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Inverter-Based Resources (IBR) in the Modern Grid

How IBRs are reshaping reliability. Technology, behavior, and standards evolution.

Inverter-based resources do not fail like synchronous machines. They trip together, at the same threshold, across a region. This reference covers how IBRs behave, what the disturbance record shows, and what the Order No. 901 standards now require.

Energy Compliance, Inc. Professional Reference

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Foreword

This professional reference is one of a series Energy Compliance, Inc. publishes for registered entities and the people who run their compliance programs.

I have spent more than thirty years on every side of the bulk electric system. I have operated control centers as a Reliability Coordinator, Transmission Operator, and Power System Operator. I have audited grid facilities and signed off on findings as a senior compliance auditor. I have worked enforcement matters from inside the regulator's process. For the last several years I have advised registered entities directly through the firm I founded.

The entities that do reliability well share a common habit. They take the standards seriously without confusing them with reliability itself. They know that a NERC Reliability Standard is a floor, not a ceiling. They know that compliance is something an auditor evaluates, while reliability is something a system either delivers or does not. They prepare for audits by building programs that survive real questions, not binders that look thick.

That is the perspective these references try to share. Each one focuses on a single topic: a standard family, an operational function, a regulatory framework, or an emerging industry challenge. Each one walks through how the topic actually works.

These references are written for the compliance manager who wants to understand the system, not just memorize requirements. For the legal counsel who has to brief a board

honestly. For the senior operator who has been told that compliance and reliability are the same thing and suspects they are not. And for the new compliance hire who got handed a binder and told good luck.

These references are not marketing material disguised as content. They are the result of three decades of doing this work and watching it succeed and fail. I have written them in the same voice I use in a control room or in front of a Regional Entity audit team: direct, grounded in evidence, and honest about what the standards do and do not require.

Energy Compliance exists because much of the consulting offered to registered entities today is structured for billable hours rather than for outcomes. Every engagement is overseen by a senior practitioner. We do not bring five people to a meeting that needs one. We automate the work that should be automated, and we apply senior judgment to the work that requires it. If that approach matches what you are looking for in a compliance partner, the back of this reference has our contact information.

If not, the reference still belongs to you. Take what is useful. Apply it well. And remember the only test that ultimately matters: when the system needs to perform, does it?

Rob Smith

Founder and Principal, Energy Compliance, Inc.

Executive Summary

Inverter-based resources have changed the structural composition of the Bulk Electric System. Synchronous machines, the generators that have set system frequency for a century, now share the system with solar, wind, and storage connected through power electronics. The implications are not theoretical. They show up in real-time operations, in interconnection studies, in protection coordination, in the Reliability Standards FERC directed in Order No. 901, and in the registration of Category 2 IBR owners and operators that took effect on May 15, 2026.

The points this reference makes, chapter by chapter:

- **Inverter-based resources do not fail like synchronous machines.** They trip together, at the same threshold, across a region. That is a governance issue, not just an engineering one.
- **The grid sees what the inverter sends.** Conservative programming makes the resource look weaker than it is. Aggressive programming can destabilize what it was supposed to support.
- **IBR control settings are reliability artifacts.** The settings that left the factory are no longer just engineering choices.
- **Synchronous machines provide inertia automatically. Inverters provide fast frequency response on purpose, if at all.** The difference is whether the response is built in or programmed in.
- **System strength used to be a byproduct of how many synchronous machines were online.** Now it is a planning constraint.
- **Order No. 901 is not the final answer to IBR oversight.** It is the beginning of one.

What has changed since this paper was first written is that the standards have arrived. PRC-028-1 (IBR disturbance monitoring) became effective April 1, 2025. MOD-026-2 (model verification and validation) became effective April 1, 2026, retiring MOD-026-1 and MOD-027-1. PRC-029-2 (IBR ride-through), PRC-030-1 (unexpected IBR event mitigation), and PRC-024-4 became effective October 1, 2026. Order No. 901's last filing deadline, for standards on planning and operational studies, is November 4, 2026. Chapter 10 sets out where each one stands.

1 The Emergence of Inverter-Based Resources in the Modern Grid

1.1 A Different Interface to the Grid

For many decades the North American bulk electric system was designed, operated, and planned around synchronous generation, tied together through the impedance of rotating machines and the network. That design produced system characteristics nobody had to ask for: inertia, high short circuit levels, and voltage regulation that came with the machines.

Conventionally, a synchronous machine, driven by a steam, gas, or hydro turbine, provides the interface between generation and the bulk power system. With inverter-based resources, that interface changes. A power electronic inverter or converter takes a DC input, or an AC input at varying frequency, and produces AC output matched to grid frequency and phase. That new interface brings system behaviors that differ from the synchronous machine, and conventional practices, Reliability Standards, and planning models have had to modernize to keep up.

Inverter-based resources have proliferated over the past decade for several reasons: rapid progress in power electronics, falling costs for wind, solar, and battery equipment, policy changes, and shifts in power markets. Large wind and solar photovoltaic plants and battery energy storage systems make up a growing share of installed utility-scale capacity across North America, and in some Balancing Authority Areas and planning regions they are now the main source of new generation.

1.2 Control Replaces Physics

The hallmark of IBR technology is that control functions replace what used to be electrical and mechanical behavior. In a synchronous system, frequency and voltage behavior are direct consequences of the physical properties of rotating machinery. In an IBR, frequency and voltage behavior are governed by digital control algorithms that sense the grid state and command the power electronic switches in the inverter. The consequences for reliability run in several directions at once.

NERC's disturbance analyses have documented repeated cases in which IBRs played a role in unexpected grid performance: momentary cessation, tripping, and control interactions that planning and operations staff had not anticipated. Those events make the case for understanding how large numbers of inverters act together, not just how a single resource behaves.

1.3 Capability Is Not the Same as Performance

Inverter-based resources can provide reliability services traditionally provided by synchronous generation, including frequency response and voltage and reactive control, if the right controls

are implemented and enabled. Capability on a data sheet does not become performance on the system by itself. Interconnection requirements, performance criteria, and Reliability Standards have to be in place to turn the capability into something the operator can count on.

That is why IBRs have changed the scope of standards development. They are covered in standards for modeling, protection, and planning analysis, and since 2023 FERC has directed NERC to write IBR-specific performance, data sharing, model validation, and study requirements. NERC's Reliability Guidelines carry the technical background and recommended practices that sit beside the mandatory requirements.

1.4 Not Uniform, Still Continental

The transition is not happening uniformly. Regional resource mix, transmission networks, markets, and interconnection processes all vary, and each affects how exposed a region is to IBR reliability problems. Region-specific analysis is necessary. So is a continent-wide reliability framework that treats the same physics the same way everywhere.

Understanding IBRs goes well beyond understanding the power electronics. It means coupling the technology with established reliability principles, with how IBRs are modeled in planning and operations, and with how grid operations are changing to keep the system reliable. The chapters that follow take those pieces one at a time: the technical characteristics, the system-level effects on frequency, voltage, protection, modeling, visibility, stability and restoration, and then the reliability framework that now governs them.

Chapter Summary

Inverter-based resources are a change in how resources connect to the bulk power system. Planning and operating a grid with a large share of them differs in many ways from planning and operating the grid of the past. Understanding those differences, building analysis tools to manage them, and updating procedures and standards where needed is how the industry keeps a high-IBR grid reliable. IBRs are not a reliability impairment in themselves. Their new set of parameters has to be understood and managed.

> **From the Field**
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> Inverter-based resources changed the structural composition of the BES. The standards are catching up. Synchronous machines defined the grid for a century; inverters are redefining it inside two decades. Reliability has to hold in both.

2 Fundamental Characteristics of Inverter-Based Resources

2.1 Defined by the Connection, Not the Fuel

Inverter-based resources are characterized by how they connect to the grid, not by the energy source. Whether the source is solar, wind, or storage, an IBR always includes power electronic equipment that converts its output to current and voltage that match grid specifications. NERC's Glossary definition says exactly this: a plant or facility whose devices export Real Power through a power electronic interface, such as an inverter or converter, operated together as a single resource at a common point of interconnection. Solar PV, Type 3 and Type 4 wind, battery energy storage, and fuel cells are the listed examples.

An inverter is, in essence, a controlled current or voltage source. A synchronous generator produces AC because its rotor turns. An inverter produces AC by switching semiconductor devices according to a programmed control strategy, and that strategy dictates how the resource responds to changes in voltage, frequency, and phase angle.

2.2 No Physical Inertia

One defining characteristic matters most when inverters make up a large share of capacity. There is no rotating mass locked in synchronism with the grid. In a synchronous machine, the stored energy of rotation resists rapid changes in frequency because the machine physically turns in step with the system. An inverter can emulate a fast response through controls, but that response is different in kind. It depends on measuring, filtering, and processing signals and then acting on them. True inertia is passive. It needs no measurement and no processing. NERC's work on frequency response has returned to this distinction repeatedly as IBR penetration grows.

2.3 Grid-Following and Grid-Forming Controls

Inverters are often described by control approach. A grid-following inverter synchronizes to an existing grid voltage waveform, usually through a phase-locked loop, and injects current based on what it measures. It assumes a strong grid established by other resources. A grid-forming inverter establishes its own internal voltage and frequency reference and behaves more like a voltage source. Grid-forming control is most often discussed for systems with little synchronous generation. Treat both terms as descriptions of functionality. A real inverter may combine characteristics of each.

2.4 Different Behavior Under Stress

IBRs sense and respond to voltage excursions, frequency deviations, and faults differently from synchronous machines. Modeling and performance verification at the scale of the fleet, not just the unit, is how that risk gets understood. Chapter 9 covers the events.

Fault current. Conventional protection relies on synchronous generators supplying large fault current for as long as the fault persists. An inverter's fault current is limited by the rating of its semiconductor switches and shaped by its control functions, so it is typically not far above rated current and its character is set by the control strategy. Chapter 5 covers what that means for relaying.

Reactive power and voltage control. IBR reactive capability is set by control settings and current limits, not by inherent machine characteristics. Many IBRs can change reactive output quickly within their limits and can provide meaningful voltage support. How much that is worth depends on the needs of the interconnection, the coordination required by the Transmission Operator, and system conditions.

Control complexity. Every IBR relies on layered controls: the phase-locked loop and current regulators at the inner layer, plant-level voltage and power controls above them, and protection functions throughout. Those layers interact with each other and with the grid, and the result can be non-intuitive system dynamics. Planning and simulation tools have to capture that complexity for the analysis to be trusted.

2.5 Not All Inverters Are Created Equal

By design or as a byproduct of other choices, IBR characteristics vary widely across technology, manufacturer, firmware version, and operating conditions. Much of the current technical discussion centers on aggregate and regional effects rather than on a single generic model of "an inverter." Those characteristics drive frequency response, voltage performance, protection, and restoration, and understanding them is the starting point for every chapter that follows.

Chapter Summary

Inverter-based resources do not have the mechanical characteristics that give synchronous machines inertia and sustained fault current. Their dynamic performance, in steady state and during disturbances, is determined by the control algorithms in their digital controllers. That combination creates both challenges and opportunities. Modeling, analysis, and verification of IBR behavior are therefore essential, especially at high penetration.

> **From the Field**
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> An inverter-based resource is defined by its connection, not its source. Solar, wind, and storage all behave like IBR because of the inverter, not because of the fuel. The grid sees what the inverter sends: program it conservatively and the resource looks weaker than it is; program it aggressively and it can destabilize what it was supposed to support. The control settings are now reliability artifacts. The settings that left the factory are no longer just engineering choices. They are compliance choices.

3 System Frequency Behavior and Inverter-Based Resources

3.1 How Frequency Has Been Held

System frequency holds steady only while real power supplied equals real power demanded. For most of the grid's history that balance has rested on two things synchronous machines provide: inertial response and governor response.

In a system with many synchronous machines, a sudden imbalance is first met by the stored rotational energy of the machines. They slow the rate of frequency decline during a shortfall and damp the rise during a surplus. That inertial response is immediate and continuous, and it needs no measurement or control signal. Primary frequency response follows, as governors adjust mechanical power input in response to the change in speed.

3.2 What Changes with Inverters

Inverter-based resources do not natively provide physical inertia. The inverter decouples the resource's output from grid frequency. Any frequency response comes from control algorithms that measure frequency and other quantities and then adjust output. Within their physical and operating limits, many IBRs can provide frequency response through those controls, raising or lowering real power according to defined parameters. Those adjustments are not physics. They are the product of settings, operating agreements, and performance criteria established through interconnection requirements and operating procedures.

The timing and shape of IBR frequency response also differ. Measurement delay, filtering, and control execution time give the response fast and slow components that look different from a governor's. Properly coordinated, a fleet of inverters can arrest and stop a frequency decline. Poorly coordinated, or inconsistent across resources, the same fleet can become a source of unexpected behavior.

3.3 The Disturbance Record

The disturbance record makes the risk concrete. NERC's event analyses have repeatedly found IBRs reducing output or entering momentary cessation in response to system faults and frequency or voltage excursions, adding to the very imbalance the system was trying to recover from. Those events exposed sensitivity to protection settings and the need for ride-through requirements designed to match system needs. That finding led directly to the ride-through standards described in Chapter 10.

The June 4, 2022 Odessa disturbance shows the stakes. As FERC described it in Order No. 901, a normally cleared single-line-to-ground fault led to a loss of 2,555 MW of synchronous and IBR generation, and Texas Interconnection frequency fell to 59.7 Hz. The loss nearly reached

the 2,750 MW Resource Loss Protection Criteria for the Texas Interconnection under BAL-003-2. Texas underfrequency load shedding begins at 59.3 Hz. That is how close a routine fault came to a firm-load event.

3.4 Lower Inertia, Faster Events

As more non-synchronous generation comes online, the inertia supplied by the remaining synchronous machines falls. With less stored energy, the rate of change of frequency after a large loss of generation is higher. Protection and control schemes designed for a high-inertia system, including underfrequency load shedding programs, were built around slower frequency changes, and their performance at higher rates of change has to be studied rather than assumed. A lower-inertia system needs faster frequency response, from whatever source, to stay stable.

3.5 Capability Versus Obligation

There is a critical distinction between frequency response capability and frequency response obligation. Frequency-related requirements in the NERC standards apply to specific registered functions, and whether a particular IBR is subject to them depends on registration and the applicability section of each standard. This reference does not advise on any individual entity's obligations. The point is that system frequency performance remains a shared responsibility, measured at the Balancing Authority and Interconnection level, and IBRs are now a large part of the resources that responsibility depends on.

Chapter Summary

Frequency response has traditionally rested on the inertia and governor response of synchronous machines. Inverter-based resources move that basis from physics to measurement, set points, and communication. Properly used, inverter-based frequency support is a valuable asset. Poorly coordinated control and protection can hurt frequency stability, and the disturbance record shows it already has. That is a major reliability challenge, and it grows with penetration.

> **From the Field**
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> Synchronous machines provide inertia automatically, as a byproduct of physics. Inverters provide fast response on purpose, if at all. The difference is whether frequency response is built in or programmed in. A grid dominated by inverters can be stable, but stability is no longer a free byproduct. It has to be designed, configured, and verified. Frequency events on inverter-heavy systems happen faster, with less warning, and the standards are being revised to that reality.

4 Voltage Performance and Reactive Power Considerations

4.1 From Excitation to Control Strategy

Voltage performance is a basic element of bulk electric system reliability. It affects equipment performance, power quality, and stability. Voltage regulation and reactive support have traditionally come from synchronous machines, static var compensators, and transmission system design. Significant levels of IBRs challenge those established practices.

A synchronous generator supplies or absorbs reactive power as a function of its excitation and operating state, and its voltage response is continuous and tied to the physics of the machine. An IBR supplies or absorbs reactive power by controlling the components of its output current according to its control strategy. Voltage response moves from physics-dominated to control-dominated behavior, and that changes how voltage control has to be coordinated.

4.2 Fast, Precise, and Limited

Many IBRs can control reactive output faster and more precisely than conventional excitation systems, within their limits, and that speed can be used for voltage control in areas with high IBR penetration. The limits matter. IBR reactive capability is bounded by current limits rather than excitation limits, and there is an inherent trade-off between real and reactive current. At high real power output, reactive capability may be sharply limited. Planning and operating decisions have to account for that trade-off, and NERC's IBR guidance makes the same point.

4.3 Voltage Ride-Through

Voltage ride-through during transient conditions is one of the key performance measures for IBRs. NERC's disturbance reports document events in which large numbers of IBRs tripped or entered momentary cessation in response to voltage excursions that would not have caused a loss of conventional generation. In the Canyon 2 Fire event of October 9, 2017, as Order No. 901 recounts from the NERC and WECC report, momentary cessation was a major cause of the loss of IBRs when voltages rose above 1.1 per unit or fell below 0.9 per unit. Those findings drove the push for consistent ride-through expectations, consistent modeling of ride-through in transient stability studies, and, ultimately, PRC-029.

4.4 System Strength and Control Interactions

System strength, often described as short circuit strength or available fault current, affects voltage performance at high IBR penetration. Weak system conditions can destabilize inverter controls and reduce the system's ability to regulate voltage. Planning studies have examined cases where reduced system strength increases voltage sensitivity and drives interactions between nearby IBRs.

Utilities increasingly need to coordinate several voltage-regulating devices in the same area. Transmission voltage is shaped by generation, static var compensators, load characteristics, and inverters together. When many IBRs respond to the same voltage signal without coordination, the result can be voltage oscillation or poor control. Coordination is the remedy.

4.5 Recovery After the Event

Beyond steady state, the dynamic behavior of inverters during transients and voltage recovery now matters as much as anything else in meeting voltage performance requirements. How fast an inverter's output recovers after a voltage event can significantly affect system recovery and stability, and NERC disturbance reports document cases where the timing and sequence of inverter recovery shaped how system voltages came back. That is why dynamic performance has to be evaluated, not inferred from steady-state studies.

Regional characteristics matter here too. Transmission configuration, load composition, and resource mix vary widely, and so do the voltage issues that result. Region-by-region analysis against the applicable planning criteria is how the impact of IBRs on voltage gets assessed.

Chapter Summary

On a system with more inverter-connected resources, voltage performance is determined by reactive power control strategies rather than by the inherent characteristics of rotating machines. Inverters can provide a high level of voltage control on very short time scales. Whether they actually support the grid in a given situation depends on operating margins, grid topology and impedance, and coordination with other voltage control devices. NERC's disturbance reports have documented inconsistent ride-through during faults and a lack of coordinated control, and they make a clear case for grid-wide voltage performance analysis.

> **From the Field**
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> Reactive power from inverters is fast, programmable, and conditional. From synchronous machines it was slower, automatic, and continuous. The two are not interchangeable. The voltage profile of an inverter-rich system depends on the firmware, which makes firmware updates reliability events. A resource that cannot ride through a voltage disturbance can leave the system in worse shape than a resource that was never there. Disconnection during a disturbance is the failure mode PRC-029-2 is written to prevent.

5 Protection Systems and Fault Response Implications

5.1 Protection Built on Synchronous Fault Current

Fault protection identifies and isolates faults to prevent or limit equipment damage, protect people, and preserve system stability. Existing protection design and reliability analysis were built around the known fault behavior of synchronous machines and passive network components. Growing IBR penetration means those practices have to account for inverter fault behavior and its effect on protection performance.

During a short circuit, a synchronous generator typically supplies fault current several times its full-load rating, and it keeps supplying it until protection clears the fault. That high, predictable fault current has supported conventional protection methods based largely on current magnitude and direction for decades.

5.2 What Inverters Supply Instead

Power electronic devices, including inverter-based generation, STATCOMs, and converter-based HVDC terminals, supply much less fault current. It is limited by device ratings, typically not far above rated current, and its magnitude, phase angle, and sequence components are set by the control strategy rather than by machine physics. Protection designed on the assumption of much higher fault current can be challenged, and the challenge grows with the IBR share of the local system.

Distance protection, overcurrent protection, and directional elements can all be affected. Situations are foreseeable in which more inverter-connected generation lengthens fault detection time or reduces the security or dependability of protection zones. As the resource mix changes, the impact on protection has to be assessed rather than assumed.

Inverter control during faults is another factor. Some inverter controls protect the inverter by reducing current or switching into a protective mode. That self-protection is necessary, but in aggregate it can change how faults present to relays in ways existing protection practice did not anticipate.

5.3 Grounding and Recovery

Ground fault behavior also differs. The grounding configuration of an IBR plant and its collector system determines its contribution to ground fault current, and that has to be represented correctly in protection coordination studies.

Protection performance also includes how the system recovers after the fault is cleared. The timing of inverter restart and output recovery plays a significant role in stabilizing the system and

restoring voltage. Protection settings alone no longer determine protection performance on a modern system. Inverter controls are part of the answer.

5.4 Technology-Neutral Standards, New Inputs

The standards covering protection system maintenance, coordination, and misoperation analysis remain largely technology-neutral. PRC-004-6, for example, requires misoperation identification and correction for Protection Systems for BES Elements regardless of the generating technology behind them. What has changed is the input. