Inverter-Based Resource Risk Assessment

Recommendations for Regulatory Bodies to Support Risk Mitigations for Inverter-based Resources during the Energy Transition in the Western Interconnection

PREPARED FOR:

Western Interconnection Regional Advisory Body
1600 Broadway, Suite 1020, Denver, CO 80202
T: 720-897-4600
W: www.westernenergyboard.org

PREPARED BY:

Elevate Energy Consulting Services, LLC
Spokane, WA, USA
E: info@elevate.energy
W: www.elevate.energy

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EXECUTIVE SUMMARY

The generation resource mix across the Western Interconnection continues to rapidly transition to increasing levels of renewable energy resources, predominantly inverter-based resource (IBR) technologies such as wind, solar photovoltaic (PV), battery energy storage (BESS), and hybrid plants consisting of multiple of these technologies. This rapid change presents unique opportunities and challenges for ensuring bulk power system (BPS) reliability and resilience. IBRs are introducing new and emerging BPS reliability risks that must be managed by the electricity sector in an effective, efficient, and agile manner. Past large-scale grid disturbances in California, Utah, Texas, North America and globally have highlighted systemic risk issues that need to be addressed by an array of stakeholders – ranging from regulatory bodies and policymakers to transmission providers and generator developer/owner/operators to associated original equipment manufacturers (OEM) and service providers.

Figure ES.1 illustrates a core set of systems integration challenges that are likely to emerge as IBR penetration levels rise. As this report highlights, the Western Interconnection has a relatively higher IBR penetration level than many other parts of North America today and those levels are expected to rise rather quickly. However, each utility likely has a different level of capabilities and experience with IBR integration based on their past IBR growth and future projections. Therefore, which of the issues outlined in Figure ES.1 may differ by system and entity; however, entities are likely to face each of these challenges or risks as their own system experiences increasing levels of IBRs moving forward. Therefore, it is important to develop and implement mitigating measures effectively and proactively. These mitigation measures will need to be implemented by appropriate stakeholders to address these challenges in the years ahead. However, it should be highlighted that the pace of change the electricity sector is experiencing necessitates swift and effective action in this area.

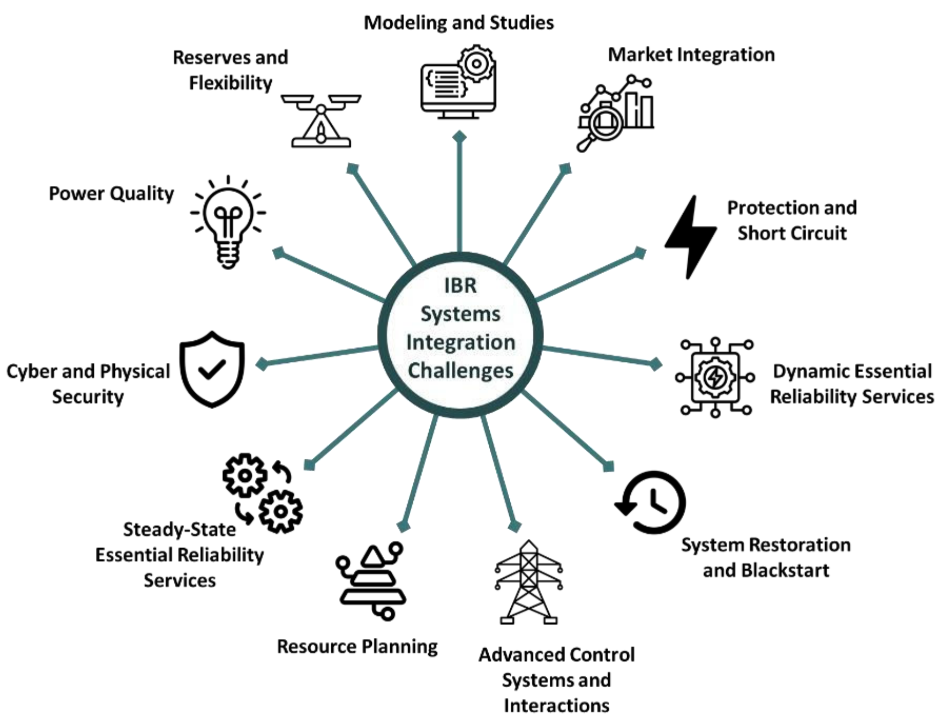

Figure ES.1. IBR Systems Integration Risks and Challenges

The Western Interconnection Regional Advisory Body (WIRAB) advises the Federal Energy Regulatory Commission (FERC), North American Electric Reliability Corporation (NERC), and Western Electricity Coordinating Council (WECC) on matters pertaining to electric reliability in the Western Interconnection which may involve proposed reliability standards, key risk priorities, and other topics that are in the West's economic and societal benefits.

This assessment highlights grid reliability challenges that need to be addressed as industry collectively works through the energy transition and provides evidence that immediate attention is needed to address the foundational aspects of a reliable BPS from different angles and from a diverse set of stakeholders. This work culminates in the following near-term, medium-term, and long-term recommendations where WECC and its members, transmission providers (e.g., TOs, ISO/RTOs, etc.), WIRAB and its members, and State utility commissions are all key stakeholders for these recommendations (see **CHAPTER 4: *Key Findings and Recommendations***):

- **Near-Term (1–2 Years) Recommendations**
    - Template Facility Interconnection Requirements (WECC)
    - Targeted Stakeholder Engagement on Emerging IBR Topics (WECC)
        - IBR Interconnection Challenges, grid forming training and needs, EMT modeling and studies, integrated resource planning, flexibility metrics and energy assurance, etc.
    - Harmonized Adoption of IBR Requirements (NERC/FERC)
    - State Regulatory Emphasis of IBR Requirements Enhancements (State PUCs)
- **Medium Term (3–4 Years) Recommendations**
    - Proactive Stakeholder-Engaged Risk Mitigation (WECC)
    - Pilot Projects for Emerging IBR Risk Mitigations (WECC)
    - Regional Reliability Standard for Unified IBR Requirements (WECC)
- **Long-Term (2030+) Recommendations**
    - Transitioning Toward a Grid Code Approach in the West

State utility commissioners also can help play a pivotal role in driving meaningful enhancements in addressing these energy transition risks. Recommendations for how State commissioners can engage in this discussion include (again, see **CHAPTER 4: *Key Findings and Recommendations*** for more details):

- Advocate for Enhanced and Harmonized Transmission Owner Interconnection Requirements:
    - Inquire About and Support Adoption of IEEE 2800-2022
- Promote Coordination Between State and Federal Authorities
- Encourage and Support Utility Investment in Grid Modernization
- Support Streamlining of Interconnection Processes
- Stay Informed on Active Industry Efforts in This Area

These actions can help state utility commissioners play a proactive role in enhancing interconnection requirements and contributing to a more reliable and resilient bulk power system.

Table of Contents

LIST OF ACRONYMS

Acronym	Definition
BES	Bulk Electric System
BESS	Battery Energy Storage System
BPS	Bulk Power System
EMT	Electromagnetic Transient
ERO	Electric Reliability Organization
ERS	Essential Reliability Service
FERC	Federal Energy Regulatory Commission
GIA	Generator Interconnection Agreement
GIP	Generator Interconnection Procedure
GO	Generator Owner
GOP	Generator Operator
IBR	Inverter-Based Resource
IEEE	Institute of Electrical and Electronics Engineers
IRP	Integrated Resource Plan
IRPS	NERC Inverter-Based Resource Performance Subcommittee
ISO	Independent System Operator
NERC	North American Electric Reliability Corporation
OEM	Original Equipment Manufacturer
PV	Photovoltaic
RAS	Remedial Action Scheme
RMS	Root-Mean-Square
ROCOF	Rate of Change of Frequency
ROP	Rules of Procedure
RPS	Renewable Portfolio Standard
RSTC	NERC Reliability and Security Technical Committee
RTO	Regional Transmission Organization
SCR	Short Circuit Ratio
TO	Transmission Owner
TOP	Transmission Operator
WECC	Western Electricity Coordinating Council
WIEB	Western Interstate Energy Board
WIRAB	Western Interconnection Regional Advisory Body

INTRODUCTION

Background and Scope

The Western Interconnection Regional Advisory Body (WIRAB) is a Section 215(j) regional advisory body that has the authority to advise the Federal Energy Regulatory Commission (FERC), the North American Electric Reliability Corporation (NERC), and the Western Electricity Coordinating Council (WECC) on matters pertaining to electric grid reliability in the Western Interconnection (see Figure I.1). This may include advising on proposed reliability standards, WECC governance and budgets, and other topics that are in the West's economic and societal benefits. WIRAB seeks consensus among its members prior to submitting advice on important reliability matters and FERC may give deference to the advice of WIRAB.

Figure I.1. WIRAB States

The unprecedented growth of renewable, inverter-based resources (IBRs) is the single largest driver of grid transformation across North America. Past work by the Electric Reliability Organization (ERO) Enterprise has repeatedly highlighted the risks associated with abnormal inverter performance, inaccurate IBR modeling and studies, poor IBR commissioning practices, and the need for proactive risk mitigation particularly in the West to address these issues before a large-scale outage occurs. The ERO Enterprise continues to also highlight that the magnitude and frequency of occurrence of these types of issues is rising rapidly and needs to be addressed immediately.

There are increasing concerns from FERC and the ERO that industry may not be addressing emerging reliability risks associated with this energy transition and grid transformation in the most effective, efficient, and agile manner. IBRs continue to connect to the grid with potential underlying modeling and performance issues as well as introducing unique challenges that must be managed. It is imperative that the full capabilities of modern inverter technology be used to maximize the benefits this new technology can provide to the grid. Underutilizing modern inverter technology may undermine a successful energy transition as well as have serious adverse impacts on ratepayers. This paper explores risks that IBRs may present to BPS reliability; however, IBRs can present unique benefits and opportunities for BPS reliability if planned, designed, and operated in a manner that supports BPS reliability.

In 2024, WIRAB commissioned this assessment of IBR-related risks in the Western Interconnection. The assessment focuses specifically on growing levels of IBRs in the West, and potential regulatory and policy recommendations that could more proactively address challenges during the energy transition and help ensure a reliable, resilient, and affordable BPS across the Western Interconnection. The assessment is intended to introduce unique perspectives and thought-provoking considerations for WIRAB stakeholders that could expedite effective regulatory action that supports Western stakeholders broadly.

Growth of IBRs Across the West

The Western Interconnection is experiencing a rapid growth of renewable energy resources driven by economics, renewable energy policies, and Renewable Portfolio Standards (RPS). Most states and many utilities across the Western Interconnection have some form of RPS or voluntary renewable energy targets (see Table I.1).[1] Examples from a brief review of IRPs from for some larger utilities across the West also highlight the rapid rise of IBRs:

- **Idaho Power:**[2] The Idaho Power 2023 IRP Preferred Portfolio includes around 6,375 MW of IBRs (1800 MW of wind, 3325 MW of solar, and 1250 MW of BESS).
- **NV Energy:**[3] The NV Energy 2024 IRP includes adding 1,000 MW of solar, 1,000 MW of BESS, and 400 MW of natural gas peaking units.
- **PacifiCorp:**[4] The PacifiCorp 2023 IRP includes more than 9,800 MW of new wind, 2,000 MW of storage,[5] 3,760 MW of solar (mostly paired with BESS), 5,385 MW of natural gas, and 5,550 MW of energy efficiency and demand response.
- **Xcel:**[6] Xcel highlights in its Phase I Colorado Clean Energy Plan 2021 IRP that "unprecedented amounts of renewable energy" will be added to the grid, with plans for over 3,500 MW of wind and solar, over 1,800 MW of storage, and 670 MW of natural gas.

