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Emerging Reliability Issues for the Bulk Power System

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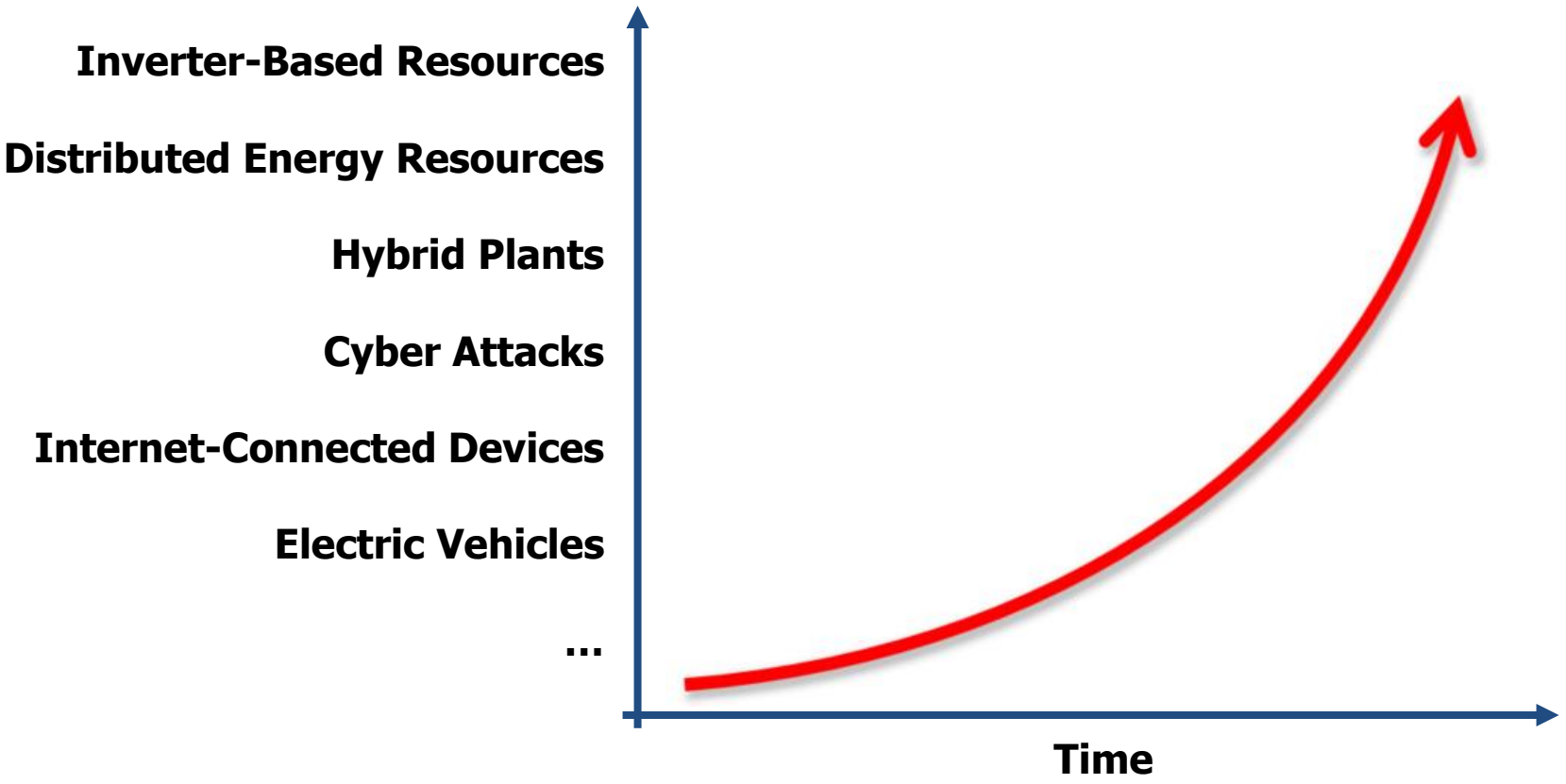
RELIABILITY | RESILIENCE | SECURITY




Rapid Evolution of the Energy Sector



Three Topics for Consideration

- **Changing nature of the bulk power system**
  - Evolving transition to inverter-based resources
  - New technologies and controls
  - Changing grid dynamics
- **Evolution of distribution system and customer technologies**
  - Distributed energy resources and aggregators
  - Prosumers and customer-side technologies
  - New markets and policies
- **Integration of security and engineering**
  - Protection of critical assets and cyber systems
  - Coordinated cyber-physical system considerations
  - Rapidly evolving area of focus by all applicable entities

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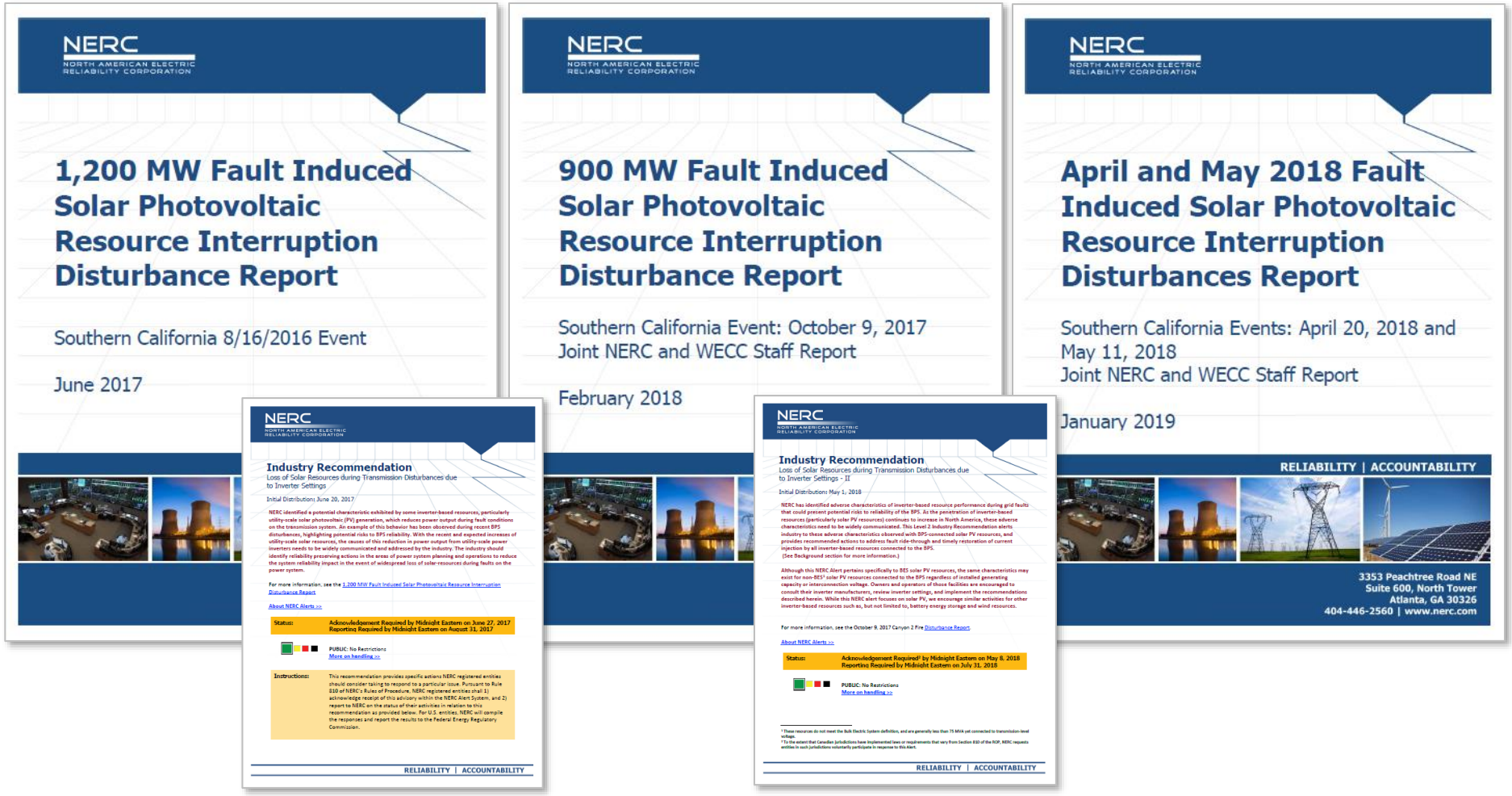
Changing Technologies and Grid Dynamics on the Bulk Power System

