Grid Reliability During Abnormal Operations

ESIG

ENERGY SYSTEMS INTEGRATION GROUP

Power Systems are Rarely "Fully Intact"

- **There will always be planned and unplanned outages:**
  - Routine transmission maintenance
  - Emergency transmission maintenance
  - Area interchange fluctuations
  - Carbon-based outages
  - Market-based outages
- **What is "abnormal" in the context of this training?**
  - Focusing on typical "sudden" disturbances
    - What causes typical disturbances
    - What happens to the power system when disturbances happen
    - How to ensure reliability throughout and following the disturbances
    - Importance of ridethrough criteria in ensuring reliability

What Disturbs the Grid?

- **Natural Disturbances**
  - Acts of Nature: storms, lightning, flooding, wind, fire, geomagnetic disturbances
  - Wildlife
- **Technological Disturbances**
  - Failures of physical or digital infrastructure
- **Human-driven Disturbances**
  - Accidents
  - Physical attacks
  - Cyber attacks
  - Other intentional acts meant to disrupt the power system

What Disturbs the Grid?

Threats	Technologies/Sectors	Potential Impacts
Temperature Change	**Generation**	
	Biopower	Crop damage and increased irrigation demand
	Hydropower	Reduced generation capacity and operational changes
	Solar PV	Reduced generation capacity (e.g., higher heat can impact panel efficiency)
	Thermal technologies (coal, geothermal, natural gas, nuclear, concentrated solar power)	Reduced generation efficiency and capacity
	Transmission and distribution	Reduced transmission efficiency and capacity
	Demand	Increased demand for cooling
Water Availability and Temperature	**Generation**	
	Biopower	Decreased crop production
	Hydropower	Reduced generation capacity and operational changes
	Thermal technologies	Reduced generation capacity
Wind Speed Changes	**Generation**	
	Wind	Variations in generation capacity, making investments harder to pay back or generation harder to predict long-term
Sea Level Rise	**Generation** Bioenergy Hydropower Solar PV Thermal technologies Wind	Physical damage to infrastructure and power disruption/loss—all generation technologies
Extreme Events (e.g., storms, short-term extreme heat events, floods, fires, and other natural disasters)	**Generation** Bioenergy Hydropower Solar PV Thermal technologies Wind	Physical damage to infrastructure and fuel sources, and power disruption/loss—all generation technologies
	Transmission and distribution	Reduced transmission efficiency and capacity Reduced transmission efficiency and capacity
	Demand	Unpredictable changes to peak electricity demand
Technological	**Generation** Bioenergy Hydropower Solar PV Thermal technologies Wind	Physical damage and power disruption/loss—all generation technologies
	Transmission and distribution	Physical damage and reduced transmission capacity
	Demand	Unpredictable demand
Human-caused (e.g., cyberattacks, accidents, and physical attacks/ malicious events)	**Generation** Bioenergy Hydropower Solar PV Thermal technologies Wind	Physical damage and power disruption/loss—all generation technologies
	Transmission and distribution	Physical damage and reduced transmission capacity
	Demand	Unpredictable demand

Source: NREL

Transposing Real Life to Reliability Planning

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- **Events that disturb the power system come in many shapes, sizes, and timeframes**
  - Planning for "every" possible eventuality must be balanced with cost to do so
  - NERC standards (i.e. TPL series) and local reliability councils specify what **must** be planned for
- **Many complex occurrences can be transposed to simple planning contingencies**
  - Fuel loss – reduced nameplate or trips
  - Car crash into substation – equipment trip
  - Cyber attacks – generator or element trips

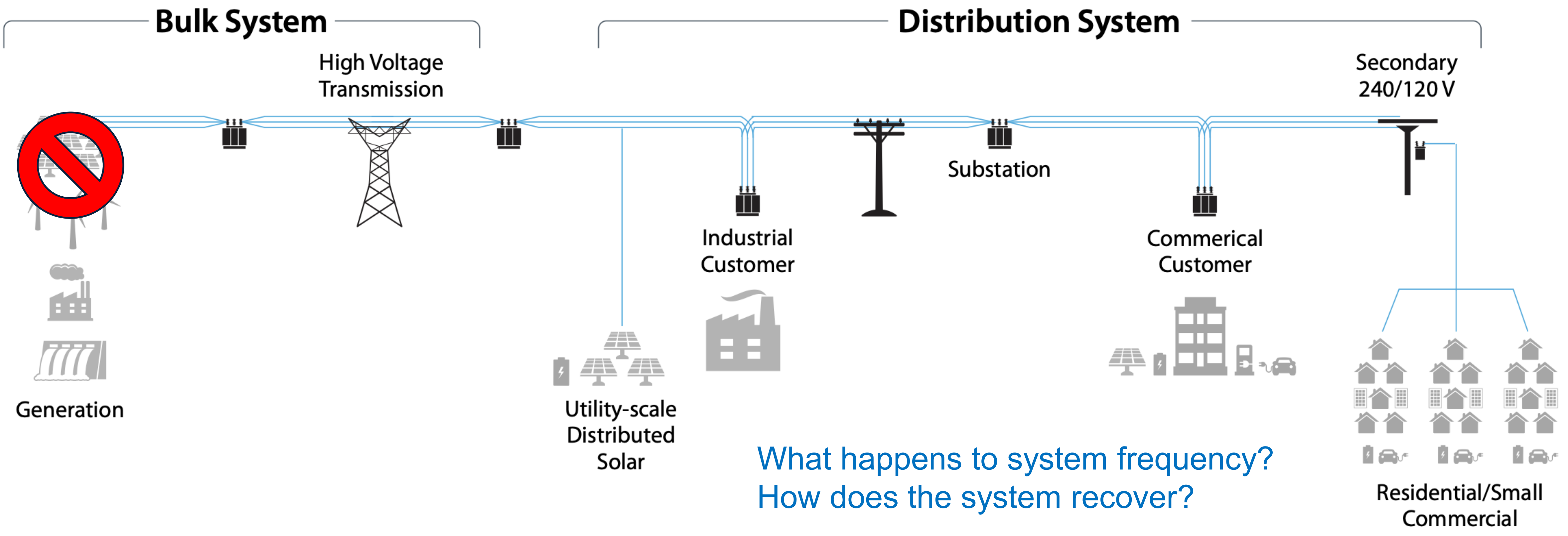
Threat Likelihood Scores		Threshold Descriptions
Categorical	Numerical	
High	9	Accidents
Medium-High	7	More likely to occur than not.
Medium	5	May occur.
Low-Medium	3	Slightly elevated level of occurrence. Possible, but more likely not to occur.
Low	1	Very low probability of occurrence. An event has the potential to occur but is still very rare.

Source: NREL

Categorizing Disturbances

- **Most real-world grid disturbances fall into just a few categories**
  - Generator trip
  - Load trip
  - Transmission element trip or enter service
  - (Reduced nameplate-type disturbances should be handled in the long-term timeframe through resource adequacy)
- **Even these simple categories have nuance**
  - Contingency events are messy
    - Some contingencies have automatic actions included in the events
  - Contingencies as used in the interconnection and planning processes often exclude return to service behaviors
  - Contingencies may cascade and are difficult to model

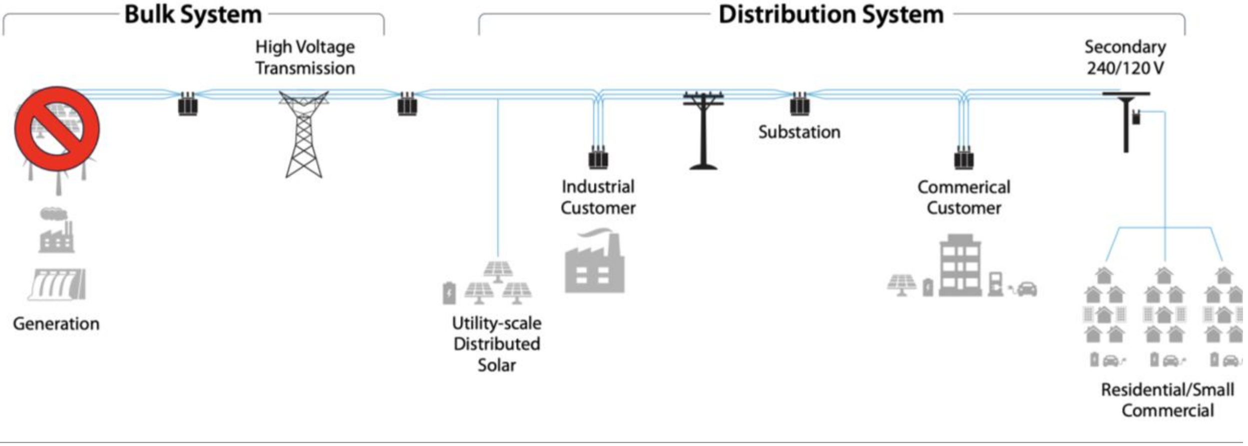
Disturbance Examples: Generator Trip

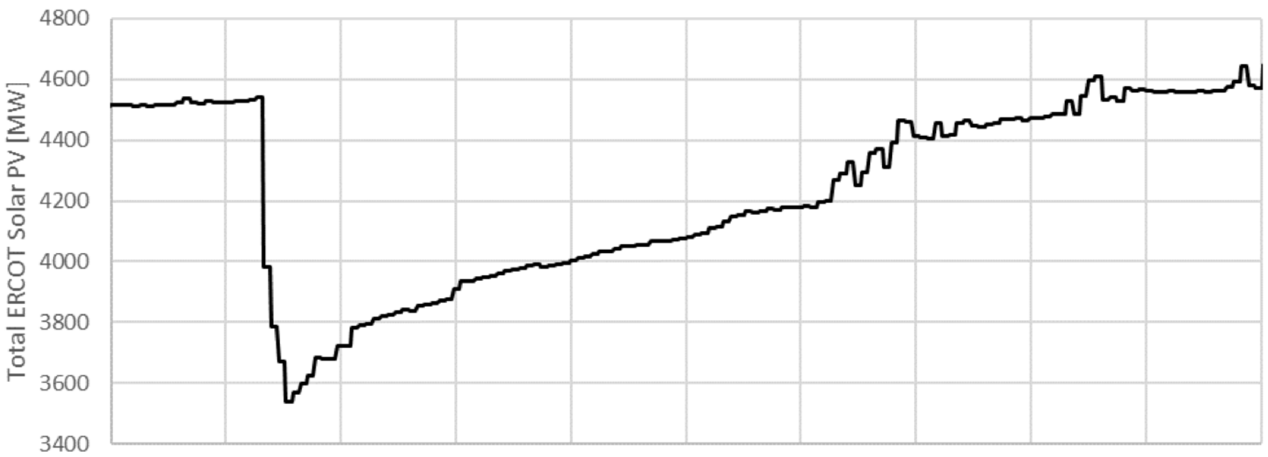


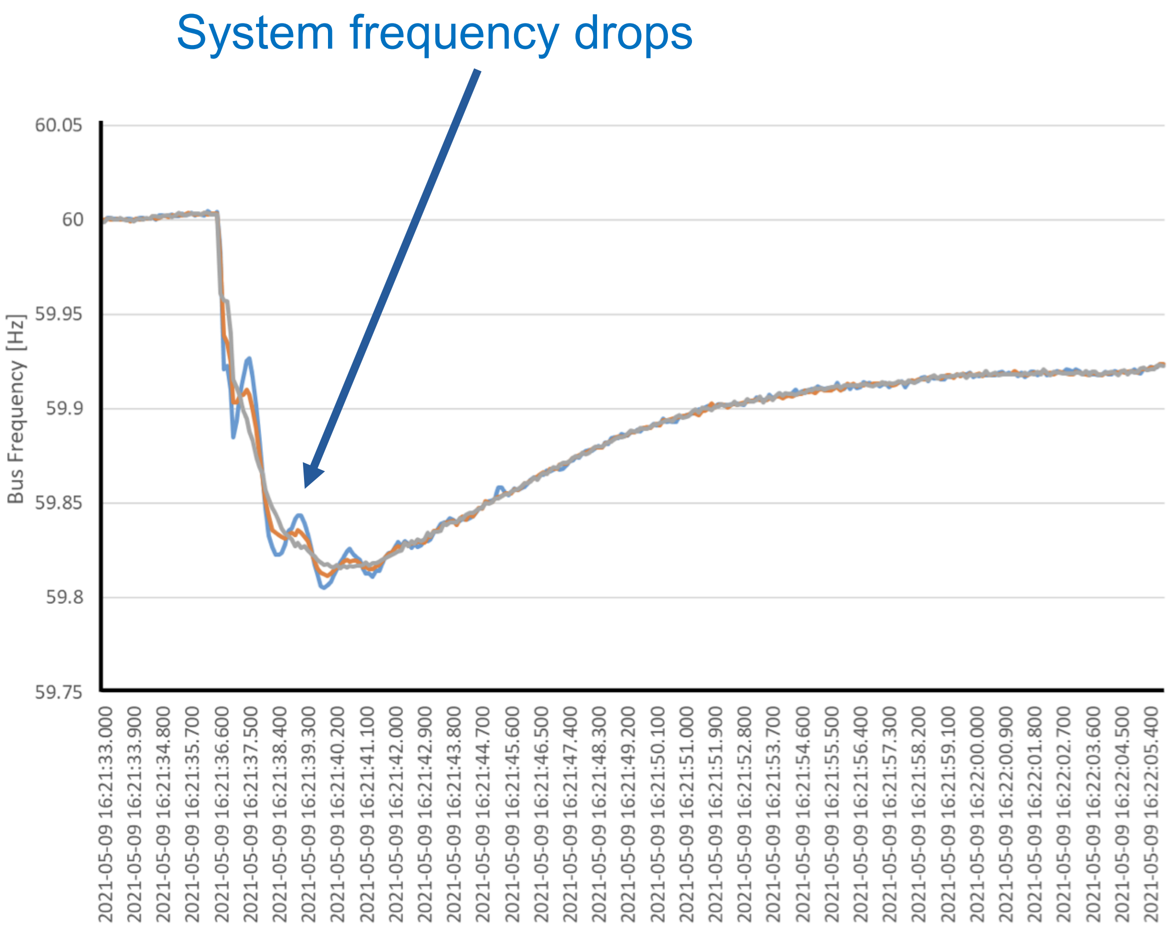
What happens to system frequency?
How does the system recover?

Source: NREL

Disturbance Examples: Generator Trip



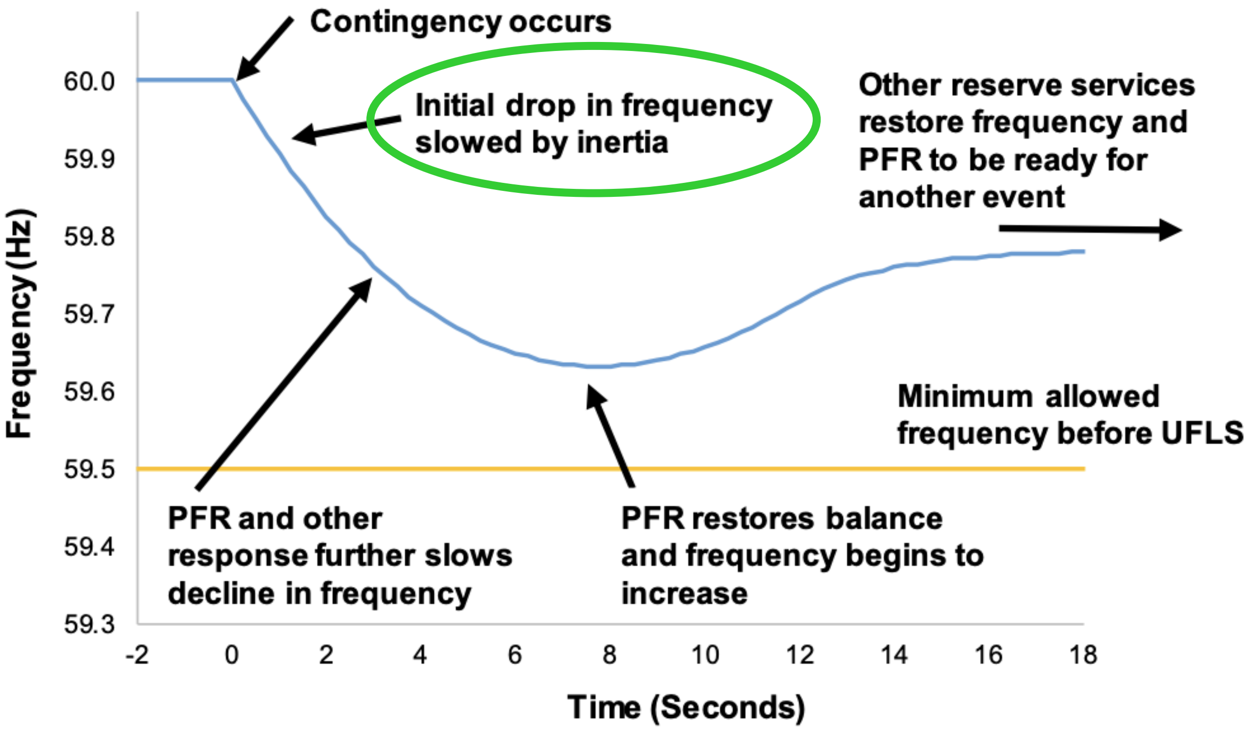




Source: [NERC]

Successful Recovery From Low Frequency

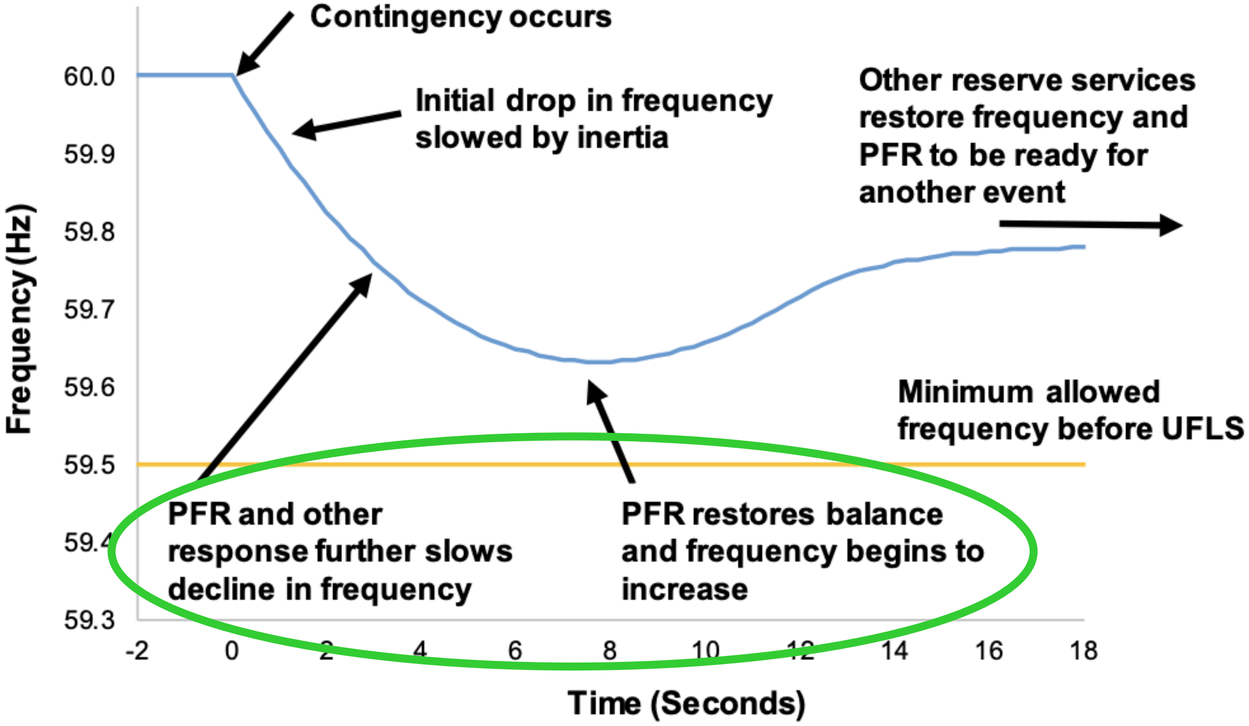
- **Inertia provides “first” response in the current paradigm**
  - Spinning mass-driven synchronous machines resist changes to system frequency based on physics
- **Current power system planning and resource mix depends on inertia**
  - Current underfrequency load shedding programs depend on slowed ROCOF and arrested nadirs



Source: [NREL]

Successful Recovery From Low Frequency

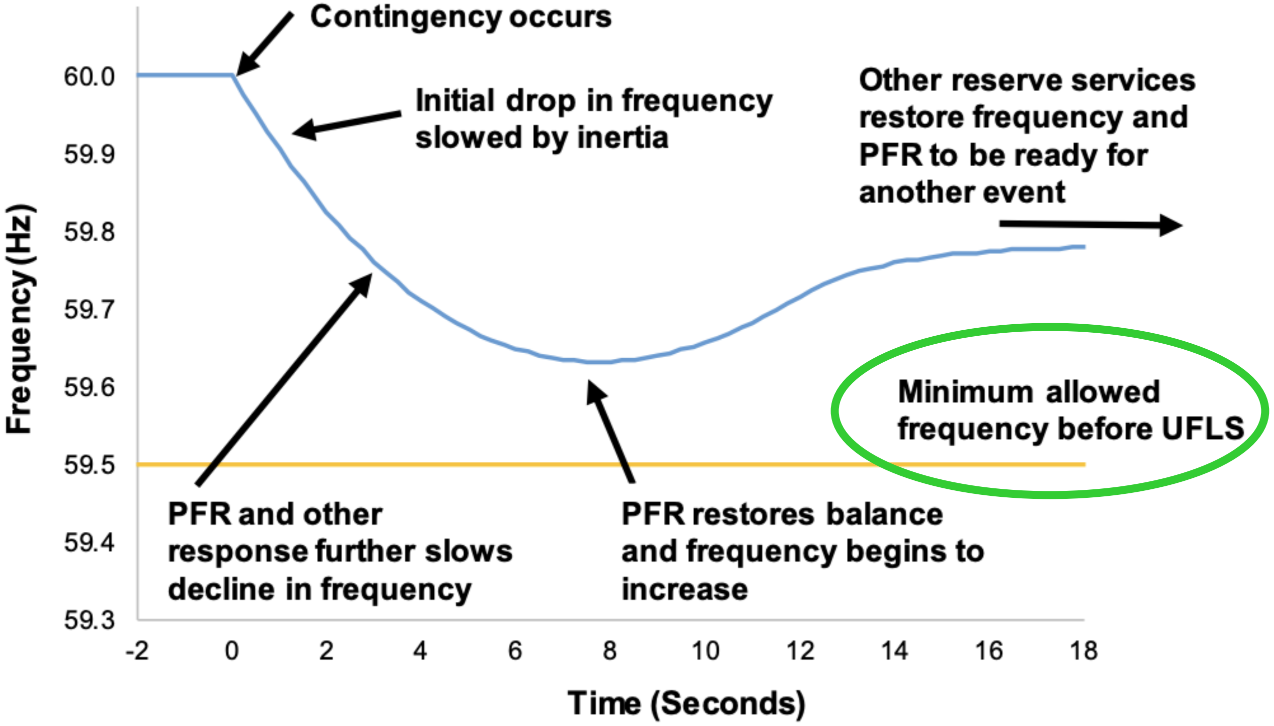
- **Primary frequency response and other response comes next**
  - These controls need to be paramterized prior to disturbance
  - Adjust active power injection to slow frequency dip and help return to nominal
- **Control needs may need adjusting as the system changes**
  - Sufficient PFR droops, deadbands, ramp rates, etc. are dependent on current system needs
  - How to ensure sufficient “extra” energy?



Source: NREL

Successful Recovery From Low Frequency

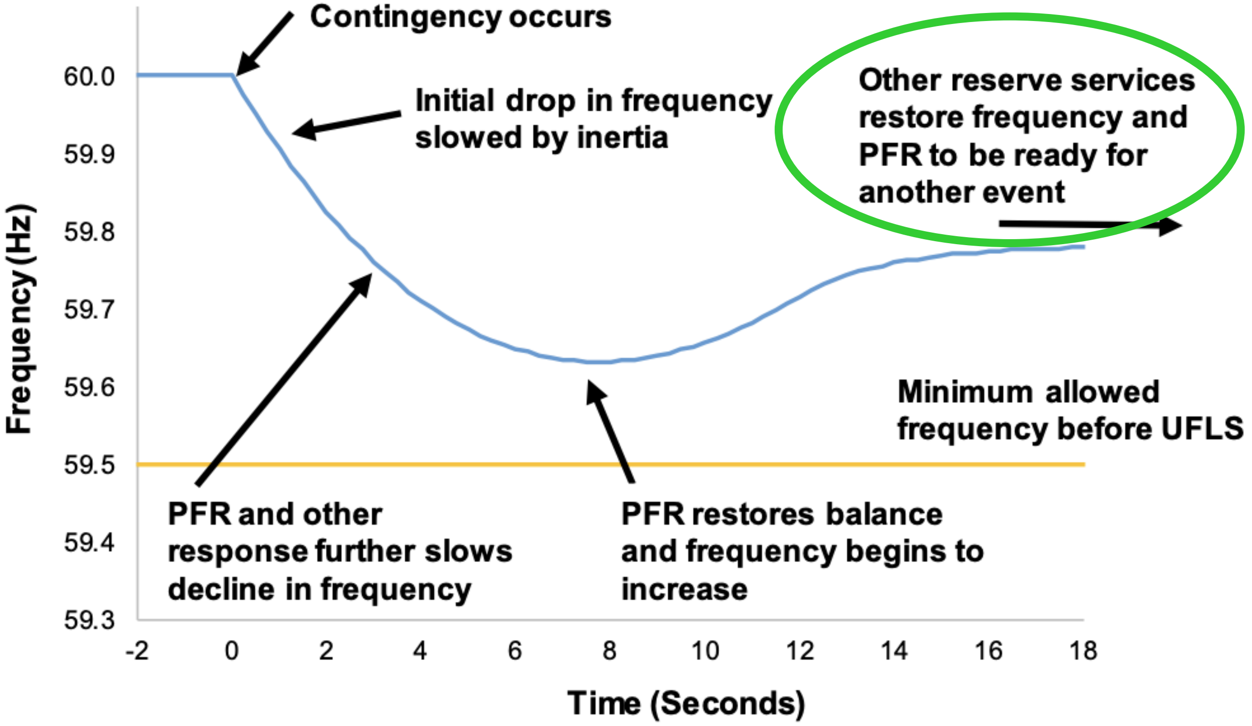
- **Post-event response needs to consider "extremes" like UFLS thresholds**
  - UFLS thresholds trigger plans to remove firm loads to keep the system intact
  - Frequency ridethrough capability of all critical equipment must be considered
- **As power system changes, capabilities and thresholds must be analyzed**



Source: NREL

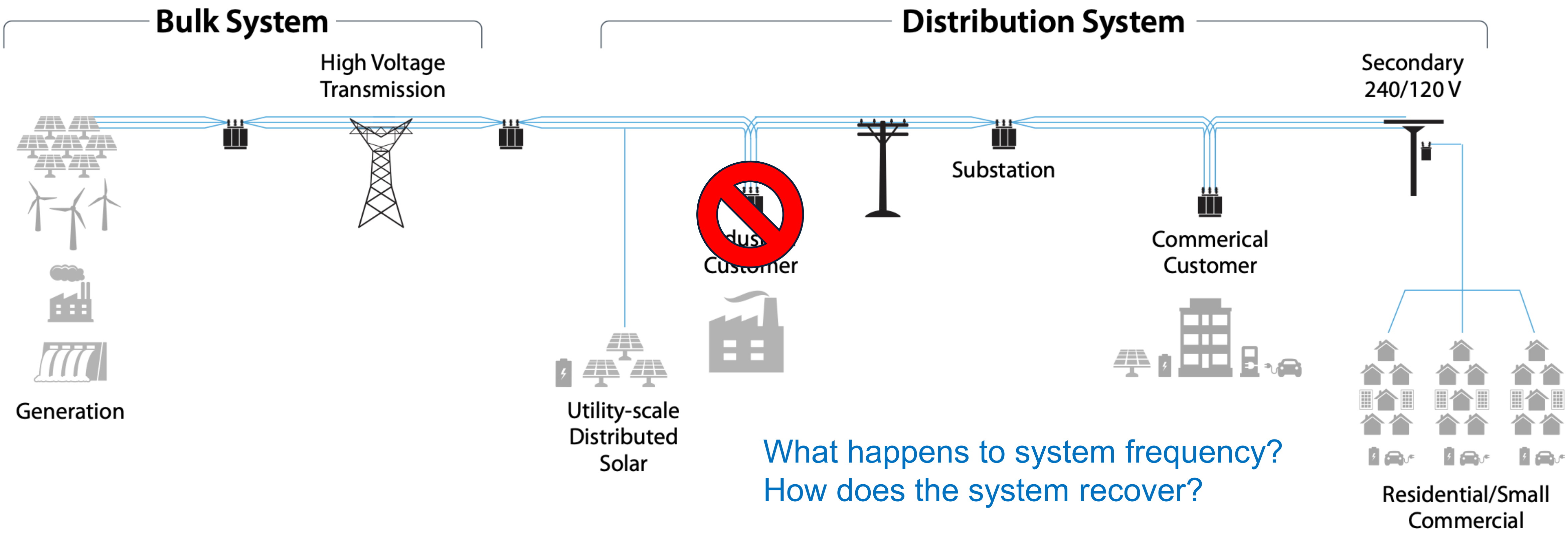
Successful Recovery From Low Frequency

- **Operators react to balance the system**
  - Once the physics-based and automated actions occur operators can rebalance the system and move frequency back to nominal
  - This allows units who provided PFR response to return to their normal operating point
    - This is critical to ensure sufficient capabilities are available for future events
- **Current paradigm is heavily dependent on spinning reserves and quick-ramping machines**



Source: NREL

Disturbance Examples: Major Load Trip



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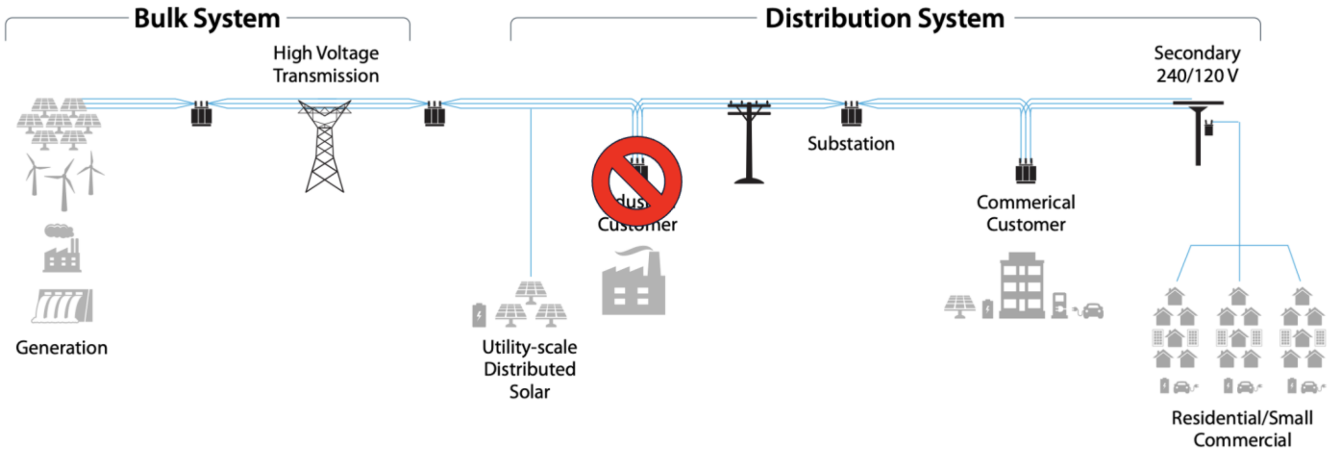
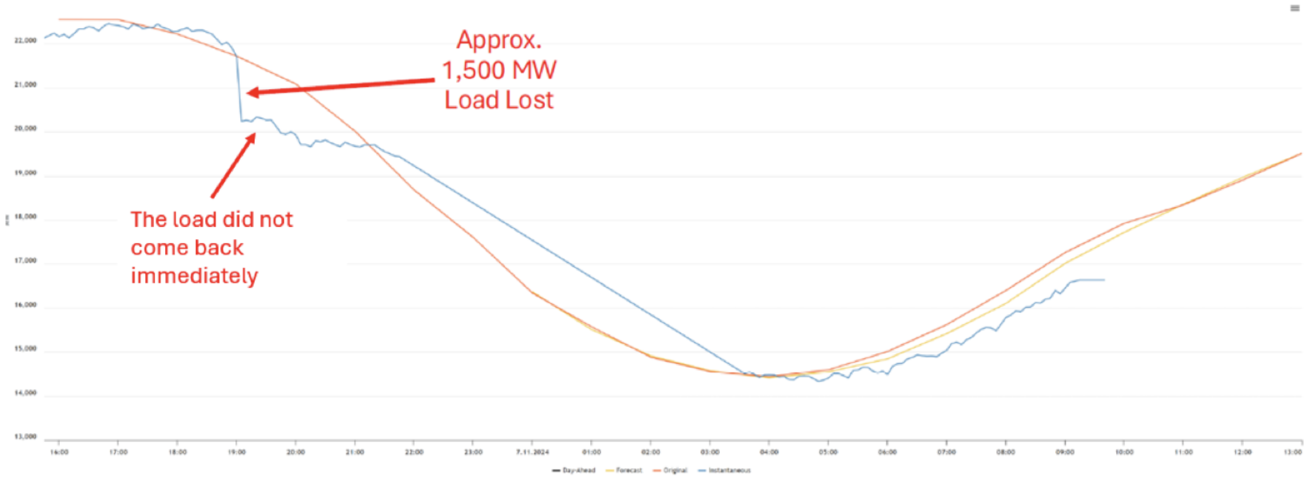
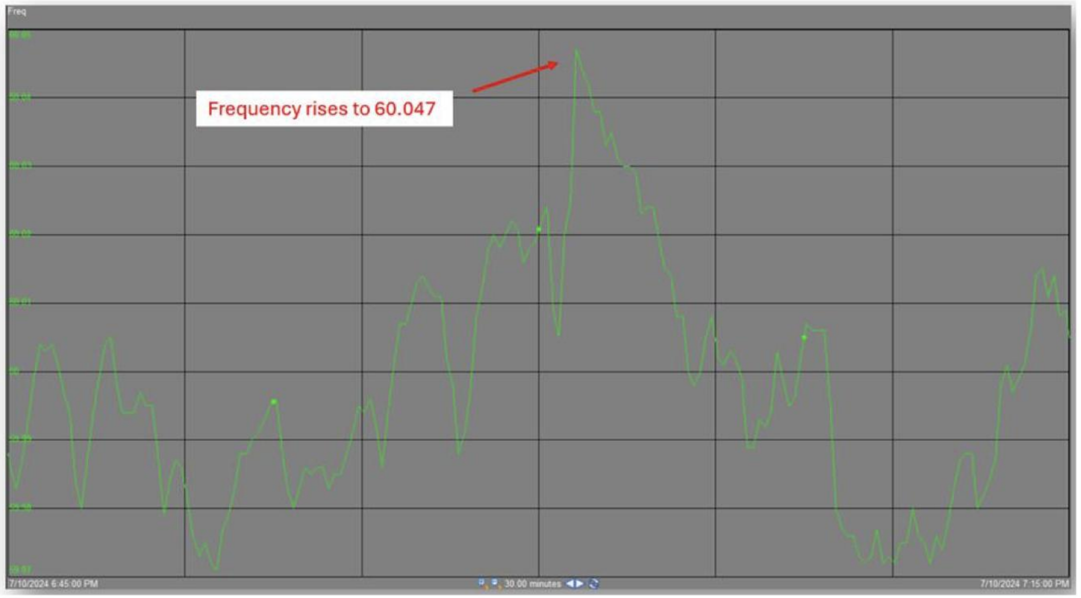


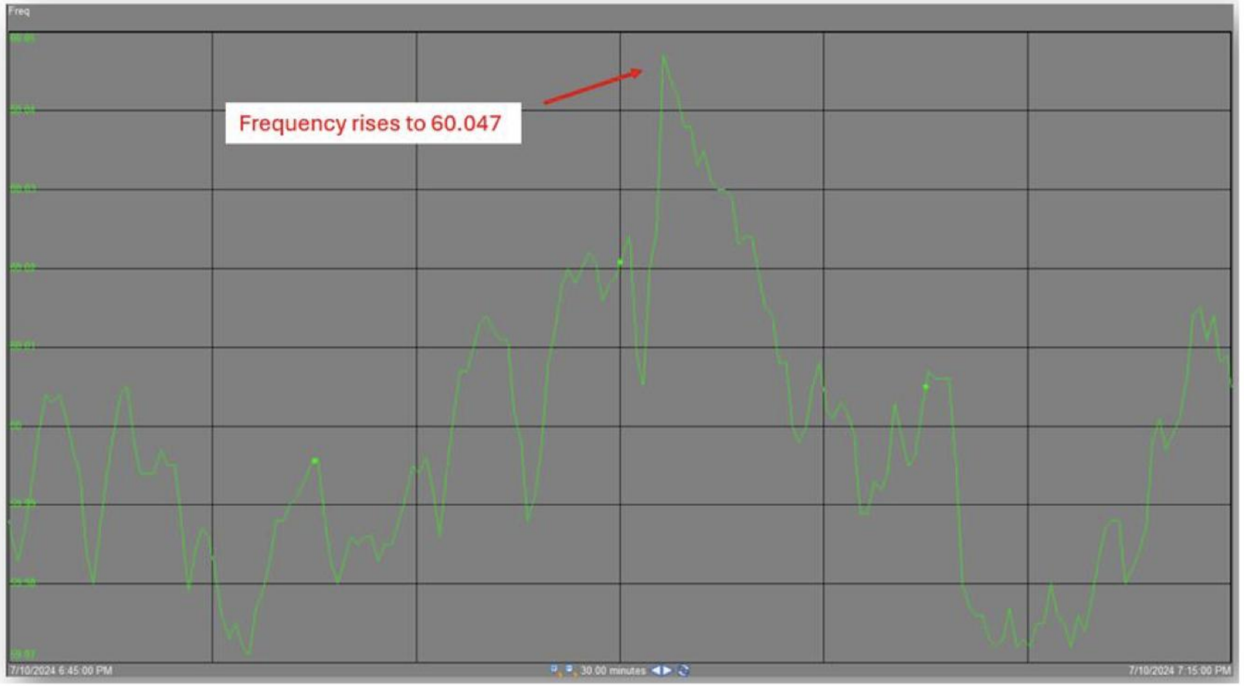




Source: NERC

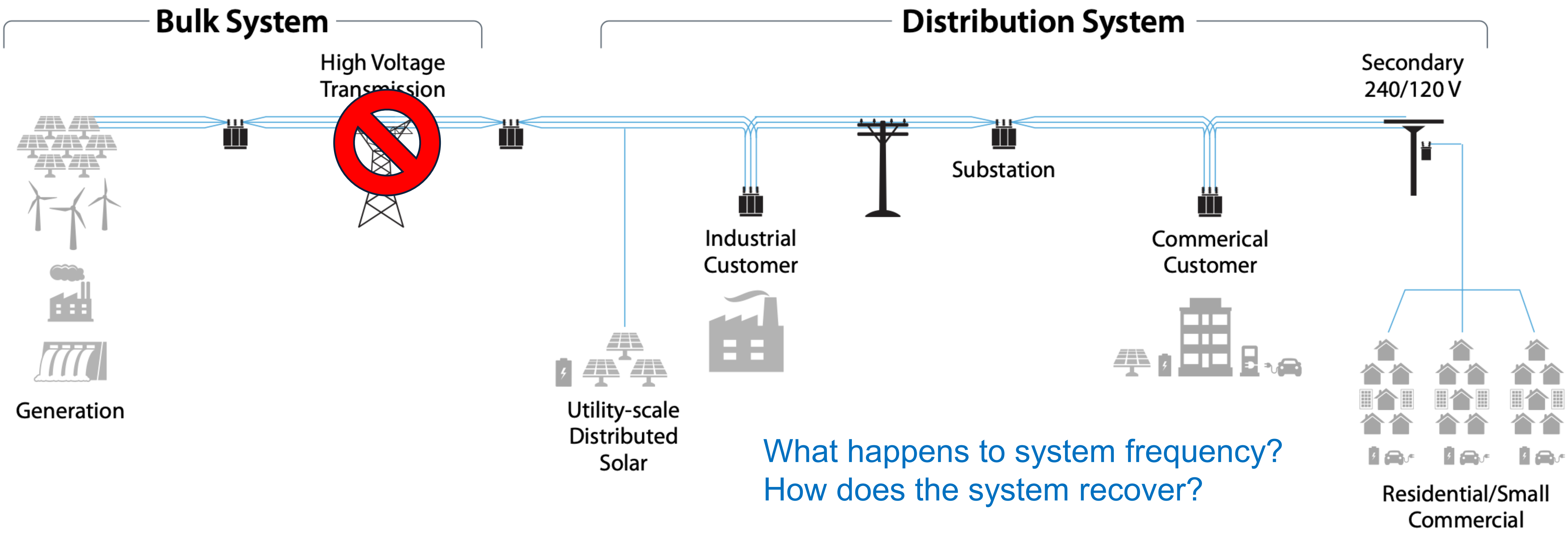
Successful Recovery From High Frequency

- **Similar to recovery from low frequency**
  - "Easier" due to no need for extra energy
    - PFR curtails online generation
  - Same fundamentals apply
- **Industry typically does not focus on high frequency as a major event**
  - How will this change with higher large load penetration?



Source: [NERC]

Disturbance Examples: Major Transmission Trip



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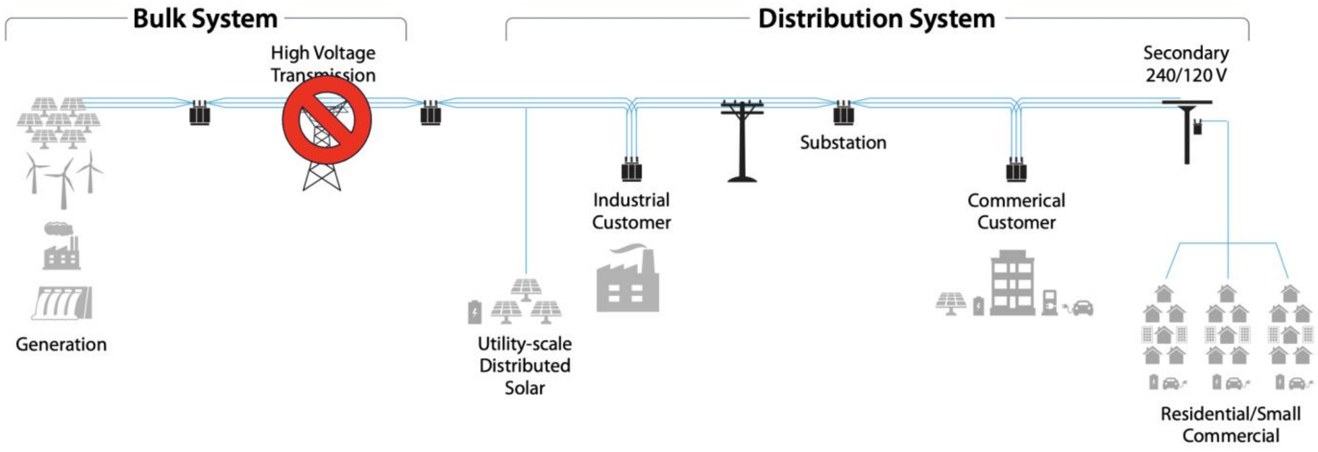
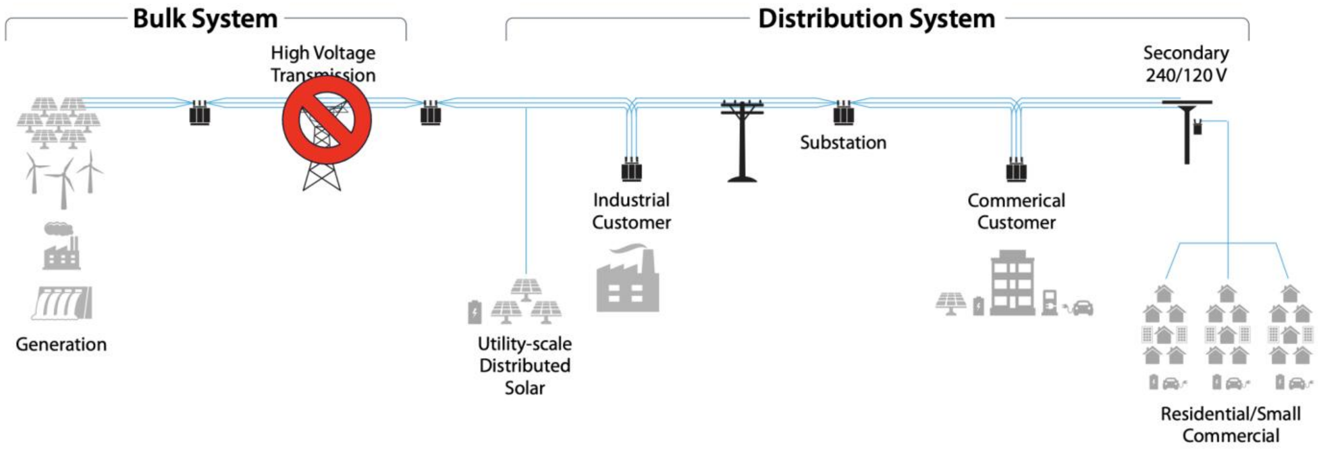
Disturbance Examples: Major Transmission Trip



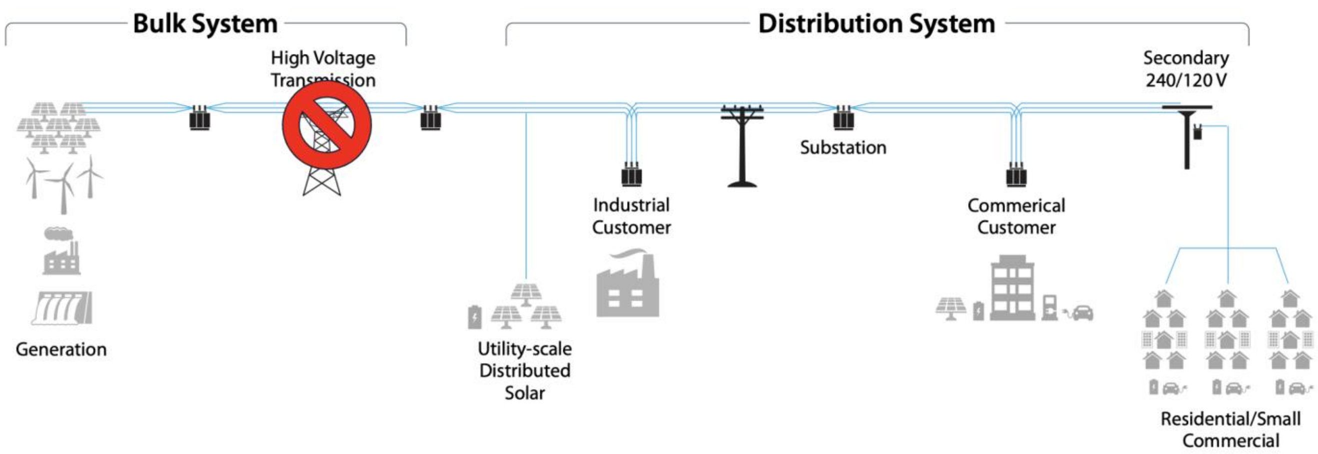
- **Transmission trip at this location may "look" very similar to generator trip**
- **Considerations in addition to frequency dip**
  - Are there any radial connections?
  - Are there now overloads caused by changing flows?
    - Will these cascade?

Disturbance Examples: Major Transmission Trip



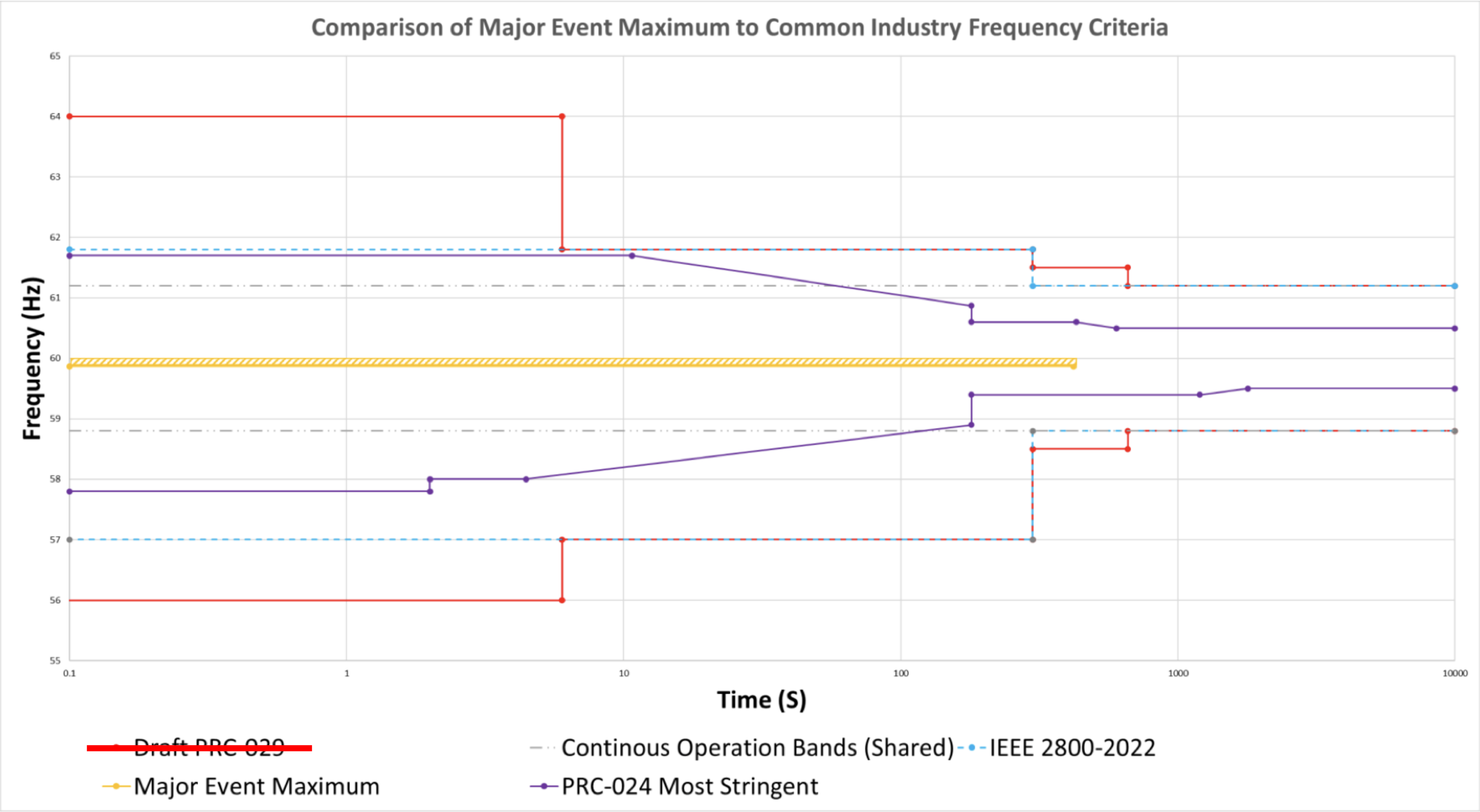
- **Depending on the location, transmission trips can raise or lower system frequency**
  - This would trigger similar inertial and PFR responses
  - This would necessitate similar rebalancing actions from operators
  - Fundamentals of frequency excursion recovery apply

Disturbance Examples: Major Transmission Trip



- **Considerations based on new transmission topology**
  - Overloaded elements
    - Hard to ”control” around
    - Require posturing of the system for the “next” event due to timeframe
  - Opportunities for voltage collapse
    - Can “control” around with detailed special studies
    - Also require posturing of the system or remedial action schemes or other special operations

Why Haven’t We Discussed Frequency Ridethrough?



Source: NERC

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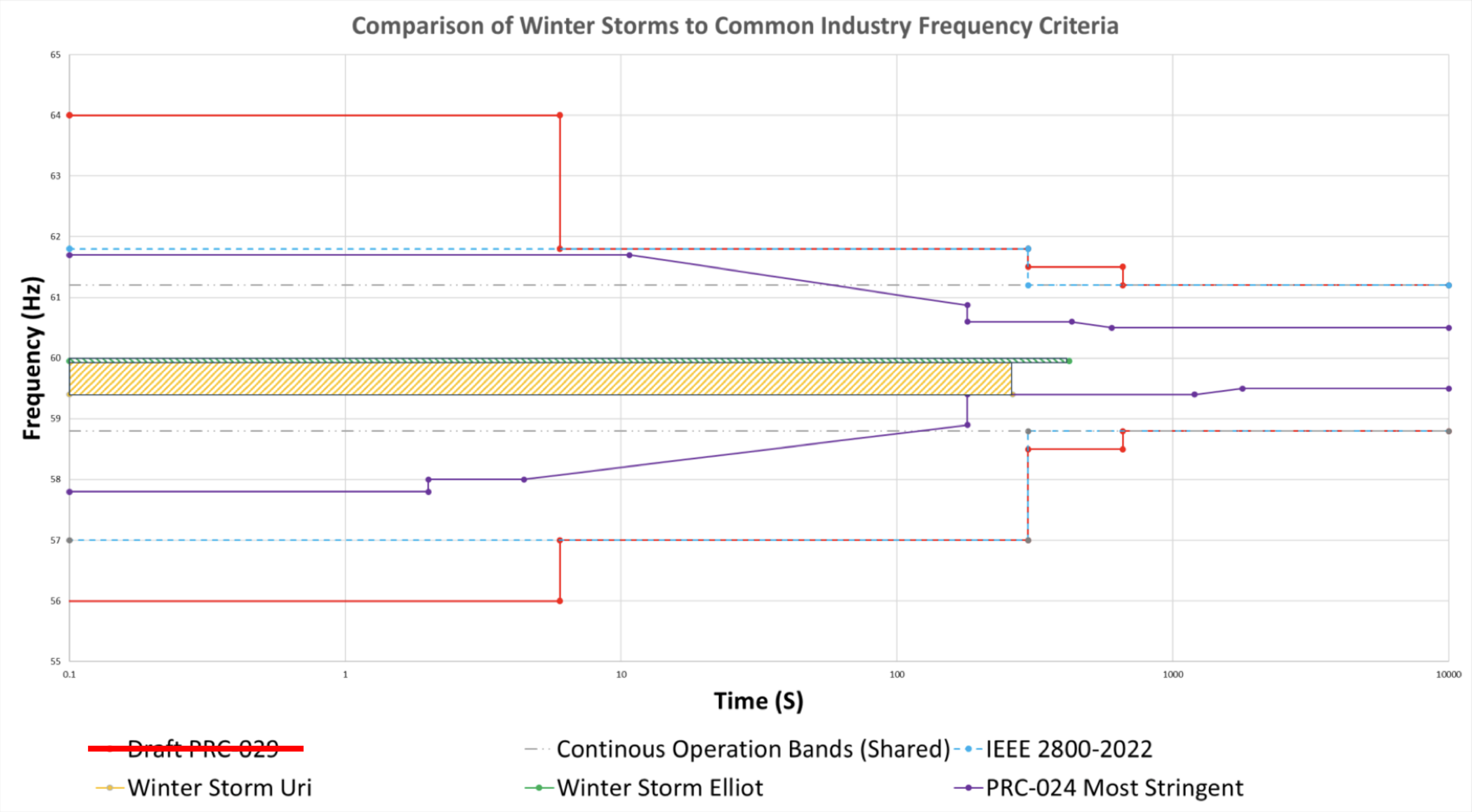

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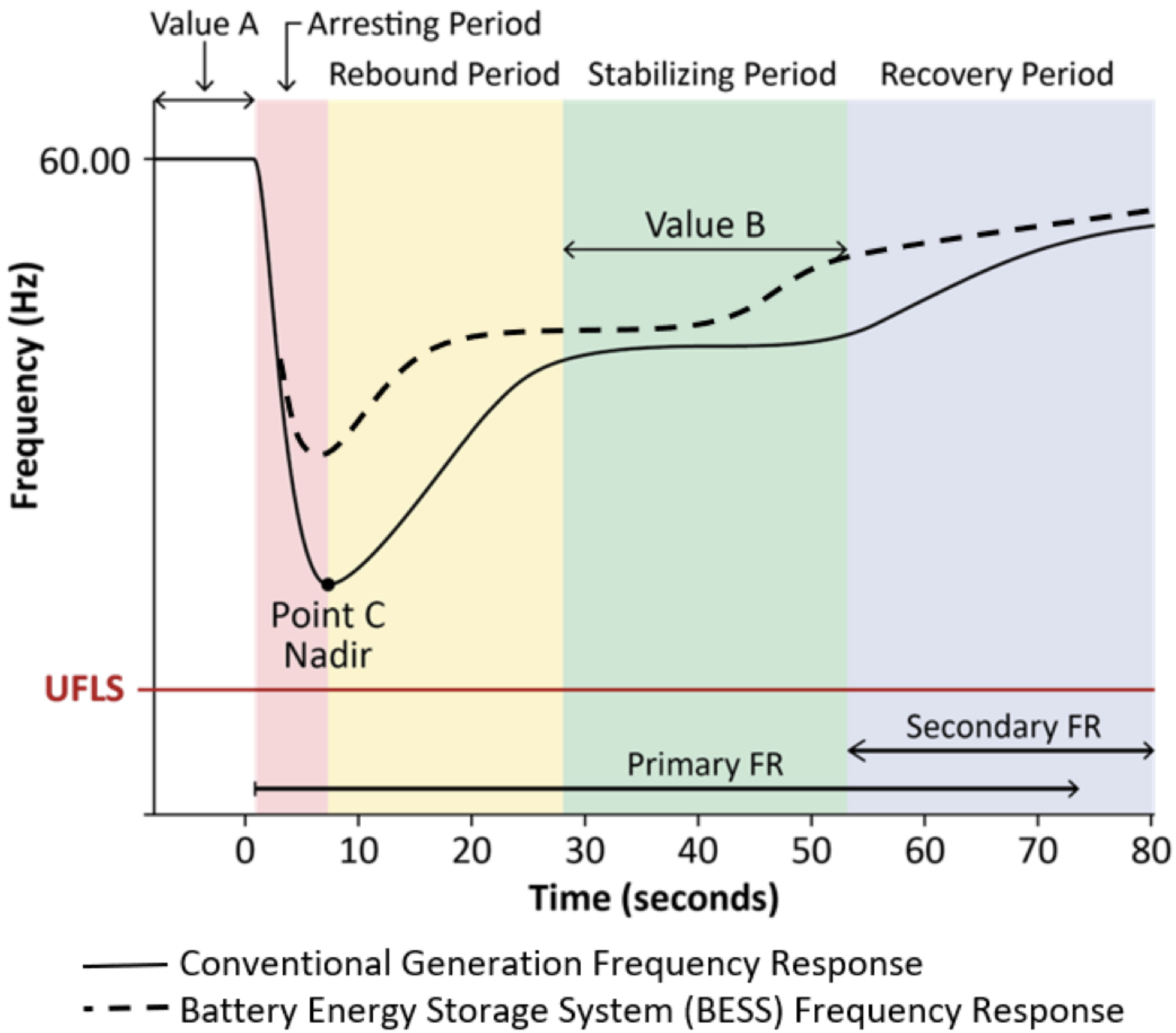
Brief Detour for Andrew to Talk UFLS

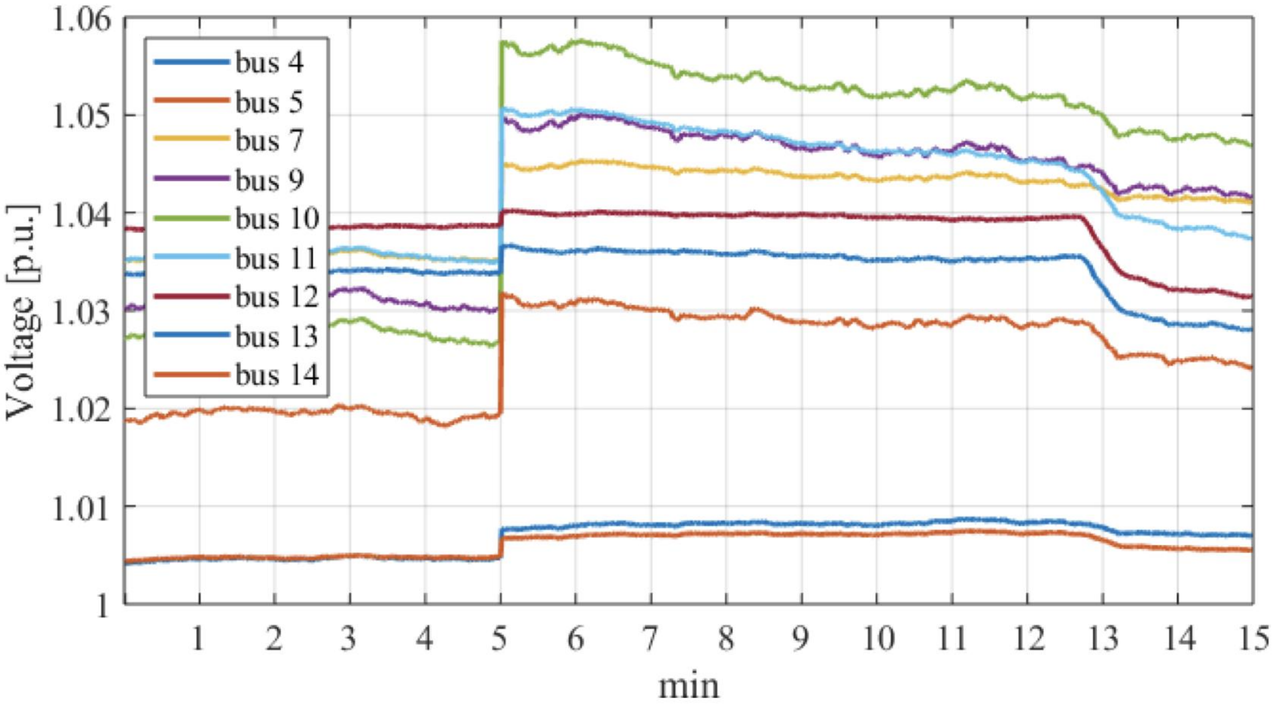


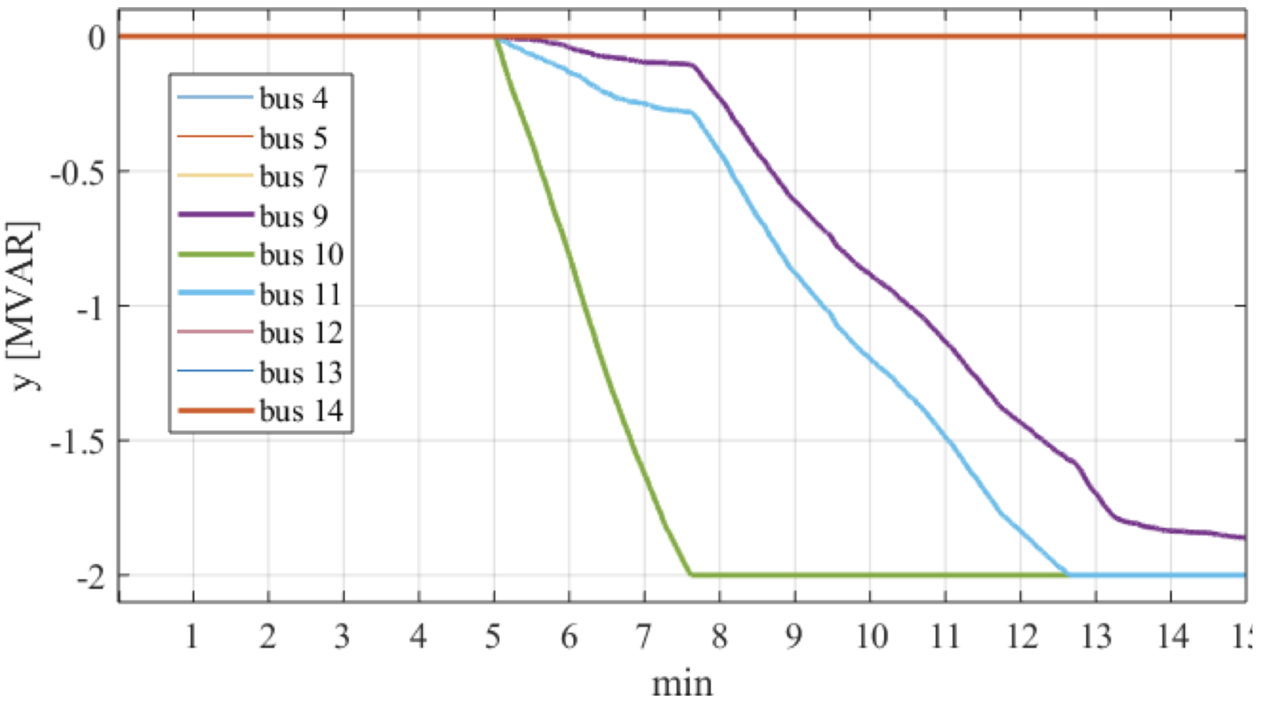
Source: NERC

Voltage Disturbances

- **While frequency disturbances are wide-spread, voltage deviations are not**
  - Voltage disturbances are localized phenomenon
  - Generators or other capable facilities use controls to recover and maintain their own voltages
  - Each resource performs their voltage ridethrough independently based on their individual measured voltages
    - Different from frequency response with system-wide coordination
      - Voltage response is often not coordinated during abnormal conditions
- **Voltage disturbances often exceed normal operation thresholds**
  - Voltage disturbances are more “severe” from a percent change perspective
  - Resources enter ridethrough modes
    - These modes’ primary function is to keep the resource online while ensuring no damage occurs to the equipment
      - Most ridethrough requirements allow tripping when damage may occur
  - Coordination of ridethrough controls is critical

Voltage Disturbances





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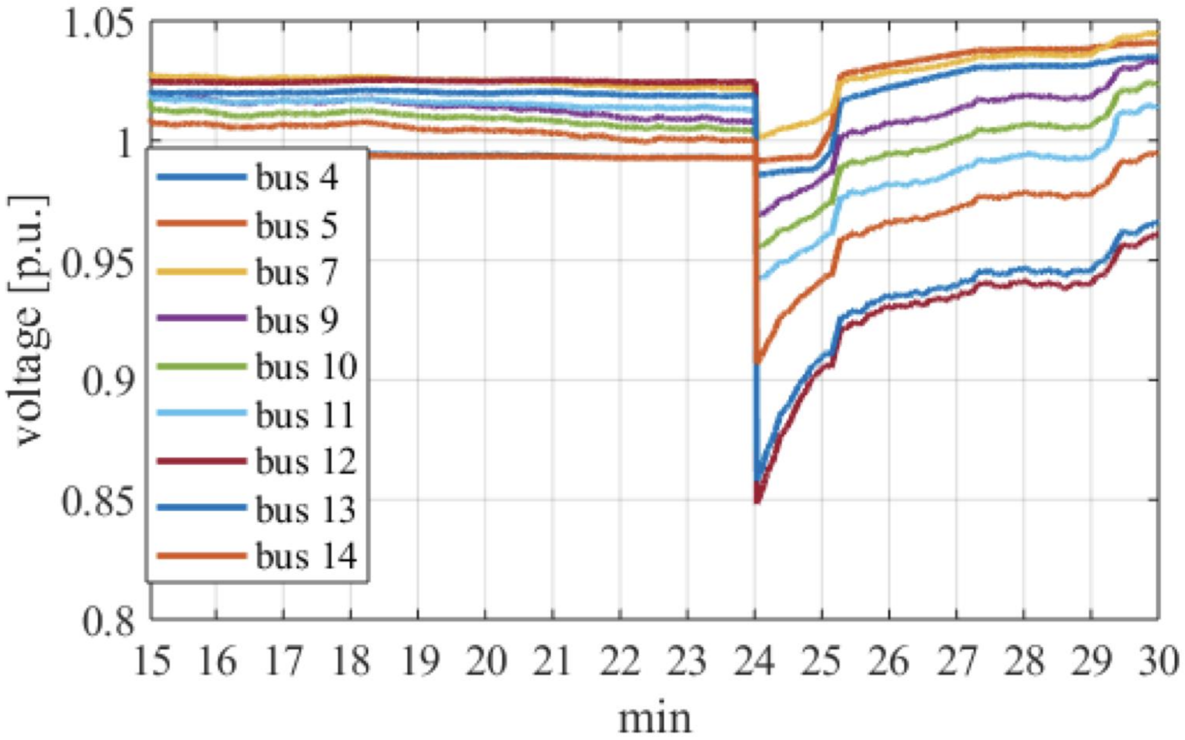
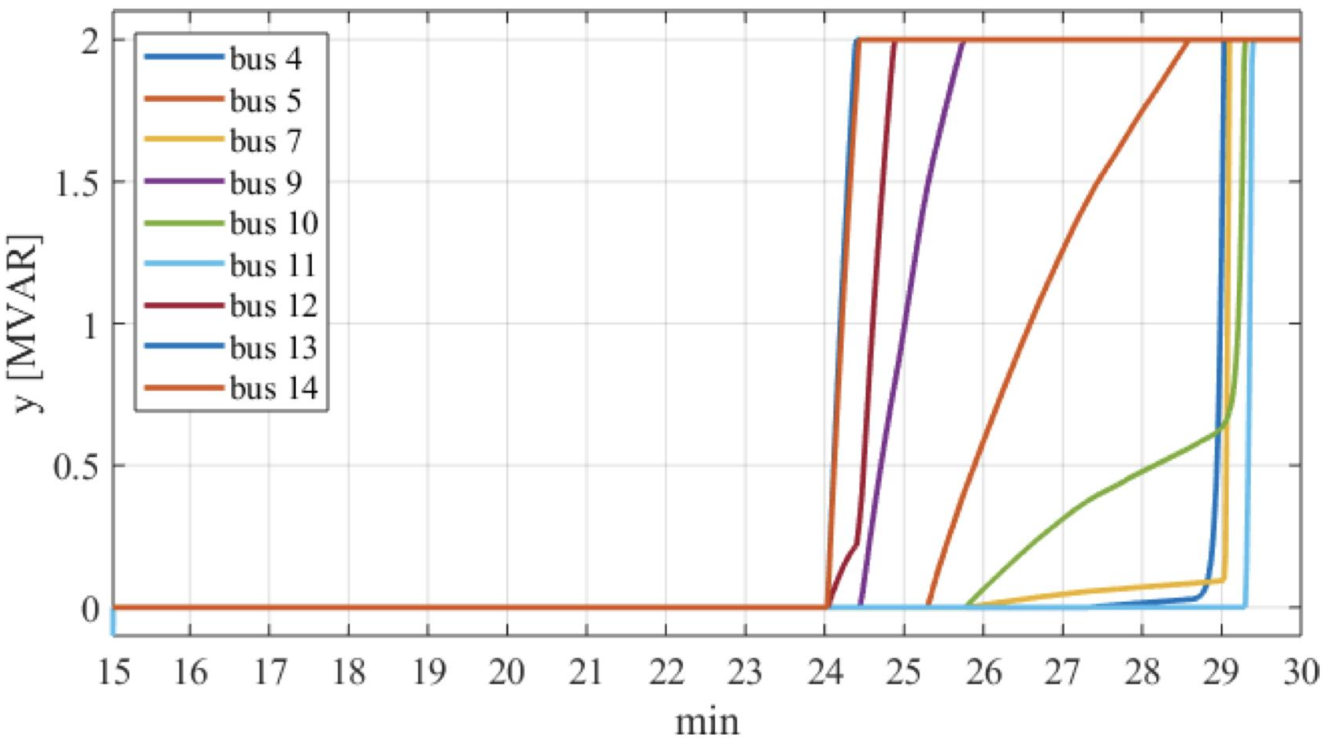
Voltage Disturbances





Source: NREL

Voltage Disturbance Mitigations and Recovery

- **Sufficient ridethrough criteria are necessary to ensure resources stay online**
  - This is particularly critical for IBR
  - Reduced ridethrough capability can cause cascading issues
  - Ridethrough criteria are a balance between system needs and equipment capabilities
    - These must be confirmed throughout the interconnection process and with interconnection studies
- **Ridethrough controls must be properly parameterized**
  - Resources can ”drive themselves to failure”
  - There is no one size fits all for ridethrough controls
  - Important to consider “hand-off” between normal operations > ridethrough > and back to normal
  - How will these fast, independent controls react to eachother?

Additional Considerations for Abnormal Operation

- **Voltage and frequency excursions are only a subset of abnormal conditions**
  - Oscillations
    - Forced and natural
  - Harmonic resonance
  - Unbalanced faults
  - Controller interactions
  - Severely weak systems
  - Geomagnetic disturbances
  - Relay misoperation
  - Many others…
- **Some of these will be discussed in more detail throughout this week and at the EMT Training in December**

Where Do Interconnection Studies Help

- **Stability in both normal and abnormal conditions depends on thorough interconnection processes and studies**
  - The tools used to posture the system, mitigate severity of disturbances, and recover from those disturbances depend on accurate representations of all components of the power system
- **Inaccurate data, models, and improper study practices undermine stakeholder's ability to plan the system**
  - Closing these gaps in the interconnection studies timeframe is critical in the emerging paradigm (more to come later)
  - **Bad inputs = Useless results**