Table I.1. Renewable Portfolio Standards by State

State	Type	Description
Washington	RPS	15% by 2020, greenhouse gas neutral by 2030, 100% renewable/zero-emitting by 2045
Oregon	RPS	Reduce emissions by 80% by 2030, 90% by 2035, 100% by 2040
Idaho	-	-
Montana	-	-
Wyoming	-	-
California	RPS	44% by 2024, 52% by 2027, 60% by 2030, 100% clean energy by 2045
Nevada	RPS	50% by 2030, non-binding 100% carbon-free by 2050
Utah	Target	20% by 2025
Colorado	RPS	30% by 2020 for IOUs,[7] 100% clean energy by 2050 for utilities ≥ 500,000 customers
Arizona	RPS	15% by 2025
New Mexico	RPS	40% by 2025, 80% renewable by 2040, 100% zero-carbon by 2045
Texas	RPS	10,000 MW by 2025

[1] https://www.ncsl.org/energy/state-renewable-portfolio-standards-and-goals
[2] https://docs.idahopower.com/pdfs/AboutUs/PlanningForFuture/irp/2023/2023-irp-final.pdf
[3] https://www.nvenergy.com/publish/content/dam/nvenergy/brochures_arch/cleanenergy/IRP-Info-Sheet.pdf
[4] https://www.pacificorp.com/content/dam/pcorp/documents/en/pacificorp/energy/integrated-resource-plan/2023_IRP_Update.pdf
[5] Including batteries collocated with solar, standalone batteries, and pumped storage hydro (which is not an IBR).
[6] https://www.xcelenergy.com/staticfiles/xe-responsive/Archive/SPS-New-Mexico-IRP.pdf
[7] 10% or 20% for municipalities and cooperatives, based on size.

The generator interconnection queues govern the procedures and agreements for generators seeking access to the transmission system[8] and they provide a clear indication of the types of technologies being pursued over the next decade or so. Presently, the vast majority of newly connecting generators to the BPS are IBRs – solar photovoltaic (PV), wind, battery energy storage systems (BESS), and hybrid plants consisting of these technologies (see **Figure I.2**). Over 97% of the generator interconnection queues in the Western Interconnection are comprised of IBRs today.[9]

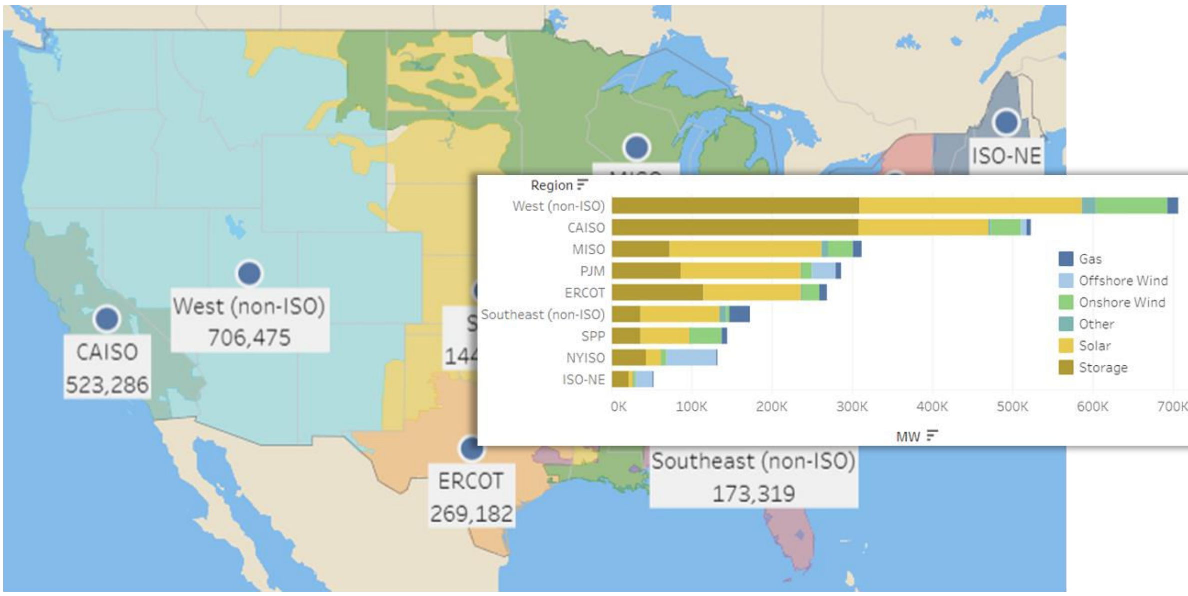

Figure I.2. Generation queues across the United States [Source: LBNL]

The 2023 WECC *Western Assessment of Resource Adequacy*[10] also highlighted that the Western Interconnection expects 95 GW of resource additions over the next 10 years, with 80% of those interconnections being solar PV, energy storage (mostly BESS), and wind (see **Figure I.3**). While not all of these proposed projects are likely to materialize, this is another credible indicator that the majority of new resource additions in the West are expected to be IBRs moving forward.

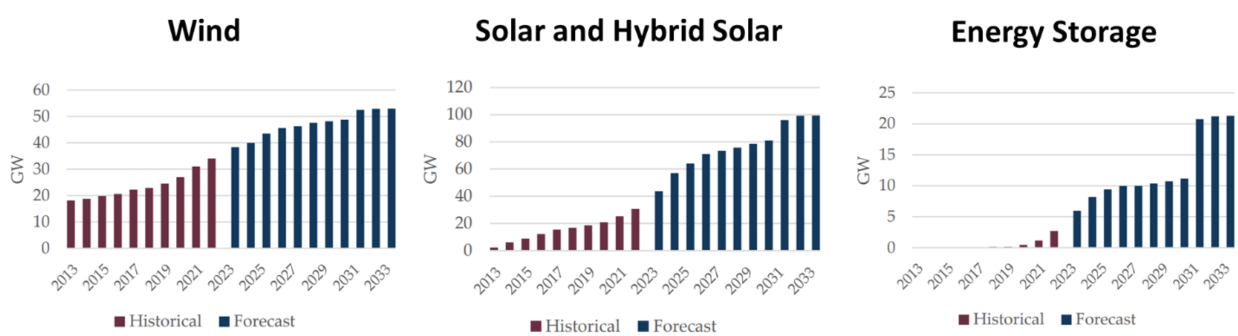

Figure I.3. Historical and planned Wind, Solar, and Storage in the WECC [Source: WECC]

8 https://www.ferc.gov/electric-transmission/generator-interconnection
9 https://emp.lbl.gov/maps-projects-region-state-and-county
10 https://www.wecc.org/Administrative/2023%20Western%20Assessment%20of%20Resource%20Adequacy.pdf

Both these assessments send a clear and definitive message that the future power grid in the West will be increasingly dominated by IBRs in the years ahead. Therefore, it is imperative for industry to prepare for and minimize potential risks for that future state.

IBR Risk Assessment Process

With IBR levels rapidly growing across the West, this assessment briefly explains potential challenges that may arise, issues industry has faced thus far, risk mitigations being pursued, and potential gaps where additional recommended actions may help mitigate reliability risks across the Western Interconnection. Figure I.4 illustrates the high-level process used for conducting this assessment.

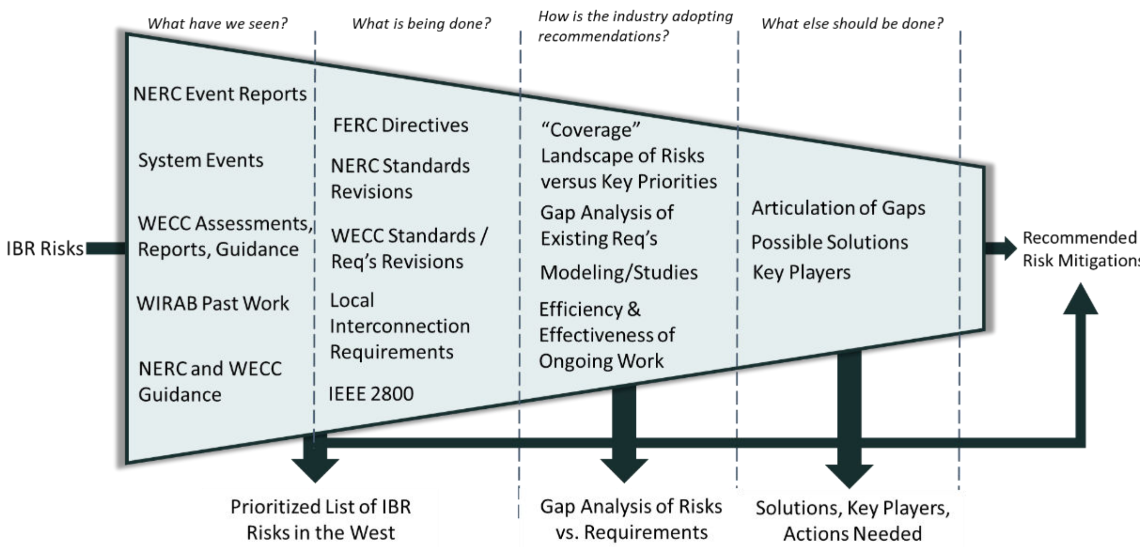

Figure I.4. IBR Risk Assessment Process

This work provides unique perspectives to the following questions for WIRAB and its stakeholders, focusing specifically on the activities of FERC, NERC, and WECC given WIRAB's unique role of providing West-wide input to these efforts:

- What led to the increasing number of large-scale IBR-related events across the West and other Interconnections? What are the root causes of those events?
- What solutions are available to mitigate those risks and what is being done to implement them in the West?
- Are the current risk mitigation measures by industry and regulatory bodies sufficient to keep up with the rapid pace of change occurring across the West?
- How can new regulatory requirements strike a balance between uniformity and flexibility?
- Are current planning and operational requirements and practices adequately studying future grid states to identify potential risks early and proactively develop solutions?
- How do we move from admiring the problems associated with grid transformation and the energy transition to effectively addressing those problems with least-cost, proactive risk mitigations?

CHAPTER 1: Prioritized List of IBR Risks in the West

The energy transition toward renewable energy resources is transforming the BPS across the US and around the world. There are many ways to identify, analyze, and articulate the risk landscape presented by IBRs (and the unique benefits and opportunities that IBRs can provide). This assessment takes a two-pronged approach. First, systems integration[11] challenges associated with IBRs are outlined (e.g., essential reliability services such as frequency control, protection system operation, stability, etc.).[12] Second, these challenges are considered within the lifecycle of an IBR plant – from resource procurement to interconnection and commissioning processes and into grid operations, modeling, and studies. Before defining and prioritizing these risks, let us first explore some formative events leading up to this assessment.

Observations and Indicators of IBR Performance Risks

There are multiple examples of large system-wide outages that serve as early indicators of high IBR challenges ahead more broadly across electricity networks around the world. Below are a few examples.

NERC Disturbance Reports

NERC has reported on abnormal IBR performance and associated risks posed by IBRs for nearly a decade (see **Figure 1.1**), first starting with the infamous Blue Cut Fire disturbance involving many solar PV resources that abnormally responded to a normally cleared BPS fault event. A dozen or so other events subsequently occurred in the years following, and NERC published multiple reports documenting key findings and recommendations for industry including important guidance documents that were used in the early developments of IEEE 2800-2022.[13,14] In 2022, multiple events involving the abnormal performance of BESS were identified and then in 2023 a large disturbance involving multiple solar plants in Southwest Utah also occurred, noting the first major IBR-related event in the Western Interconnection outside California.