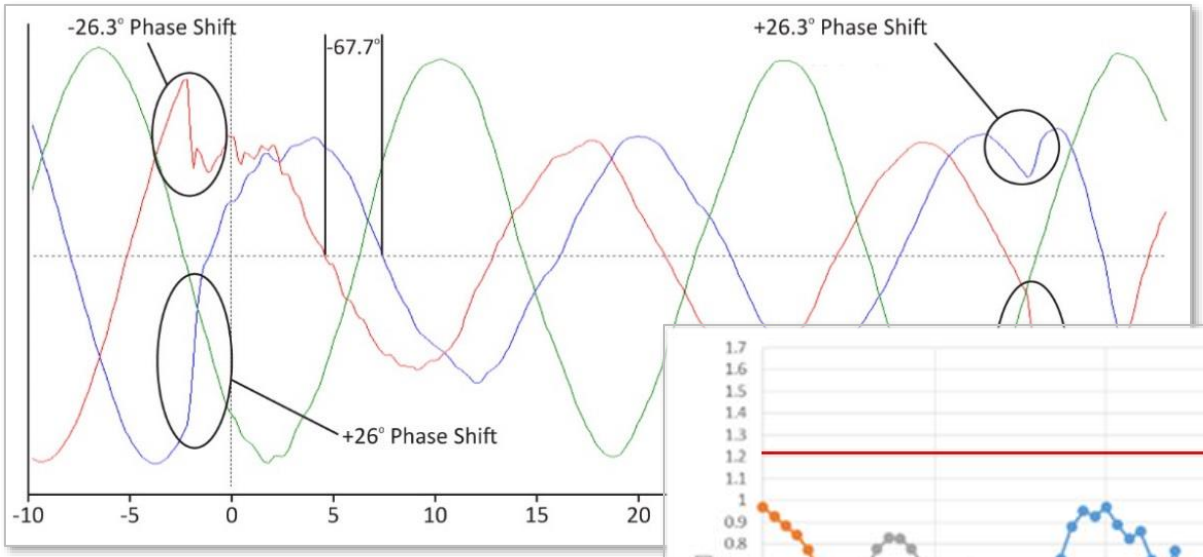
NERC Inverter-Based Resource Performance Task Force (IRPTF)

