Meeting the Challenges and Seizing the Opportunities of a Changing Energy Landscape

Kevin Curtis
Vice President, Electric Transmission

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Welcome to Richmond!

Safety Message

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Safety Message

We often fail to consider the consequences of a ticket or an accident because…

- Everyone else is speeding.
- I am late for work/meeting/kids.

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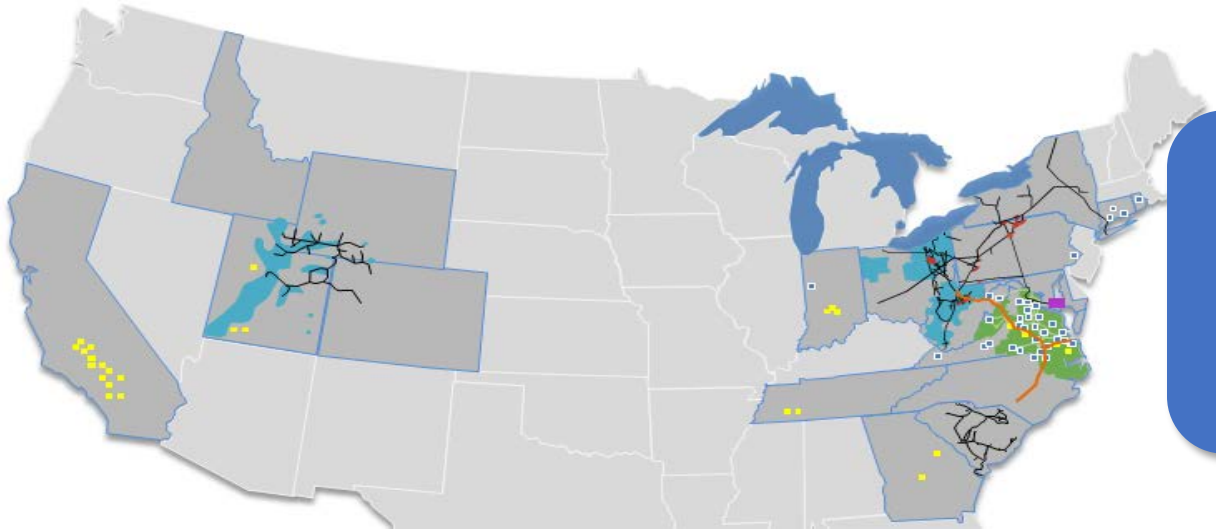
Dominion Energy Profile



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

- 24,100 MW of electric generation (includes ~1,920 MW of solar generation)
- 6,700 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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Dominion Energy – A Focus on Core Values

Safety	Ethics	Excellence	Embrace Change	One Dominion Energy (Teamwork)
Our highest priority is keeping our employees and communities safe	*Doing right and doing well are inseparable*	*Best in class performance helps drive long-term value creation*	*Sustainable performance depends on how well we support one another*	*Innovative culture drives approach to clean energy and workforce opportunities*

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Characteristics of our "New Normal"

Challenges & Opportunities

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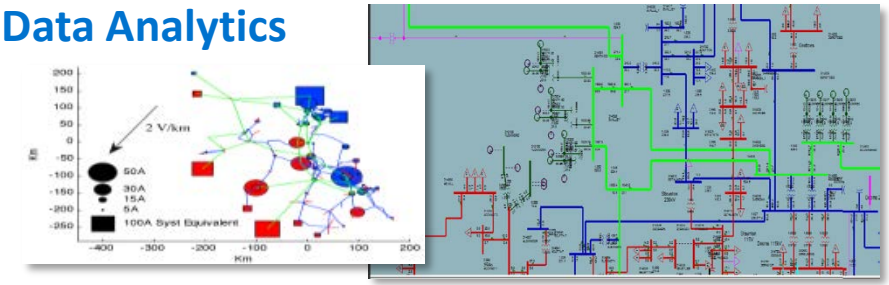
EMERGING CHALLENGES & THREATS

Renewable, Intermittent Generation; Loss of Inertia; Changing Location of Generation

Natural Events; Extreme Weather

Need for Advanced, Integrated Modeling & Grid Data Analytics



Man-made Events

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HEMP & IEMI Mitigation Strategy

