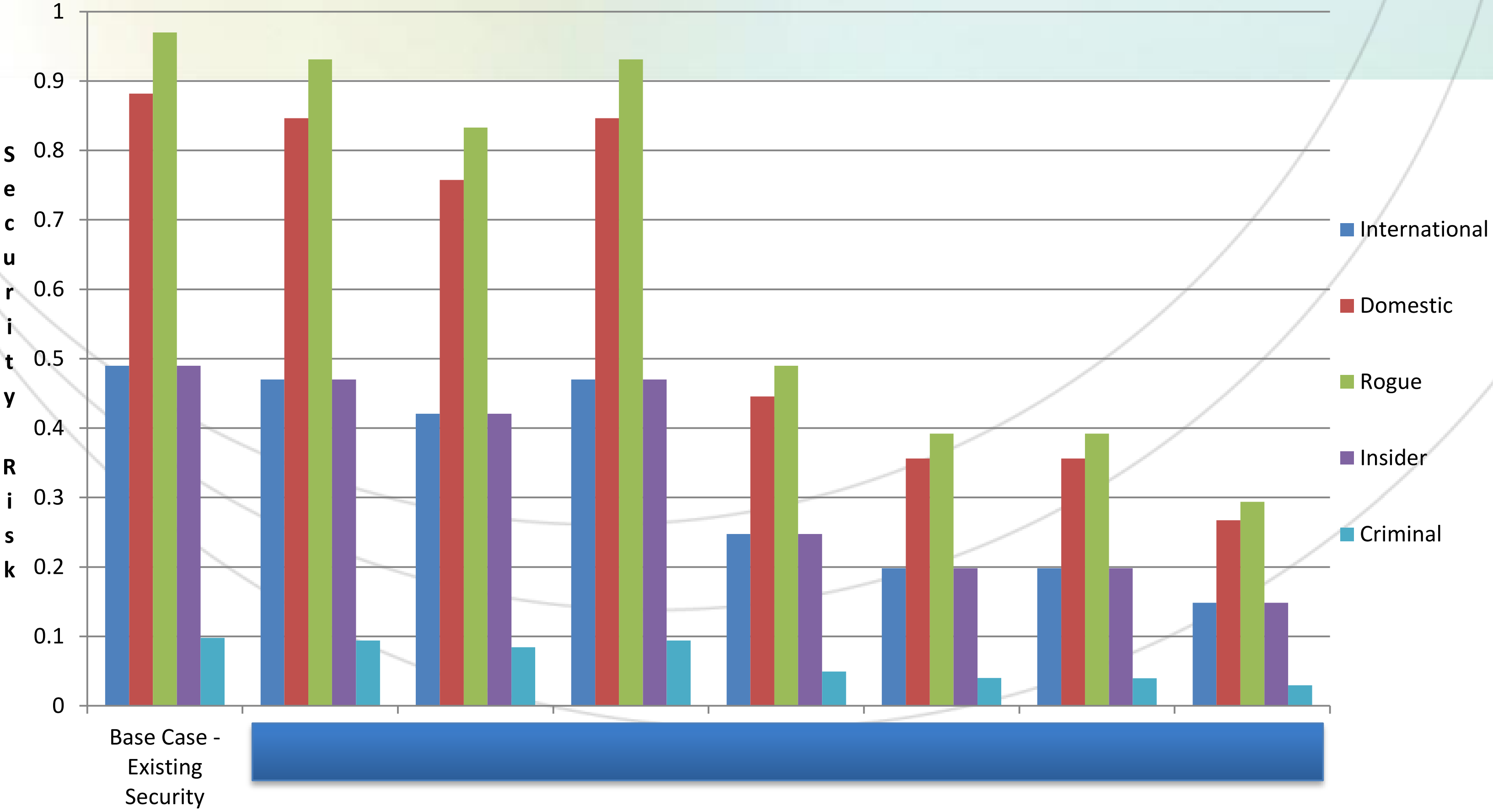
Threats analyzed - substations

- Domestic terrorist
  - Ecological, militia/paramilitary, ideological, fanaticism
- International terrorist
- Criminals
  - Thieves, gangs, vandals, protesters
- Rogue (lone wolf)
- Insider
  - Employees, contractors, consultants
- Rogue Country - HEMP

**Tracked using Threat Based Intelligence Initiative –
ATC Corporate Security system with information support
from law enforcement, DHS, FBI, utilities and others**

Control enclosure fire: rogue/lone wolf

Control enclosure fire: mitigation packages



ATC tested the 7 security upgrade/mitigation packages against 5 adversaries and 5 worst case vulnerabilities. 175 ATC-specific scenarios. 35 are represented above.

