Energy Delivery Resilience:

Safety, Reliability, and Recovery

Robert L. Allison

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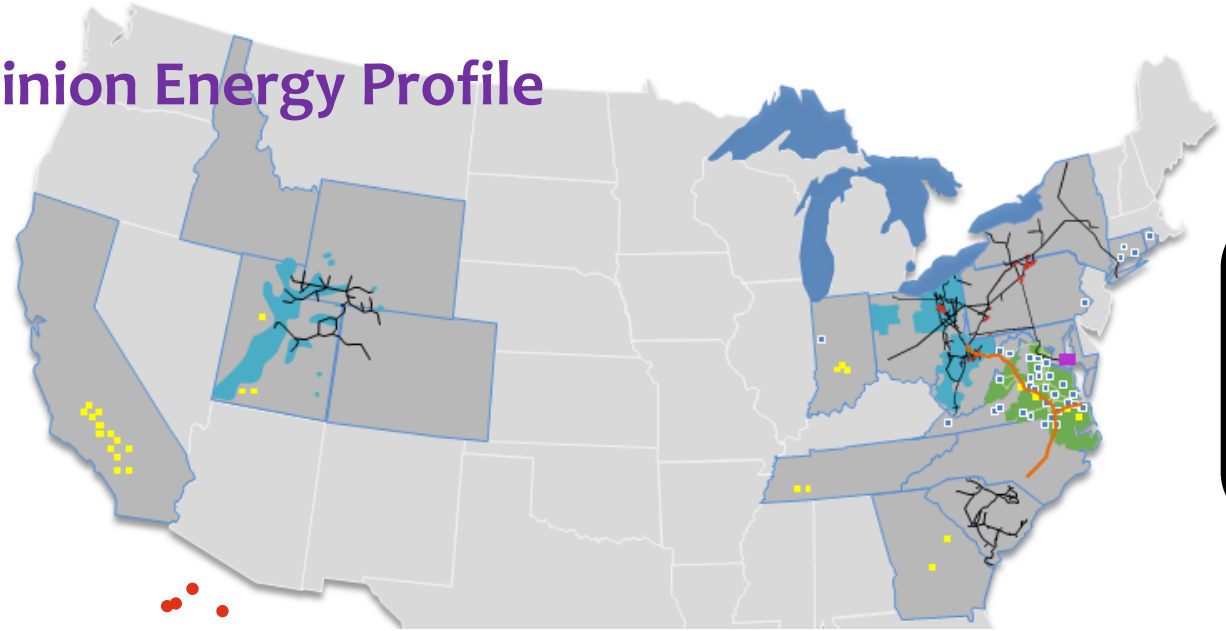
Dominion Energy Profile



One of the nation's largest producers and transporters of energy.

- 26,200 MW of electric generation
- (includes ~765 MW of solar generation)
- 6,600 miles of electric transmission
- 2.6 million electric customers in VA and NC
- Atlantic Coast Pipeline (subject to regulatory approval)
- 15,000 miles of natural gas transmission, gathering and storage pipeline
- 1 trillion cubic feet of natural gas storage operated
- Dominion Energy Cove Point LNG Facility
- 2.3 million natural gas customers in 5 states
- 1.4 million non-regulated retail customers in 17 states (not shown)

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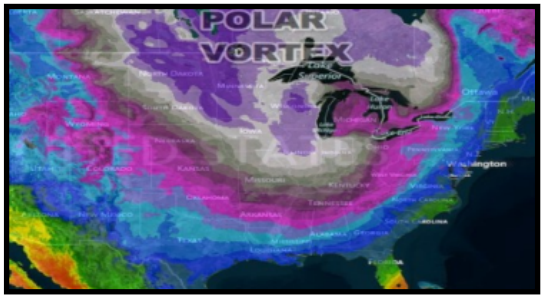
Maintaining Safety, Reliability and Resiliency Among Today's Electric Grid Challenges

- **Natural events**
  - Hurricanes, tornadoes, derecho events
  - Geomagnetic disturbances
  - Earthquakes
  - Polar vortex
- **Man-made events**
  - Terrorism (physical/cyber)
  - Electromagnetic
  - Copper theft
- **Changing location and mix of generation**
  - Planning horizon is reduced causing less time for construction of long-term solutions




THE WALL STREET JOURNAL.