- **Fundamental grounding is key for EMP mitigation**
  - Bleed the energy into the ground at substations and along transmission lines
  - Use grounding fundamentals for day-to-day grid operations and events, and use as basis for EMP/IEMI mitigation
- **Cost prohibitive to EMP harden all facilities, so went with a layered approach**

Build in **layers** of EMP/IEMI protection that sequentially reduce the power and threat:

Fence → Cable Shielding → Control House → Panels → P&C Devices

Substation Ground Mat
Transmission Line Tower Grounding

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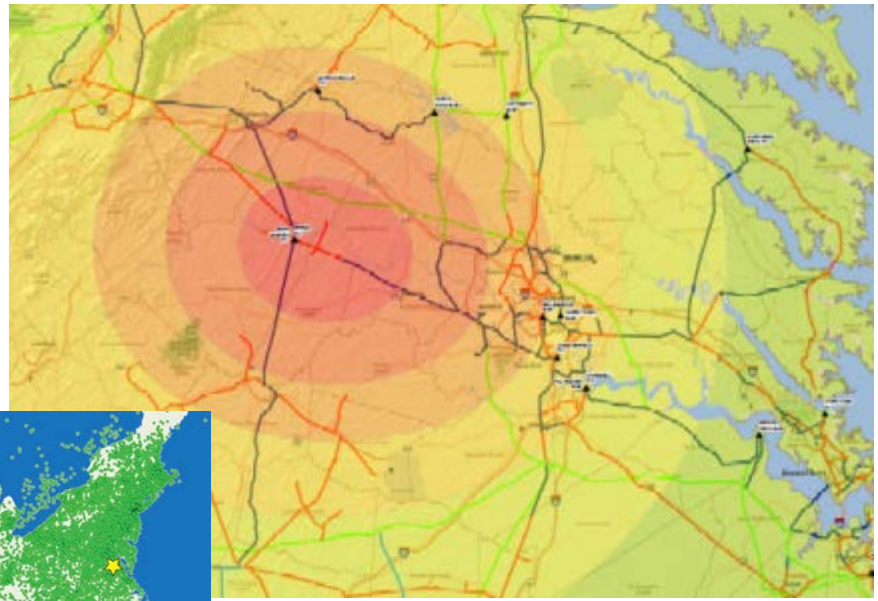
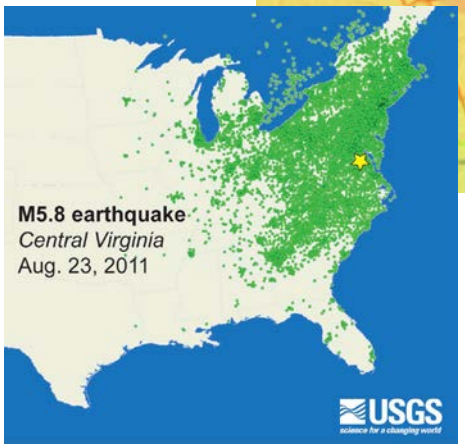
Earthquakes: Understand and Prepare Accordingly

- Worked with USGS to develop hazard potential map
- Based on results, modified designs to reduce potential for damage
  - Moved to using resin impregnated polymer (RIP) bushings
  - Seismic battery racks
  - Reviewed/updated control house building designs
  - Replaced certain electromechanical relays with digital relays





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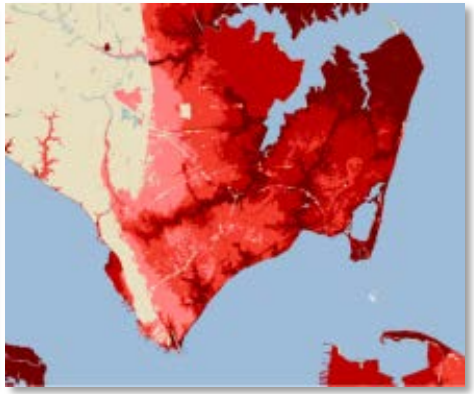
Hurricanes, Flooding, and Extreme Wind

- 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
- Control house buildings designed to handle 120+ MPH winds
- Use of steel or concrete transmission structures with additional wind loading criteria
- Use of redundant insulation for critical crossings



