Update on LLTF White Paper 2

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July LLTF Meeting
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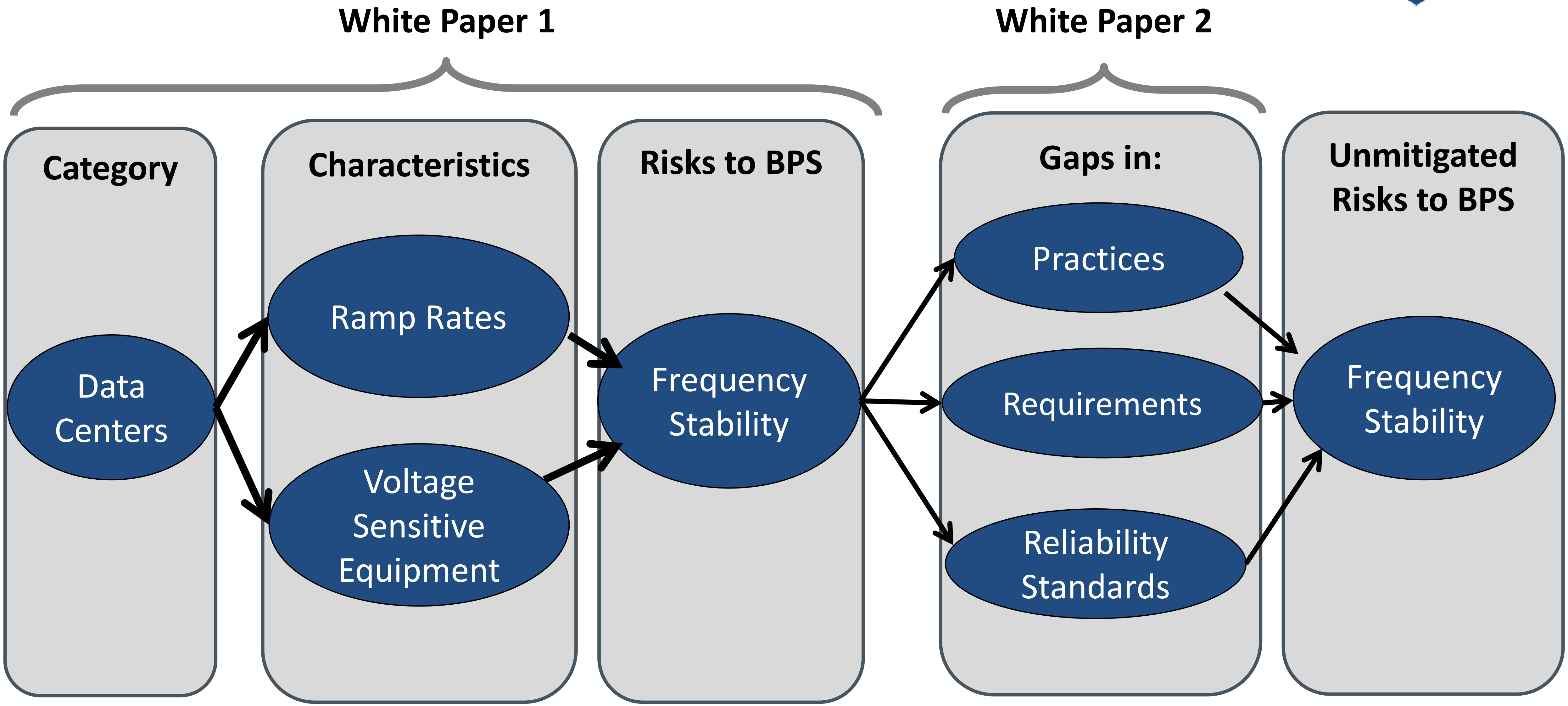
White Paper 2: Gap Analysis



This is only one example to demonstrate the structure.

LLTF and RSTC Comments; Paper Delay

- Received ~350 comments
- White Paper 2 Subgroup:
  - Reviewing and making changes based on comments during 7/14-7/25.
  - ~3 hours of meetings almost every week day
  - About ~140 comments have been addressed

- With the large number of comments we have received, we are needing to delay the paper to the October RSTC meeting for approval (previous plan was September RSTC meeting).