Figure 1.1. Infamous NERC Reports of IBR Events in the West

[11] Systems integration refers to the harmonization of power system elements, controls, protections, and processes including IBRs and synchronous generation, advanced grid technologies, and conventional network components to ensure reliable, affordable, and efficient delivery of electricity to end-use customers.

[12] The Energy Systems Integration Group (ESIG) is a non-profit organization with the intent of exploring these technical systems integration challenges in much more detail and fosters open collaboration across industry stakeholders.

[13] https://www.nerc.com/pa/rrm/ea/Pages/Major-Event-Reports.aspx

[14] https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx

The NERC reports have documented risks that IBRs may pose to the BPS if not addressed in a timely and proactive manner. In addition, NERC has repeatedly highlighted resource adequacy and energy assurance issues as well as interconnection challenges. Many of the IBR performance-related risks stem from inadequate interconnection requirements that establish a clear expectation for how IBRs should be reliably integrated to the BPS. NERC also stressed the need to improve modeling and study requirements for IBRs to ensure accurate studies result in reliable decisions during the interconnection, planning, and operations horizons.

2016 South Australia Blackout

In 2016, South Australia experienced a complete blackout event due to extreme weather conditions that resulted in many grid faults and damage to transmission infrastructure. Wind plant protection operated unexpectedly, resulting in a sustained power reduction which caused a significant increase in power import through the main interconnection tie line. This triggered a special protection system (i.e., remedial action scheme (RAS)) that tripped the interconnector and caused islanding of the network from the rest of the Australian system. This caused a large frequency fluctuation and inability to support stable operation of the system, resulting in a blackout in the islanded network. The blackout event was another notable IBR-related event due to the unexpected tripping of wind plants due to protections not previously well understood, as well as the interactions with RAS and inability to sustain system stability when islanded due to large rate of change of frequency (ROCOF), challenges controlling voltage, and lack of grid stabilizing attributes from existing IBRs.[15]

2019 United Kingdom Load Shedding Event

In 2019, a large power outage occurred in the United Kingdom that interrupted over 1 million customers caused by a routine fault on the BPS. A large synchronous generator and a large offshore wind plant unexpectedly tripped as well as some distributed energy resources (DERs), causing frequency to drop rapidly that subsequently tripped a very large amount of DERs across the system. The combined loss of generation caused frequency to further decline and resulted in load shedding. This event illustrated how large-scale events involving the response and interactions between multiple resource types (e.g., synchronous, IBRs, DERs) can lead to grid reliability risks.[16]

2021 and 2022 Odessa Disturbances in Texas

In 2021, Texas experienced the unexpected tripping of a large amount of solar PV resources from a wide array of causes that resulted from a normally cleared fault at a synchronous generation facility. Texas had undergone a rapid rise in solar PV growth in the years prior, and this large-scale abnormal IBR performance event raised concerns of the systemic risk issues previously identified in California. Subsequently, in 2022, a nearly identical fault occurred that resulted in a substantially larger generator tripping event that also involved IBRs and synchronous generation tripping offline, nearly exceeding Texas' largest resource loss protection criteria. Electric Reliability Council of Texas (ERCOT) and its resource entities convened a

[15] https://www.aemo.com.au/-/media/Files/Electricity/NEM/Market_Notices_and_Events/Power_System_Incident_Reports/2017/Integrated-Final-Report-SA-Black-System-28-September-2016.pdf

[16] https://www.ofgem.gov.uk/sites/default/files/docs/2020/01/9_august_2019_power_outage_report.pdf

stakeholder group to deploy mitigations to nearly all existing and newly connecting resources across the Texas system.[17,18]

Systems Integration Challenges with Growing IBRs

Ongoing large-scale grid disturbances involving IBRs set a backdrop for outlining a more comprehensive set of systems integration challenges. Generating resources have historically provided "services" to the BPS, either procured or inherently provided;[19] however, this assessment takes a broader approach by exploring a wider spectrum of systems integration challenges regarding IBR integration. **Table 1.1** shows a breakdown of the categories of challenges and some of the areas of focus within each category. This paper does not dive deep into the specific technical details of these challenges; rather it is highlighting many of the key areas of focus that industry is collectively working on as they relate to IBR impacts to overall BPS reliability and systems integration moving forward. (Note: The challenges outlined in **Table 1.1** are not all-comprehensive as this assessment does not consider economics-related or policy-related issues associated with IBR technologies; this assessment is focused on BPS reliability-related challenges.)

Table 1.1. IBR Systems Integration Challenges

Resource Planning	• Resource Adequacy and Firm Capacity Planning • Energy Assurance and Energy Security
Security	• Cyber and Physical Security
Market Integration	• Market Design and Services; Pricing and Incentives
Modeling and Studies	• Powerflow, Dynamics, Short-Circuit, EMT • Model Quality and Model Validation • Study Assumptions, Scenarios, and Analyses
System Restoration	• Blackstart Resources (Islanded Mode Operation) • Cranking Paths
Reserves	• Regulating Reserves • Contingency Reserves – Spinning, Non-Spinning, Replacement • Ramping Reserves
Pseudo Steady-State Essential Reliability Services	• Balancing, AGC Control (Dispatchability), and Curtailment • Ramping Control and Variability Smoothing • Voltage Control • Frequency Control
Dynamic Essential Reliability Services	• Frequency Response (Fast and Primary) • Stability (Inertial Response, Controller Tuning, Etc.) • Low System Strength Operation • Grid Forming Controls • Subsynchronous Oscillations • Dynamic Performance Conformity
Protection and Short Circuit	• BPS Protection System Design • Fault Current Magnitude and Phase Relationship • Negative Sequence Current Injection
Power Quality	• Harmonics, Transients, and Flicker
RAS Design and Interactions	• RAS Controller Design • Safety Net Schemes (e.g. UFLS, UVLS)

17 https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf
18 https://www.nerc.com/comm/RSTC_Reliability_Guidelines/NERC_2022_Odessa_Disturbance_Report%20(1).pdf
19 https://escholarship.org/uc/item/75d2n2dw

The categories of services span the complete time spectrum from microseconds (i.e., protection system operation and BPS stability) to years (i.e., resource planning and long-term investment decision making). Figure 1.2 provides an illustrative representation of this spectrum of systems integration challenges and their respective timeframes.

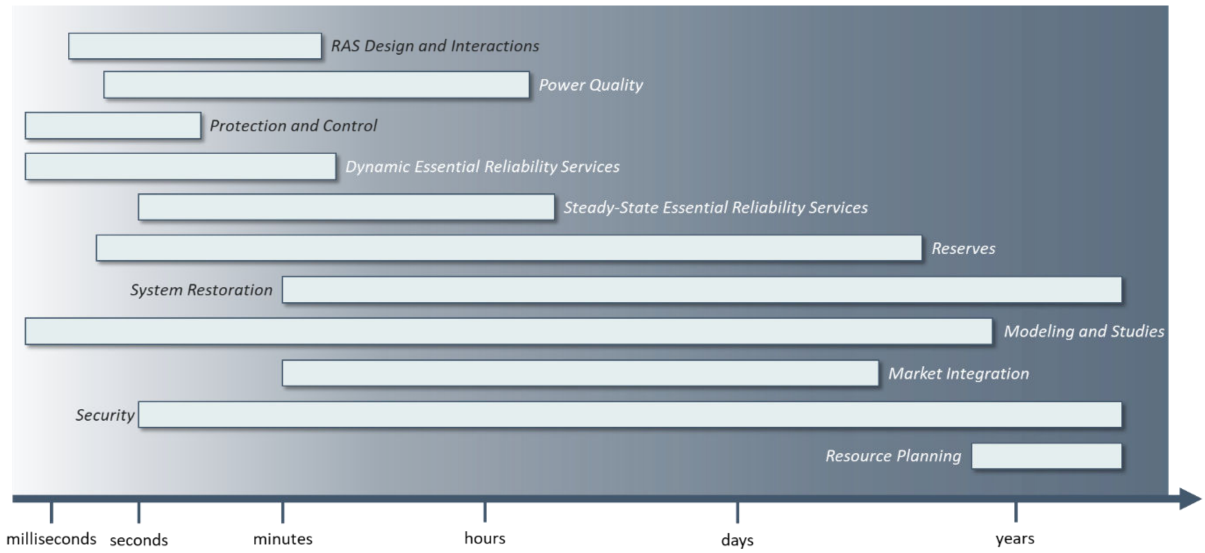

Figure 1.2. Timeframes of IBR Systems Integration Challenges

Prioritizing IBR Systems Integration Challenges

Each systems integration challenge described above was considered across the following phases of the lifecycle of an IBR plant:[20]

- **Resource Procurement:** This encompasses all aspects of studying and procuring sufficient resources as well as pre-queue entry for proposed generator interconnection requests.
- **Long-Term Transmission Planning:** This encompasses the long-term planning horizon and how IBRs can affect BPS planning decision making.
- **Generator Interconnection Process:** This includes all aspects of working through the generator interconnection queue process from initial request up through trial operation and commissioning.
- **IBR Plant Commissioning:** This specifically focuses on the IBR commissioning practices leading to trial operation and commercial operation date.
- **Operations:** This includes operational planning and real-time operations as well as electricity market operations.

With this matrix of systems integration challenges versus phases of an IBR plant lifecycle, the impacts that IBRs can have on BPS reliability were assessed using the following high-level criteria:

- What is the magnitude or pervasiveness of the challenge presented?

[20] Again, there are many ways to describe how systems integration challenges affect different aspects of grid planning, engineering, and operations. The authors chose this approach for its simplicity and straightforward nature.

- Are there technological solutions to address the challenge and, if so, are they cost-effective and ready for deployment?
- Is the challenge well understood and are the tools, models, and studies available to fully understand potential risks?

Figure 1.3 shows the relative risk ranking and risk prioritization for the various systems integration challenges across the different IBR lifecycle phases. Note again that all these issues are worthy of industry attention; however, those risks with higher risk priority percentage on the chart stand out more so than others in terms of how IBRs can impact grid reliability in the years ahead.

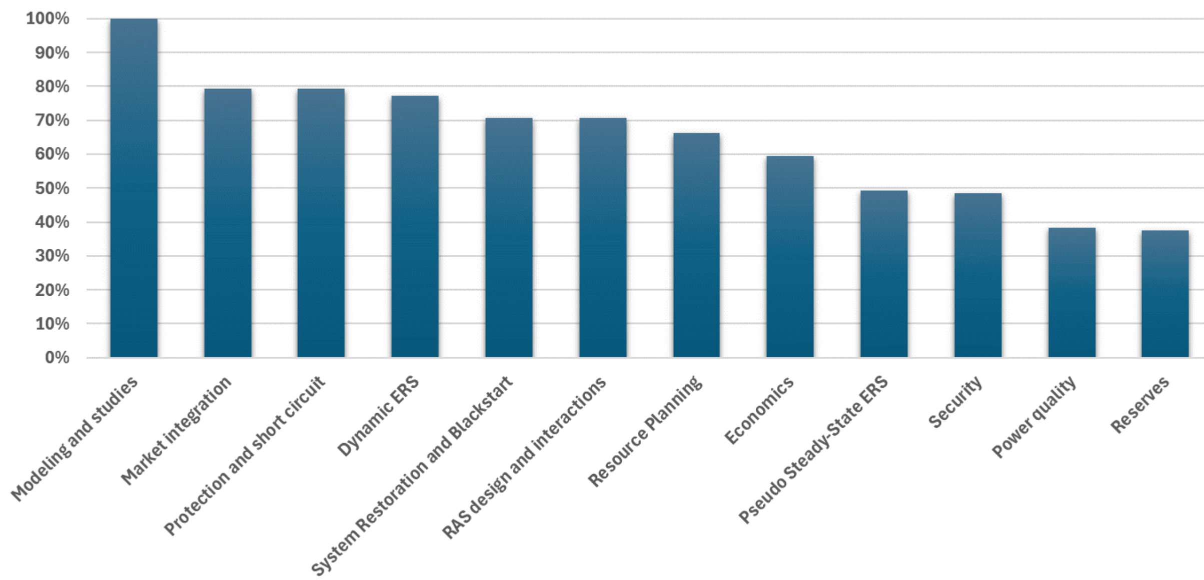

Figure 1.3. IBR Risk Priorities for Systems Integration through an IBR Lifecycle

There are many other ongoing initiatives and risk mitigation efforts across the ERO Enterprise such as extreme weather transmission planning, cold weather preparedness, cyber and physical security resilience, energy assurance, probabilistic planning, generator availability data reporting for IBRs, and others. Given WIRAB's advisory role of WECC, NERC, and FERC, and the focus of this assessment being specifically on IBR risks, the following chapters are going to focus on FERC and ERO Enterprise activities in the area of IBR-centered risk mitigations and the role that requirements and standards play in ensuring grid reliability under rapid grid transformation. Challenges and risks focused on markets, economics, security, etc., are not a focal point of this assessment.