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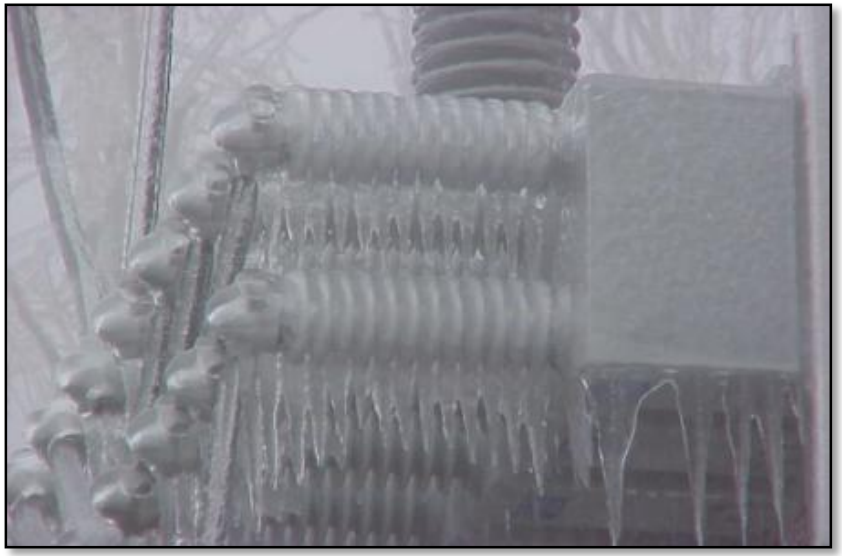
Cold, Snow, and Ice



1.5 inches of ice

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New and Improved Designs to Reduce Outages

Use of resistive glazed insulators or stepped shed designs

Gas insulated switchgear mounted indoors

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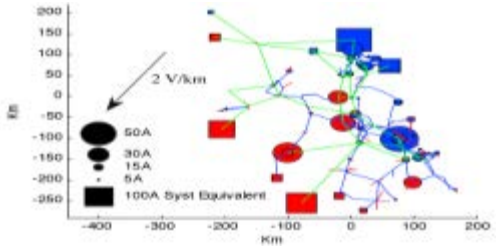
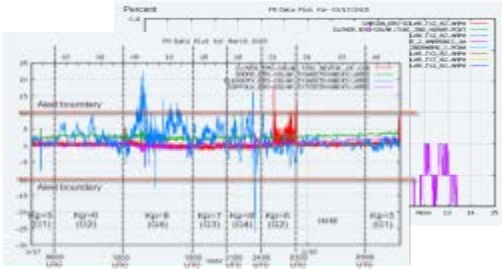
Space Weather: GMD and GIC

GMD/GIC Modeling & Study



GIC mapping and power flow

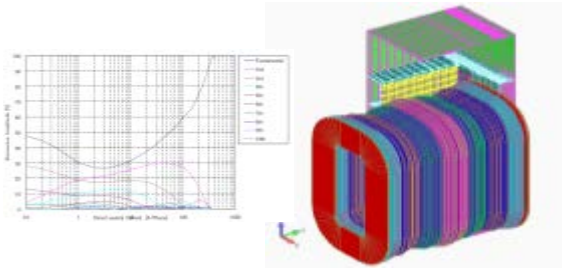


Event analysis with real-time monitor records

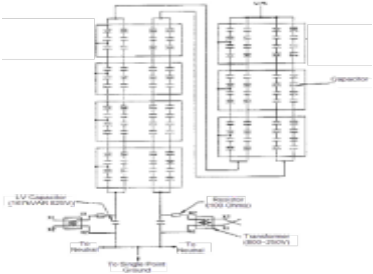
NASA Virginia Tech NOAA EPRI ELECTRIC POWER RESEARCH INSTITUTE

Industry collaboration

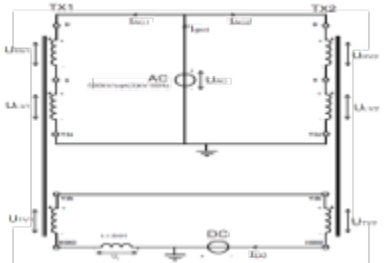
Equipment Enhancement



Improved EHV transformer design and manufacturer testing



Improved capacitor bank protection scheme



Future: On-site test on DVP EHV transformers

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Enhanced Substation Security