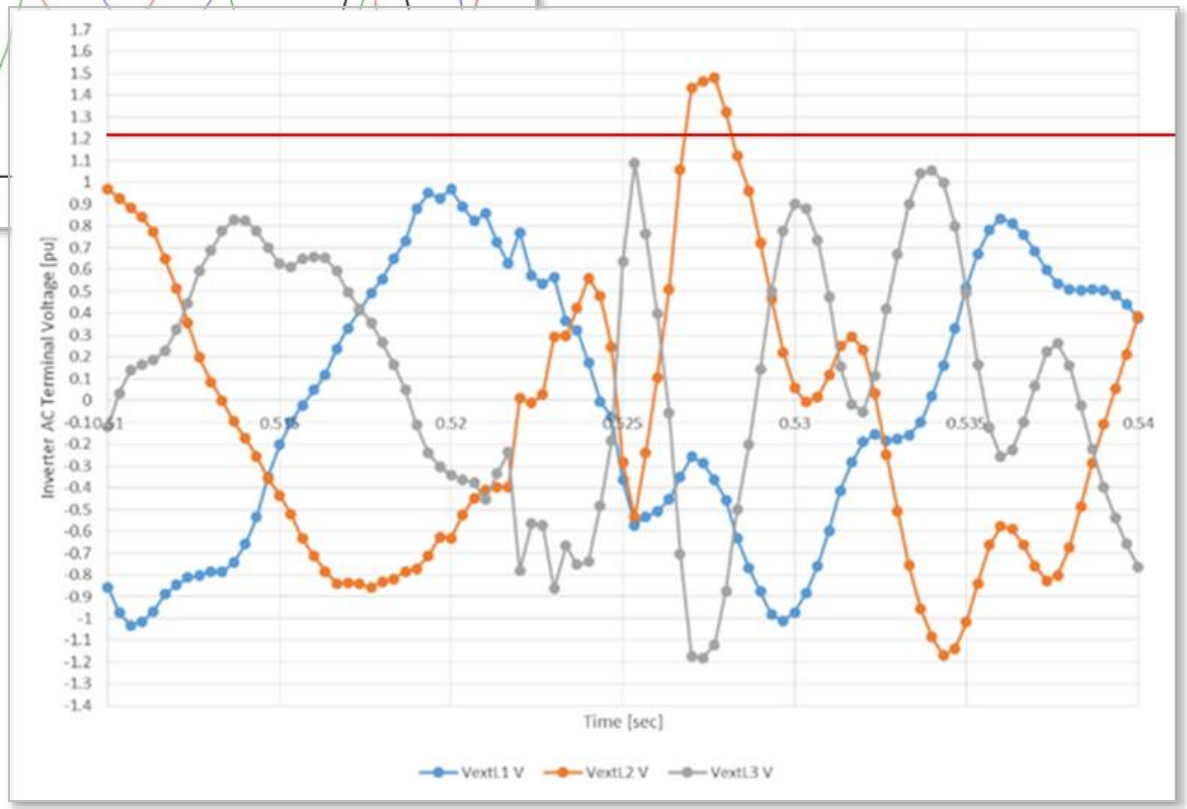


NERC Disturbance Reports and Alerts

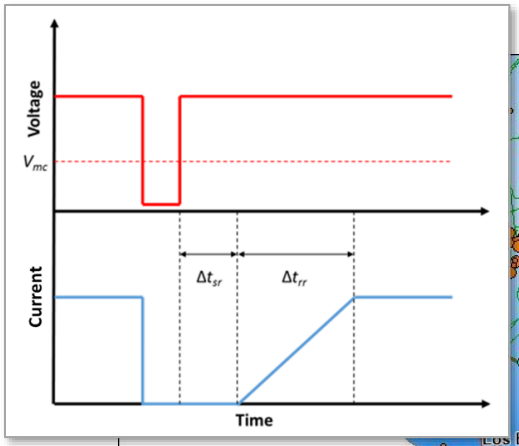


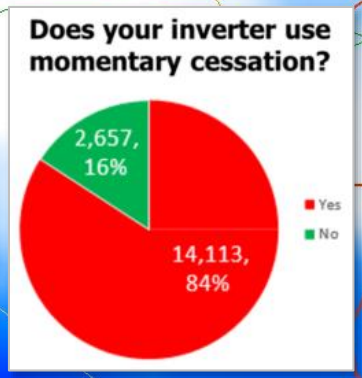
Various Types of Inverter Tripping





Momentary Cessation – NERC Alert I





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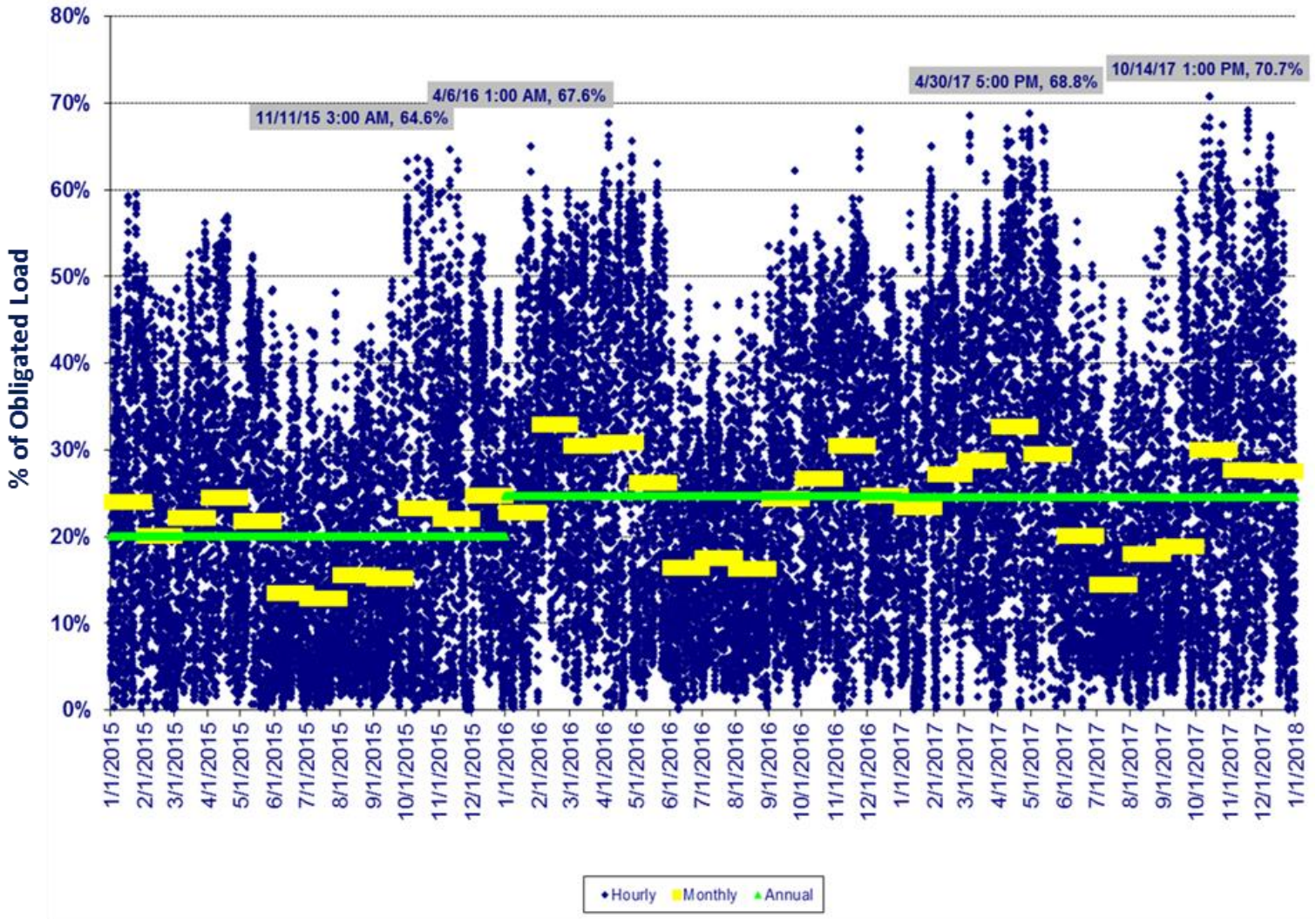
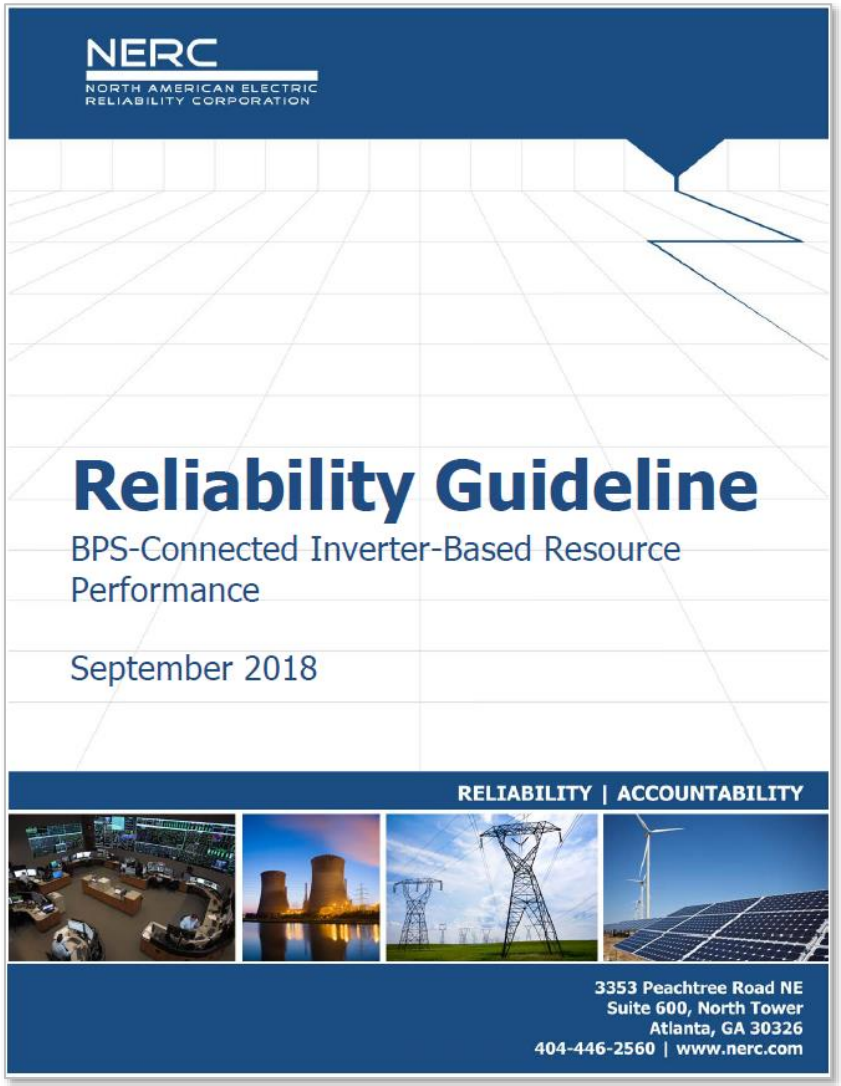
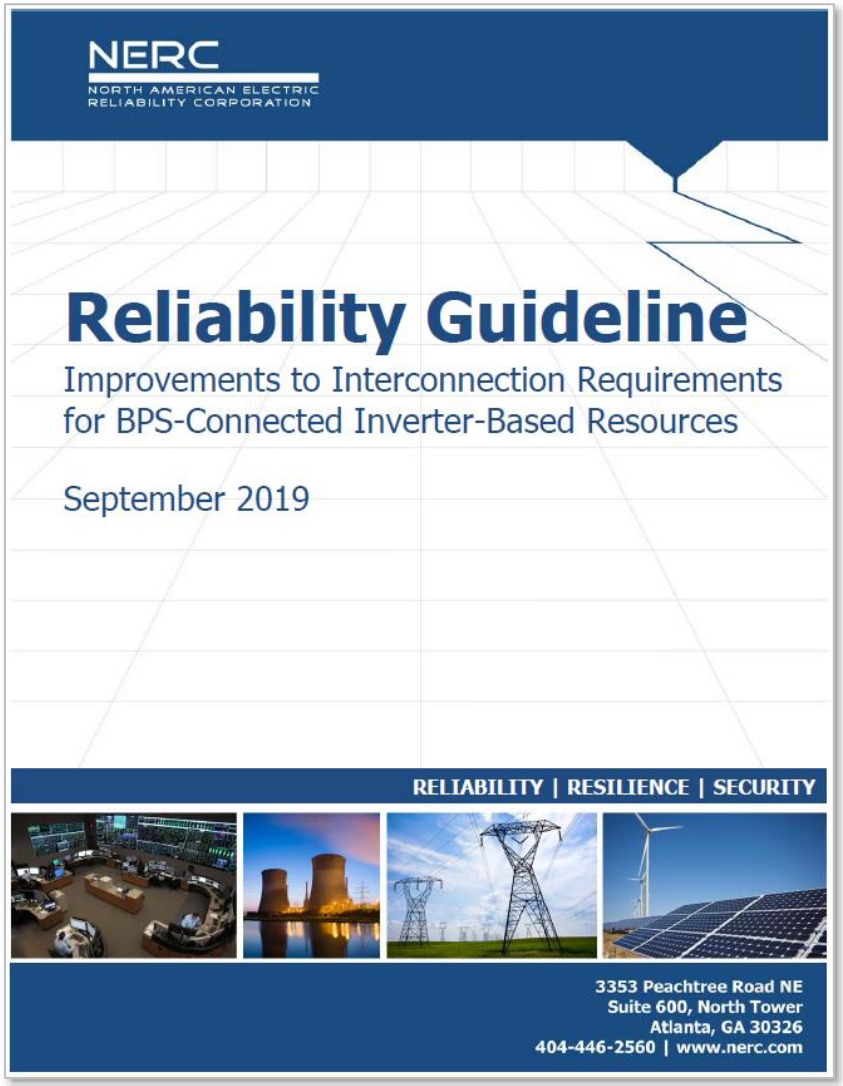
"Energy Transition" to High Penetrations of IBRs