CHAPTER 2: Current Industry Risk Mitigation Activities

Risk mitigation efforts are underway across jurisdictions and stakeholders in the Western Interconnection. This chapter lays out efforts across FERC, NERC, WECC, and industry stakeholders (see **Figure 2.1**).

FERC Orders and Directives

Starting at the federal level, FERC issued landmark directives regarding IBRs including:

- **FERC Order on Registration of IBRs (November 2022):** FERC directed NERC to identify and register owners and operators of BPS-connected IBRs that are not currently registered with NERC under the Bulk Electric System (BES) definition that have an "aggregate, material impact on the reliable operation of the BPS."[21]
- **FERC Order No. 2023 (July 2023):** FERC reformed its *pro forma* generator interconnection procedures (GIP) and generator interconnection agreements (GIA) "to address interconnection queue backlogs, improve certainty, and prevent undue discrimination for new technologies."[22,23,24]
- **FERC Order No. 901 (October 2023):** FERC directed NERC to develop new or modified Reliability Standards that "address reliability gaps related to inverter-based resources" in the areas of data sharing, model validation, planning and operational studies, and performance requirements.[25]

Figure 2.1. Jurisdictions and Stakeholders

FERC Order 2023

FERC Order No. 2023 was predominantly focused on reforming the generator interconnection queue process with significant changes to the GIPs and GIAs moving to a "first-ready, first-served" cluster study approach with expedited study timelines, allowing for technological advancements, and requiring assessment of alternative technologies.[26] However, the order specifically included the following requirements for IBRs:

- **Modeling:** Interconnection customers are required to submit to the transmission provider:
  - A validated user-defined RMS positive sequence dynamic model
  - An appropriately parameterized generic library RMS positive sequence dynamic model that corresponds to a model listed in a new table of acceptable models or a model otherwise approved by WECC
  - A validated EMT model if the transmission provider performs an EMT study as part of the interconnection study process
- **Ride-Through Performance:** Frequency and voltage ride-through, within equipment limitations, is required which includes continued active power production performance criteria during and post-

[21] https://www.ferc.gov/media/e-1-rd22-4-000
[22] https://www.ferc.gov/media/e-1-order-2023-rm22-14-000
[23] https://www.ferc.gov/explainer-interconnection-final-rule
[24] https://www.ferc.gov/media/e1-rm22-14-001
[25] https://www.ferc.gov/media/e-1-rm22-12-000
[26] This included the *pro forma* Large Generator Interconnection Procedure (LGIP), Small Generator Interconnection Procedure (SGIP), Large Generator Interconnection Agreement (LGIA), and Small Generator Interconnection Agreement (SGIA).

disturbance, minimized reduction in active power while providing reactive power support, no artificial limitations in dynamic reactive power capability, and return to pre-disturbance active power output levels with no artificial ramp rate restrictions.

A significant focus for industry moving forward will be how to effectively implement FERC Order No. 2023 process reforms – expedited study timelines, allowing changes throughout the interconnection process, etc. – without degrading grid reliability during this process.

NERC IBR Registration Initiative

NERC submitted to FERC a three-phase work plan regarding IBR registration activities (see **Figure 2.2**) following the FERC Order on Registration of IBRs.[27] Phase 1 (2023-2024) involved revisions to the NERC Rules of Procedure (ROP), which were approved by FERC at their June 2024 Open Meeting. The ROP revisions involve revising the Generator Owner (GO) and Generator Operator (GOP) Registry Criteria to include owners and operators of non-BES IBRs that either have or contribute to an aggregate nameplate capacity of greater than or equal to 20 MVA, connected through a system designed primarily for delivering such capacity to a common point of connection at a voltage greater than or equal to 60 kV.[28] These newly registering entities will be referred to as Category 2 GOs and Category 2 GOPs. The IBR Registration effort will bring the coverage of NERC-jurisdictional IBRs (in terms of number of resources) from around 84% to 98%, which is more consistent with past trends for synchronous generator GO registrations.[29]

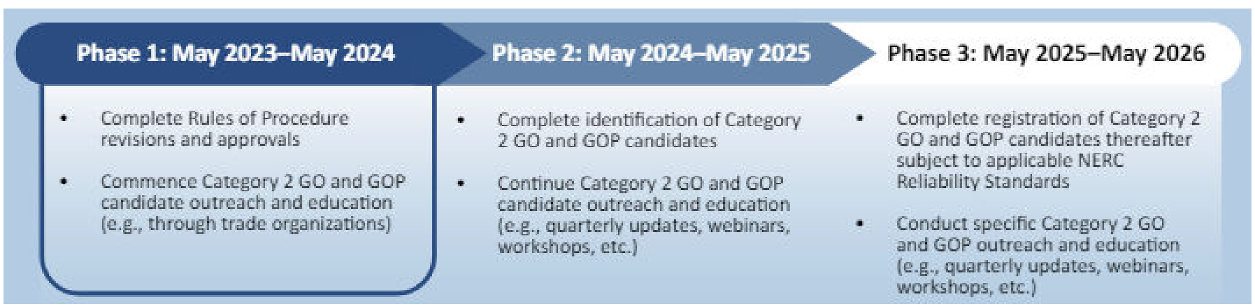

Figure 2.2. IBR Registration Milestones [Source: NERC]

Phase 2 (2024-2025) will involve outreach, education, and initial registration of applicable Category 2 GOs/GOPs; Phase 3 (2025-2026) will involve completing the registration of applicable Category 2 GOs/GOPs and their applicable IBR facilities, and then applying applicable NERC Standards to those newly registered entities and facilities.

NERC Standards Developments for Order 901

NERC created a standards prioritization approach[30] that categorizes each NERC standards development project based on whether it involves a FERC or NERC Board directive, has a regulatory deadline, or is linked to strategic ERO Enterprise risk priorities. NERC submitted a work plan in response to FERC Order No. 901

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[27] https://www.nerc.com/comm/RSTC/Documents/IBR_Registration_Quick_Reference_Guide.pdf
[28] NERC explains that the aggregation method is consistent with the NERC BES Inclusion I4 aggregations.
[29] NERC Work Plan for IBR Registration: https://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/IBR%20Registration%20Work%20Plan_final.pdf
[30] https://www.nerc.com/pa/Stand/Documents/Priortization%20PPT_February%202024.pdf.pdf

that laid out its plans regarding four key milestones regarding filings to FERC that address the standard development directives. All projects were therefore ranked high priority. The key milestones include:[31]

- **Milestone 1 (due January 2024):** Informational filing of work plan.
- **Milestone 2 (due November 2024):** Revisions for IBR disturbance monitoring (PRC-028), IBR ride-through performance (PRC-029), and post-event IBR performance validation (PRC-030)
- **Milestone 3 (due November 2025):** Revisions for IBR and DER data sharing and model validation, which is presently revamping three existing modeling-related standards development projects:
    - Project 2020-06 Verifications of Models and Data for Generators[32]
    - Project 2021-01 Modifications to MOD-025 and PRC-019[33]
    - Project 2022-02 Uniform Modeling Framework for IBR[34]
- **Milestone 4 (due November 2026):** Revisions for planning and operational studies related to IBRs, which has yet to be fully defined by NERC at this time.

The directives in FERC Order No. 901 issued to NERC are some of the most expansive NERC Reliability Standards revisions since FERC Order No. 693. The Order 91 directives impact IBR design and commissioning, grid planning and operations, modeling and studies, among other topics. However, all directives are based on backward-looking risks that NERC has observed and assessed for nearly a decade; therefore, it is important to ask whether these directives will suffice under such a rapidly changing IBR landscape and whether a more agile approach is fundamentally needed.

NERC IRPS Activities

The NERC Inverter-Based Resource Performance Subcommittee (IRPS), a stakeholder group under NERC's Reliability and Security Technical Committee (RSTC),[35,36] has published various guidelines and reports that have led to some regulatory actions including standard authorization requests (SAR) for new or enhanced NERC Reliability Standards revisions, as well as FERC Order No. 901.[37] The IRPS is presently working on a few activities:

1. White Paper: BPS-Connected IBR Commissioning Best Practices
2. SAR: Revision to FAC-001 and FAC-002
3. Reliability Guideline: Recommended Approach to Interconnection Studies for BPS-Connected IBRs

The proposed SAR mirrors the clauses of IEEE 2800-2022 in terms of proposed enhancements to interconnection requirements and emphasizes a lack of industry adoption of voluntary recommendations put forth in NERC guidance. The SAR does not recommend adoption of IEEE 2800-2022 directly; rather, it takes a roundabout approach wherein individual TOs are responsible for enhancing their requirements in

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31 NERC Informational Filing on Order 901 Implementation: https://www.nerc.com/FilingsOrders/us/NERC%20Filings%20to%20FERC%20DL/NERC%20Compliance%20Filing%20Order%20No%20901%20Work%20Plan_packaged%20-%20public%20label.pdf
32 https://www.nerc.com/pa/Stand/Pages/Project-2020_06-Verifications-of-Models-and-Data-for-Generators.aspx
33 https://www.nerc.com/pa/Stand/Pages/Project_2021-01_Modifications_to_MOD-025_and_PRC-019.aspx
34 https://www.nerc.com/pa/Stand/Pages/Project2022-02ModificationstoTPL-001-5-1andMOD-032-1.aspx
35 https://www.nerc.com/comm/RSTC/Pages/IRPS.aspx
36 https://www.nerc.com/comm/RSTC/Pages/default.aspx
37 https://www.nerc.com/comm/Pages/Reliability-and-Security-Guidelines.aspx

a manner duplicative with IEEE 2800-2022. This concern will be discussed in more detail in subsequent sections and illustrates how regulatory uncertainty and lack of unification can lead to inconsistencies and gaps that could lead to reliability risks.