- Perimeter barriers
  - Anti-cut
  - Anti-climb
  - Anti-ram
- Ballistic protection
- Access control
- Improved lighting
- Increased electronic surveillance
- Installation of resin impregnated polymer bushing and low oil trip on transformers

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HIGHLIGHTING KEY INITIATIVES AND OPPORTUNITIES

Data Centers

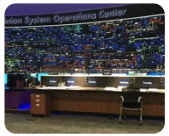
Solar

Electric School Buses

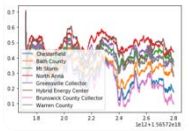
Energy Storage Pilots

Offshore Wind

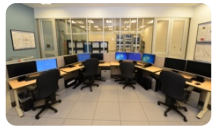
Mobile Equipment



New System Operations Center



Synchrophasor Analytics



Advanced Simulation

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Data Centers

- **Highlights**
  - Dominion serves 49 data center companies
  - 2019 peak demand is 1.3GW
- **Connection Activity**
  - 24 connections in 2019
  - Expect 10-15 per year
- **Market**
  - 70% of world's internet traffic runs through Northern VA
  - Land at a premium
- **Growth**
  - 2017 – 115MW
  - 2018 – 270MW

Anytime you watch a video or download music and photos to your iPod or cell phone you are accessing a Data Center which hosts multiple "server farms" for YouTube, Facebook, Google

The typical Data Center uses the same amount of electricity of 6,250 homes

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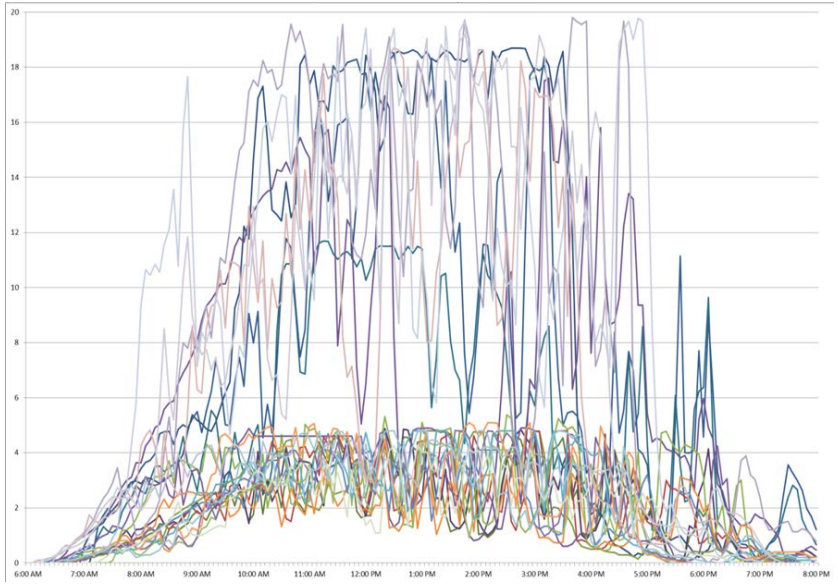
Solar

- North Carolina #2 solar state, features 690 MW of connected solar gen. (445 MW on distribution)
- Over the last two years, Dominion Energy has grown solar fleet to ~1,350 MW in service, in construction or under development
- DEV is actively evaluating 447 queue requests totaling over 44,000 MW of potential new generation - more than double DEV's current system load. Queue Includes:
  - 5,600 MW of offshore wind
  - One 1,200MW solar project
  - 1,500 MW batteries
- Spotsylvania (500MW) to become one of largest constructed solar farms in USA, currently in process of construction and interconnection.
- Interconnection costs in excess of $300M are very common right now

Solar output on a partly cloudy day July 5, 2017



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Electric School Buses

- One bus reduces CO_2 emissions by 54,000 pounds each year
- Air quality inside is 6x better than non-EV models
- New Vehicle to Grid Technology
- Increased Safety
- Lower Cost + Less Maintenance

https://www.dominionenergy.com/ourpromise/innovation/electric-school-buses

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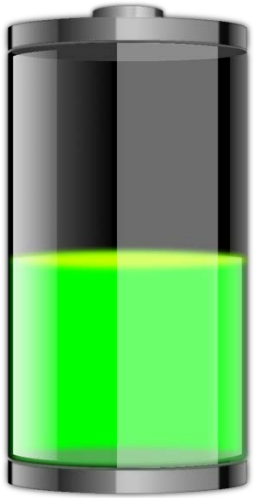
Five Battery Pilot Projects at Dominion Energy