SNIPER ATTACK

Mystery Assault On Power Grid

Water Wind Solar

Biomass Fuel cell Microgrid

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Key Considerations for Recovery

Customer Expectations for extreme events

- **Transmission Restoration**
  - Network integrity is initial focus
  - Must provide offsite power to nuclear plants
- **Transmission service to Distribution substations**
  - Provide power within 3 days (Customers' accept)
  - Provide power within 5 days (Customers' not happy)
  - Provide power greater than 7 days (Utility has failed mission)
- **Dominion looks for 7 days as Maximum transmission restoration for *ALL* events – Natural or Man-made**

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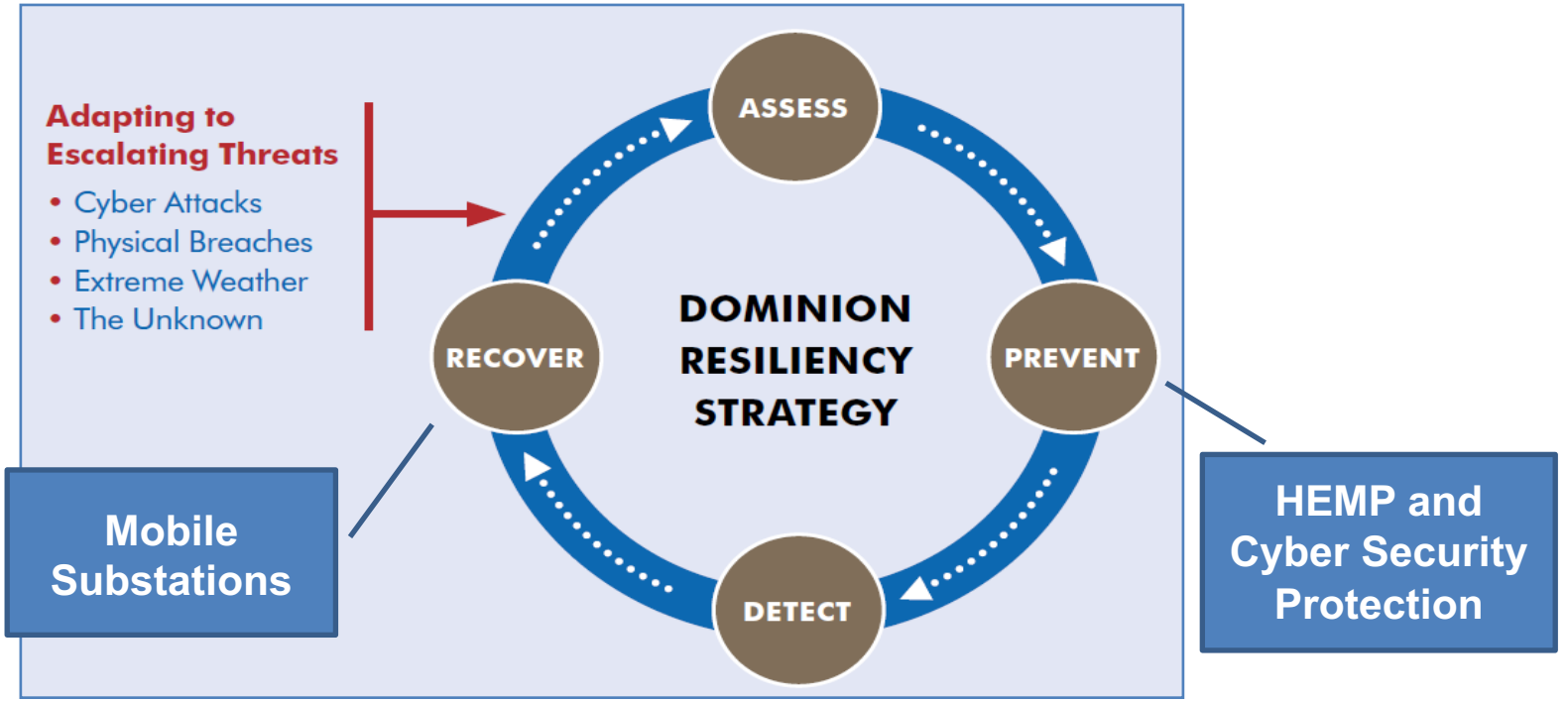
Resiliency Strategy: A Layered Approach



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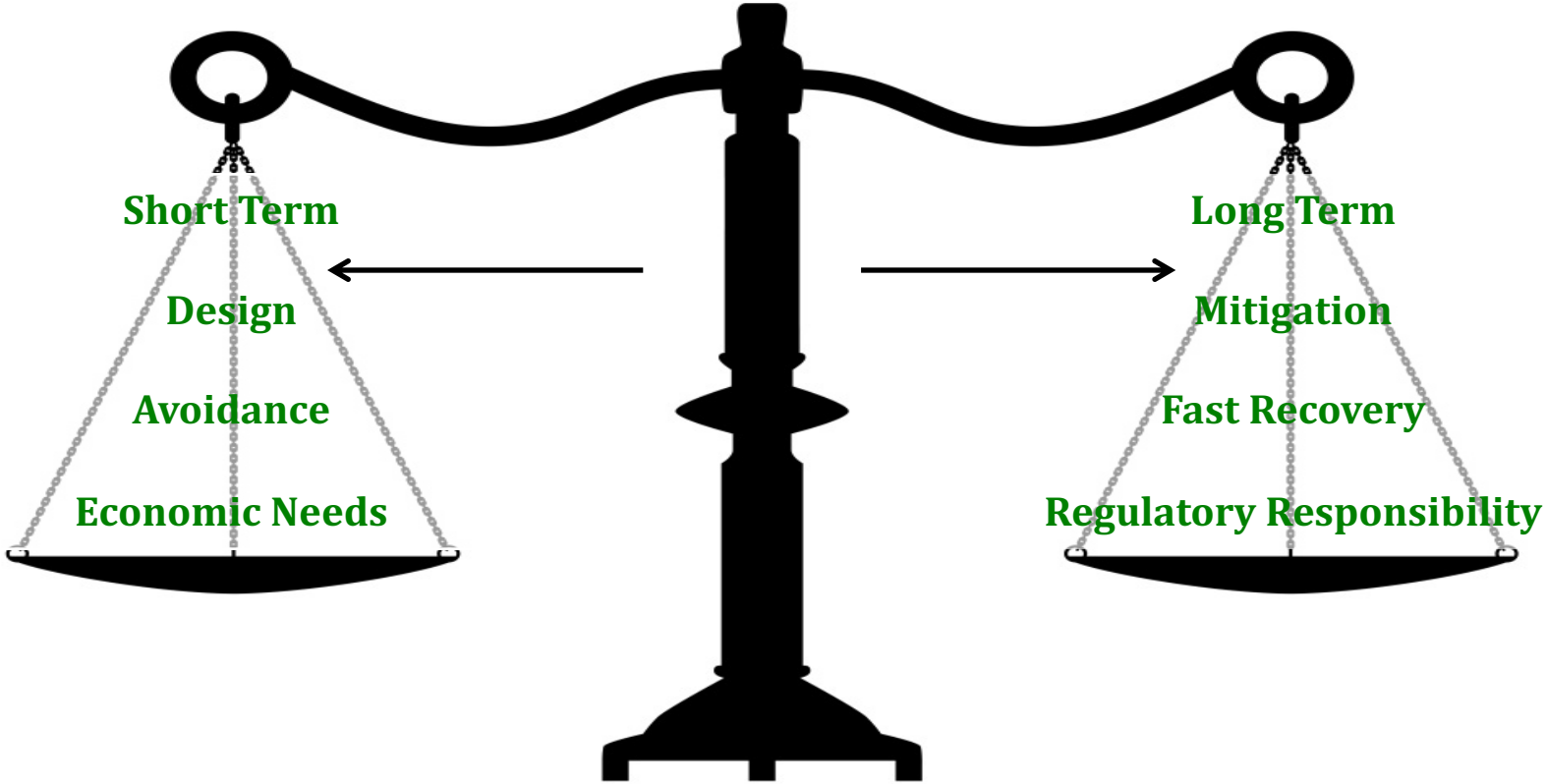
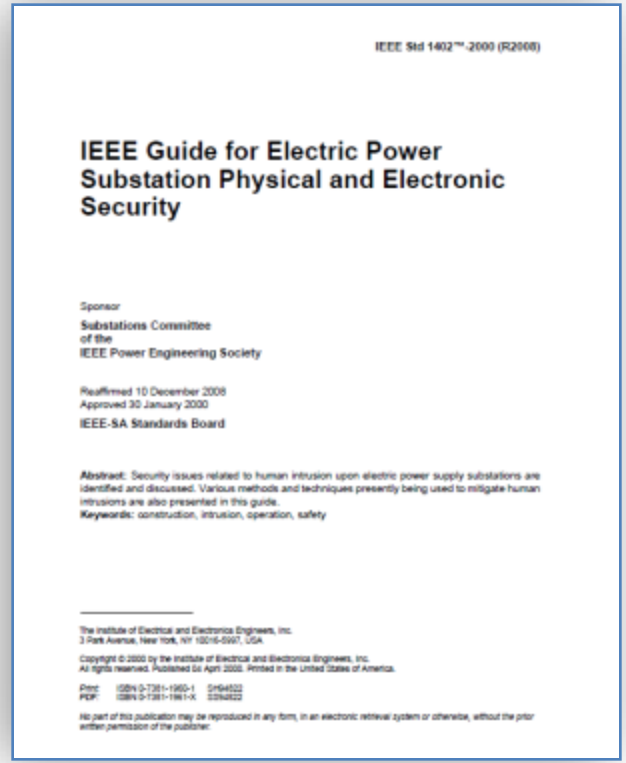
Operations and Design Philosophy



Take Advantage of Worldwide Experiences

Engineers Active with IEEE and CIGRE



IEEE Std 1402™-2000 (R2008)

IEEE Guide for Electric Power Substation Physical and Electronic Security

Sponsor

Substations Committee
of the
IEEE Power Engineering Society

Reaffirmed 10 December 2008
Approved 30 January 2000

IEEE-SA Standards Board

Abstract: Security issues related to human intrusion upon electric power supply substations are identified and discussed. Various methods and techniques presently being used to mitigate human intrusions are also presented in this guide.
Keywords: construction, intrusion, operation, safety

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IEEE PES Power & Energy Society®

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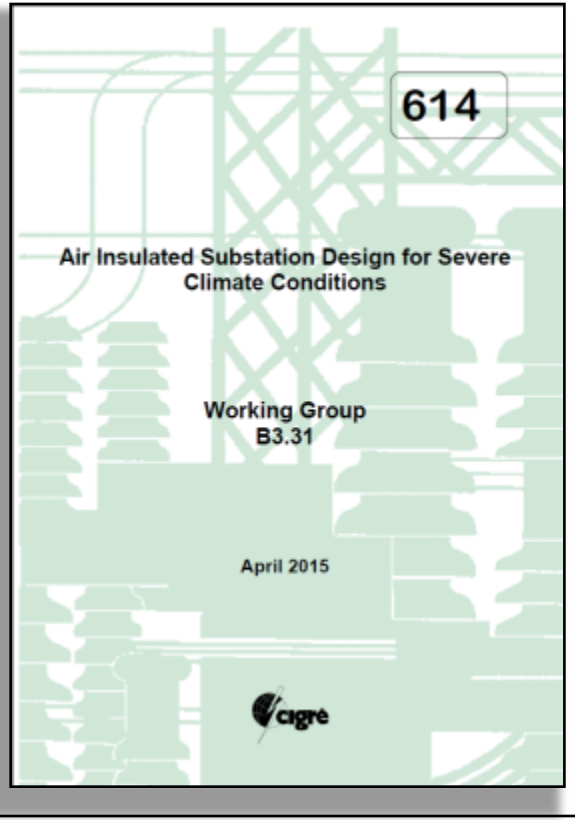

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Natural Disasters
Building for Resiliency

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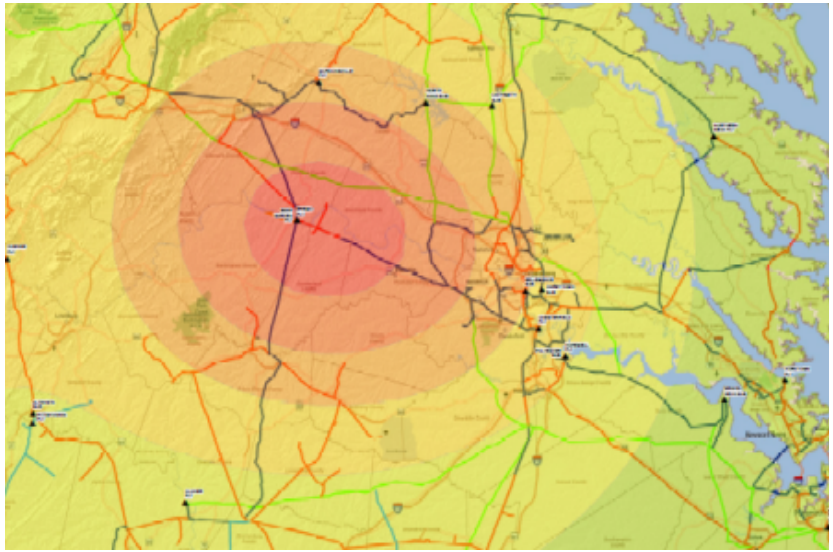
Earthquakes

Understand potential and prepare accordingly

- **Work with USGS to develop hazard potential map**
- **Based on potential - modify designs to reduce potential for damage**
  - Resin Impregnated Bushings
  - Seismic Battery Racks
  - Review Control Building design
  - Replace certain electromechanical relays with digital relays



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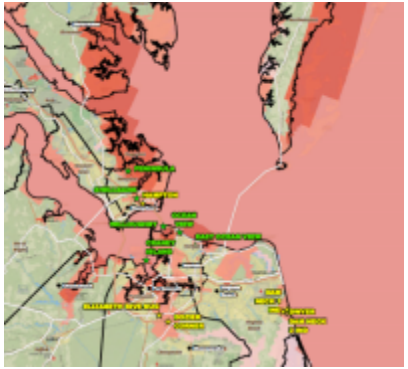
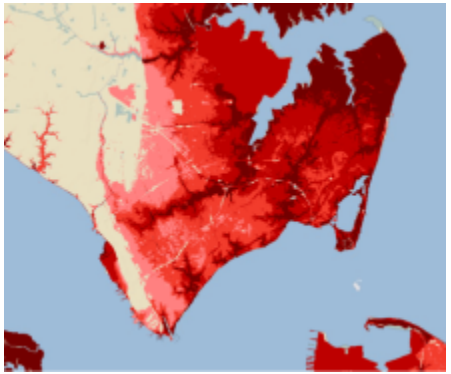
Hurricanes / Flooding

Preparation In Advance

- Use of NOAA *Slosh Model* to develop flood potential maps
- Elevate critical equipment during facility upgrades using this data
- Prepare with temporary measures such as temporary barriers





Short Term Mitigations

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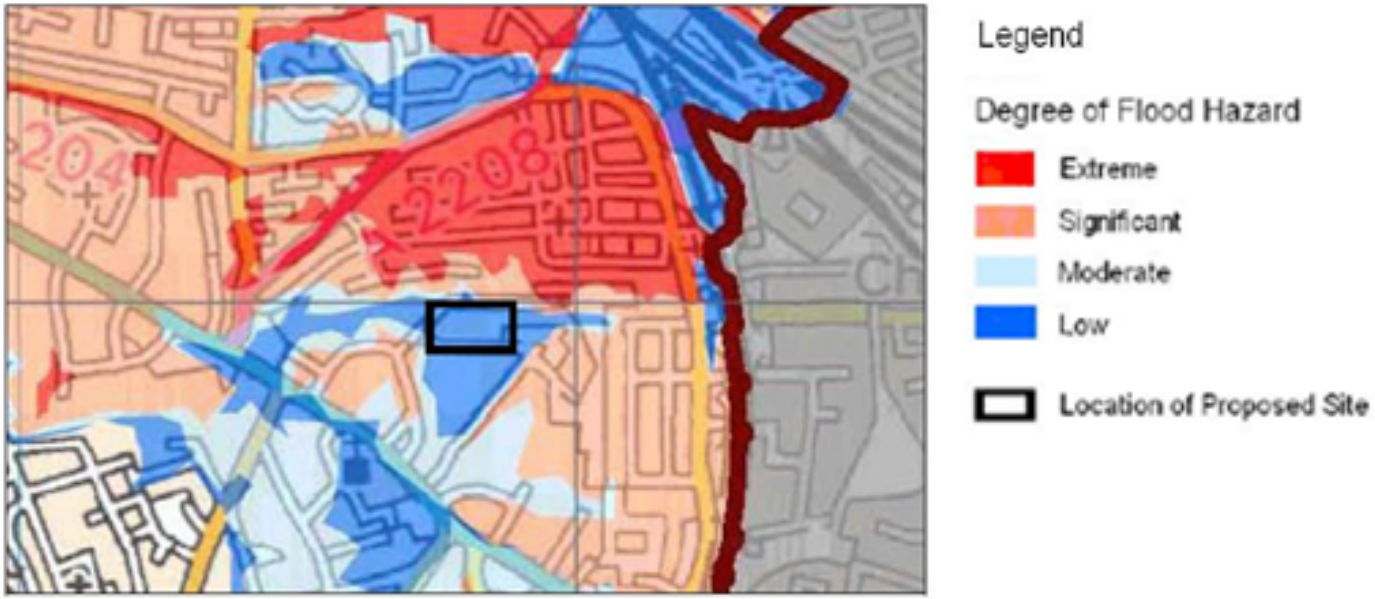
Long Term Flooding Evaluation

Substation Locations are evaluated for the timeframe of Equipment Design Life



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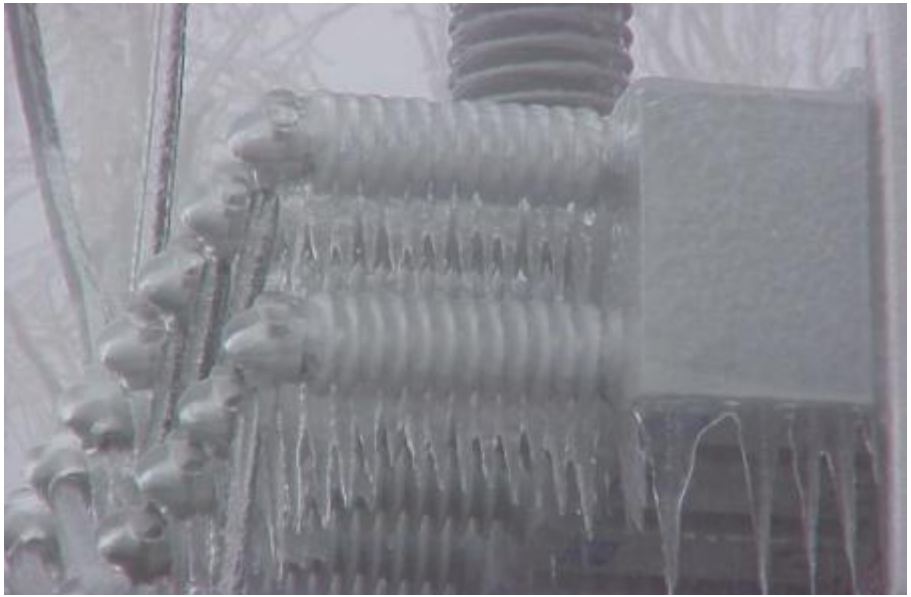
Cold, Snow and Ice

Weather extremes challenges outdoor insulation



1.5 inches of ice

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Cold, Snow and Ice

Designs to reduce outage impact

Use of Resistive Glaze Insulators
Or Stepped Shed Designs

Gas Insulated Switchgear mounted indoors

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Extreme Winds

Tornadoes, Hurricane, Derecho events

- **Harden designs**
  - Control enclosures to handle 120+ MPH wind
  - Use of Steel or Concrete transmission structures with additional wind loading criteria
- **Insulation designs**
  - Use of redundant insulation for critical crossings
  - Use of polymer insulators
  - Consider contamination impacts for coastal environments

Substation Design Vulnerabilities

Design to reduce outage risk – Eliminate Single Point Vulnerability

Equipment	Problems	Methods of Mitigation
Insulators	-Design Strength -Application Limitations -Which Insulator Bells or Station Post?	* Redundant Design * Compression Orientation Best Practice (Post Insulators) * Dead End Bell In Tension Best Practice
CT/PT Combination Units	-30 Year Design Life -Single Point Failure Vulnerability -No Monitoring or End of life Detection -Series Connected Device	* Separate CT and PT Devices * CVT(PT) Online Failure Monitoring * Tap Connection No Loss Of Phase
Switch Closing and Terminal Connections	-Switch Stress -Load Dependent -Operator Dependent	* Flex Leads at Terminal Pad Connections * IR Scans After Closing or Load Changes * Design For Insulator and Base Deflection
Transmission Line Splices	-30 Year Life -Problems with Workmanship	* Replace or Refurbish with Splice Shunts * Test Energized with " OHM STICK" * Test Deenergized with "Micro Ohm" Tester

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Physical Hardening Risk Assessment Modeling

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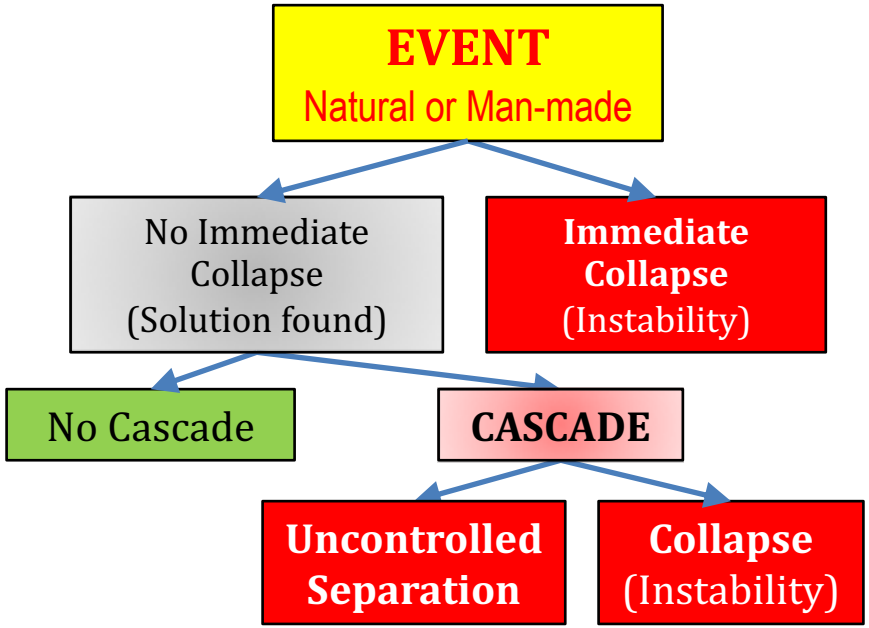
Introduction

Models – A Critical Step

- Models needed to define resiliency risk
- Models provide clarity to stakeholders of need
- Existing Models are too cumbersome for the future we now face
- Dominion Engineers worked with Oak Ridge National Laboratory and PJM Interconnection to develop a new Resiliency Model that has been shared with the industry.



Cascading is the catalyst to determine instability and uncontrolled separation

pjm

OAK RIDGE National Laboratory

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Physical Security

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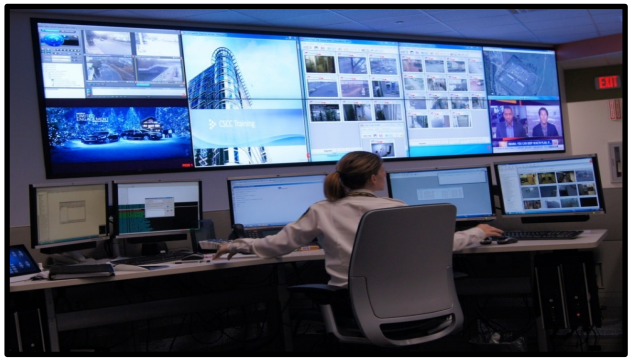
Physical and Cyber Security at Key Locations

- Perimeter barriers
  - Anti-cut, anti-climb, anti-ram, IEMI benefits
- Ballistic protection
- Increased electronic surveillance
- Latest in cyber security controls, systems and network operations
- Layered protection at substations for EMP/IEMI hardening
- Fleet of mobile equipment for rapid restoration of service



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Dominion Energy's New System Operations Center

Now OPERATIONAL!

- Resiliency and hazard mitigation part of core design
- Design and performance requirements
  - Simplicity and flexibility
  - Standards:
    - Uptime Tier Levels, TIA-942
    - LEED
    - Physical and cyber security
    - Hardened for earthquakes, tornadoes and EMP

Electromagnetic Pulse (EMP)

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Background on EMP and IEMI

- **High-altitude Electromagnetic Pulse (HEMP):**

  Partnering with EPRI on project P34.114: "EMP Grid Resiliency: Transmission Vulnerability and Mitigation" to continue the academic and industry research to understand the characteristics of HEMP, and its impact to power systems, communication systems, and transportation systems.

- **Intentional Electromagnetic Interference (IEMI):**

  Partnering with EPRI on project P37.114: "Physical Security and EMP/IEMI" to study the impact of IEMI to electric substations and the best mitigation strategies.

- **EPRI introduction video of EMP project:**

  https://www.youtube.com/watch?v=D31RFJ00sd8&feature=youtu.be

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Dominion Energy EMP Mitigation

- Large Power Transformers designed for GMD / EMP withstand
- Digital protection & control systems designed for greater transient withstand
- Lightning protection on our T&D systems help with EMP
- Primary distribution voltage of 34.5kV is less susceptible to insulator damage from EMP event
- Additional transmission mobiles and spare power transformers geographically spread to speed restoration, if needed
- New System Operating Center hardened for EMP

Geomagnetic Disturbances (GMD)

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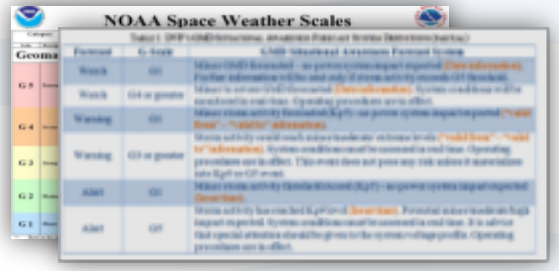
Dominion Energy GMD Mitigation Plan

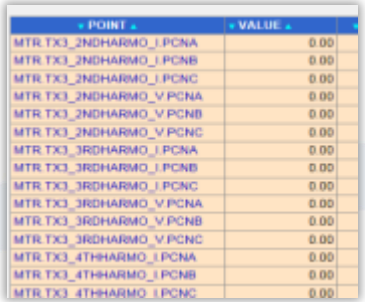
Provides EMP-E3 Protection

Situational Awareness



Situational Awareness System

DVP GIC Visualization Tool



POINT	VALUE
MTR.TX3_2NDHARMO_I.PCNA	0.00
MTR.TX3_2NDHARMO_I.PCNB	0.00
MTR.TX3_2NDHARMO_I.PCNC	0.00
MTR.TX3_2NDHARMO_V.PCNA	0.00
MTR.TX3_2NDHARMO_V.PCNB	0.00
MTR.TX3_2NDHARMO_V.PCNC	0.00
MTR.TX3_3RDHARMO_I.PCNA	0.00
MTR.TX3_3RDHARMO_I.PCNB	0.00
MTR.TX3_3RDHARMO_I.PCNC	0.00
MTR.TX3_3RDHARMO_V.PCNA	0.00
MTR.TX3_3RDHARMO_V.PCNB	0.00
MTR.TX3_3RDHARMO_V.PCNC	0.00
MTR.TX3_4THHARMO_I.PCNA	0.00
MTR.TX3_4THHARMO_I.PCNB	0.00
MTR.TX3_4THHARMO_I.PCNC	0.00

Real Time
Harmonics Alarm

Operations

Dominion's GMD Operational procedures follow:

- DVP SOC EMER002: Solar Magnetic Disturbances Procedures
- PJM Manual 13, Section 3.7: Emergency Operations
- NERC Standard EOP-010-1: Geomagnetic Disturbance Operations
- NERC Standard TPL-007-1: Transmission System Planned Performance During Geomagnetic Disturbances