Other NERC Activities

As noted previously, there are other ongoing NERC activities and Standards development activities that indirectly relate to IBRs but are considered outside the scope of this assessment. Examples include:

- **Energy Assurance:** Multiple NERC Standards revisions are underway with Project 2022-03 and Project 2024-02 related to energy reliability assessments to ensure sufficient energy availability and assurance with increasingly intermittent and variable resources (much of which are IBRs).[38,39] The NERC Energy Reliability Assessment Task Force (ERATF) developed a concept paper on this topic that partially led to these efforts.[40]
- **Transmission Planning for Extreme Weather:** FERC issued Order No. 896 in June 2023 directing NERC to develop or modify standards to address a lack of long-term planning requirements for extreme heat and cold weather events, including modifications to NERC TPL-001-5.1.[41] Efforts are underway to develop a benchmark planning scenario/case for both steady-state and transient stability analyses that includes widespread impacts of extreme weather. These studies must also include corrective actions to mitigate instances where performance requirements are not met.[42]
- **Cyber and Physical Security Enhancements:** The Electricity Information Sharing and Analysis Center (E-ISAC) continues to hold workshops, trainings, and events for industry to gain insights and recommendations regarding security topics.[43] Additionally, there are multiple NERC Standards projects underway related to cyber and physical security standards enhancements for CIP-002,[44] CIP-003,[45] and CIP-014.[46]
- **Cold Weather Preparedness:** NERC has held small group advisory sessions for Registered Entities to prepare for cold weather conditions. NERC also developed NERC EOP-012 for generator cold weather conditions and continues to modify the standard based on directives from FERC.[47]
- **Interregional Transfer Capability**: Congress mandated in the Fiscal Responsibility Act of 2023 that NERC conduct a study of the interregional transfer capability between areas of the interconnected transmission system. The study aims to identify existing transfer capabilities, make recommendations on "prudent additions" to the amount of electric power that can be moved between areas, and recommendations on how to achieve and maintain these total transfer capabilities.[48]

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[38] https://www.nerc.com/pa/Stand/Pages/Project2022-03EnergyAssurancewithEnergy-ConstrainedResources.aspx
[39] https://www.nerc.com/pa/Stand/Pages/Project-2024-02-Planning-Energy-Assurance.aspx
[40] https://www.nerc.com/comm/RSTC/ERATF/ERATF%20Energy%20Adequacy%20White%20Paper.pdf
[41] https://www.ferc.gov/media/e-1-rm22-10-000
[42] https://www.nerc.com/pa/Stand/Pages/Project-2023-07-Mod-to-TPL00151.aspx
[43] https://www.eisac.com/s/
[44] https://www.nerc.com/pa/Stand/Pages/Project%202021-03%20CIP-002%20Transmission%20Owner%20Control%20Centers.aspx
[45] https://www.nerc.com/pa/Stand/Pages/Project-2023-04-Modifications-to-CIP-003.aspx
[46] https://www.nerc.com/pa/Stand/Pages/Project_2023-06_CIP-014_Risk_Assessment_Refinement.aspx
[47] https://www.nerc.com/pa/Stand/Pages/Project-2024-03-Revisions-to-EOP-012-2.aspx
[48] https://www.nerc.com/pa/RAPA/Pages/ITCS.aspx

WECC Studies of IBR Risks

WECC has not developed any Regional Reliability Standards in response to any of the IBR risks identified by the ERO Enterprise. Rather, WECC has conducted some reliability studies exploring future grid reliability risks:

- **Grid Forming Inverter Study:** This study explored the integration of grid forming (GFM) IBRs to replace or complement conventional grid following (GFL) IBRs and its impacts on supporting frequency response in the Western Interconnection with decreasing system inertia levels. The studies used a relatively new generic model of GFM technology, as opposed to actual OEM-supplied models, but showed that increasing the deployment of GFM resources can have a significant positive impact on Western Interconnection frequency stability. Recommendations urged Planning Coordinators to consider GFM technology moving forward and the WECC Underfrequency Load Shedding Working Group to further explore generation loss events in the West.[49,50]
- **Changes in Grid Strength Study:** This study explored the changes of fault current and system strength levels for an incremental replacement of synchronous generation with IBRs. No significant changes in fault current level or grid short-circuit ratio (SCR) were identified. WECC recommended (1) its Short-Circuit Modeling Subcommittee to continue working with software vendors and industry to establish recommendations on how IBRs are represented in short circuit models and (2) industry to urge inverter OEMs to share modeling data to enable the creation of improved short-circuit models for IBRs.[51,52]

Both studies are introductory exploratory studies to further define WECC-wide grid reliability impacts of IBRs and can serve as a foundational basis for further work. However, the recommendations do not urge more detailed analysis or mitigating measures to be put into place at this time. This is an area that could be further codified by WECC and its stakeholders – defining further next steps to explore these types of concepts with more granularity.

Industry Efforts to Manage IBR Risks

Some transmission providers (i.e., Transmission Owners (TOs) and/or ISO/RTOs) have begun taking actions to minimize risks of increasing levels of IBRs across their system. This may include improving generation interconnection requirements, adapting transmission planning and interconnection processes, enhancing IBR modeling requirements and studies, adopting new operating procedures and real-time tools, etc. An example includes proactive adoption of IEEE 2800-2022, which is discussed in more detail below.

These entities appear to have relatively higher levels of IBRs today and experience managing a system with higher levels of IBRs. Additionally, some of these entities are larger in size and therefore have the resources and capabilities to adapt more quickly during the energy transition. These types of considerations are a focal point of the risk assessment described in **CHAPTER 3:** ***Gap Analysis of Risks***.

49 https://www.wecc.org/Administrative/Grid%20Forming%20Inverter%20Study%20Overview.pdf
50 https://www.wecc.org/Administrative/Grid%20Forming%20Inverter%20Study%20Report.pdf
51 https://www.wecc.org/Administrative/Changes%20in%20Grid%20Strength%20Overview.pdf
52 https://www.wecc.org/Administrative/Changes%20in%20Grid%20Strength%20Study.pdf

IEEE 2800-2022 IBR Interconnection and Interoperability Standard

IEEE 2800-2022, *Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems*, establishes uniform technical minimum requirements for the interconnection, capability, and performance of IBRs interconnecting with transmission and sub-transmission systems (see **Figure 2.3**).[53] IEEE 2800-2022, like all IEEE standards, is a voluntary standard that requires enforcement by an "authority governing interconnection requirements (AGIR)."[54] This entity should be one that is responsible for the interconnection of IBRs to the BPS such as the transmission provider (TO, ISO/RTO, or other regulatory body). The higher up the regulatory framework that IEEE 2800-2022 can be adopted, the more uniformity and consistency that will be achieved. Standardized adoption of IEEE 2800-2022 has been strongly encouraged by the U.S. Department of Energy (DOE),[55] IEEE 2800-2022 leadership and membership, and other organizations. However, both NERC and FERC have been resistant to adopting IEEE 2800-2022.

Figure 2.3. IEEE 2800-2022 Standard

IEEE 2800-2022 received high ballot results from a large body of industry experts across a broad spectrum of organizations. Many of the same experts who developed IEEE 2800-2022 are now working on IEEE P2800.2, *Recommended Practice for Test and Verification Procedures for Inverter-based Resources Interconnecting with Bulk Power Systems*, which will define the test and verification methods to demonstrate plant-level conformance with the requirements in IEEE 2800-2022.[56]

As will be discussed in **CHAPTER 3: *Gap Analysis of Risks***, IEEE 2800-2022 can serve a critically important role for ensuring reliable operation of the BPS moving forward if adopted consistently and appropriately at the regulatory level.

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[53] https://standards.ieee.org/ieee/2800/10453/

[54] An AGIR is defined as a "cognizant and responsible entity that defines, codifies, communicates, administers, and enforces the policies and procedures for allowing electrical interconnection of inverter-based resources interconnecting with associated transmission systems." An AGIR could be the ISO/RTO, a public utility commission, a municipality or cooperative board, etc.

[55] https://www.energy.gov/sites/default/files/2024-04/i2X%20Transmission%20Interconnection%20Roadmap_1.pdf

[56] https://standards.ieee.org/ieee/2800.2/10616/

CHAPTER 3: Gap Analysis of Risks

CHAPTER 1: *Prioritized List of IBR Risks in the West* laid out a subset of IBR reliability risks that should be addressed proactively either at the regulatory level and/or by individual transmission providers. As new IBR integration and systems integration challenges are uncovered, industry needs to address them in an effective, efficient, and agile manner. **CHAPTER 2: *Current Industry Risk Mitigation Activities*** highlighted various activities and initiatives underway at the FERC, NERC, and WECC level that are attempting to address these risks to some degree. This chapter will explore any potential gaps in these efforts and identify areas where additional focus and support may be needed.

Timeline of Events and Industry/Regulatory Actions

NERC started exploring BPS essential reliability services (ERS) in the mid-2010s and published the *ERS Measures Framework Report* in 2015.[57] In 2016, the Blue Cut Fire event was the first major widespread IBR-related disturbance in North America that began a sequence of over a dozen of these types of events. Most have been attributed to solar PV; however, more BESS and wind-related events are occurring in some regions with high penetration levels. In 2021 and 2022, large IBR-related events in Texas further raised the IBR risk priority level across industry since the 2022 event nearly exceeded Texas' resource loss protection criteria. NERC issued multiple Level 2 Alerts regarding IBR performance and modeling concerns. The NERC IRPS published guidelines providing recommended practices to address many of the identified risks and also initiated NERC Standards revisions projects to address gaps in NERC Standards. Concurrently, FERC addressed voltage and frequency control with FERC Order Nos. 827 and 842, respectively, and then issued FERC Order No. 901 after numerous IBR events to mandate changes to NERC Standards to fill the gaps involving IBR risks. Lastly, FERC also issued FERC Order No. 2023 to address interconnection queue backlog issues. **Figure 3.1** shows a high-level illustrative overview of industry and regulatory actions taken to-date.

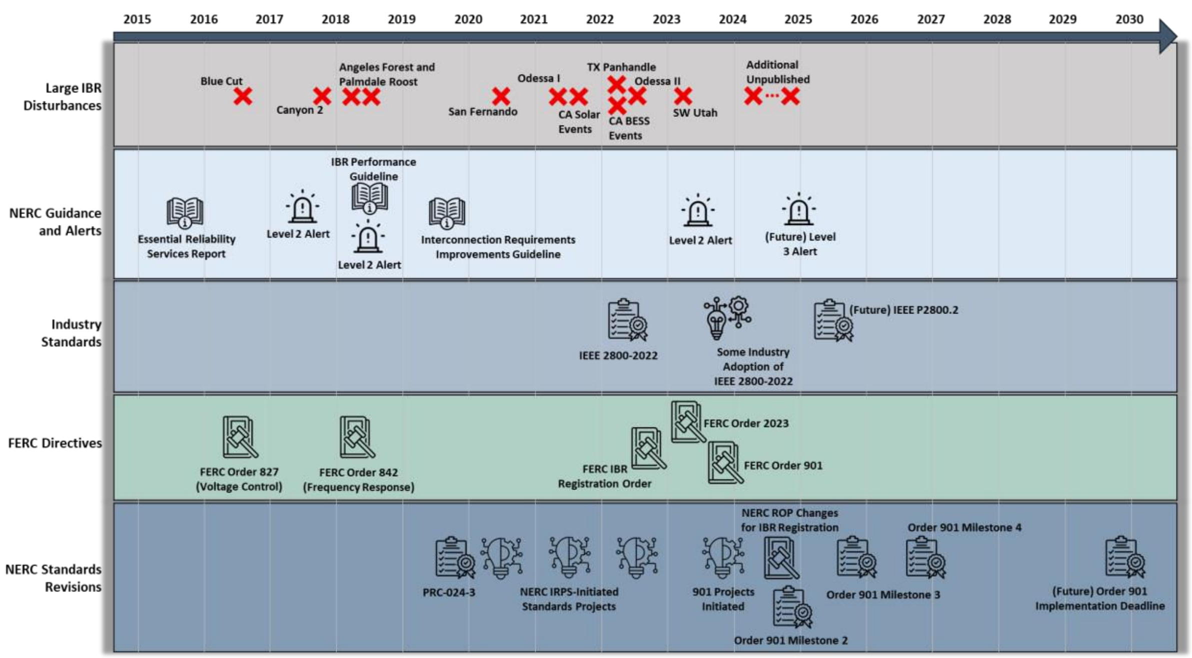

Figure 3.1. Timeline of Events, Guidance, Standards Revisions, and Directives

[57] https://www.nerc.com/comm/Other/essntlrlbltysrvcstskfrcDL/ERSTF%20Framework%20Report%20-%20Final.pdf

The industry and regulatory activities highlighted in **Figure 3.1** bring up two fundamental questions that this assessment aimed to evaluate. The first question is: Are all the identified IBR risks being addressed by the various industry mitigation activities? The second question is: How well and how quickly is the industry adopting and implementing the various industry mitigation activities? The next sections of this chapter will present the gap analysis performed to answer these two questions.