30 MW of
Energy Storage Pilots



1: Absorb PV Backfeeding

2: TX Capacity Investment Deferral

3: Backup Generation for Reliability/Resiliency

4: EV Charging Support

5: Solar + Storage

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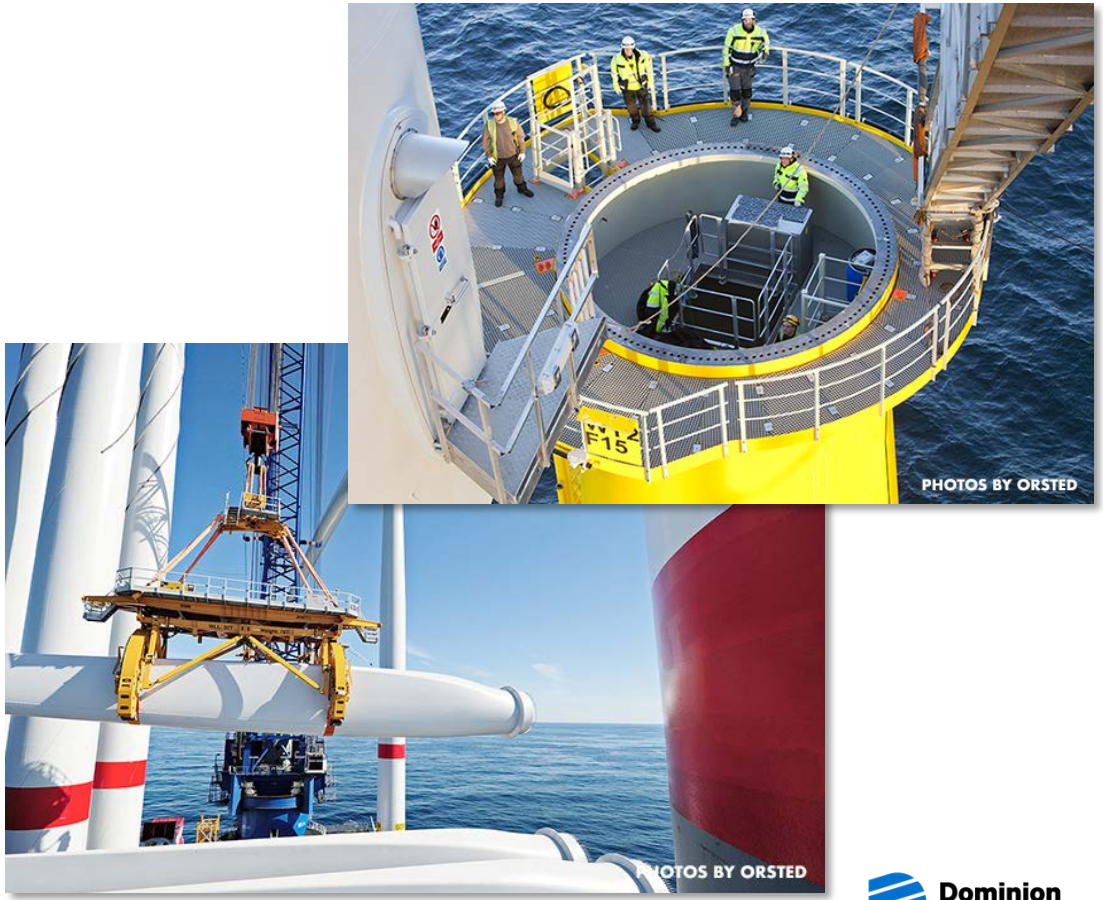
Offshore Wind

- Coastal Virginia Off-Shore Wind Project
- Two 6 MW Wind Turbines 27 miles off the coast of VA
- Second in the nation, first owned by electric utility
- Important stepping stone to commercial scale offshore wind
- Commitment to 3,000 MW of operational solar + wind by 2022



https://www.dominionenergy.com/company/making-energy/renewable-generation/wind/coastal-virginia-offshore-wind

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Deploying New FACTS Technology

- Faster response, more flexibility
- Power electronic devices continue to grow in use across the grid, from the substation to the customer
- Installing new power electronic devices across our transmission grid for dynamic support
  - Transmission STATCOMs and SVCs
  - Inverters for solar and wind generation
  - Piloting Distribution STATCOMs
- A need for engineers with both Power Systems and Power Electronics expertise

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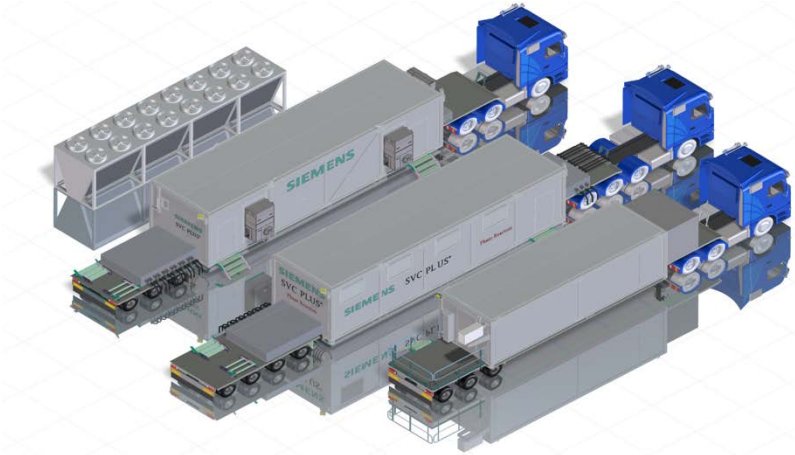
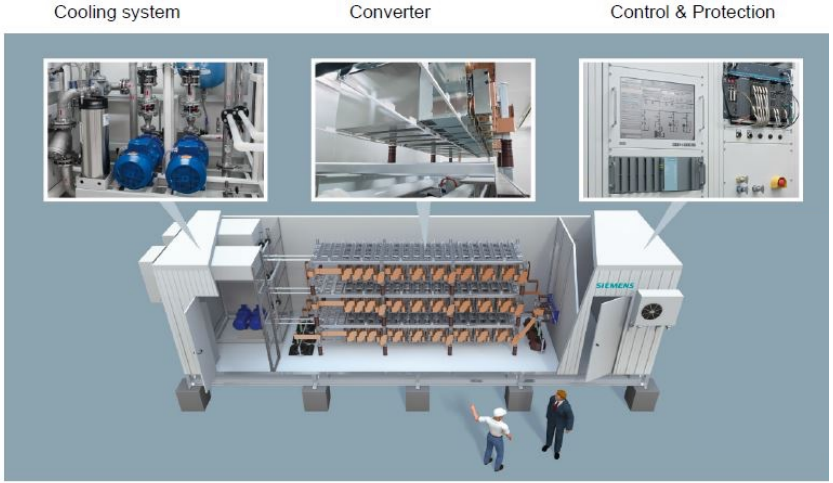
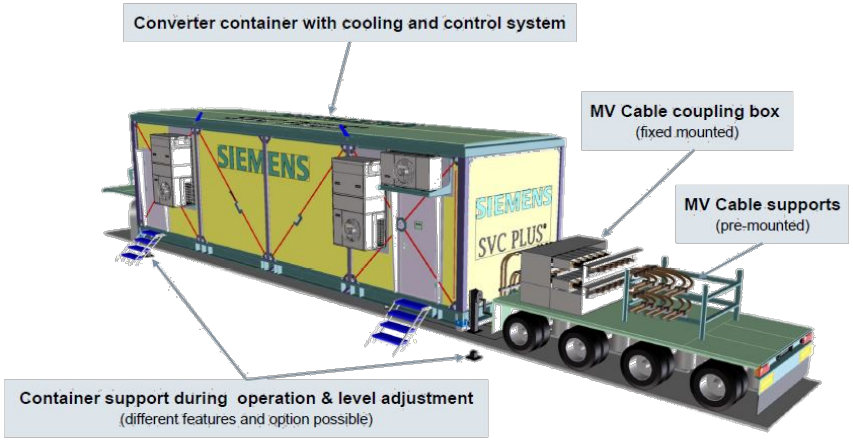
Mobile STATCOMs

- Swiss army knife for project execution
- Greater outage flexibility
- Shortens project execution time supporting higher throughput of grid improvements







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Mobile Substations & Other Mobile Equipment