Next Steps

- Finish making changes after comment period
- NERC legal, admin, and publications reviews
- LLTF review and vote
- RSTC review and vote

Interconnection Processes and Requirements

- No standardized requirement for provision of operational characteristics and validated modeling data.

- Fast data center development time versus lengthy generation/transmission development time.

- Lack of standardized interconnection procedure.
- No requirement for post-energization model validation or performance testing.

- Lack of coordination between entities during project development.

Planning and Resource Adequacy

- Lack of uniform guidance on when and how emerging loads should be integrated into planning studies.

- Fast data center development time (e.g. less than 2 years) versus traditional transmission planning horizon.

Operational and Balancing Gaps

- Large loads are not subject to coordination requirements with balancing authorities (BA) or post-event analysis reporting.
- Lack of requirements for installation of disturbance monitoring equipment.

- Lack of explicit requirements for considering behavior of large loads in assessments and situational awareness.
- Lack of specific guidance/constraints regarding large load ramp-rate limits.

- Hourly/daily demand forecast data is often incomplete and lacks granularity.
- Need for faster and more flexible balancing is not fully addressed.

- Operators often lack telemetry or observability into large load facilities
- Loads not currently considered in the most severe single contingency calculation.

Ride-Through, Stability, and Power Quality

- Lack of requesting information regarding ride-through capability of large loads during interconnection.

- Lack of coordination regarding when a load should return to pre-disturbance demand levels after a voltage disturbance.
- Lack of allowable limits for forced oscillations.

- Models used and scenarios considered in transient stability studies.
- Load modeling practices related to frequency and voltage stability studies.
- Scenarios for frequency stability studies.

Modeling of Large Loads

- Existing load models do not adequately reflect the characteristics of large power electronic loads.
- Engineers might lack necessary parameter inputs for models. Additionally, operational data to validate models may be lacking.

- Limited guidance or standardization on when/how to apply large load EMT models to studies.

- Lack of requirements for load facility owners to submit models.
- Lack of large load participation in industry forums regarding load modeling.

- Large load model validation testing procedures are not commonly used.
- No consistent industry approach regarding model quality testing of large loads.

Questions and Answers

Mitigating Risk for Large Load Interconnections

NERC LLTF Virtual Workshop

June 23, 2025

Andrew L. Isaacs

ELECTRANIX
SPECIALISTS IN POWER SYSTEM STUDIES

What are the risks?

- Synchronous Generator damage
- Degradation of system damping
- Power Quality
  - Harmonics
  - Flicker
- Ride-through failure impact
  - Voltage impact
  - Frequency impact
- IBR interaction
- Machine mode instabilities
- Interarea oscillations
- Resource Adequacy
- Steady state constraints
  - Thermal
  - Voltage
- Dynamic VAR margin
- Protection mis-operation

What are “physical” mitigations?

- Once we know there is a problem, hardware or software can be used to mitigate the problems
  - Storage (BESS, E-STATCOM, rack-level, other)
  - Dynamic VARs (STATCOM, fast caps, other)
  - Software-side changes
  - New transmission
  - RAS/SPS
  - Monitoring and protection

Requirements can mitigate risk

- Key Categories of Requirements
  - Requirements on variation in active power
  - Requirements on ramping
  - Requirements on ride-through
  - Requirements on power quality
  - Requirements on power factor
  - Requirements on monitoring
  - Requirements on modeling
  - Future? voltage control, frequency response
- Requirements need to be based first on need and consider capability
  - Need can be identified by quantifying worst case impact and working backwards to performance. This requires some study
  - Participation from multiple parties is required to identify worst case impact (generator OEMs, operators, planners)
  - Lack of care, or error in requirements has very high consequences… Too slack = reliability risk, too tight = high cost and high delay. Too vague = confusing and non-uniform, too specific = over specification and higher cost.