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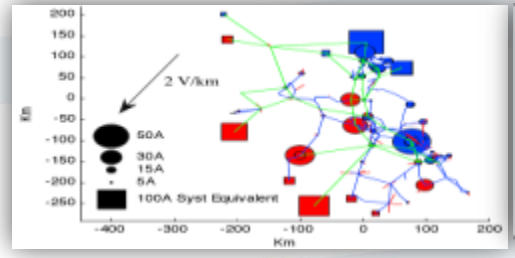
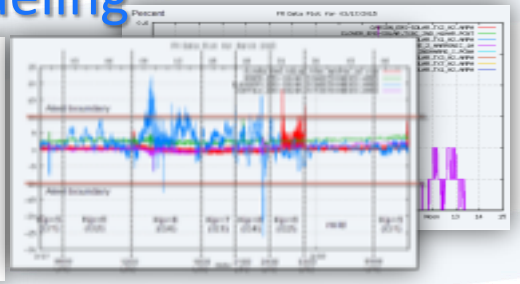
Dominion Energy GMD Mitigation Plan

Provides EMP-E3 Protection

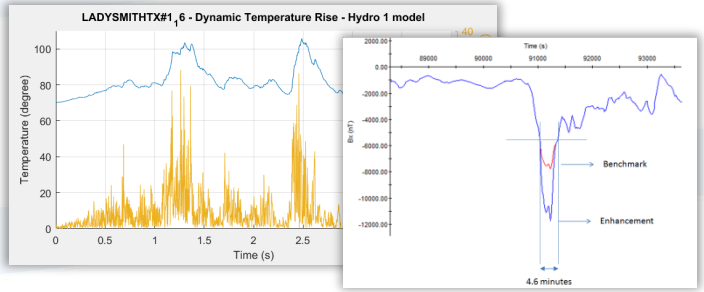
GIC Study and Modeling



GIC mapping and power flow

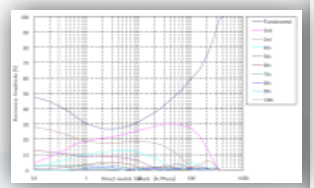


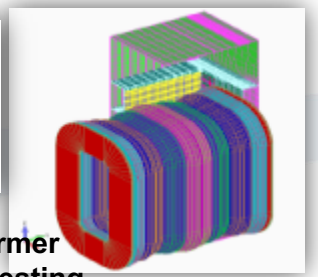
Event analysis from real-time monitoring data



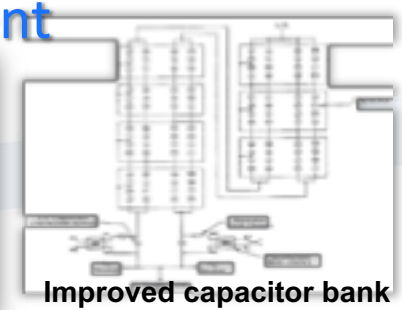
Transformer thermal assessment with consideration of local enhancement

Equipment Enhancement

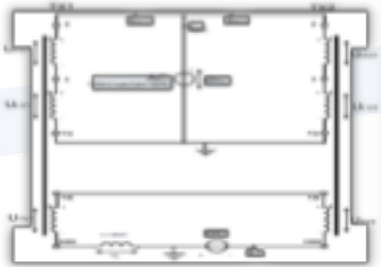




Improved EHV transformer design & manufacturer testing



Improved capacitor bank protection scheme



Future: On-site test on DE's EHV transformers

Transmission Mobile Transformers

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Industry Collaborations

Geomagnetic Disturbances

- Sitting on the NERC TPL-007 GMD Standard Drafting Team
- Sitting on the IEEE GIC Working Group
- Collaborating with USGS on GMD forecasts, and 3-D ground conductivity modeling and its implementation in GIC calculation
- Collaborating with NOAA on using a refined method to generate 1-sec resolution geo-electric field data from Fredericksburg, VA
- Collaborating with NASA on measuring local geomagnetic events via monitoring device near our Electric Transmission lines
- Collaborating with EPRI on SUNBURST GIC monitoring program

USGS science for a changing world

NOAA

NASA

EPRI ELECTRIC POWER RESEARCH INSTITUTE

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Recovery and Restoration

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Protected Storage Facilities

Three new protected regional storage facilities for emergency materials for faster response

Mobile Substations

Attributes and benefits

- **Dominion Energy's mobile substation includes standardized protection packages to allow for simple integration with existing protection schemes.**
  - Temporary deployments enjoy same reliability as permanent installations.
- **Dominion Energy's mobile substation is modular and can be used individually.**
  - A breaker failure or loss of a single phase transformer can be resolved in a fraction of the time using just the breakers or single phase units of the mobile fleet.
- **Our underground cable links allow for a large array of connections to be made – minimizing our need for disruptions to the surrounding environment and maximizing safety to personnel and the public.**
- **Mobile substations are a component of Dominion Energy's layered resiliency strategy.**

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Mobile Equipment: Versatile and Adaptable

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Mobile Equipment and Mobile Substations

Connecting to the Grid

- Rapid restoration of service (equipment and design)
- Unusual/emergency system conditions
- Provides additional flexibility

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