- Rapid restoration of service (equipment & design)
- Unusual/emergency system conditions

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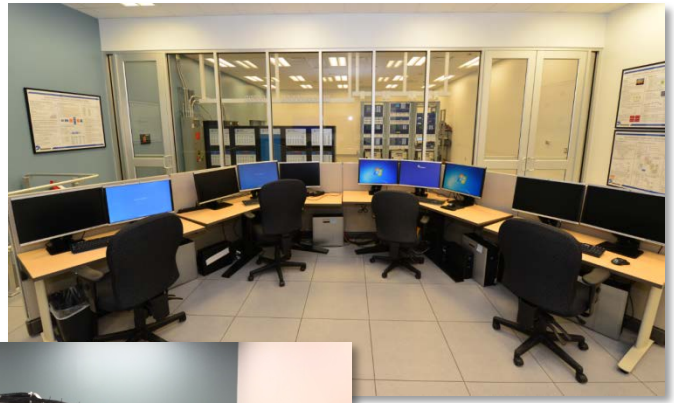
Advanced Laboratories and Simulation Capabilities

- New challenges demand better analytic capabilities
- Hardware in the loop (HIL) RTDS resources
- Include of advanced control systems for STATCOMs, SVCs, and protection & control devices
- HIL Testing of power electronic devices, including inverters and in the future batteries



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New Transmission System Operations Center

- Design and performance requirements for maintaining situational awareness, monitoring, and control of the grid
  - LEED certified
  - Uptime Institute certified design
  - Physical and cyber security
  - Hardened for earthquakes and tornadoes
  - Hardened against EMP
- Improved monitoring by upgrading our Security Control Center

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Synchrophasors Matter More Than Ever

Grid Complexity

Speed of Key Phenomenon & Behavior

Ability to Rely on Experience & Heuristics

Need for Greater Monitoring & Control

Need for Greater Quantitative Grid Insights

Simply put, our ability to work with and analyze synchrophasor data (and other high resolution sensor data) become critical bottlenecks for modernizing the grid, integrating renewable resources, and ensuring safe, reliable, and affordable delivery of electricity

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Dominion Energy's Synchrophasor Program

Robust deployment of sensors across transmission ~40K measured quantities

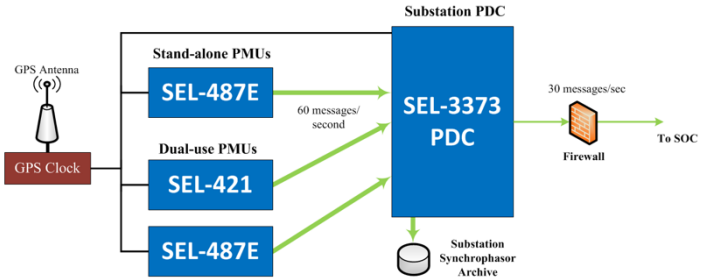
- Nearly full transmission system coverage
- Redundant in many places
- CIP and non-CIP

Active contributor in the community/industry

- NASPI
- DOE SGIG Demonstration Project – 2013
- DOE FOA970 – 2017
- Open source technologies – LSE
  - https://github.com/kdjones/lse
  - https://github.com/kdjones/openlse

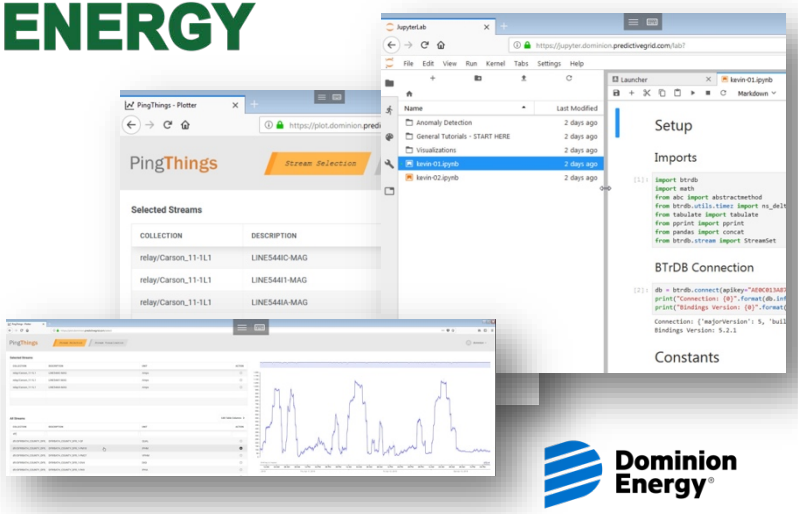
Getting into big data

- Working with PingThings & the PredictiveGrid
- New Engineering Analytics & Modeling team