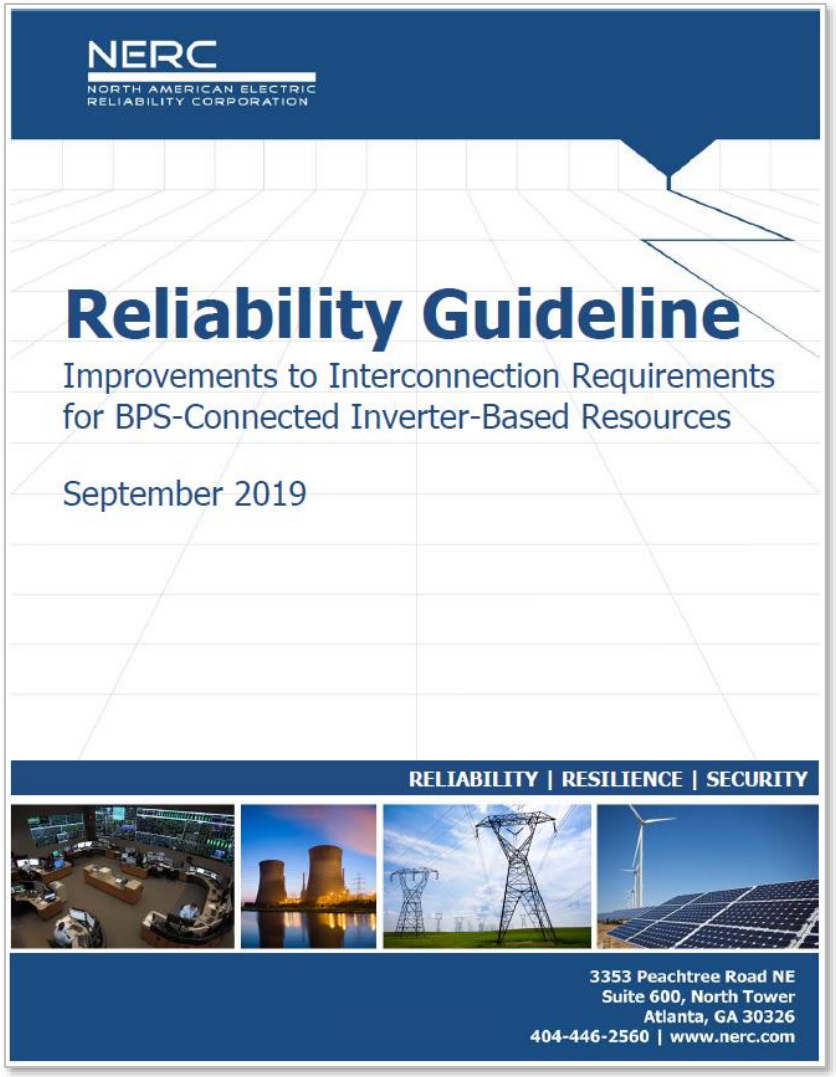


NERC Reliability Guideline





Reliability Guideline: IBRs and FAC-001 and FAC-002



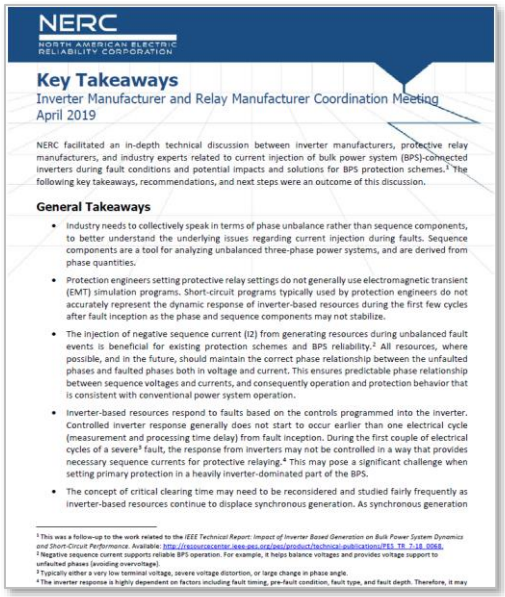
NOTICE:

ACTIONABLE RECOMMENDATIONS CONTAINED WITHIN!

- Strong recommendations to improve interconnection requirements AND interconnection study processes
- All TOs/TPs/PCs should be considering this guideline and adopting its recommendations, as applicable

Changing BPS Fault Characteristics

Factor	Synchronous World	Inverter-Based World
Fault Current Magnitude	Consistent, High	Consistent, Low
Fault Current Phase Relationship	Consistent, Predictable	Consistent, Unpredictable
Short Circuit Model Accuracy and Certainty	Mature	Immature, Evolving



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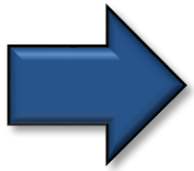
Key Takeaways
Inverter Manufacturer and Relay Manufacturer Coordination Meeting
April 2019

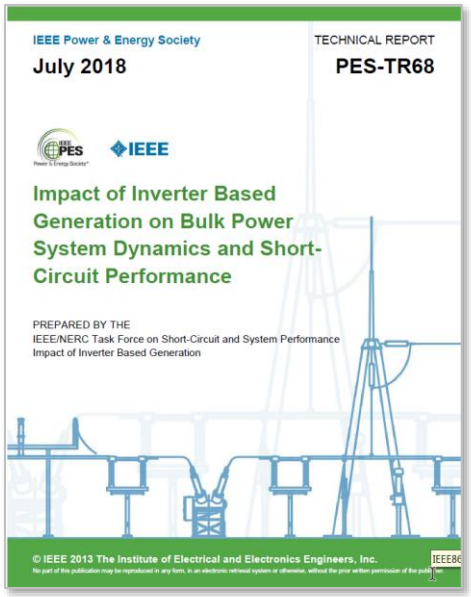
NERC facilitated an in-depth technical discussion between inverter manufacturers, protective relay manufacturers, and industry experts related to current injection of bulk power system (BPS)-connected inverters during fault conditions and potential impacts and solutions for BPS protection schemes.[1] The following key takeaways, recommendations, and next steps were an outcome of this discussion.