Example requirement derivation:

- Active power variation can cause:
  - Generator damage
  - Interarea oscillations
  - Flicker
- Each type of problem can be quantified, and reflected back to the load as a requirement.
- Requirements can be regional (need studies every time), or universal (need to be tight to capture all situations)

Example requirement derivation:

- Example:
  - Generator damage:
    - For a given change in load active power (eg. single impulse, sinusoidal forcing function, or other), quantify change in a nearby machine (look at shaft component torques, look at currents, etc).
      - Note that results will change based on:
        - System strength (results in power split between machine(s) and system)
        - Load profile.
    - Compare the changes to known capability limits (electrical and mechanical) of synchronous machines.
    - Set appropriate limits in the requirements, both in magnitude and frequency components

Once requirements are in place:

- Education needs to occur to ensure understanding of requirements
- Load entities need to pass the requirements down to sub-suppliers and software engineers. This feedback loop takes time and involves many layers!
- Example:
  - Ride-through requirement needs to reflect down to each component of the load, including power supplies, UPS, VFD equipment, active filters, and each of those components may require changes to their basic hardware designs. There may be complex supply chain issues that need to reflect top level specs.

How will you ensure requirements are met?

- Prepare to evaluate the load by:
  - Model design evaluations (similar to IBR “design evaluations” ref. 2800.2)
  - Measurement (ensure sufficient monitoring is available at each load to track performance over time)
  - Embedding clear consequences and procedures for failure to meet requirements (contracts, curtailment, penalties, etc)

Studies can mitigate risk

- Pre-requirements:
  - Studies need to consider all the bad behaviour
  - Heavy physical mitigation is likely
- Post-requirements, pre-compliance
  - Studies need to test requirements and not assume compliance
  - Physical mitigation likely as a back-up (eg. extra dynamic vars to accommodate ride-through failure)
- Post-compliance
  - Existing studies need to be modified to account for gaps in requirements or compliance, or for legacy equipment

Modeling and studies can mitigate risk:

Concern	EMT Model with protection (OEM specific)	EMT Model including switching circuitry (OEM specific)	EMT Model including grid-facing control representation (OEM specific)	EMT Model with software cycling (OEM agnostic)	OEM Specific Harmonic Model (Norton Source)	Powerflow Model	PDT Model with software cycling	PDT Model without software cycling
SSTI screening (eg. UIF)	No	No	No	No	No	Yes	No	No
SSTI due to software cycling	No	No	No	Yes	No	No	No	No
Torque impact due to fast changes in load	No	No	No	Maybe	No	Maybe	Maybe	No
SSTI due to control damping	No	No	Yes	No	No	No	No	No
SSCI due to control damping	No	No	Yes	No	No	No	No	No
Harmonic model creation	No	Yes*	Yes*	No	No	No	No	No
Harmonic evaluation	Maybe	Maybe	Maybe	Maybe	Yes	No	No	No
Flicker evaluation	No	No	No	Maybe	No	Yes	No	No
Ride-through sensitivity	Yes*	No	Yes*	No	No	No	No	No
Ride-through impact	Maybe	No	Maybe	No	No	No	No	Maybe
Frequency impact	Maybe	No	No	No	No	No	No	Maybe
IBR/FACTS interaction impact	Maybe	No	Maybe	Maybe	No	Maybe	Maybe	Maybe
Machine mode oscillations due to software cycling	No	No	No	Maybe	No	No	Yes	No
Interarea oscillations	No	No	No	No	No	No	Yes	No
Resource balancing due to ramping	No	No	No	No	No	Yes	No	No
Steady state constraints	No	No	No	No	No	Yes	No	No
Dynamic VAR margin	No	No	No	No	No	Yes	No	Yes

**Alternative to EMT modeling could be detailed laboratory testing on OEM specific equipment*

Thank you! Questions?

Reliability Guideline Drafting:

Risk Mitigation for Emerging Large Loads

Evan Mickelson, Engineer
Jack Gibfried, Engineer
NERC LLTF Meeting and Workshop
July 24, 2025

Agenda

- Process and Update
- Recommendations
- Discussion

Scope of Reliability Guideline

*For __risks not mitigated__ by**

- *Existing practices*
- *Requirements*
- *Reliability Standards*

Identified in White Paper 2

Risk Mitigation in…

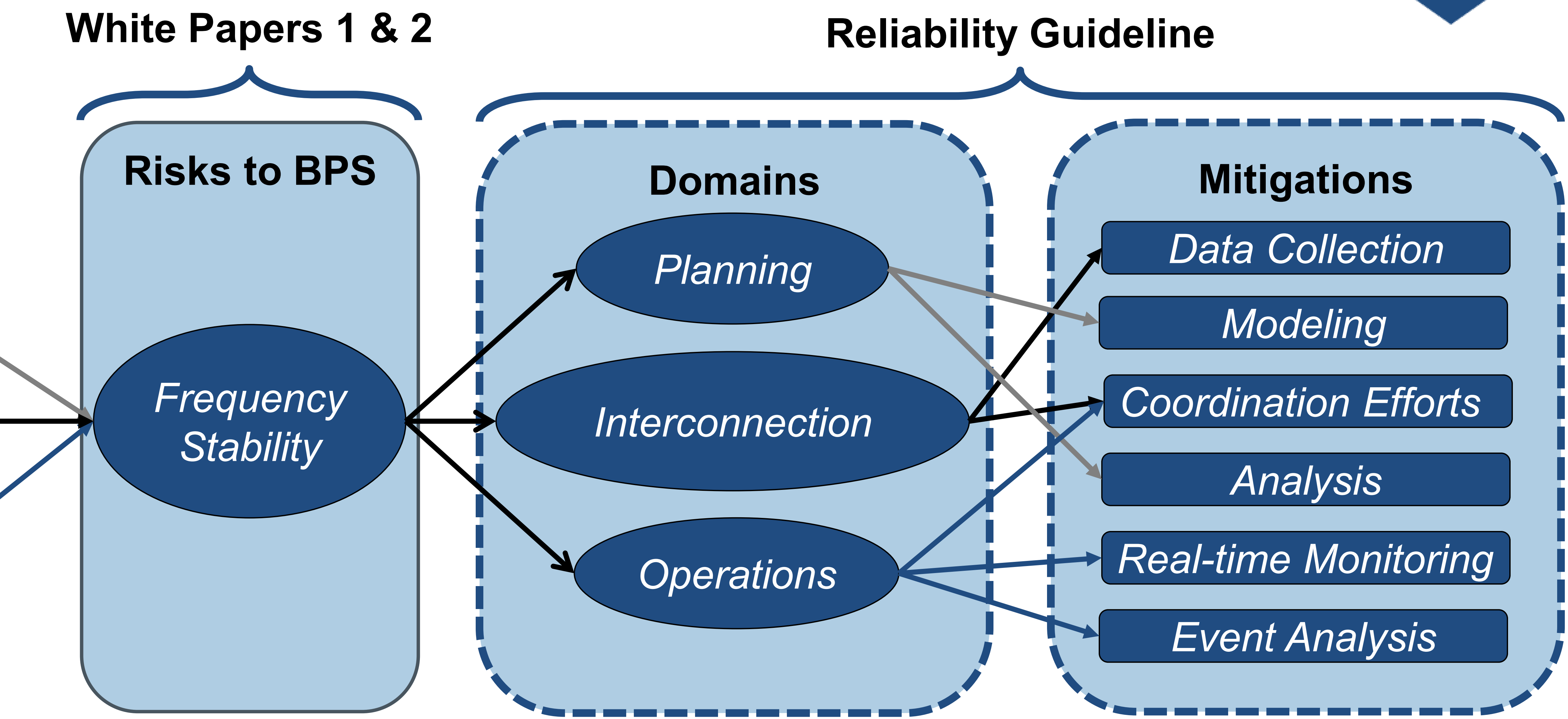
- Planning
- Interconnection
- Operations

Recommended Practices for Large Load…

- Data Collection
- Modeling
- Coordination Efforts
- Analysis
- Real-time Monitoring
- Event Analysis

May include recommended improvements to…

- Data Collection
- Modeling
- Coordination Efforts
- Analysis
- Real-time Monitoring
- Event Analysis



This is only one example to demonstrate the structure.