U.S. DEPARTMENT OF ENERGY

NASPI



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2019

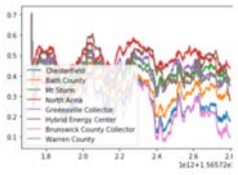
Getting into Big Data with Synchrophasor Use Cases

Currently exploring a wide variety of use cases for parameterizing the performance of the transmission grid.

Detecting Critical Operating Point

- Approaching critical operating condition (Hopf or saddle node bifurcation), oscillation damping decreases
- Autocorrelation coefficient increases rapidly near critical point, used as a metric

$$\rho(t) = \frac{\sum_{\tau=t-2\,mins:\,t} \hat{x}(\tau-1)\times\hat{x}(\tau)}{\sigma^2}$$

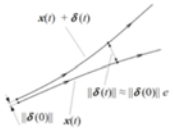


Transient Stability Detection

- The Lyapunov exponent (LE) is the principal criteria of chaos and represents the growth or decline rate of small perturbation along each main axis of the phase space system.
- Positive value gives loss of synchronism

$$\lim_{t\to\infty}\frac{1}{t}\log\frac{\|\partial x(t)\|}{\|\partial x(0)\|}$$

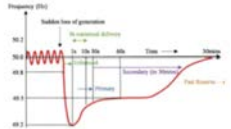
- Done on voltage phase angle at generator bus



Estimation of Inertial Response

$$M\times\dot{f} = P_{in} - P_{out}$$

- Challenges
  - P_{in} (changes with governor response) is not measured
    - Can give negative inertia values (P_{out} positively correlated with f since P_{in} changes)
  - For monitoring we need to estimate from ambient data and not only event data (using a model fit on small variations to estimate response during large disturbances)
- Some approaches –
  - Event based – Assume $P_{in} = constant$, linear regression
    $M\times\delta\dot{f} = -\delta P_{out}$
  - Ambient data
    - Large a large signal type dynamic model between f and P_{out}
    - Only large changes present are slow variations in equilibrium point



ZIP Load Model Tuning

- ZIP load model is widely used for load flow/steady state studies
  $P, Q = a_0 + a_1 V + a_2 V^2$
- Aim is to tune the model parameters online with PMU data
- Linear regression,

$$\begin{bmatrix} P(t_1),\dots,P(t_n) \\ Q(t_1),\dots,Q(t_n) \end{bmatrix} = \begin{bmatrix} a_0^P, a_1^P, a_2^P \\ a_0^Q, a_1^Q, a_2^Q \end{bmatrix} \times \begin{bmatrix} 1,\dots,1 \\ V(t_1),\dots,V(t_n) \\ V^2(t_1),\dots,V^2(t_n) \end{bmatrix}$$

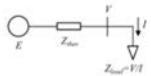
- Challenge is that load is of the form,
  $(P, Q)_{scale}\times(a_0 + a_1 V + a_2 V^2)$

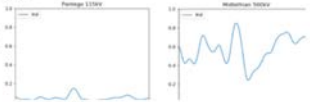
Where we don't have access to $(P, Q)_{scale}$ data

Data-driven Voltage Stability Assessment via Thevenin Equivalent

- Find load margin of each bus
- Equate external system by Thevenin circuit
- Voltage stability index based on maximum power transfer on equivalent system

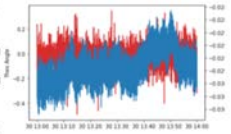
$$Ind = \frac{|Z_{load}| - |Z_{thev}|}{|Z_{load}|}$$





Angular Stability Monitoring

- To monitor steady state angular stability (saddle node bifurcation) using local line measurements
- Voltage phase angle difference across line has limited information
- Thevenin voltage phase angle difference has been shown to be a good observer
  - Monitoring it and comparing it to normal limits found through historical data or heuristic limits e.g. $\pm\frac{\pi}{2}$



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