General Takeaways

- Industry needs to collectively speak in terms of phase unbalance rather than sequence components, to better understand the underlying issues regarding current injection during faults. Sequence components are a tool for analyzing unbalanced three-phase power systems, and are derived from phase quantities.
- Protection engineers setting protective relay settings do not generally use electromagnetic transient (EMT) simulation programs. Short-circuit programs typically used by protection engineers do not accurately represent the dynamic response of inverter-based resources during the first few cycles after fault inception as the phase and sequence components may not stabilize.
- The injection of negative sequence current (I2) from generating resources during unbalanced fault events is beneficial for existing protection schemes and BPS reliability.[2] All resources, where possible, and in the future, should maintain the correct phase relationship between the unfaulted phases and faulted phases both in voltage and current. This ensures predictable phase relationship between sequence voltages and currents, and consequently operation and protection behavior that is consistent with conventional power system operation.
- Inverter-based resources respond to faults based on the controls programmed into the inverter. Controlled inverter response generally does not start to occur earlier than one electrical cycle (measurement and processing time delay) from fault inception. During the first couple of electrical cycles of a severe[3] fault, the response from inverters may not be controlled in a way that provides necessary sequence currents for protective relaying.[4] This may pose a significant challenge when setting primary protection in a heavily inverter-dominated part of the BPS.
- The concept of critical clearing time may need to be reconsidered and studied fairly frequently as inverter-based resources continue to displace synchronous generation. As synchronous generation

[1] This was a follow-up to the work related to the *IEEE Technical Report: Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance*. Available: http://resourcecenter.ieee-pes.org/pes/product/technical-publications/PES_TR_7-18_0068.
[2] Negative sequence current supports reliable BPS operation. For example, it helps balance voltages and provides voltage support to unfaulted phases (avoiding overvoltage).
[3] Typically either a very low terminal voltage, severe voltage distortion, or large change in phase angle.
[4] The inverter response is highly dependent on factors including fault timing, pre-fault condition, fault type, and fault depth. Therefore, it may





IEEE Power & Energy Society
July 2018
TECHNICAL REPORT
PES-TR68

PES IEEE

Impact of Inverter Based Generation on Bulk Power System Dynamics and Short-Circuit Performance

PREPARED BY THE
IEEE/NERC Task Force on Short-Circuit and System Performance
Impact of Inverter Based Generation

https://www.nerc.com/comm/PC/IRPTF%20Workshops/Key_Takeaways_April_2019_Inverter_Relay_Manufacturer_Meeting.pdf
https://resourcecenter.ieee-pes.org/technical-publications/technical-reports/PES_TR_7-18_0068.html

Grid Short-Circuit Strength Decreasing in Many Areas

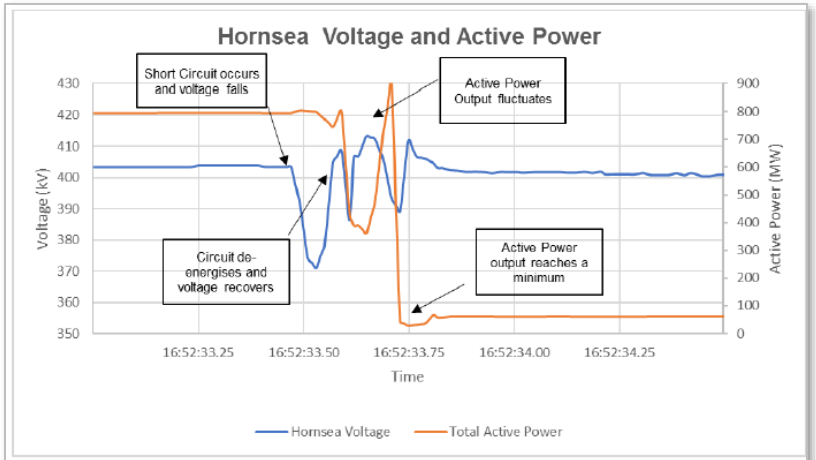


Figure 7 – Voltage and Active Power at Hornsea

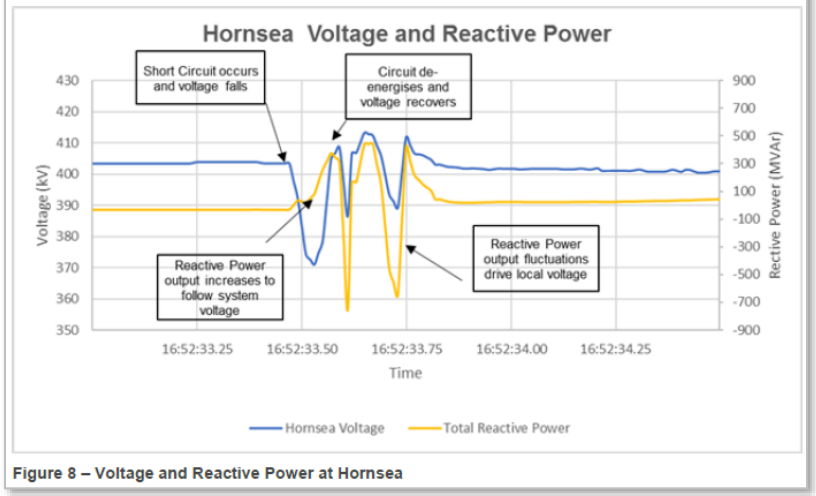
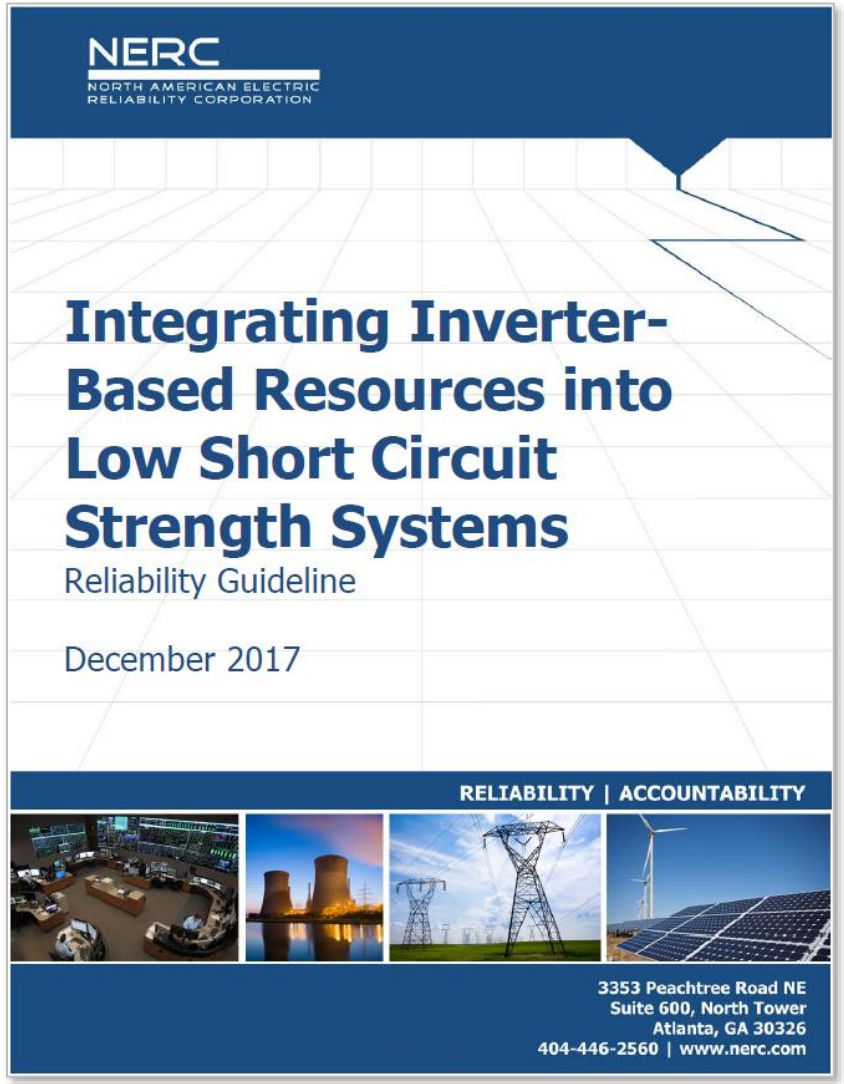
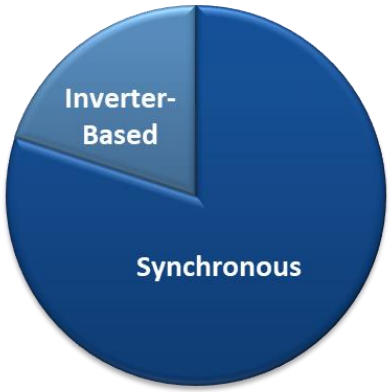