Gap Analysis on Risks versus Mitigations

With all these industry activities underway, one would assume that sufficient risk mitigations are being developed that will adequately address all the identified issues with grid reliability. However, as **Table 3.1** highlights, there are IBR risks where no significant industry efforts or regulatory policies were identified that addressed the risks.

Table 3.1. IBR Systems Integration Challenges vs. Industry Activities

Resource Planning	• Addressed by NERC Project 2022-03 – Energy Assurance
Modeling and Studies	• Addressed by IEEE 2800, FERC Order 2023, FERC Order 901, and the NERC Milestone 3 and 4 standards per Order 901
Pseudo Steady-State Essential Reliability Services	• Addressed by IEEE 2800, FERC Order 901, and the NERC Milestone 2 standards per Order 901
Dynamic Essential Reliability Services	• Addressed by IEEE 2800 (voluntary adoption) ✖ Not addressed by any draft NERC standards for Order 901
Protection and Short Circuit	• Addressed by IEEE 2800, along with the proposed SAR from IRPS ✖ Not addressed by any draft NERC standards for Order 901
Power Quality	• Addressed by IEEE 2800, along with the proposed SAR from IRPS ✖ Not addressed by any draft NERC standards for Order 901
Reserves	• Addressed by NERC Project 2022-03 – Energy Assurance
RAS Design and Interactions	✖ No active industry efforts identified
System Restoration	✖ No active industry efforts identified

This analysis highlights that Dynamic Essential Reliability Services, System Restoration, RAS Design, and Power Quality risks with IBRs are gaps in the current regulatory policy area and mandatory requirements for the industry, such as FERC Order 901 and the corresponding new IBR-based NERC Reliability Standards. However, IEEE 2800 does address two of these risk areas – Dynamic Essential Reliability Services and Power Quality – further highlighting the value and benefit of adopting IEEE 2800 by the industry, NERC, and FERC.

Gap Analysis on the Adoption of Risk Mitigations by Industry

The Western Interconnection is comprised of about eighty (80) TOs and forty-eight (48) Transmission Operators (TOPs).[58,59] As part of this risk assessment, a subset of thirty-two (32) NERC FAC-001 Facility Interconnection Requirements (FIR) documents in the Western Interconnection were analyzed to understand how well the IBR risks are being mitigated by the interconnection requirements across the Western Interconnection as of the writing of this report. FIRs reviewed were publicly available on the OATI OASIS website[60] or directly on Western Interconnection utility websites.

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[58] https://www.wecc.org/Administrative/State%20of%20the%20Interconnection.pdf

[59] https://www.nerc.com/pa/comp/Registration%20and%20Certification%20DL/NERC_Compliance_Registry_Matrix_Excel.xlsx

[60] http://www.oasis.oati.com/

Figure 3.2 provides an overview of the high-level findings regarding the review of thirty-two (32) FIRs and the enhancements that have been developed implemented thus far. Each FIR was briefly reviewed to determine the extent to which the NERC IBR Guideline,[61] IEEE 2800-2022, or the additional systems integration challenges not covered by these publications (as highlighted in Table 3.1) were incorporated. Green indicates relatively comprehensive implementation of the reference(s), orange indicates some degree of implementation of the reference(s), and red indicates little or no consideration of the references.

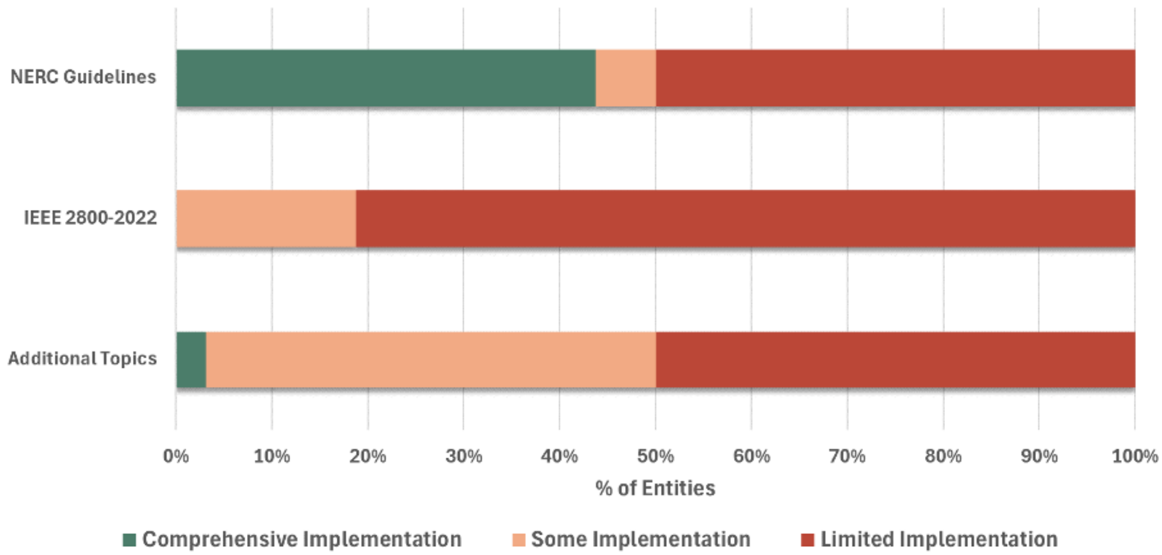

Figure 3.2. Transmission Provider FIR Enhancements

> ***NOTE:*** *Navigating the local transmission provider facility interconnection requirements, business practices, generator interconnection agreements and procedures, and other supplemental documentation is rather complex and therefore there may be gaps or missed documents in this assessment. These documents are also updated at different times by all the entities; therefore, documents may have been recently updated compared to the time of the gap analysis and writing of the report. The goal of the assessment is to get a general gauge of industry practices collectively rather than thoroughly assessing the depth and breadth of any individual transmission provider.*

Adoption of IEEE 2800-2022 in the Reviewed FIRs

As identified in the gap analysis of risks vs. mitigation measures earlier in this chapter, implementation of IEEE 2800-2022 is likely the most effective and efficient path to mitigating the IBR performance risks identified by NERC and the overall industry over the past decade. Unified adoption of IEEE 2800-2022 at the federal level (i.e., FERC and NERC) would result in the most harmonized implementation across North America; however, Western entities specifically, given the rapidly growing IBR penetration levels across the West, need to keep pace with this change and get mitigating measures in place now. IEEE 2800-2022 was approved and published in 2022, and NERC continues to emphasize enhancements to TO Facility Interconnection Requirements; TOs can enhance these requirements by adopting IEEE 2800-2022 as consistently as possible. Comprehensive adoption is generally recommended but a phased adoption of select requirements (e.g., Clause 7, 10, and 12) could also lead to risk mitigations to key concerns raised by regulatory bodies.

[61] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf

Of the 32 FIRs reviewed, only 6 reference IEEE 2800-2022 in some way. There are various adoption methods for including IEEE 2800-2022 requirements in FIRs; however, it is generally recommended that a "hybrid integration approach" be used that involves referencing the standard and providing sufficient technical details such that interconnection customers can effectively implement the standard at their IBR facilities. None of the 6 FIRs implement IEEE 2800-2022 in this way.

Overall, a few FIRs include general references to IEEE 2800-2022. A few others have included detailed references to some clauses in IEEE 2800-2022; however, practices were inconsistent. No FIRs have used a comprehensive hybrid integration approach wherein the necessary level of specificity is provided such that an interconnection customer would have enough data to comply with the requirements and seek interconnection approval effectively and efficiently.

Key Takeaway:
Only a small handful of FIRs have adopted IEEE 2800-2022 in some form. No FIRs have adopted the standard in a comprehensive manner that provides sufficient clarity and specificity such that inclusion of the standard in interconnection requirements would result in a more streamlined, effective, and efficient interconnection process for IBRs.

Adoption of NERC Guidance Regarding IBR Interconnection Requirements

NERC published multiple Reliability Guidelines prior to the publication of IEEE 2800-2022. Namely, *Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources*[62] was published in 2019 and the ERO Enterprise urged industry to implement the recommendations contained therein. These guidelines also served as foundational references for the initial draft of IEEE 2800. The guidance published recommended that transmission providers enhance their FIRs to address the IBR performance issues previously observed and other known areas of focus. **Table 3.2** provides a list of the topics covered.

Table 3.2. IBR Systems Integration Challenges	
Momentary cessation	Balancing
Phase jump immunity	Monitoring
Capability Curve	Operation in low short-circuit strength systems
Active power-frequency controls	Fault ride-through capability
Fast frequency response	Grid forming
Reactive power-voltage control	System restoration and blackstart capability
Reactive current-voltage control	Protection system settings
Reactive power at no active power output	Power quality
Inverter current injection during fault conditions	Modeling recommendations – timing, model quality, power flow, dynamics, short-circuit, EMT, benchmarking
Return to service following tripping	

Review of the FIRs found that about a third of those reviewed have adopted a limited subset of the NERC Guideline recommendations put forth; however, very few have adopted the recommendations broadly

[62] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_IBR_Interconnection_Requirements_Improvements.pdf

(other than those that have adopted IEEE 2800-2022, which covers many of the recommendations listed in **Table 3.2**).

Additional IBR-Related Requirements or Topics Addressed

When reviewing the FIRs, additional IBR-related requirements and topics were surveyed, including EMT modeling for IBRs, low short circuit strength grid conditions for inverter stability, inverter oscillations, performance validation, and subsynchronous control interactions. All of these topics are additional industry recommendations and best practices for IBRs that go beyond the NERC Guideline and even in some ways beyond IEEE 2800-2022. About half of the FIRs reviewed had some of these topics addressed, which primarily was the EMT modeling analysis for IBRs during the interconnection process. In many cases the FIRs reference the need for generation interconnection customers to submit EMT models during the interconnection process but unclear the level of EMT study and analysis performed on those models during the process.

Interconnection Requirements Enhancements in Other Areas

Other ISO/RTOs and transmission providers outside the Western Interconnection are also actively pursuing updates to their interconnection requirements. Much of the Eastern Interconnection and ERCOT are market-based and therefore the ISO/RTO typically retains much of the generator interconnection requirements, interconnection queue management, market requirements, and operating procedures. Therefore, overall, these regions are further along and able to keep pace with rapid IBR growth since these entities tend to be highly staffed and tracking industry updates closely (e.g., similar to CAISO in the West).