Tentative Timeline

Considering drafting timeline and review process, this schedule seems optimal

Stated Risks

High-Priority Risks	
Long-Term Planning	Resource Adequacy
Operations/Balancing	Balancing and Reserves
Stability	Dynamic Modeling
	Ride-through
	Voltage Stability
	Angular Stability
	Oscillations

Medium-Priority Risks	
Operations/Balancing	Short-Term Demand Forecasting
	Lack of Real-Time Coordination
Long-Term Planning	Demand Forecasting
	Transmission Adequacy
Stability	Frequency Stability
Security Risks	Cyber Security
Load Shedding Programs & System Restoration	Manual Load Shed Obligations
	Automatic UFLS Programs

Low-Priority Risks	
Power Quality	Harmonics
	Voltage Fluctuations
Load Shedding Programs & System Restoration	System Restoration

The following Slides are <u>DRAFT ONLY</u>

Mitigation for Ride Through

EXAMPLE ONLY

Mitigation Category	Planning Domain	Interconnection Domain	Operations Domain
1. Data Collection	- Collect expected ride-through behavior from similar load classes. - Historical LL disconnection events.	- Require ride-through curves and equipment specs as part of LL interconnection request. - Collect settings for protection relays, UPS logic, and auto-transfer schemes.	- Gather telemetry to understand real-time LL behavior during system faults (e.g., via PMUs or high-speed SCADA).
2. Modeling	- Include representative ride-through assumptions for large loads in stability base cases. - Simulate range of ride-through behaviors for planning scenarios.	- Require submission of dynamic models for LLs (e.g., low-voltage behavior of power electronics or UPS). - Model how protection triggers backup transition.	- Use accurate LL models in transient and voltage stability assessment tools used for real-time and day-ahead operations studies.
3. Coordination	- Align with TO/TP on LL behavior during faults. - Plan for overlapping impacts from clustered LLs.	- Coordinate interconnection study assumptions between TO, TP, and LL developer to reflect realistic fault ride-through capability.	- Clarify LL operational behavior during grid events and confirm alignment with grid needs (e.g., avoid simultaneous trip).
4. Analysis	- Conduct scenario analysis on LL tripping during contingencies (e.g., LL trip + N-1 fault). - Evaluate need for mitigation (e.g., VAR support).	- Study impacts of LLs that have poor ride-through capability. - Quantify grid enhancements or protection coordination needed.	- Include LL trip scenarios in contingency analysis tools (e.g., RTCA, transient security assessment). - Assess impacts on frequency and voltage stability.
5. Real-Time Monitoring	Not used in long-term planning,	- Require installation of high-speed data acquisition (e.g., PMUs) at POI for LLs above MW thresholds.	- Continuously monitor LL voltage/frequency performance during events. - Detect early signs of poor ride-through behavior (e.g., alarms for auto-transfer or trip).
6. Event Analysis	- Feed post-event LL behavior into future ride-through assumptions. - Update planning models to reflect actual LL trip thresholds.	- Use commissioning test results or past event data to calibrate LL behavior in models.	- Perform post-event analysis to assess whether LLs stayed online or tripped. - Correlate with PMU/SCADA data to refine operational protocols or alarms.

Overall Outline

- Introduction
- Risk Mitigation
  - Data Collection
  - Long-Term Planning and Resource Adequacy
  - Operations/Balancing
  - Stability
  - Resilience
  - Physical/Cyber Security
  - Power Quality
- Conclusions

*For each **unmitigated** risk, how is it mitigated via [data collection/modeling/…] in the [planning/interconnection/ops] domain*