Figure 8 – Voltage and Reactive Power at Hornsea

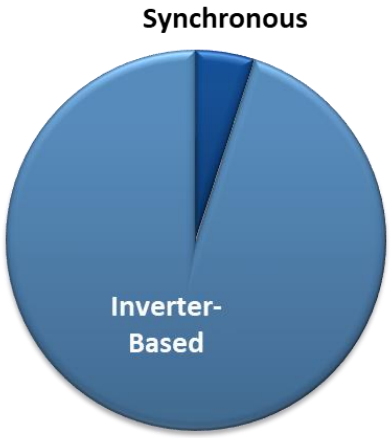
[Source: Ofgem]



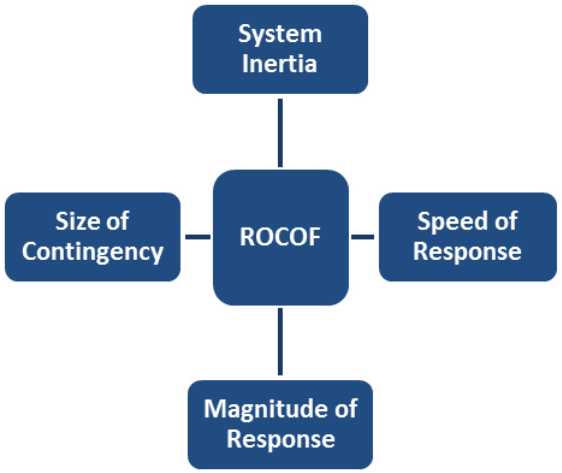
White Paper: FFR Concepts and BPS Reliability Needs



Historically…



Possible Future…

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Fast Frequency Response Concepts and Bulk Power System Reliability Needs

NERC Inverter-Based Resource Performance Task Force (IRPTF)
White Paper

March 2020

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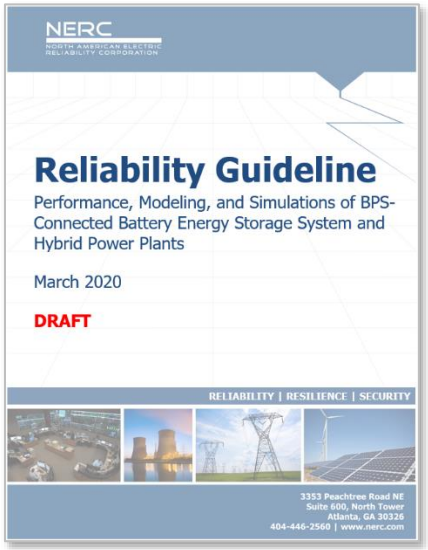
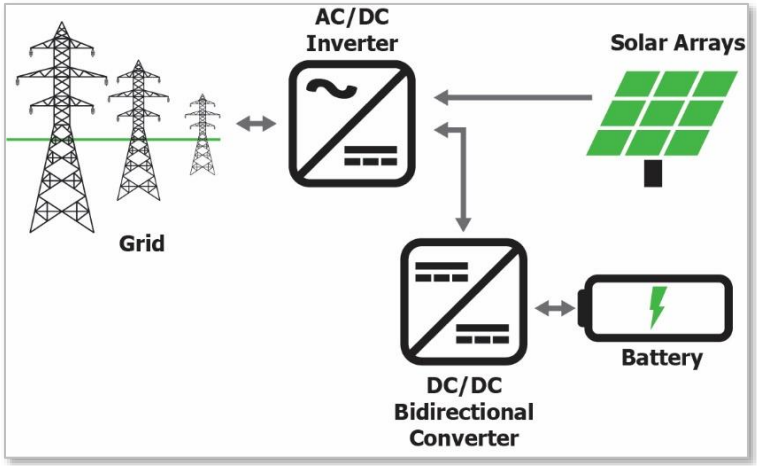
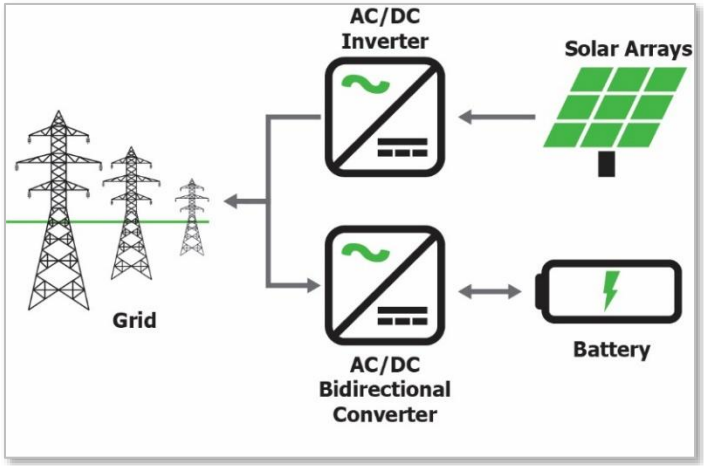
Technical Reports on BPS-Connected IBR Modeling and Studies

