WECC

Failure Mode Mechanisms Analysis
Extreme Weather Applications

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Session Objectives

- NERC Failure Mode Mechanism Working Group (FMM, FMMWG)
- Introduce Failure Mode Mechanisms / Failure Mode Analysis
- Applications: FMM Analysis Featuring Cold Weather Subset to Extreme Weather
- Failure Mode Mechanism Resources Available to Registered Entities
- Questions and Answers

Presenters wish to thank and acknowledge Mr. Richard Hackman for offering his extensive experience and expertise in the preparation of today's material. Regrettably, Mr. Hackman was unable to join us today.

NERC Failure Modes and Mechanisms Working Group

- Result of 2013 NERC AC Equipment Task Force

"Analyze common BES equipment to determine failure modes and mechanisms (FMM) trends and patterns, and improve BES reliability by providing information useful for reducing equipment failures."

- Maintain the Addendum for Events with Failed Station Equipment and processes to collect data associated with failure of station equipment;
- Investigate and identify FMM of BES equipment;
- Derive solutions from FMM studies to
  - Detect and measure the progress of active FMM in BES equipment;
  - Avoid, prevent or delay the progression of BES equipment failures;
  - Promote using "good industry practices" in the inspection and maintenance of BES equipment.
  - Analyze common BES energy sources to determine failure modes and mechanisms.
- Investigate and identify FMM of generating equipment associated with synchronous and inverter-based energy resource interconnections.
- Derive solutions from FMM studies to:
  - Detect and measure the progress of active FMM in energy resource equipment,
  - Avoid, prevent or delay the progression of energy resource equipment failures,
  - Promote using "good industry practice" in the inspection and maintenance of energy resource equipment.

Reference to the NERC FMMWG

NERC Failure Modes and Mechanisms Working Group

Equipment	Status
Generic Bushing	Release Rev
Oil-Filled Power Transformer	Release Rev
Wire Wound Electromagnetic Potential Transformer	Release Rev
Coupling Capacitor Voltage Transformer	Release Rev
Optical Voltage Transformer	Release Rev
Wire Wound Electromagnetic Current Transformer	Release Rev
Optical Current Transformer	Release Rev
SF6 Breaker	Release Rev
Air Blast Breaker	Release Rev
Oil Breaker	Release Rev
Switch	Release Rev
Oil-Filled Reactor (Inductor)	Release Rev
Capacitor Bank	Release Rev
Surge Arrester	Release Rev
Electromagnetic Relay	Release Rev
Static Relays	Release Rev
Microprocessor Relay	Release Rev
Power Line Carrier	
String Inverters (Solar Applicatio	Release Rev
Large Inverters (HVDC Applications)	
Substation Batteries (Lead Acid)	
Substation Battery Chargers	
Uninterruptible Power Supplies	
Generic Gas Units Cold Weather FMMs	
Wind Generators Cold Weather FMMs	

Registered entities may request any of the 18 Released Diagrams, as needed, from the Event Analysis groups of their ERO Region

Southern Company

TVA

Pacific Gas and Electric

NY Power Authority

FPL

Bonneville Power Administration

hydro one

ATC American Transmission Company

OPG

Xcel Energy

LS Power
Innovation and Investment in Energy

Midwest Reliability Organization

Western Area Power Administration

MSOE University
Milwaukee School of Engineering

Primoris

RWE

OG&E

Clemson University

NREL Transforming Energy
National Renewable Energy Laboratory

FirstEnergy

AREVON

Failure Modes

Failure Mechanisms

Slido Poll:
Failure Mode Analysis
vs.
Root Cause Analysis

What differences come to mind when we talk about Failure Mode Analysis versus Root Cause Analysis?

Failure Mode (Effects) Analysis vs. Root Cause Analysis

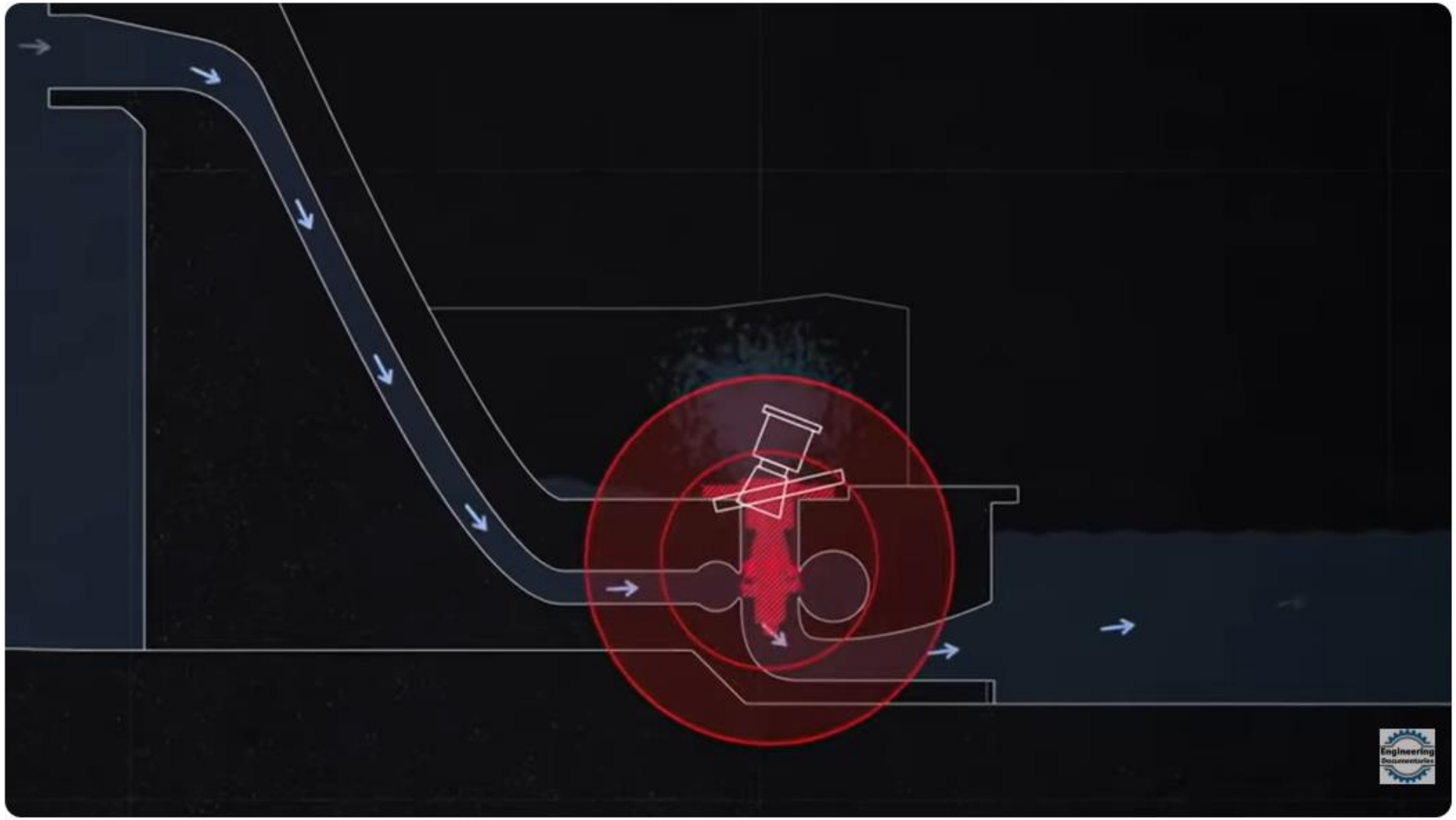
Failure Mode Analysis

- Process-based, methodical, rigorous
- Proactive, Preventive
- Forward looking, Systems-based, Systems' perspective
- Identify and rank failure modes, often multiples of them
- Essential where catastrophic failure(s) can render extreme consequences (loss of life, loss of plant, etc.)
- Often requires broad-based perspective of what could go wrong, and in what sequence(s) and combinations
- Useful in prioritizing, registering Risks *f*{RPNs, Registers}
- Can be time consuming and require extensive expertise
- Reusable, particularly in equipment/systems. Up-front work need not be repeated if multiple events (effort-per-event economy)
- May use Lessons Learned from RCAs of events or failures to improve preventive postures
- Can help prevent regulatory lapses from occurring
- Reduce the probability of "Failure scheduling you"

Root Cause Analysis

- Process-based, methodical, rigorous
- Reactive, after impact (events, realized risks, failures)
- Event-specific analysis
- The "Failure scheduled{s} you!"
- Backward-looking, e.g., 5x (or more) "Whys"
- Useful to tailor Mitigation Development (Remediating activities, prevention activities)
- Precision-based yet may not expose hidden, unrealized risks or other modes of potential failure or impact outside the "why" or "Swiss Cheese Model"
- Failure mode mechanisms identification does occur, but at risk of becoming piecemeal, and can be repeated over and over
- Lessons Learned (LLs)
- Can help justify the need for broader FMA/FMEA campaigns

Failure Modes



After-the-fact analysis: Sayano-Sheshenskaya (Russia) Unit 2 failure, circa 2009.
Source: YouTube / Engineering Documentaries

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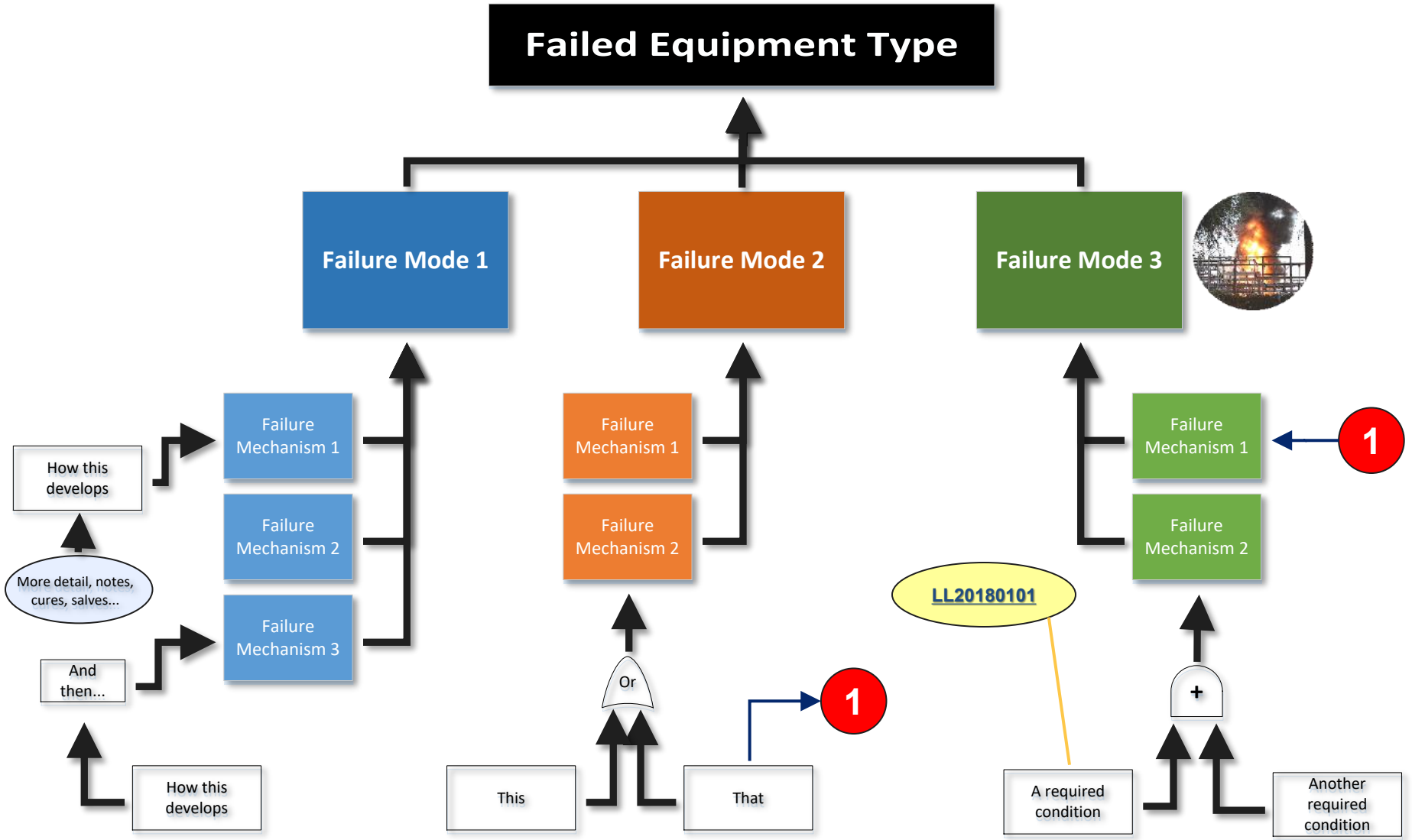
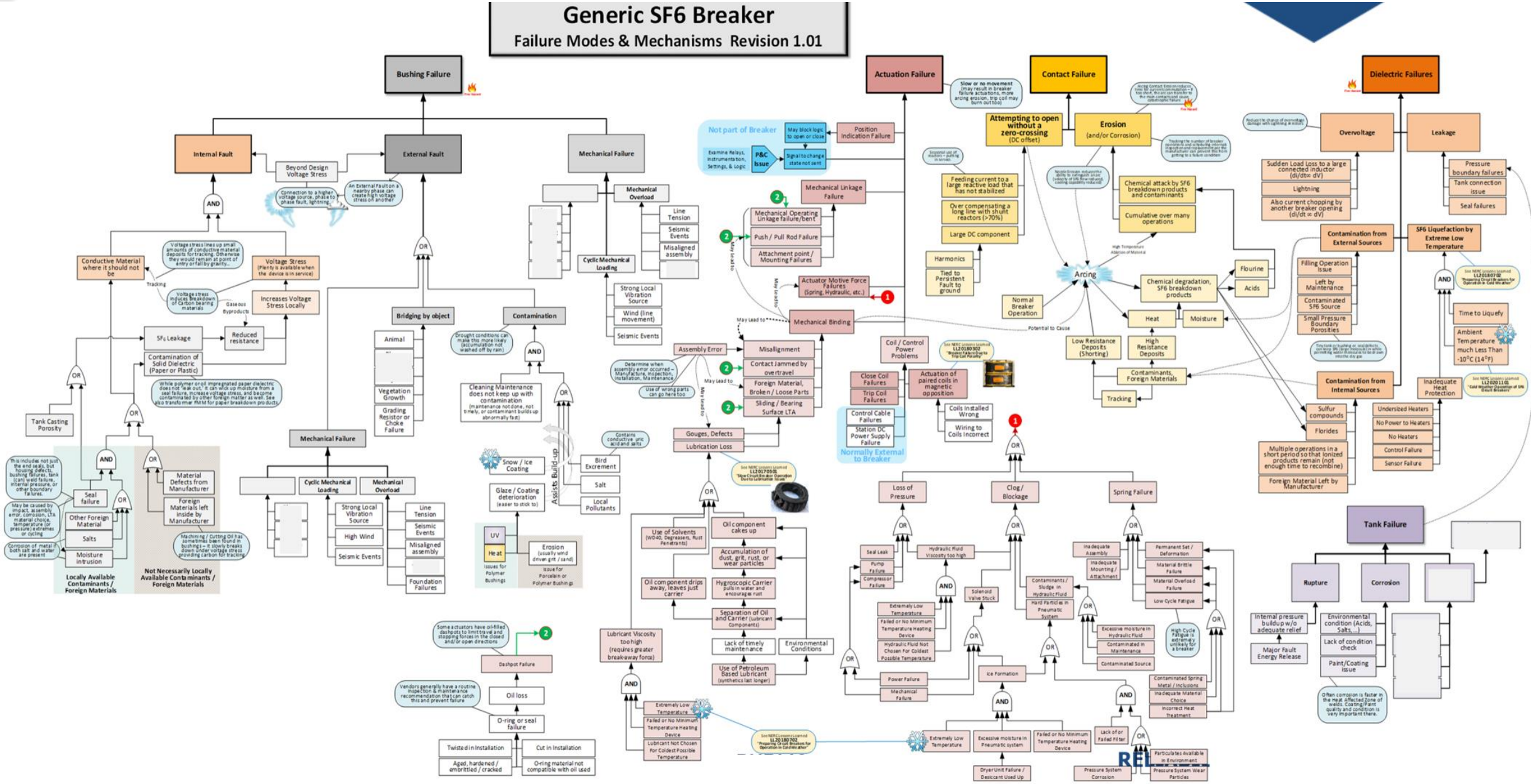
Failure Modes and Mechanisms

- **Failure Modes** are what gets your attention
- **Failure Mechanisms** are how the equipment gets going on the path to a failure
  - Equipment Failures have logical cause-and-effect relationships behind them.
  - Physical Evidence Examination and Root Cause Analysis can reveal what Failure Mechanisms were involved.
  - Aging is not a cause. It is a term for slow-moving Failure Mechanisms.
  - Failure Mechanisms are detectable. Many can be stopped or at least slowed down so they can be corrected before causing a failure.