Examples of ongoing activities in other areas include:

- **MISO:** MISO has undergone a relatively extensive review of IEEE 2800-2022 clauses and how they effectively integrate with existing MISO rules.[63] MISO proposed a three-phased approach moving from ride-through requirements to core system support, to expanded system support; eventually they intend to integrate remaining support services from IBRs such as blackstart and higher fault current levels. This effort culminated with FERC approving the MISO filing to revise their GIA to include requirements from IEEE 2800-2022.[64] Furthermore, MISO has also proposed draft GFM requirements for BESS to proactively enhance stability of the MISO system as IBR levels rise.[65]
- **ERCOT:** ERCOT has also undergone a lengthy process to modify generator ride-through requirements for both existing and newly connecting IBRs with Nodal Operating Guide Revision Request (NOGRR) 245.[66] IEEE 2800-2022 requirements were integrated into this NOGRR for newly connecting resources and a "ride-through maximization" concept was introduced for all existing resources to minimize potential IBR-related ride-through failure risks. ERCOT also enhanced their dynamic modeling requirements for IBRs, introducing more stringent equipment change management processes that require testing of IBR plant models used in reliability studies. These changes were codified in Planning Guide Revision Request (PGRR) 109 approved in April 2024. In July 2024, ERCOT also approved changes to its disturbance monitoring equipment requirements

[63] https://cdn.misoenergy.org/20240312%20IPWG%20Item%2004c%20IBR%20Performance%20Requirements%20IEEE%202800%20(PAC-2024-2)632110.pdf
[64] https://elibrary.ferc.gov/eLibrary/filelist?accession_num=20240607-3041
[65] https://cdn.misoenergy.org/20240604%20IPWG%20Item%2004b%20Draft%20GFM%20BESS%20Performance%20Requirements%20Whitepaper%20(PAC-2024-2)633112.pdf
[66] https://www.ercot.com/mktrules/issues/NOGRR245#keydocs

with NOGRR 255, similarly mirroring what is in IEEE 2800-2022. Lastly, ERCOT has also proposed GFM requirements and test procedures for BESS.[67]

- **New York State Reliability Council (NYSRC):** NYSRC oversees Reliability Rules in New York that shall be complied with by the New York Independent System Operator (NYISO) and all entities engaging in electric transmission, ancillary services, energy and power transactions on the New York power system. NYSRC, in February 2024, approved revisions to its Reliability Rules that incorporated a comprehensive hybrid integration approach to IEEE 2800-2022 implementation. The new rules describe each clause of IEEE 2800-2022 and how it will be enforced as well as any exceptions, modification, clarifications, and additional requirements.[68]
- **Southern Company:** Southern Company has developed a standalone *Interconnection Requirements for Transmission-Connected Inverter-Based Resources* document, effective August 2023.[69] The requirements comprehensively incorporate IEEE 2800-2022 clauses, with the exception of Clause 8. Additional information, details, and requirements are also contained in their document with drawings, diagrams, tables, and flowcharts to effectively communicate the requirements to the interconnection customer.
- **Duke Energy:** Duke has implemented comprehensive IBR-specific interconnection requirements that incorporate IEEE 2800-2022 using the hybrid integration approach around March 2023. The clauses of IEEE 2800-2022 are integrated into a broader set of IBR requirement and clarification and exception are documented thoroughly.[70] Additionally, Duke has also developed multiple other requirements documents related to IBR risk issues that industry has dealt with over the past decade. These range from IBR plant verification processes to IBR plant commissioning practices, reactive power and primary frequency response capability verifications, post-event data monitoring and collection, and other topics. Duke likely has the most extensive set of IBR-specific requirements that implement and well-exceed IEEE 2800-2022 minimum requirements and most comprehensively address NERC guideline recommendations.[71]

Key Findings from Gap Analysis

IBR integration risks are accelerating given past events and the exponential growth of renewables on the system; however, these risks can be addressed to maximize the value that IBR technologies can bring to the BPS moving forward. This gap analysis aimed to evaluate how the industry is working on evaluating and, more importantly, implementing solutions to the IBR risks across the system, specifically working to identify if risk mitigations are being implemented widely and at a pace that matches or exceeds the rapidly growing interconnection of IBRs on the grid.

This analysis highlights that collectively the industry may be struggling to implement risk mitigation measures and solutions in a timely manner that keeps up with the exponential interconnection of IBRs on the system. From the voluntarily adoption and implementation of risk mitigations to regulatory policy efforts that include mandatory reliability standards, both pathways may not be happening at a pace necessary to keep up with the rapidly changing resource mix and grid transformation. NERC guidelines

[67] https://www.ercot.com/files/docs/2024/07/09/2024_07_ERCOT_IBRWG_ERCOT%20Advanced%20Grid%20Support%20Inverter-based%20ESRs%20Assessment%20and%20Adoption%20Discussion_v1_.pdf
[68] https://www.nysrc.org/wp-content/uploads/2024/02/RR-151-Procedure-Document-2-9-2024.pdf
[69] http://www.oasis.oati.com/woa/docs/SOCO/SOCOdocs/SOCO_Inverter-Based-Gen_Interconnection-Technical-Requirements.pdf
[70] http://www.oasis.oati.com/woa/docs/CPL/CPLdocs/TECP-STD-TFP-00016_-_Rev._001.pdf
[71] See the OATI OASIS® site (http://www.oasis.oati.com/cpl/index.html) under "Generator Interconnection Information; IBR Interconnection."

were published in 2018 and 2019, and the IEEE 2800-2022 standard was published in 2022, yet in the Western Interconnection there are still many that have yet to implement the recommendations and solutions defined in these publications. The future mandatory NERC reliability standards being developed from FERC Order 901 are still two years away from being fully completed, and six years away from final implementation. Meanwhile, thousands of gigawatts of IBRs are being interconnected in the Western Interconnection.

There are many reasons for these delays in adopting new requirements and risk mitigations. The industry is incredibly busy working to expand the transmission and distribution grid, interconnect new generation resources and loads, upgrade aging infrastructure, and working to operate the bulk power system on a 24/7/365 basis. There will inevitably always be a "lag" by the industry and regulatory bodies in adopting and mandating new risk mitigations due to all the existing workload and limited available resources across the industry, especially among the smaller utilities and cooperatives who are the most resource constrained. However, if we as an industry we do not work to address these lags and improve the speed at which we implement risk mitigations to match the exponential growth and change our system is undergoing, we will continue to see larger and larger risks and events that will significantly impact grid reliability and all customers across the country.

We as an industry need uniformity in our requirements and standards, education/training/guidance for all entities large and small, and move to an overall more proactive approach to our regulatory policies and standards to address emerging risks before they grow to be so large and complex that the reliability of our grid is at risk. **CHAPTER 4:** ***Key Findings and Recommendations*** further explores a set of recommendations covering these ideas on how we can collectively work as an industry to move faster in addressing the IBR risks we know now and the future ones coming as the energy transition continues.

CHAPTER 4: Key Findings and Recommendations

While there are many benefits and opportunities that IBR technology brings to the BPS, this assessment highlighted the grid reliability challenges that must be addressed as industry collectively works through the energy transition. IBR-specific reliability challenges are pervasive, spanning grid planning, engineering, and operations. Large-scale grid events around the world illustrate key areas of focus moving forward and the ERO Enterprise continues to strongly emphasize the need for proactive action. FERC has issued multiple directives and the ERO Enterprise is working with industry stakeholders to implement these mandates.

It is critical to not lose sight of the fact that many of the issues being addressed by current regulatory actions are foundational – the need for data sharing, generator ride-through performance, accuracy of modeling and studies, etc. – and may not be adequately addressing more significant systems integration challenges that the sector will face as the energy transition continues. Examples include lower system strength levels, decreasing system inertia, controller interactions challenges, adoption of grid forming (GFM) technology, need for electromagnetic transient (EMT) simulations at-scale, planning and operating with increased uncertainty, grid/resource hardening to extreme weather, and many other issues. Therefore, immediate attention is needed to address these foundational aspects of a reliable BPS from different angles and from a diverse set of stakeholders, so that we may begin working on the even more difficult challenges facing us as the energy transition progresses further.

Recommended WIRAB Advisory Feedback for WECC and the ERO Enterprise

Given WIRAB's advisory role to the ERO Enterprise and FERC, as well as how State public utility commissions (PUCs) can support grid reliability challenges ahead, Figure 4.1 shows a breakdown of near-term, medium-term, and long-term recommendations based on the assessment completed. WECC and its members, transmission providers (e.g., TOs, ISO/RTOs, etc.), WIRAB and its members, and State PUCs are all key stakeholders for these recommendations.

Near Term
1-2 years

1. WECC more directly and closely support industry enhance Facility Interconnection Requirements for IBRs (standardized template for enhancements, ideally implementing IEEE 2800 standard)
2. WECC conduct targeted regional training (and engage technical industry with working groups) for IEEE 2800, IBRs, EMT, GFM, and more
3. FERC and/or NERC adopt and implement IEEE 2800-2022 in Reliability Standard(s) – harmonized requirements for IBR capability and performance
4. State PUCs emphasize need for proactive enhancement of interconnection requirements (e.g., adopting IEEE 2800-2022)

Medium Term
3-4 years

1. Proactive stakeholder-engaged risk mitigations by WECC for emerging systems integration challenges for IBRs
   - GFM, oscillations, decreasing system strength and inertia, etc.)
2. WECC support pilot projects for emerging IBR risk mitigations (e.g., GFM, EMT, etc.)
3. If no NERC/FERC adoption of IEEE 2800-2022, WECC create a Regional Reliability Standard adopting IEEE 2800-2022 (and future P2800.2)
   - Harmonized West-wide IBR req's.

Long Term
2030+

1. The West consider shifting toward regional grid code approach including:
   - Proactively develop risk mitigations ahead of them occurring (leverage WECC studies program)
   - Independently developed and/or stakeholder-driven (by technical group(s))
   - Technical details defined in code
   - Harmonized across Region
   - Supports smaller entities
   - Clear compliance obligations and enforcement
   - Flexibility for utility-/system-specific needs allowed
   - Applicable to large loads, VPPs, etc.

Key Players in West: *WECC (and its members), Transmission Providers (TOs, ISO/RTOs, etc.), WIRAB, State PUCs*

Figure 4.1. Near-, Medium-, and Long-Term Recommendations

Near-Term (1–2 Years) Recommendations

Template Facility Interconnection Requirements (WECC): NERC continues to emphasize that enhancements to Facility Interconnection Requirements are strongly recommended to address IBR performance risks. WECC could support transmission providers across the West – both large and small entities – by providing a forum for discussing these enhancements and could even work toward developing a standardized template for IBR-related requirements. This IBR requirements template could include implementation of IEEE 2800-2022 and address any other WECC-specific areas of focus. WECC could issue strong recommendations to its members that this unified IBR requirements template should be implemented across the West based on the work done by WECC and its members. Harmonization of interconnection requirements across the West would help ensure reliability of the BPS while also helping speed up the interconnection process of newly connecting IBRs.

Targeted Stakeholder Engagement on Emerging IBR Topics (WECC): WECC is providing industry education and outreach activities such as its *Reliability in the West* discussion series.[72] These types of activities help provide general awareness to broad industry stakeholders of the key reliability initiatives and activities underway at WECC, in the West, and within the electricity sector. In addition to these activities, WECC may consider expanding its education, coordination, and outreach activities to support more in-depth engagement with stakeholders that can lead to deliverables that help drive risk mitigation activities. Examples could include:

- **IBR Interconnection Challenges:** Targeted information sharing between grid planners and operators, renewables developers and owner/operators, equipment manufacturers, etc., to better understand the unique challenges facing the interconnection process for Western Interconnection entities.
- **Grid Forming Training and Needs:** Collaborative discussions and presentations on utility plans for grid forming technology broadly, with detailed presentations on adoption strategies, lessons learned, etc.; presentations from equipment manufacturers to help address transmission planner/provider questions and concerns.
- **EMT Modeling and Studies:** Focused training and presentations on EMT modeling for IBRs, EMT modeling plans for WECC, EMT model sharing and case creation for future high IBR conditions, and supporting transmission planners overcome immediate EMT-related modeling and study challenges.
- **Integrated Resource Planning:** Sharing best practices and learnings across resource planners, balancing authorities, reliability coordinators, and utilities; develop key takeaways and recommendations from industry stakeholders to help drive consistent approaches and best practices moving forward.
- **Flexibility Metrics and Energy Assurance:** Brainstorming, sharing, and developing consistent recommendations regarding how balancing authorities, transmission operators, and reliability coordinators can measure and assess the level of flexibility with existing and future resource mixes, particularly with increasing levels of variable IBRs on the BPS and distributed energy resources (DERs).