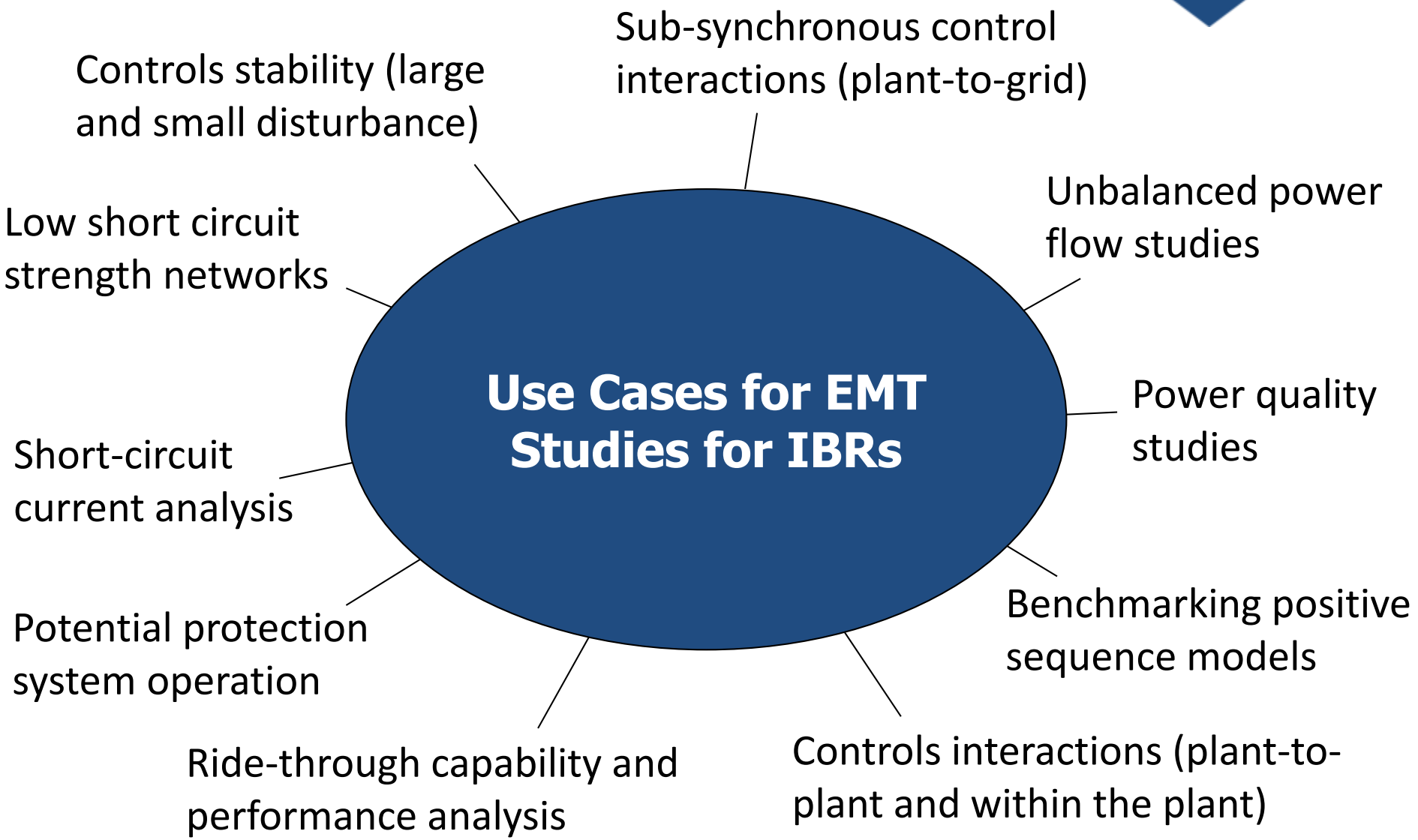
BESS and Hybrid Power Plants







Possible Studies using EMT Models



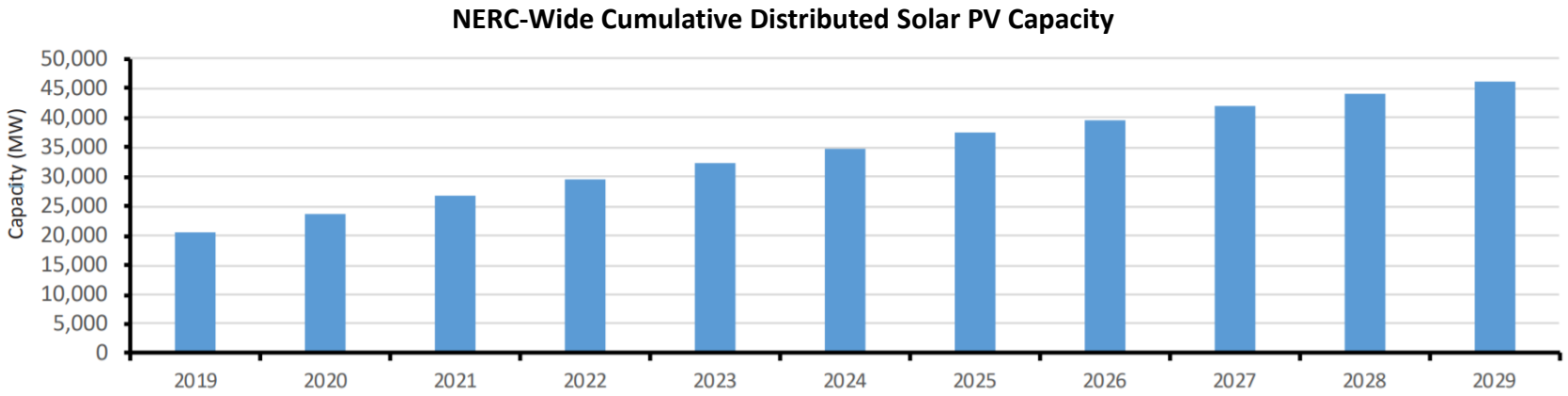
NERC System Planning Impacts of Distributed Energy Resources Working Group (SPIDERWG)