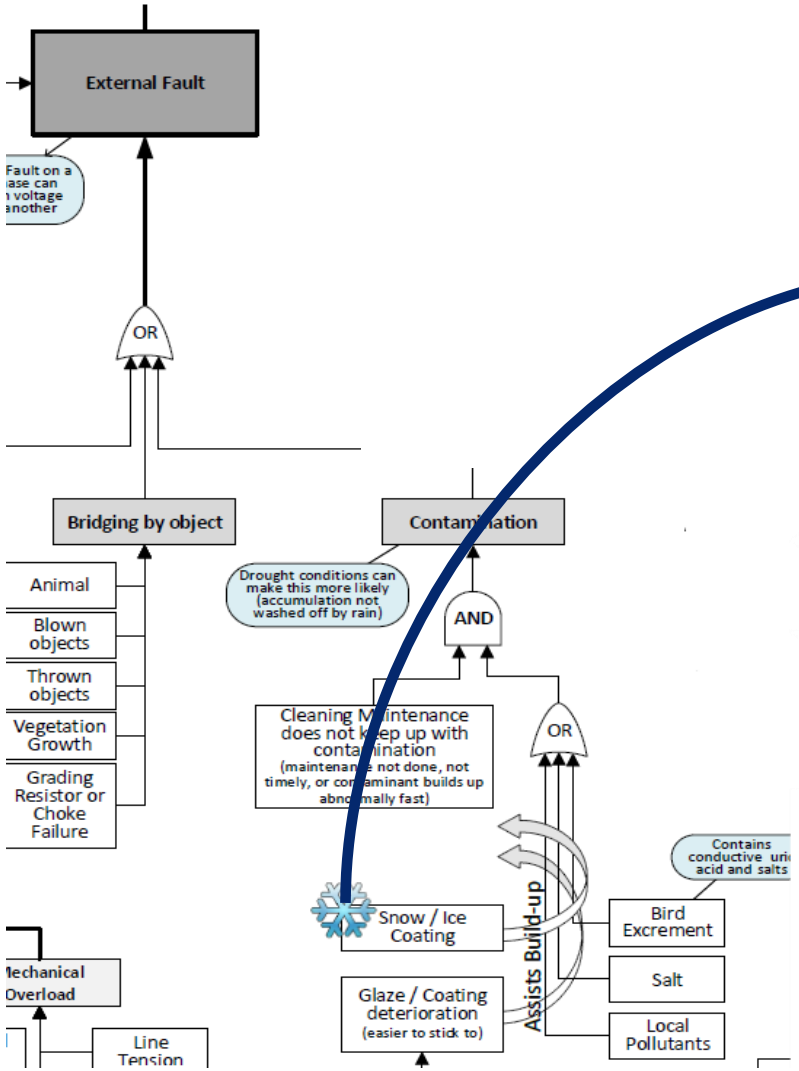
FMMWG: Generic Failure Mode Mechanisms Diagram



Detailed FMM Diagram: SF6 Breaker



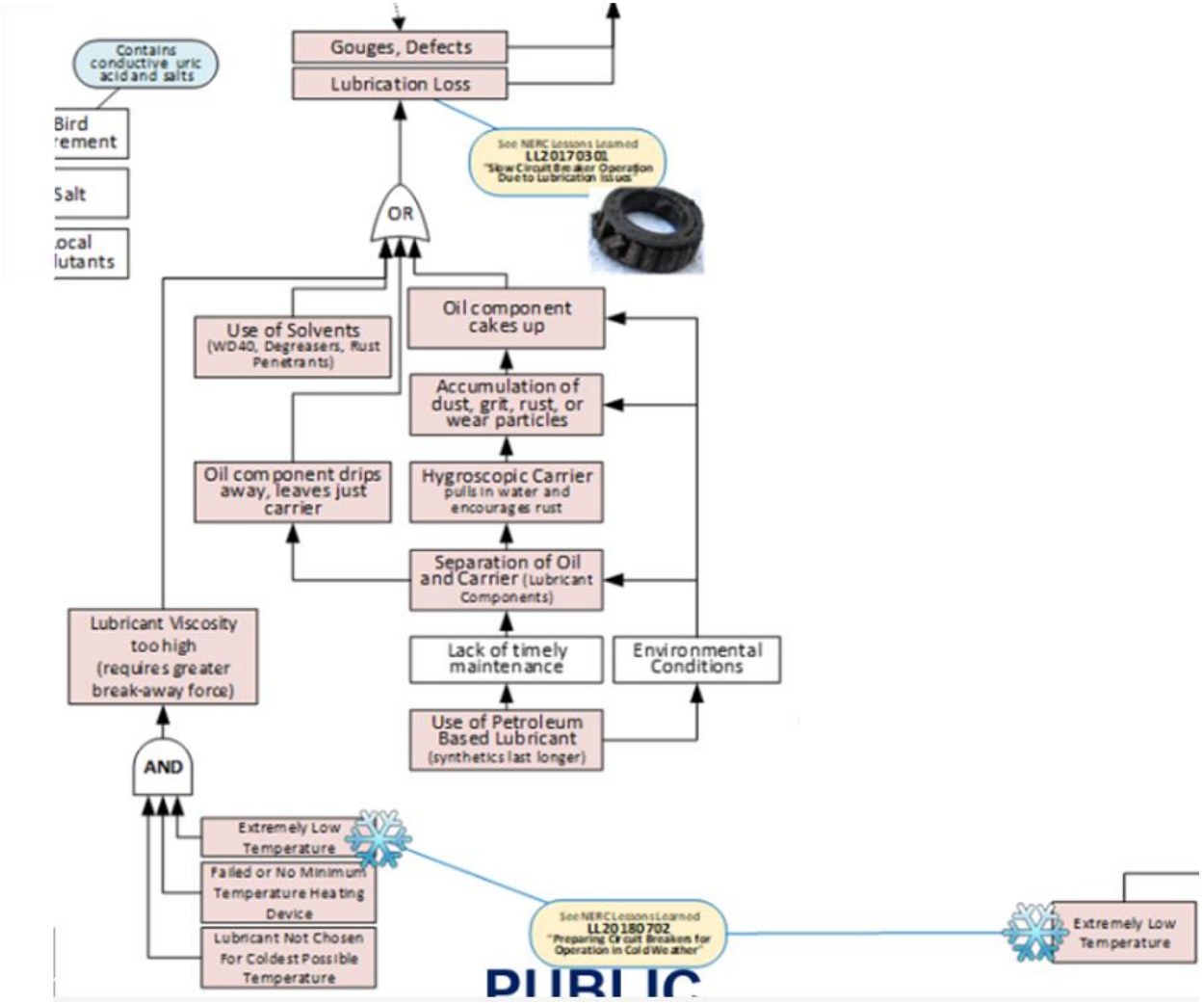
FMMWG/SF6/Cold Weather Mechanism



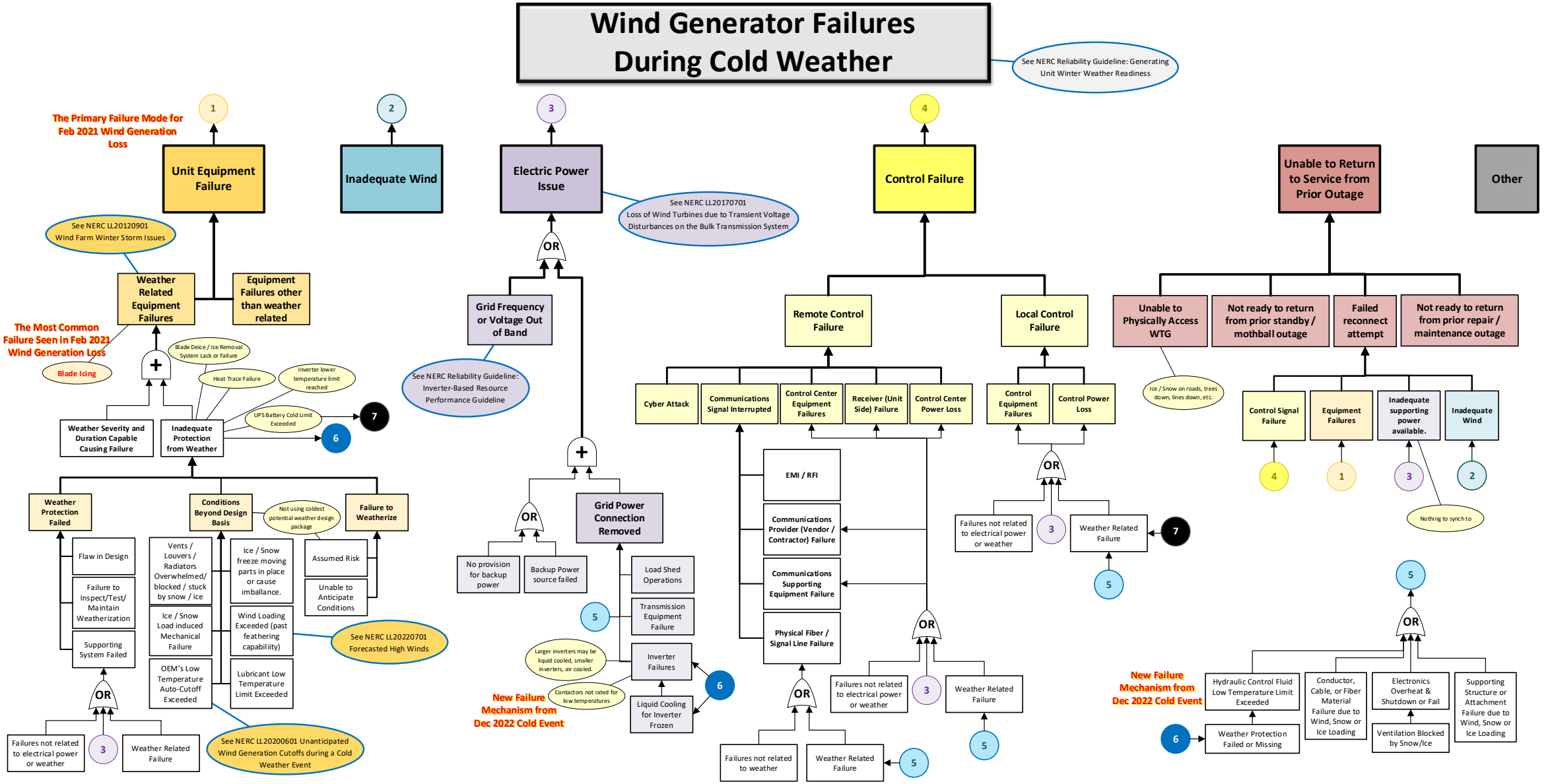
Snow/ice with other factors

Example with Cold Wx Failure Mechanism

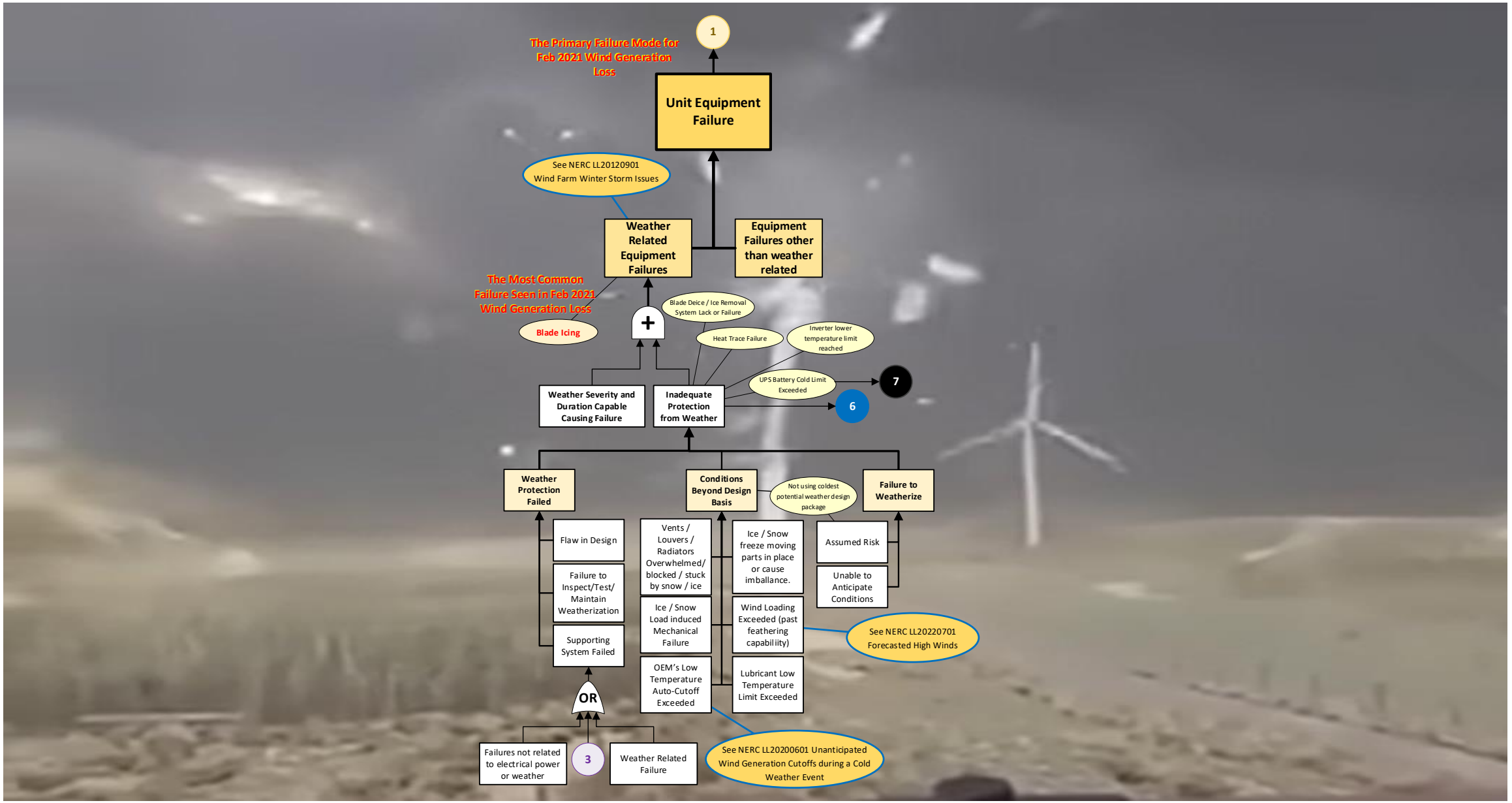
- Cold Wx Augments SF6 Breaker Actuation Risks



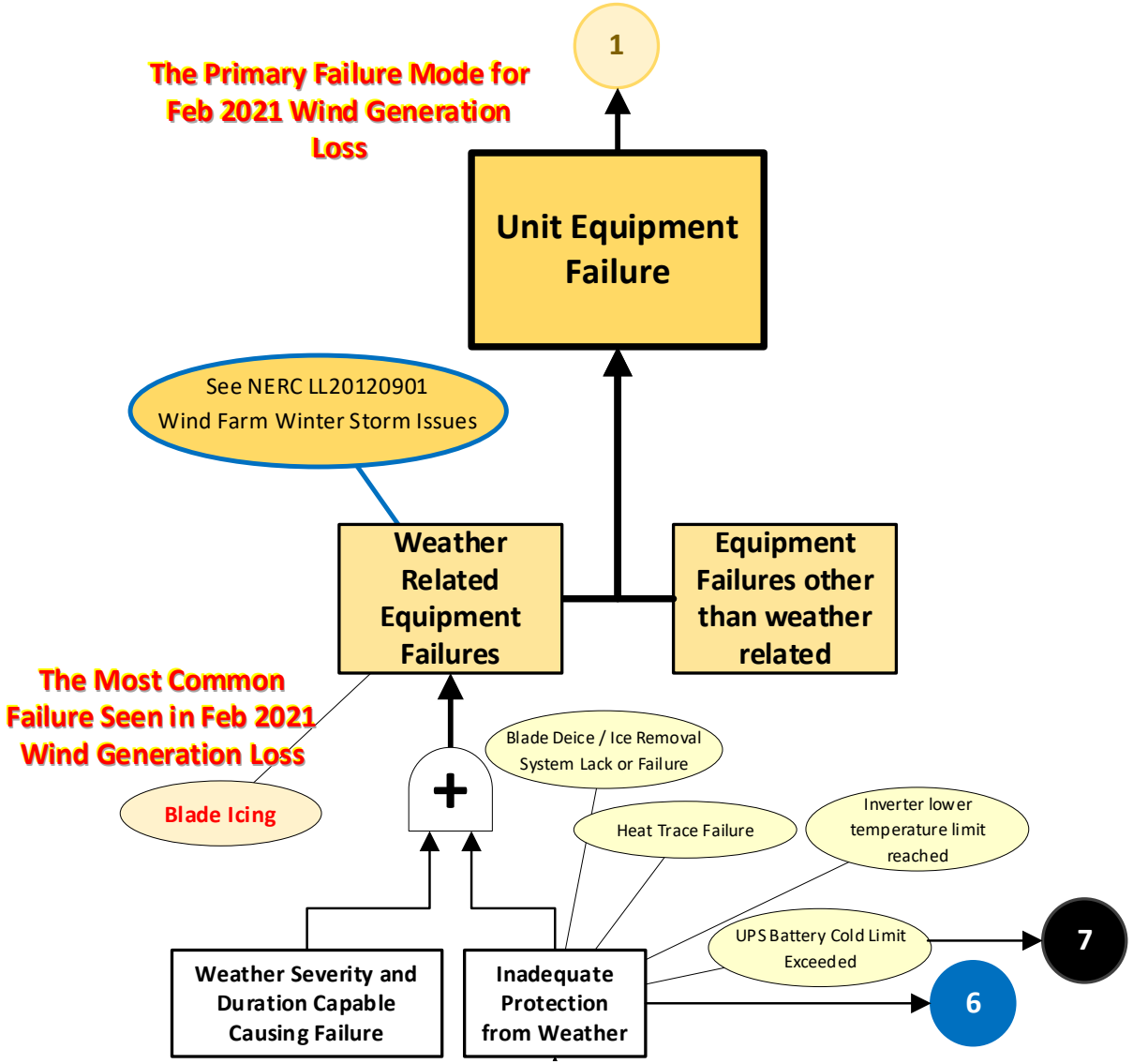
Failure Mode Mechanisms—Wind Generators and Cold Wx (Draft)



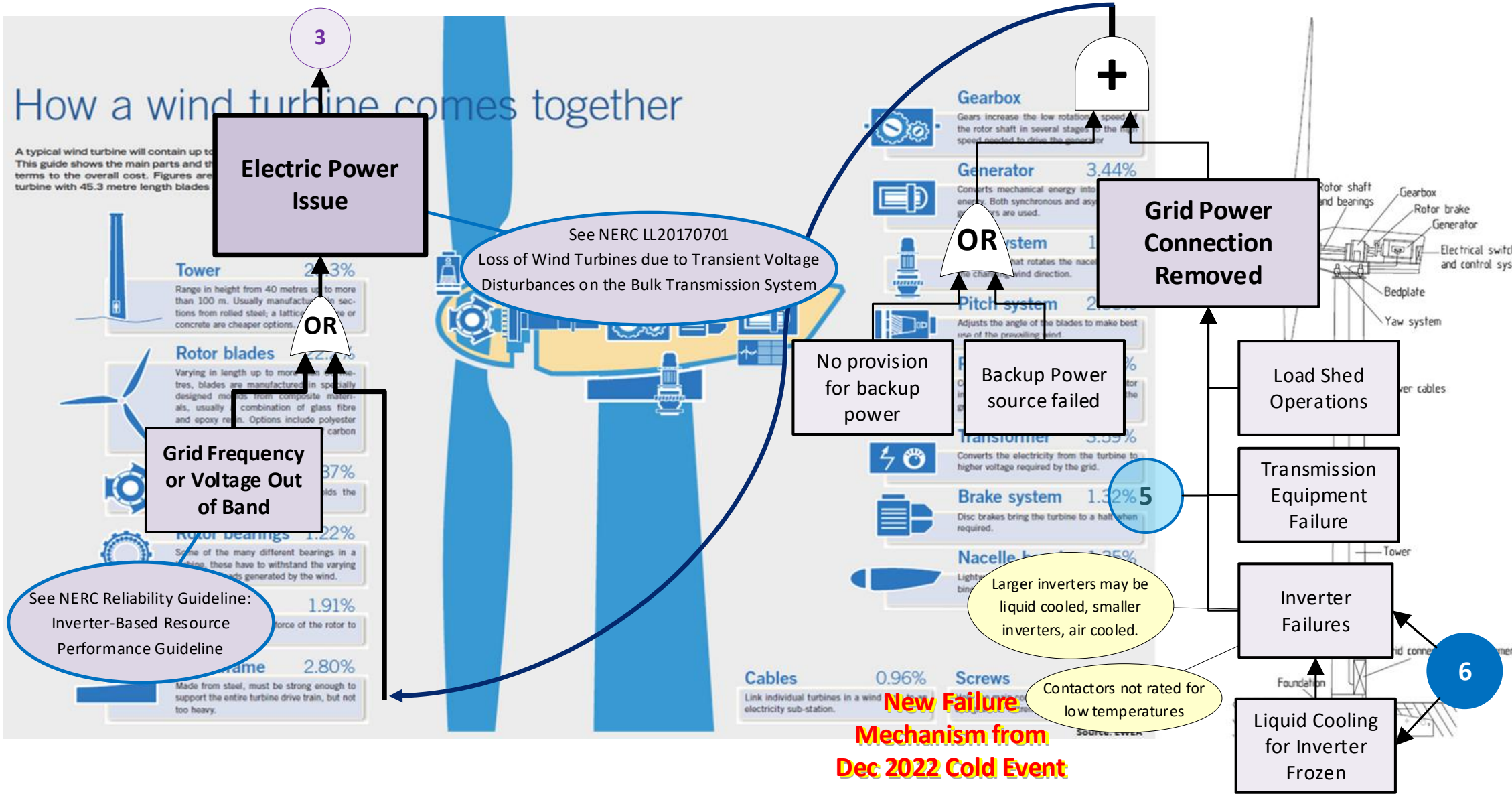
Failure Mode Mechanisms—Wind Generator Wx FMMs (1)



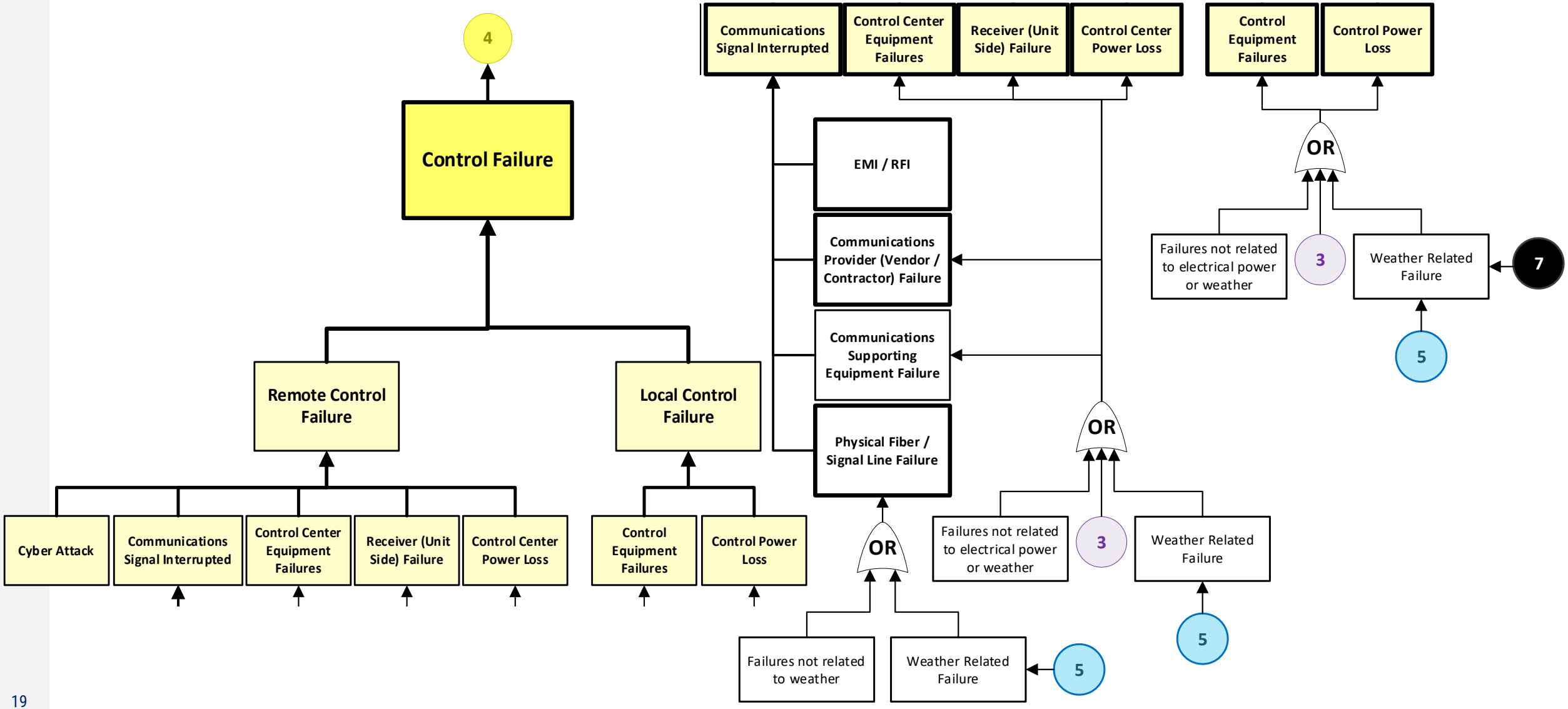
Failure Mode Mechanisms—Wind Generator Wx FMMs (1)