Data Collection

- Large Load → TO/TP
  - **Milestones:** design, construction, commissioning
  - **Forecasted Demand (Real & Reactive):** Seasonal, daily, hourly
    - Forecasted during interconnection, daily forecasted load
  - **Ramping Behavior:** Variability during normal operations, disclosure of cyclical ramping
  - **Load Details:** One-line, LMWG Data Center Questionnaire
  - **Dynamic Modeling:** validated positive sequence model, site-specific EMT model
    - As-planned/designed, as-built, as-left
  - **Ongoing:** customer-initiated load reduction performance validation
  - **ALL ABOVE ITEMS SHOULD BE UPDATED THROUGH DESIGN, CONSTRUCTION, AND COMMISSIONING**
- TO/TP → BA, PC, RC
  - **All the above**
  - **Define data requirements:** for interconnection and commissioning

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Long-Term Planning and Resource Adequacy

Theme

Ongoing data sharing and coordination between TO/TP/BA/PC/RC

Comprehensive requirements and study process for LL

- TO/TP/BA/PC/RC
  - **Establish comprehensive study process using steady state and dynamic models to assess reliability impacts that consider the unique characteristics of Large Loads**
  - **Coordinate within region to share latest data** on interconnections and modeling data
  - **Ensure approved interconnections are reflected in future load interconnection studies**
  - **Incorporate loads that have firm agreements** into annual planning cases
- BA/RC/RC
  - **Establish uniform standard** within the regional coordinator's organization for a maturity matrix for each project

Operations and Balancing

Theme

Real-time data sharing decreases uncertainty and risks

Need communication line for emergencies

High speed recorders needed for event analysis

- LL → TO/TP/BA/PC/RC
  - **Telemetry:** statuses, demand
  - **Near-Term Forecasting:** Provide operating plan to grid operator
  - **Demand Response**
  - **Establish real-time communications channel**
  - **High-Speed Recording:** Needed for event analysis

Stability – Large Loads

Theme

LLs to provide as-planned, as-built, as-left dynamic models
(including some level of validation and verification)

- LL → TO/TP/BA/PC/RC
  - **Dynamic Model:** Provide as-planned facility dynamic model, update throughout construction
  - **Model Validation:** Provide some level of model validation
  - **High-Speed Recording:** Needed for event analysis and model validation

Stability – Planners and Operators

Theme

Planners/operators should define dynamic modeling requirements

Utilities to study stability concerns specific to LL and enforce SOL/IROLs

Design and implement reasonable performance requirements that ensure system stability

- TO/TP/BA/PC/RC
  - **Dynamic Model Requirements:** create model quality and verification requirements for as-planned, as-built, and as-left models of load facilities
  - **Fault Performance and Customer-Initiated Load Reductions:** define performance requirements
  - **Study:** new scenarios specific to LL (fault-induced customer-initiated load reduction & reconnection)
  - **SOL/IROL:** SOLs and IROLs related to customer-initiated load reduction should be identified and monitored

Theme

If LLs are used for UFLS or system restoration, specific criteria should be met

Some LL should be prioritized for restoration (gas compressor stations, etc.)

- TO/TP/BA/PC/RC
  - **Analysis:** identify loads that are critical to restoration

Theme

LLs (if not already) should implement security controls that align with NERC CIP standards

Power Quality

Theme

LLs to ensure harmonic distortions comply with existing PQ standards

- LL/TO/TP/BA/PC/RC
  - **Power quality monitoring:** Should be monitored at LL terminal

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Feedback Opportunities

Soliciting Feedback through August 15

- Please share any feedback live in the meeting
- Any further feedback please send to
  - Evan.Mickelson@nerc.net
  - Jack.Gibfried@nerc.net
  - **Subject Line:** LLTF Risk Mitigation Discussion

Ongoing Questions

- Is inability to energize a new load due to underbuilt transmission a risk to BPS reliability?

- Is delaying the energization representing an inability to serve load?

Ongoing Questions

- What on-fault and post-fault performance requirements ensure grid stability while remaining reasonable for LL to implement?

- At what stages can LL give certain levels of detailed modeling?

Final Call for Reliability Guideline Volunteers

Simply email us to get involved!

Evan.Mickelson@nerc.net

Jack.Gibfried@nerc.net

Questions and Answers