Control enclosure: design updates

- Weather
- Intentional Attacks

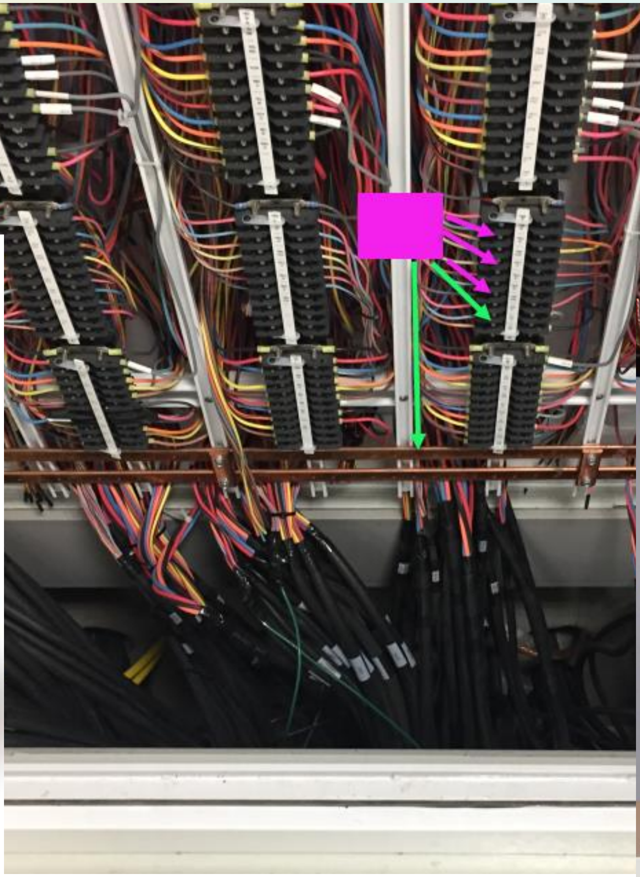
HEMP assumptions (based on EPRI study)

- All ATC sites are impacted
- All existing metal enclosures/buildings can be easily modified to obtain 20-30dB radiated energy reduction
- Conductive energy will cause 5-15% line terminal loss (E1 with 25-50kV/meter field) – High consequence with loss of load
- Need for Blackstart event (E1 +E3 will saturate transformers and cause voltage collapse)
- All RTUs, Routers and Communications need to work due to black start requirement, awareness of relay failures
- Generation and Distribution not considered
- Mitigation will reduce line E1 loss to 0-5% - Low consequence – help restoration efforts after Blackstart

Mitigation options-
Retrofit cost for stations with metal enclosure

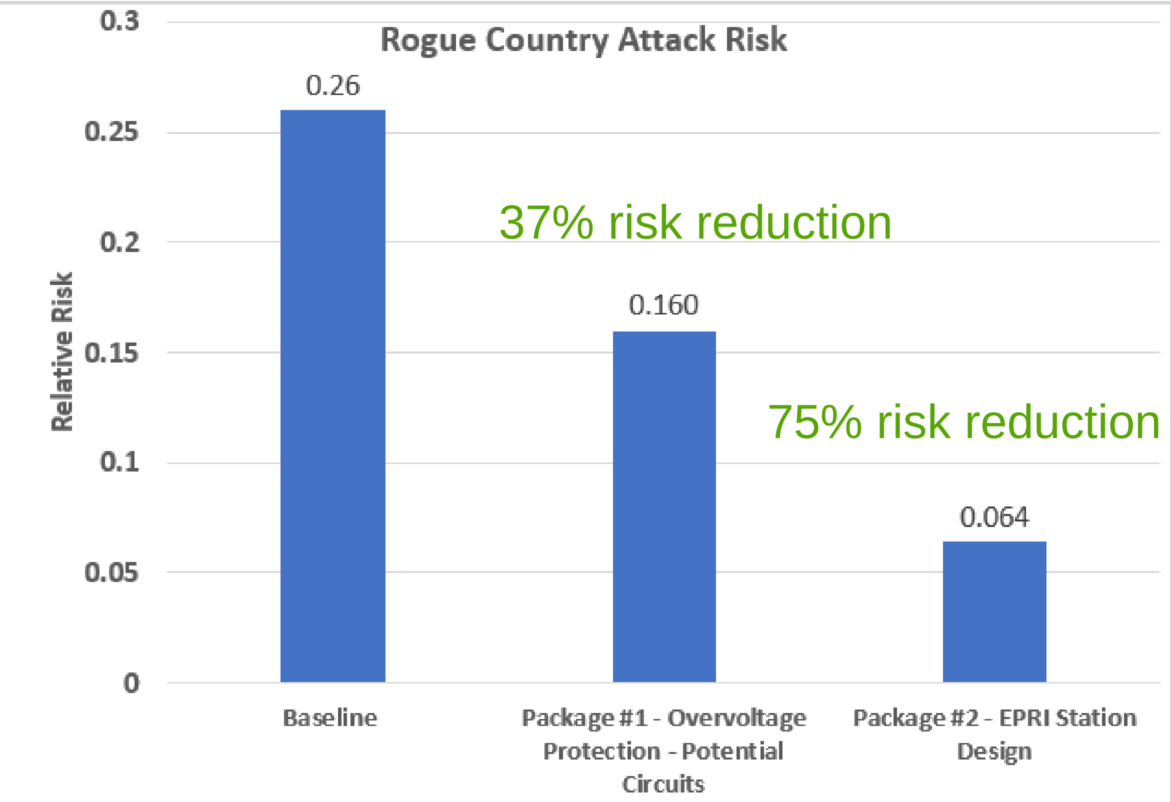
- Base Case – No mitigation **No Cost**
- Package #1 – Low Voltage Arresters/RF Seals **$$**
  - Low voltage arresters on potential circuits
  - Arresters on GPS, cell antennas
  - RF seal on doors and penetrations
  - RF seal on termination cabinet
- Package #2 – Recommended EPRI Package **$$$$$$**
  - Package #1 above plus
  - Shielded cables, grounded on both ends
  - Marshalling cabinet near enclosure entrance

Conductive voltage – mitigation package #1 Termination cabinet – low voltage arresters



Reliability considerations – TBD
Unintended consequences??

Preliminary RAM-T risk assessment
Relative risk reduction

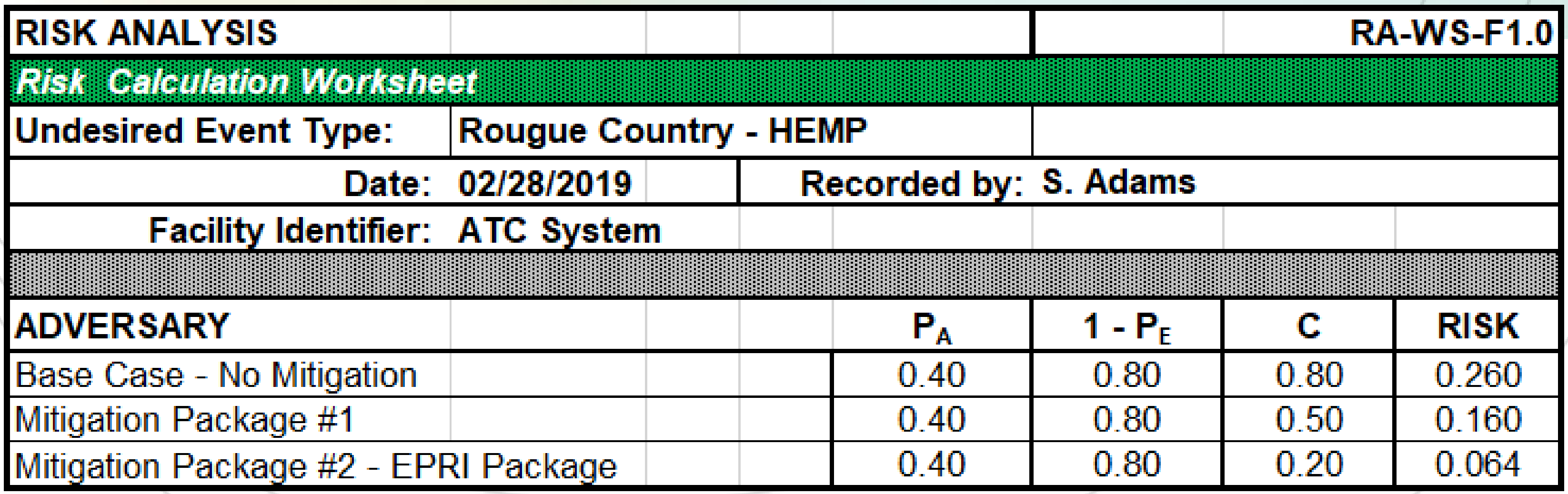


Department of Homeland Security considers the **threat** and **likelihood** of a HEMP attack **Low**