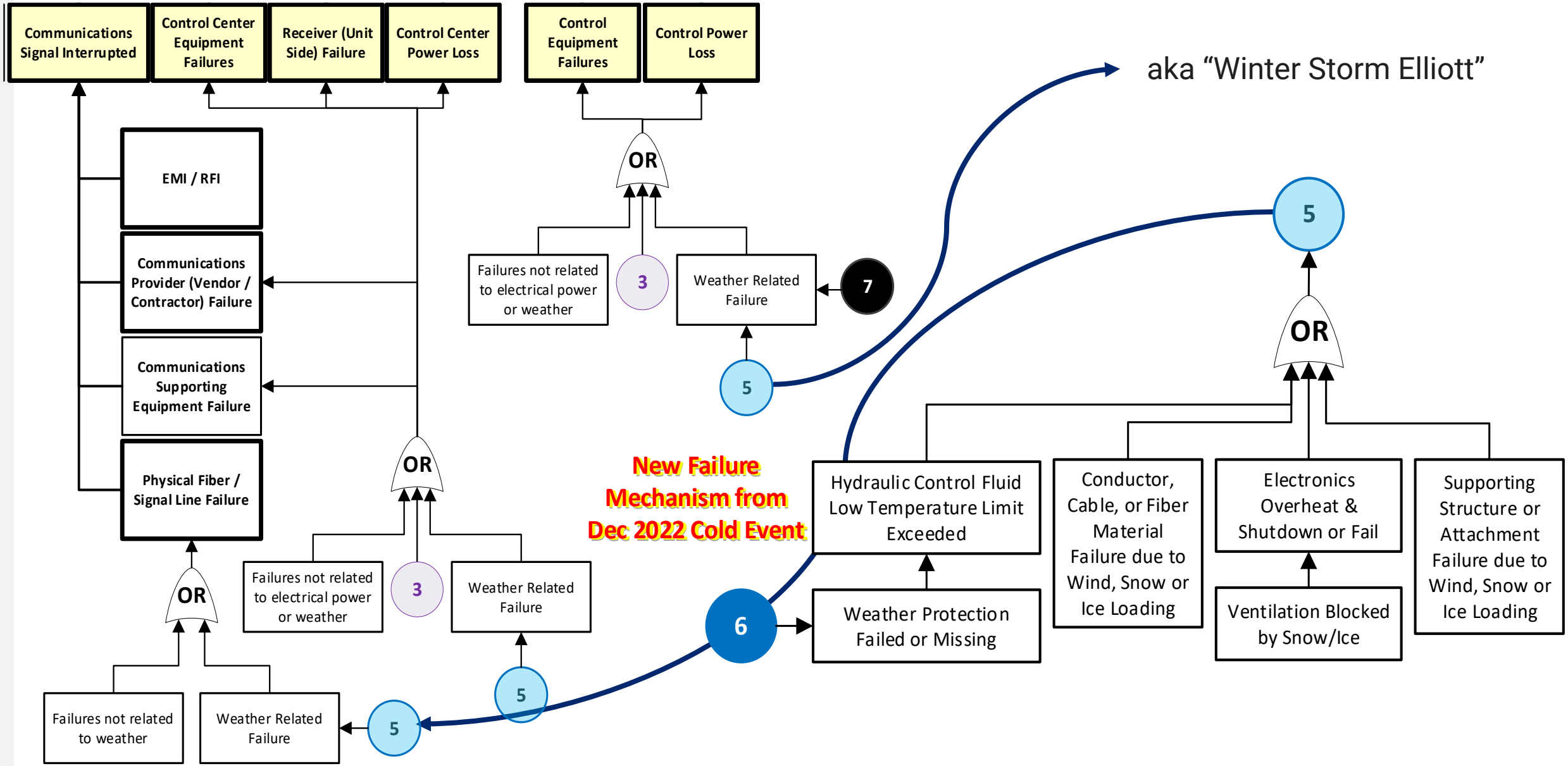
Failure Mode Mechanisms—Wind Generator with Wx FMMs (3,5)



Failure Mode Mechanisms—Wind Generator with Wx FMMs (4)



Failure Mode Mechanisms—Wind Generator with Wx FMMs (5,6)

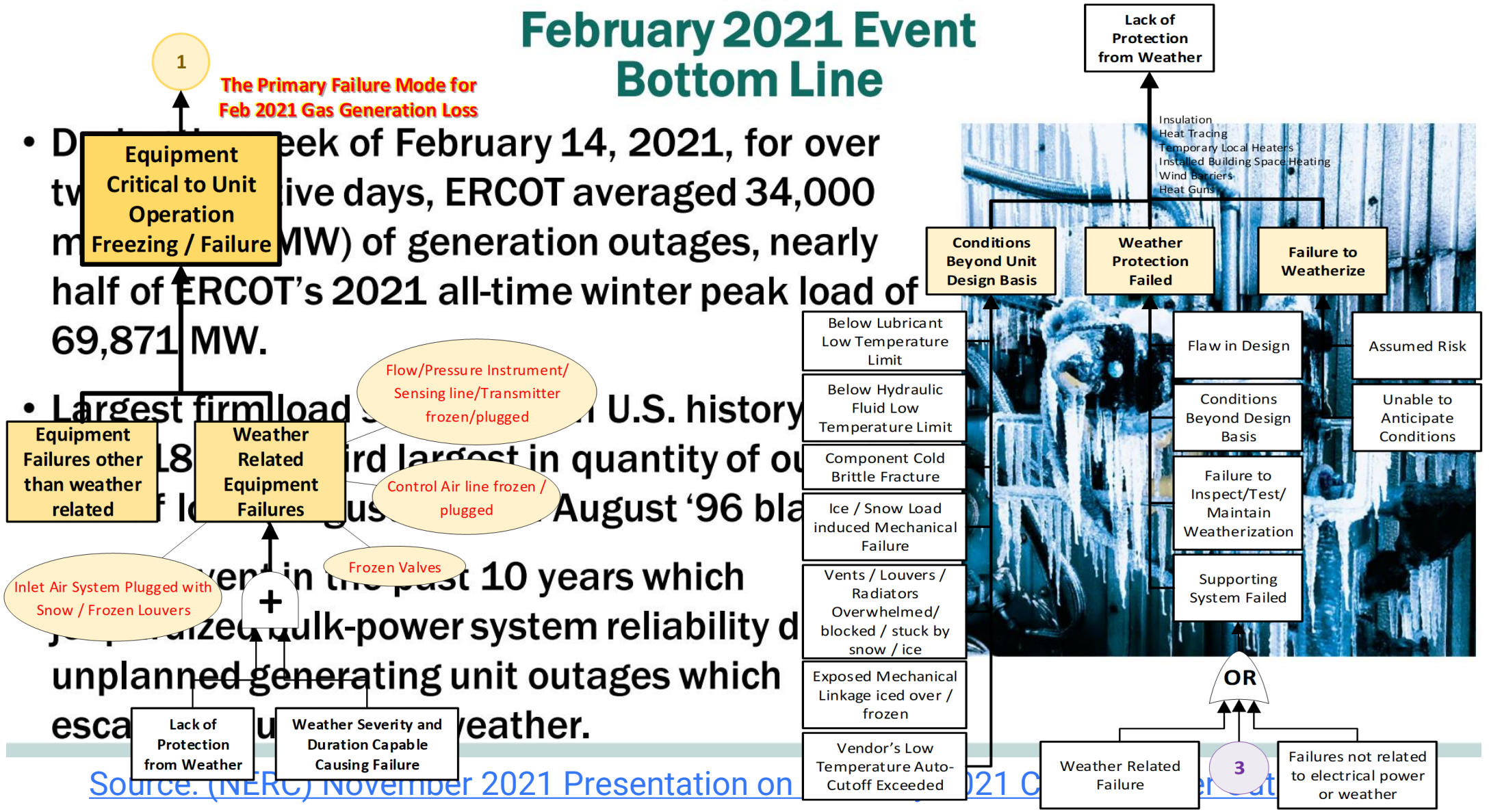


Failure Mode Mechanisms
Combustion Turbine
Inlet Icing Example

Failure Mode Mechanisms Gas Generation loss from Cold Wx

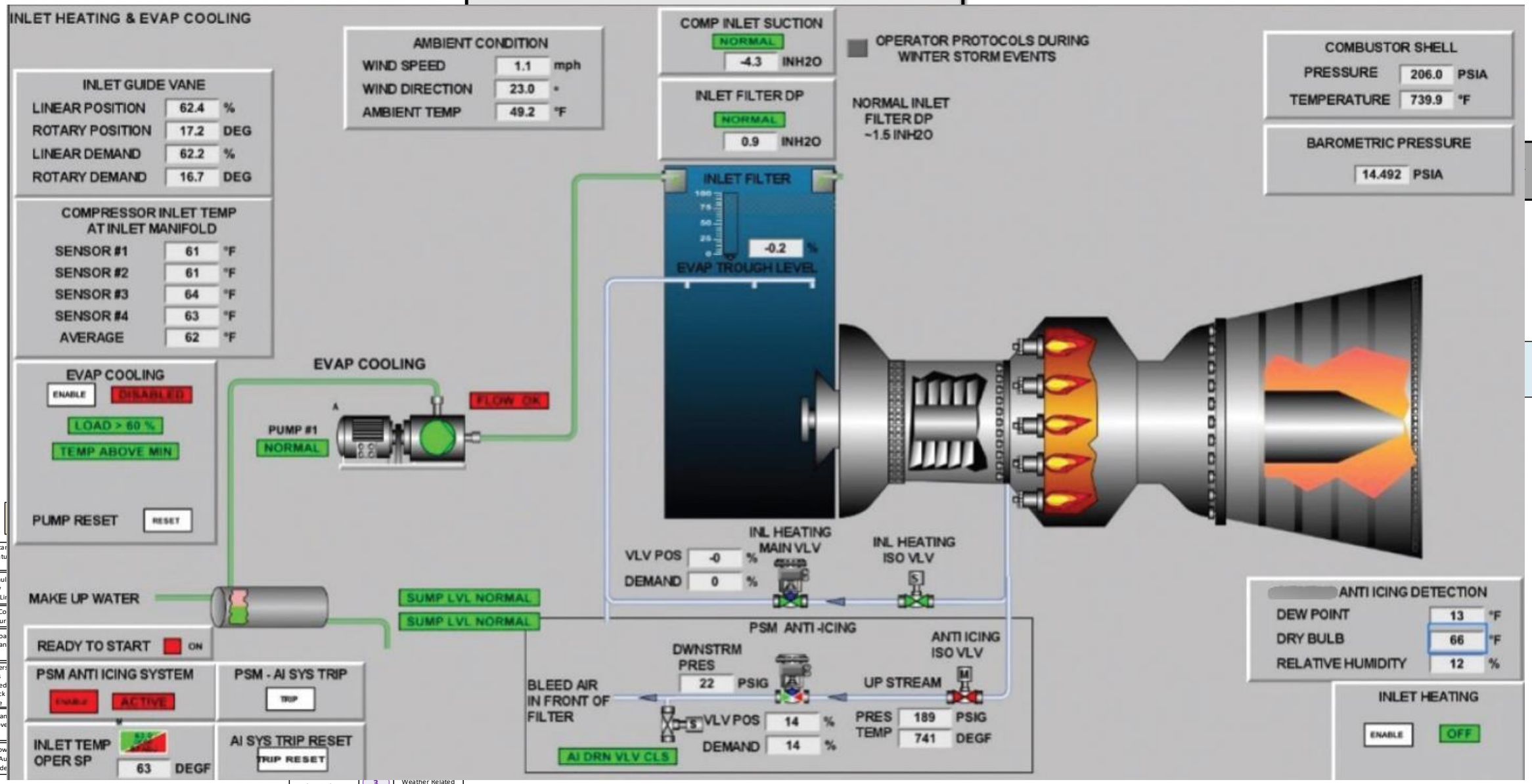
February 2021 Event Bottom Line

- D… …eek of February 14, 2021, for over tw… …ive days, ERCOT averaged 34,000 m… …MW) of generation outages, nearly half of ERCOT's 2021 all-time winter peak load of 69,871 MW.
- Largest firm load … U.S. history … …ird largest in quantity of ou… …August '96 bla…
- …vent in the past 10 years which …ulk-power system reliability d… unplanned generating unit outages which esca… …eather.