Aggregate Impacts of Distribution-Connected Energy Resources

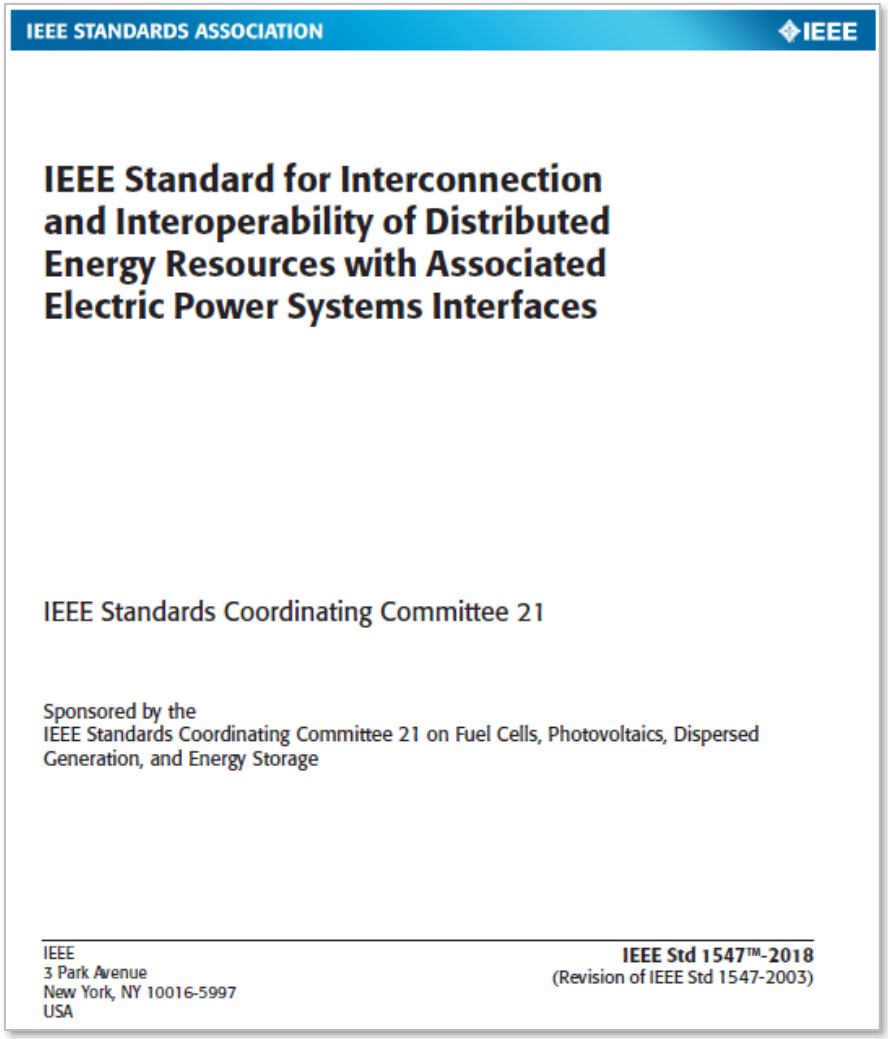


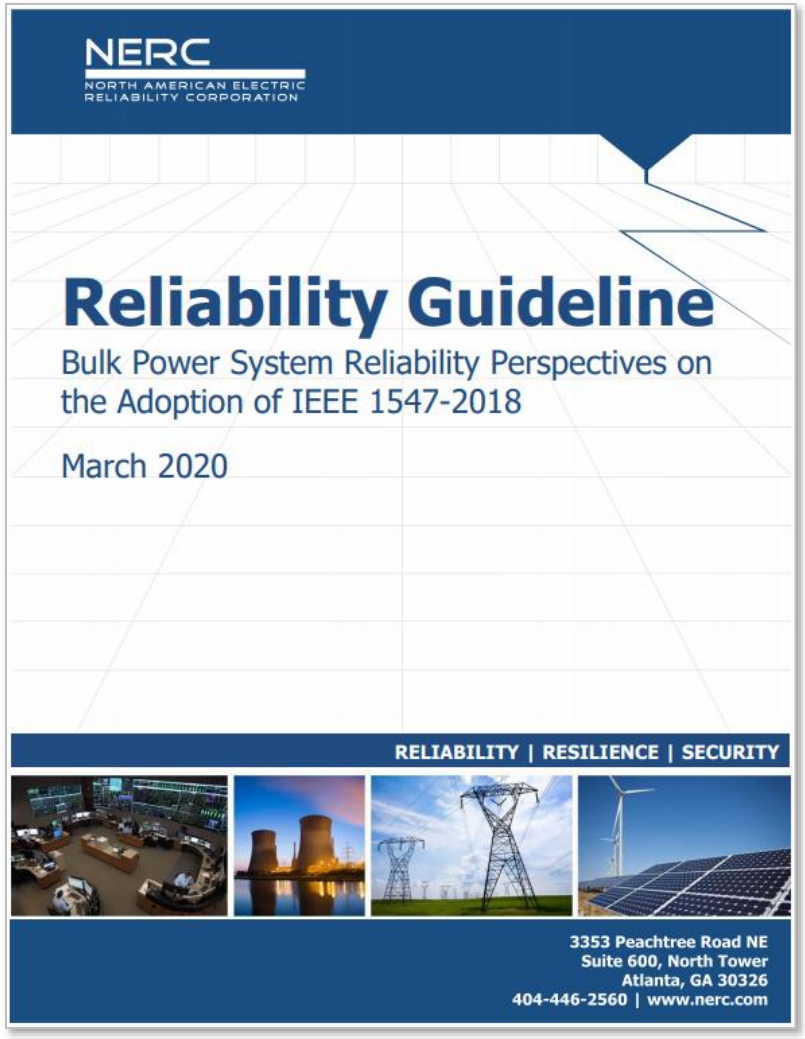
Continuing Trends in DERs

- Continued rapid growth of distributed solar PV
- Distributed energy storage entering market rapidly
- Public interest in DERs and microgrids for increased resilience
  - Example: California public power shutoffs, wildfires, hurricanes, storms
- Focus on customer-side opportunities for grid flexibility
  - Coordinated DER, energy storage, and smart load controls
- Transportation electrification
- New market opportunities and regulations – e.g., FERC Order 2222



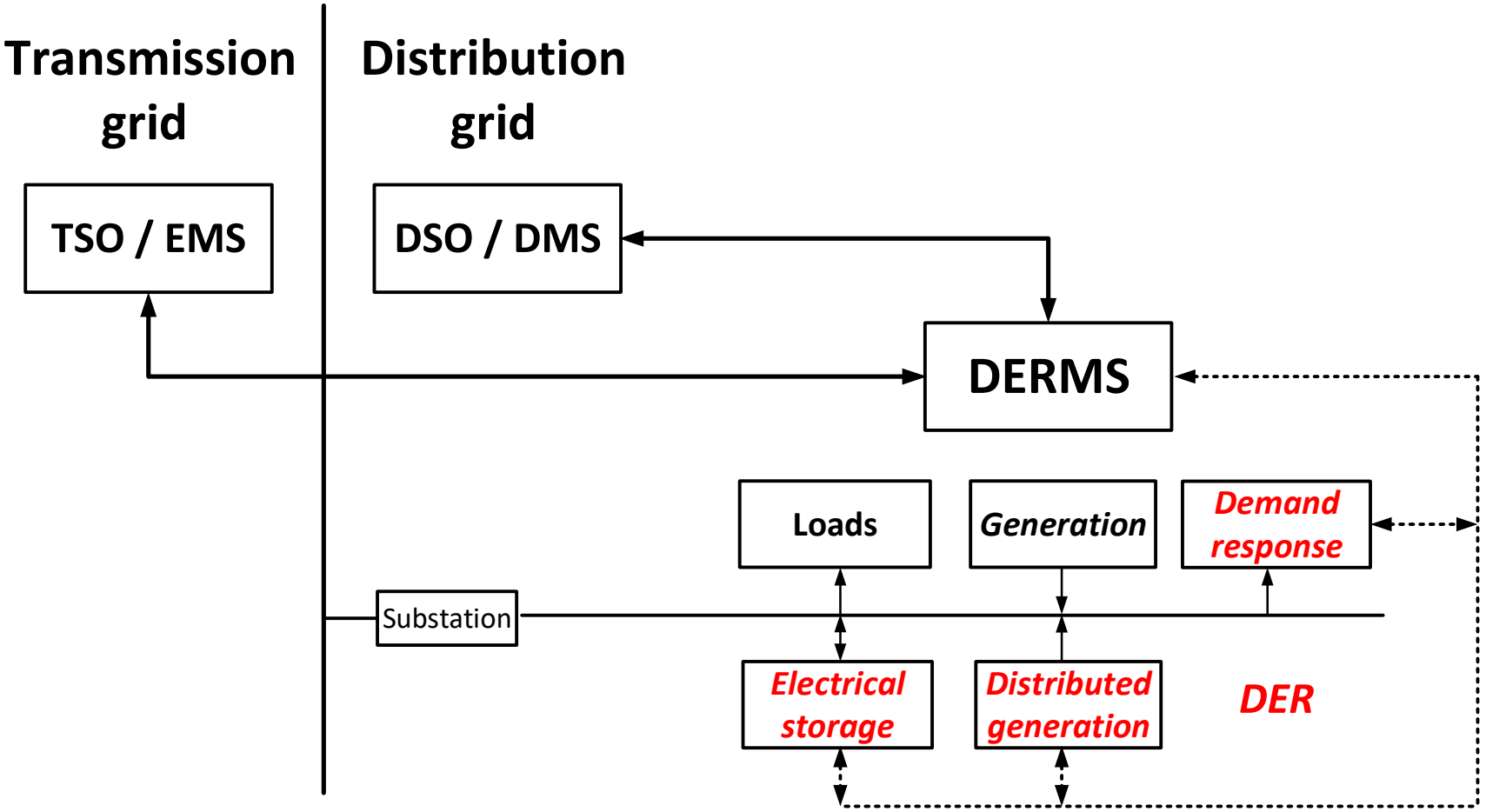
IEEE 1547-2018 and BPS Reliability Perspectives





Source: IEEE SA

Distributed Energy Resource Management Systems (DERMS)



Source: IEEE P2030.11

Portion of the distribution grid

Integration of Physical Security, Cyber Security, and Engineering Practices

NERC Security Integration and Technology Enablement Subcommittee (SITES) (future)

Integration of Security and Engineering

Historically…

Today…

Customer Technology Advancements

- Multi-sector evolution
  - Industrial, commercial, residential
- Boundary-spanning security concerns
  - Distributed energy resources (DERs)
  - DER aggregators and DERMS
  - Internet of Things
    - Connectivity of “everything”…
  - Electric vehicles
  - Battery storage and microgrids

Source: Home Appliances World

Source: Electrive

Key Security Threats and Challenges

- Supply chain compromise
- Increased sophistication of social engineering
- Remote access – employees, vendors, third-party and foreign control centers
- Boundary-spanning security risks
- Convergence of IT and OT networks
- Recovery from coordinated physical-cyber attacks
- Organizational compliance-centric focus
- Lack of security integration
- Lack of qualified security personnel and resources in industry
- Compromise of operational technology (OT) networks leading to electrical system outage or loss of life
  - Compromise of protection systems in key transmission locations
  - Compromise and control of BPS or distribution elements
  - Compromise of energy supply
  - Loss of situational awareness (e.g., Ukraine 2015)

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Questions and Answers

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