Consequences of an attack are **High** to **Very High** without mitigation

Mitigation can reduce relative risk by 37-75%

Relative risk reduction – RAM-T calculation



RISK ANALYSIS **RA-WS-F1.0**

Risk Calculation Worksheet

Undesired Event Type: **Rougue Country - HEMP**

Date: **02/28/2019** **Recorded by:** **S. Adams**

Facility Identifier: **ATC System**

ADVERSARY	**P_A**	**$1 - P_E$**	**C**	**RISK**
Base Case - No Mitigation	0.40	0.80	0.80	0.260
Mitigation Package #1	0.40	0.80	0.50	0.160
Mitigation Package #2 - EPRI Package	0.40	0.80	0.20	0.064

Risk = P_A x (1-P_E) x C

P_A = Likelihood of attack

(1-P_E) = Security system ineffectiveness

C = Consequences

Note: High = 0.9 Medium = 0.5 Low = 0.1

Source: Sandia National Labs

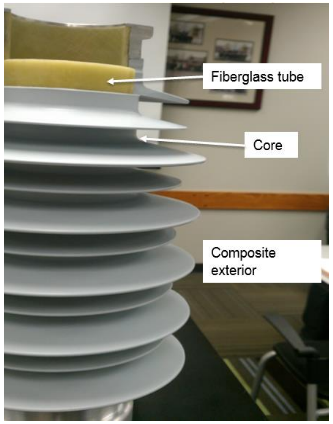
Actions available now (with confidence in the design event??)

- Station Design-
  - RF mitigation (-30dB) on building
    - door seals and building penetrations (HVAC, antennas, etc.)
    - termination or marshalling cabinet
    - grounding design
    - shielded control yard cables
- Equipment-
  - Specifications – relays, routers, RTUs, etc.
    - IEC 60255 for radiated energy
    - IEEE 1613 for environmental
    - IEEE 1588 for time synchronization
  - Transformer design – GMD half cycle saturation
- Expand fiber communication network- (public networks??)
- Sparing- relays, other equipment
- Station Reprioritization- Interconnect, local network, Blackstart and loss of load
- EPRI Study – design basis, mitigation and unintended consequences

Conductive door gasket

ATC physical security strategy

- Prioritize first!
- Risk Analysis: Design Basis and RAM-T analysis
  - Threats, Vulnerabilities, Consequences
- Mitigation
  - Design
  - Controlled failure mode
- Intelligence: ATC Corporate Security/law enforcement
  - Track evolving threats using Threat-Based Intelligence Initiative
- Detect
  - Intrusion detection
- Delay
  - Hardened design
- Respond
  - Communicate with law enforcement/Security
  - Stop the attack before damage!
- Resiliency – risk is never zero
  - Response plans
  - Partnerships (contractors, suppliers, Emergency Management)
  - Spare equipment



Detect – Delay – Respond - Resiliency

Quick deployment control enclosure

Resiliency

Thoughts??

Scott Adams
Asset Manager
906-779-7930
sadams@atcllc.com

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Identify Realistic Mitigation Goals

Prioritization of Mitigation Strategies

Aaron Shaw, American Electric Power
EMP Task Force Technical Workshop
July 25, 2019

RELIABILITY | ACCOUNTABILITY

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Discussion Objectives

- In reference of the work completed by EPRI, how does a utility prioritize mitigation steps within utility infrastructure
- Prioritize threats based on installation type
  - Substations and Plants
  - Control Centers
  - Critical Loads
- Obtain feedback and recommendations for the EMP Task Force on Strategic Recommendations

Emphasis on:

Phase 1

- Strategic Recommendations

Strategic Recommendations (Phase 1)

***** DRAFT – Input Needed *****

Recommendation 1

- Develop list of electronic device types in Substations and Power Plants

Recommendation 2

- Develop guidance for installation and routing of control/communications cable in substations and power plants

Recommendation 3

- Develop industry guidance for control center mitigation strategies

Recommendation 4

- Develop equipment risk assessment guidance for E1 and E3

Recommendation 5

- Develop an industry guide to shielding electronic devices and equipment

Strategic Recommendations (continued)

*** DRAFT – Input Needed ***

1) **Develop list of electronic device types in Substations and Power Plants impacted by E1**
   Objective: provide a comprehensive list of various types of electronic devices that could be impacted by HEMP E1 environment. List could include systems associated with generator limiter controls, environmental controls, SCADA, Protection Systems, etc.
2) **Develop guidance for installation and routing of control/communications cable in substations and power plants**
   Objective: provide technical references via IEEE/IEC standards that provide guidance on installation of <600V cable and bonding and grounding in a substation and power plant environment that deals with EMP surges.
3) **Develop industry guidance for control center mitigation, response, and recovery**
   Objective: develop guidance for control centers on appropriate levels of hardening needed for the types of equipment used in a control center for mitigation. Identify response and recovery protocols necessary for installations with no mitigation provisions.
4) **Develop equipment risk assessment guidance for E1 and E3**
   Objective: develop risk assessment guidance for certain types of installations and equipment used relative to E1 or E3 HEMP environments (e.g. unshielded cable = high risk, E/M relays = low risk)
5) **Develop an industry guide to shielding electronic devices and equipment**
   Objective: develop guidance and technical references to shielding practices to protect electronic devices in substations and power plants (e.g. metal control buildings, metal enclosures, etc)

Questions and Answers

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Identifying Critical Assets

RELIABILITY | ACCOUNTABILITY

HEMP Critical Asset Identification

Knowledge Gaps Discussion

Ken Braerman, BGE, an Exelon Company
EMP Task Force Technical Workshop
July 25, 2019

RELIABILITY | ACCOUNTABILITY

Discussion Objectives

- Provide an opportunity for industry, and other partners, to participate in the conversation
- Discuss how the industry (e.g., typical planner / operator) might approach the task of identifying critical assets for HEMP protection
  - Identify key functions and corresponding components to be addressed
  - Inform future conversations and efforts (Phase 2 and Phase 3)
- Obtain feedback and recommendations for the EMP Task Force

Emphasis on:

Phase 1

- Strategic Recommendations

Strategic Recommendations (Phase 1)

***** DRAFT – Input Needed *****

Recommendation 1

- Provide direction for identification of Monitoring and Control function critical assets, focus on sustaining control facility operation.

Recommendation 2

- Provide direction for identifying assets critical to perform System Restoration of the BES following a HEMP event.

Recommendation 3

- Provide direction to identify assets needed to recover and sustain reliable operation of the BES following a HEMP event.

Recommendation 4

- Provide direction to identify supporting assets critical for continued operation following a HEMP event.

Strategic Recommendations (continued)

*** DRAFT – Input Needed ***

1: ***Provide direction to the industry on how to identify assets critical for Monitoring and Control of the BES, including information on HEMP protection ride through and recovery strategies.***
objective: Provide practical information to the industry on how to identify critical components, based on their ride through or recover function, needed to be protected to sustain BES Monitoring and Control capability including control facilities (control rooms, data centers/EMS servers, and associated ancillary vital equipment) as well as communication and SCADA infrastructure needed for BES operation (communications centers - data/voice, etc.)

2: ***Provide direction to industry on how to identify assets critical for System Restoration of the BES following a HEMP event.***
objective: Provide practical information to the industry to identify critical components that need to remain functional following an HEMP event in order to ensure system restoration capability including quantity and location of black start generation resources (cranking path protection, control schemes, black start generator controls, and associated cranking paths), and restoration plan's dependency on: non-black start units, interconnect tie line facilities and substations, and spared assets.

Strategic Recommendations (continued)

*** DRAFT – Input Needed ***

3: ***Provide direction to the industry on how to identify assets needed to recover and sustain reliable operation of the BES following a HEMP event.***
objective: Provide practical information to the industry to identify critical components, as assessed singularly and in the aggregate, that need to remain functional post a HEMP event in order to ensure continued reliable operation, including elements such as Interconnect tie lines and substations, EHV transmission substations, DC lines, large MW/MVAR resources, regulation/frequency controlling resources, protection and control schemes, generator controls, BES assets used to supply defense facilities, governmental facilities, critical infrastructures (gas, etc.), other critical load centers, and other items.

4: ***Provide direction to the industry on how to identify and protect supporting assets that are critical for continued operation post a HEMP event.***
objective: Provide practical information to the industry to identify critical supporting assets that need to remain functional following a HEMP event in order to ensure restoration and operational capability, including quantity and location of items such as utility vehicles, employee communications equipment, test/calibration/measurement equipment, laptops/computers, other spared equipment (High Voltage, P&C), and other items.

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Questions and Answers

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Feedback and Next Steps

RELIABILITY | ACCOUNTABILITY

Questions and Answers