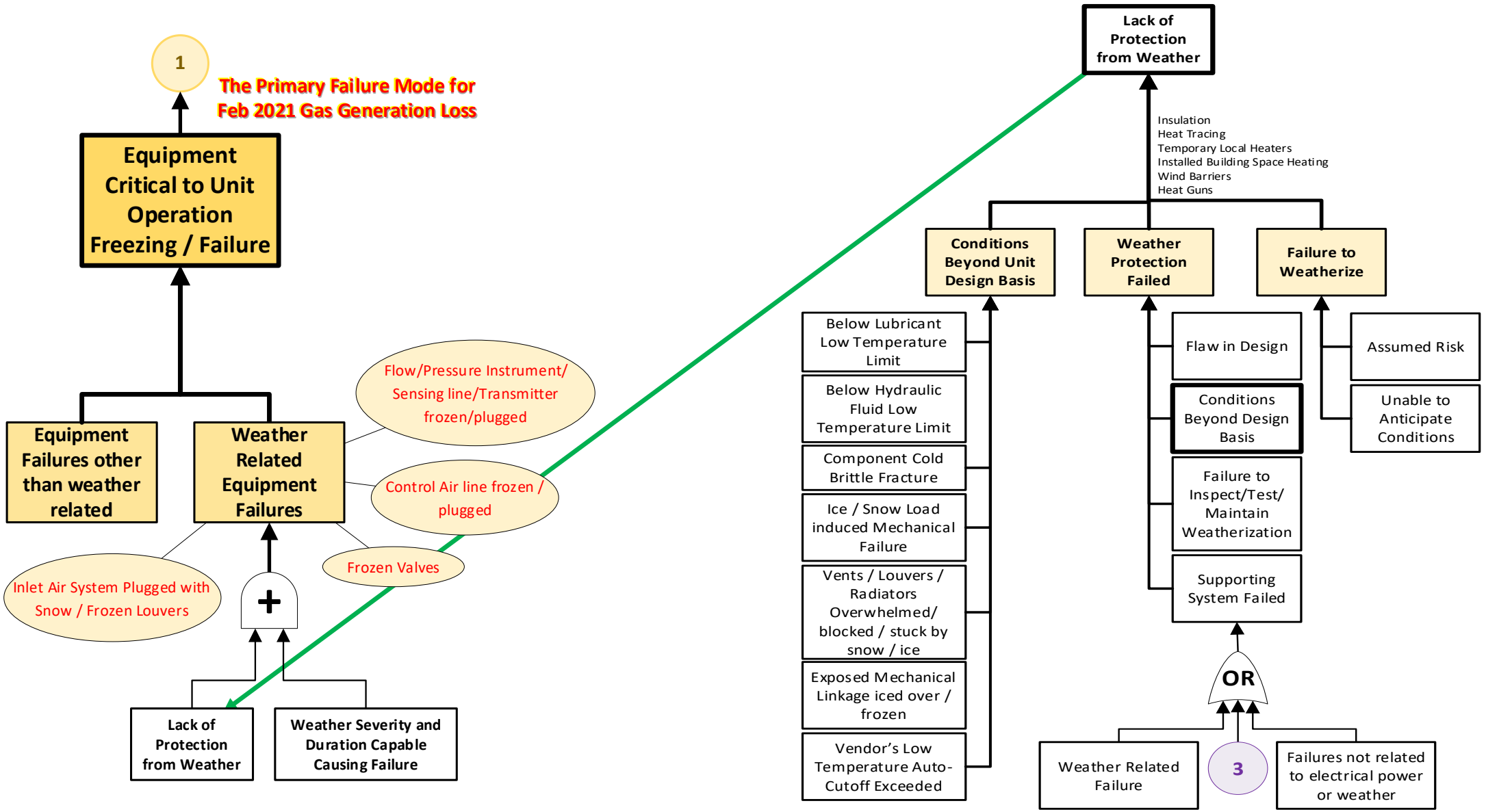


Source: (NERC) November 2021 Presentation on …021 C… …er …at

Failure Mode Mechanisms—Generic Failure Mode Model

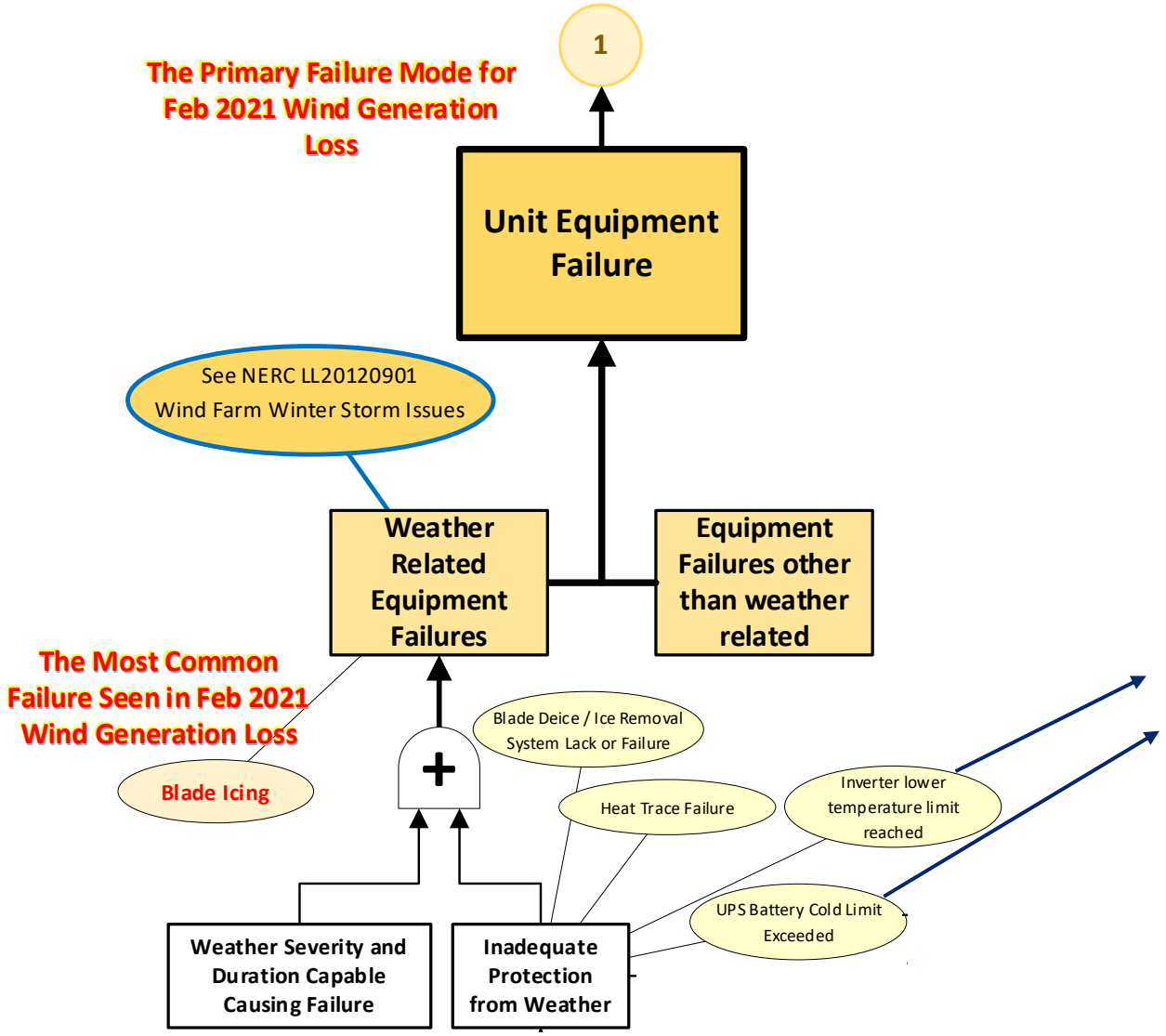


Failure Mode Mechanisms (1) Gas Generation loss from Cold Wx



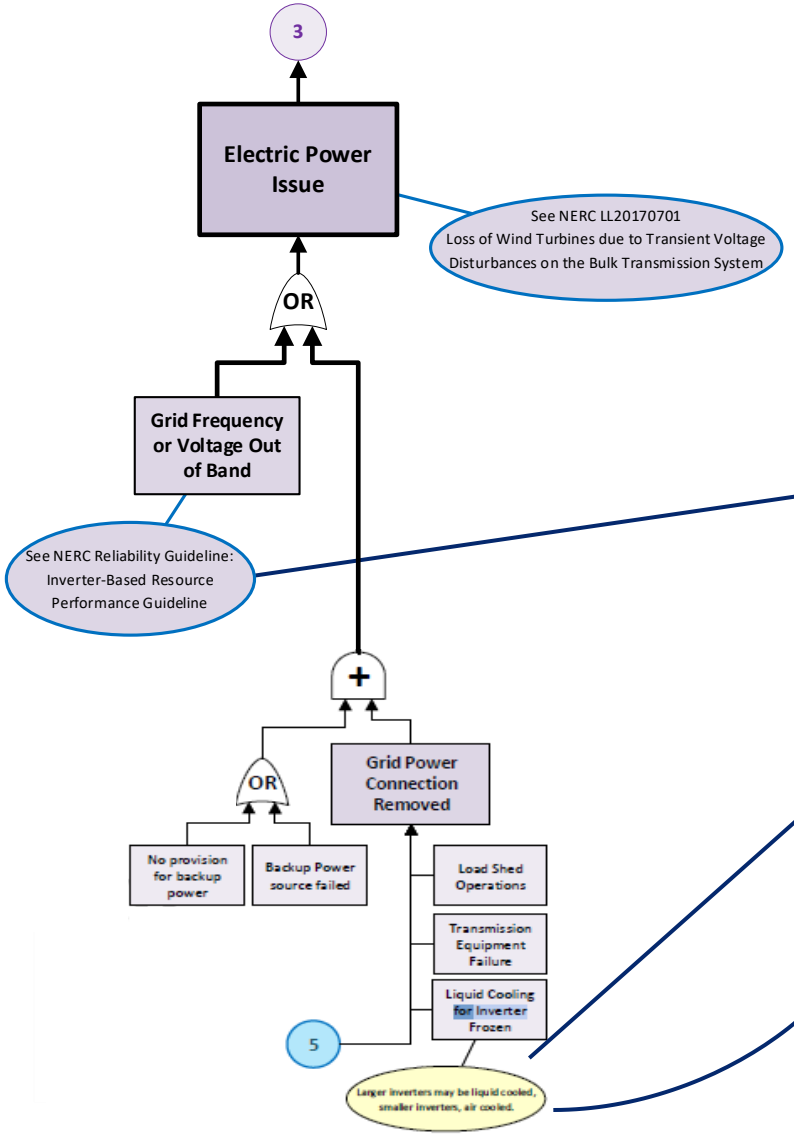
Failure Mode Mechanisms
Inverter Breakout

Failure Mode Mechanisms—Inverters



- ✓ Inverter mapping from draft diagram
- ✓ Applicable beyond Wind Turbine installations

Failure Mode Mechanisms—Inverters



Known issue: Coolant froze during a cold weather event!

"Large Inverters may be liquid cooled, smaller inverters air cooled."

See also: NERC Reliability Guideline page 4

NERC Presentation 09/2025—17 Cold Weather Lessons Learned

LL20110902 Adequate Maintenance and Inspection of Generator Freeze Protection

LL20110903 Generating Unit Temperature Design Parameters and Extreme Winter Conditions

LL20111001 Plant Instrument & Sensing Equipment Freezing Due to Heat Trace & Insulation Failures

LL20120101 Plant Onsite Material and Personnel Needed for a Winter Weather Event

LL20120102 Plant Operator Training to Prepare for a Winter Weather Event

LL20120103 Transmission Facilities and Winter Weather Operations

LL20120901 Wind Farm Winter Storm Issues

LL20120902 Transformer Oil Level Issues During Cold Weather

LL20120903 Winter Storm Inlet Air Duct Icing

LL20120904 Capacity Awareness During an Energy Emergency Event

LL20120905 Gas and Electricity Interdependency

LL20180702 Preparing Circuit Breakers for Operation in Cold Weather (also 2018 Webinar w/FMM)

LL20200601 Unanticipated Wind Generation Cutoffs during a Cold Weather Event

LL20201101 Cold Weather Operation of SF6 Circuit Breakers

LL20220301 Managing UFLS Obligations and Service to Critical Loads during an Energy Emergency

LL20221201 Air Breaker Cold Weather Operations

LL20230401 Combustion Turbine Anti-Icing Control Strategy

Questions and Answers

Additional Resources

- ERO Failure Mode Mechanisms Working Group
- NERC Cold Weather Preparedness Webinar 09/05/2025 (2 hr. 25 min)
- NERC Reliability Guideline—Generating Unit Winter Readiness Current Industry Practices V4, 06/2023 {V4 latest}

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https://vimeo.com/1117539714/2d273f74fb