[72] https://www.wecc.org/wecc-document/13931

- **Remedial Action Scheme (RAS) Designs & Interactions with IBRs:** As highlighted in the risk assessment, RAS designs and interactions are not currently being investigated broadly by the industry as the penetration of IBRs increases. WECC has an opportunity to highlight this risk to the industry at large and facilitate studies and analysis for determining and mitigating any RAS risks associated with IBRs across the system. WECC's RASRS (Remedial Action Scheme Reliability Subcommittee) could take on this activity and bring attention to this potential risk to the reliability of the system.
- **System Restoration:** Black start studies are performed on a periodic basis today across the industry to update black start system restoration plans as the system is upgraded and changed. However, the future impact of black start system restoration under a grid dominated by IBRs has not been widely analyzed or studied across the system. While the ERO is performing some analysis of black start plans across the Western and Eastern Interconnections, WECC has an opportunity to further evaluate the Western Interconnection black start restoration plans under varying high penetration levels of IBRs in the West. Leading this effort will allow the West to understand how black start plans must evolve and change with a system dominated by IBRs, giving enough time to allow for additional procurements of the necessary resources and equipment to allow for reliable black start system restoration plans.

Harmonized Adoption of IBR Requirements (NERC/FERC): In the near-term, NERC and FERC should seek industry consensus and feedback around how best to adopt IEEE 2800-2022. Both organizations appear to be unwilling to adopt IEEE 2800-2022 directly or by reference and industry has expressed concerns regarding a lack of IBR standards harmonization. Therefore, more industry outreach, engagement, collaboration, and information gathering should be done quickly to identify and constructively define the most effective and efficient path forward. The current FERC Order No. 901 initiatives (e.g., NERC PRC-028, PRC-029, and NERC PRC-030) address only a fraction of the topics covered in IEEE 2800-2022 and with insufficient technical detail.

State Regulatory Emphasis of IBR Requirements Enhancements (State PUCs): In the near term, state utility commissioners and staff can consider the key takeaways and questions outlined in Additional Recommendations for State Commissions below.

Medium Term (3–4 Years) Recommendations

Proactive Stakeholder-Engaged Risk Mitigation (WECC): WECC may consider conducting focused risk mitigation studies with its members using the existing modeling and study resources it has available today. WECC is well-equipped and experienced in conducting WECC-wide reliability studies that explore potential risks or mitigating solutions. This report highlighted the work done by WECC on grid forming, frequency response, etc. To take this one step further, WECC could consider developing a study plan that more thoroughly assesses if *and when* potential new reliability risks will arise in the future.[73] Based on the findings of these studies, risk mitigation activities (with engaged stakeholders) can and should be developed well ahead of the risks manifesting. With sufficient time and resources, WECC may seek to proactively develop WECC-specific mitigations (industry efforts, alerts, Regional Reliability

[73] Using appropriate engineering judgment and risk-informed decisions making.

Standards, etc.) even if national-level requirements do not keep pace. WECC-specific Standards could always be refined and re-aligned with NERC-level requirements, as needed, in the future.

Pilot Projects for Emerging IBR Risk Mitigations (WECC): WECC may consider more proactive engagement in pilot projects to address emerging IBR risks. For example, it is well understood that increasing IBRs can lead to low system strength stability challenges and will require close screening for when and where to conduct EMT studies. WECC could pilot a small group screening method development activity. Another example could involve implementation of GFM technology on a BESS with close attention to reliability benefits or operational challenges, which could be shared widely with Western stakeholders and could lead to accelerated adoption.

Regional Reliability Standard for Unified IBR Requirements (WECC): While ERO Enterprise Reliability Standards are intended to ensure an adequate level of reliability with minimal compliance burden, it is important that they remain system-specific and sufficiently agile to keep pace with the rapid change upon the electricity sector in the coming decades. Unification and harmonization may not be possible at the ERO level (or may not be agile enough); therefore, WECC may consider high-risk areas where more targeted WECC-centric Regional Reliability Standards may be needed moving forward. System inertia challenges and fast frequency response, EMT model data sharing across TPs and PCs, low system strength conditions and GFM adoption, IBR commissioning, offshore wind, and many other areas may actually benefit from standardized approaches and requirements that actually streamline processes and practices rather than hinder industry stakeholders.

Long-Term (2030+) Recommendations

Transitioning Toward a Grid Code Approach in the West: Overhauling the entire BPS regulatory framework nationally would be nearly insurmountable without some form of catastrophic failure. However, less drastic shifts in the regulatory process could result in tangible benefits from a regulatory oversight perspective. There are high-level learnings that one can glean from comparing the current performance-based Reliability Standards approach used in North America with other electricity regulatory frameworks around the world such as ENTSO-E and other regions.[74] For example, performance based Reliability Standards are almost entirely industry stakeholder-driven unless mandated by FERC (which tends to lag serious reliability risks significantly), resulting in regulatory lag and general trends toward regulating issues that only the supermajority is dealing with presently or in the near-term. On the other hand, a grid code approach has an independent body developing regulations, codes, and requirements in consultation with industry and with oversight from an additional governing body. Similarly, the Reliability Standards are not effective until after commercial operation (the FERC GIA and GIP govern rules prior to interconnection), which leaves a chasm of regulatory attention during generator interconnection, commissioning, and into commercial operation. With a grid code approach, the detailed rules are well established and demonstration of compliance with those rules is an obligation to achieve commercial operation. Table 4.1 highlights some of the key differences between these regulatory approaches.

[74] https://www.entsoe.eu/

Table 4.1. Key Differences between Regulatory Approaches		
Category	**Performance-Based Standard Approach**	**Grid Code Approach**
Compliance and enforcement	Compliance program-oriented; cyclical audits of practices and controls; financial penalties; enforcement and monitoring start after interconnection	Focused on results and actual performance; enforcement against documented proof of compliance (verification); starts during interconnection process; stringent accountability
Technical depth and breadth	Generally relatively high-level, process-oriented requirements; technical details left to registered entities to define	Technical details contained in code with local flexibility to modify as needed (with oversight)
Technology differences	Historically technology-agnostic; evolving practices in this area	Technological-specific requirements clearly defined
Risk priorities and focuses	Mostly known, past, or observed risks; relatively minimal focus on future risks	Defines conditions for accessing the electricity grid; contained set of obligations to entities
Agility	Stakeholder misalignment of risk prioritization can cause delays or inaction	Stakeholder engagement can delay action; independent
Requirements development	Small set of nominated stakeholders develop draft standards, seek industry consensus	Independent body drafts codes & guidelines in close collaboration & consultation with industry experts & stakeholders; oversight by governing bodies
Structure and applicability	Entity applicability spread across dozens of standards	Entity applicability (e.g., generators or large loads) contained within one network code[75]
Policy alignment	No direct alignment between standards and energy policies, leading to potential risks	Governing body reviews draft standards to ensure energy policy objectives are met

Additional Recommendations for State Commissions

Many of the IBR challenges and risks presented are within FERC and NERC jurisdiction regarding generator interconnection procedures and agreements, administering the open access transmission tariff, and establishing TO Facility Interconnection Requirements per NERC FAC-001. However, State utility commissioners can play a pivotal role in helping drive meaningful enhancements in this area. Recommendations of how State commissioners can engage in this discussion include:

Advocate for Enhanced and Harmonized Transmission Owner Interconnection Requirements: Commissioners should engage with utility (TO) constituents within their state about what IBR-specific interconnection requirement enhancements are being made *proactively* to address the rapidly rising IBR levels. These efforts should not be reactive; rather, they should be proactive to prepare for growing levels of IBRs. The recommended place to house technical interconnection requirements is in the TO FIRs rather than the power purchase agreements (PPAs) or other contracts. Relying on the FERC GIA/GIP alone and/or the NERC Reliability Standards may not provide sufficient requirements for IBR plant design decisions, which could lead to unexpected risks. Further, commissioners may consider advocating for streamlined and effective IBR plant commissioning practices to ensure data sharing and unified understanding of IBR plant design and as-built setting which can help all involved parties support a more reliable and resilient BPS.

- **Inquire About and Support Adoption of IEEE 2800-2022:** State commissioners can help drive utility adoption and implementation of IEEE 2800-2022 in their interconnection requirements,

[75] https://www.entsoe.eu/network_codes/

which supports a harmonized approach for IBR interconnections. These requirements are comprehensive and cover nearly all the IBR risks posed across Interconnections in North America reported by NERC thus far. Technical requirements should be included in TO FIRs; however, additional high-level requirements should also be included in utility request for proposals (RFPs) for new resources or included in discussions for utility integrated resource/system plans (IRPs/ISPs).

Promote Coordination Between State and Federal Authorities: Commissioners can encourage improved coordination and alignment between state regulatory bodies and FERC by engaging in collaborative discussions with FERC and regional transmission organizations (RTOs)/independent system operators (ISOs), and utilities. State commissioners can ensure that state-level concerns and objectives are considered in the federal rulemaking process, which includes impacts to their utility constituents. State commissioners advocating for national harmonization and uniformity will help drive those aspects at the FERC and NERC level rather than relying on each individual TO to develop their own IBR requirements.

Encourage and Support Utility Investment in Grid Modernization: Commissioners should understand that the variable and uncertain nature of the current and future system will necessitate utility investments in grid infrastructure such as FACTS devices, advanced protection and control systems, and long-term transmission upgrades. Additionally, advanced modeling, studies, and analyses may be needed as part of large capital projects. By supporting and approving investments in new and advanced grid technologies, commissioners can help create a more reliable, resilient, and flexible grid of the future to handle high IBR conditions.

Support Streamlining of Interconnection Processes: Commissioners should advocate for and implement measures that streamline the interconnection process for generators, reduce unnecessary delays, and avoid administrative burdens. A big part of streamlining is ensuring that only credible projects are introduced into the interconnection queue. Commissioners may engage with utilities regarding how they seek to optimize the interconnection queue for credible projects and avoid speculative projects while meeting the obligations and directives of FERC Order No. 2023. Are utilities building any technical rigor into the first-ready, first-served approach (e.g., selection of plant equipment, IBR plant designs, etc.)? Commissioners should also understand that technical rigor (modeling and study work) is necessary to ensure accurate decisions are made for grid reliability purposes. A delicate balance between speed of interconnection and technical rigor is necessary. These same concepts also apply to the load interconnection requests, particularly with the growing prevalence of large data centers and industrial loads in many areas.

Stay Informed on Active Industry Efforts in This Area: Commissioners and their staffs can remain educated and informed on these initiatives by staying involved in industry workshops, conferences, webinars, hearings, and other collaborative forums being held by FERC, NERC, IEEE, DOE, and other industry trade organizations. Education initiatives can also raise awareness about the benefits of robust and uniform interconnection standards.

These actions can help state utility commissioners play a proactive role in enhancing interconnection requirements and contributing to a more reliable and resilient bulk power system.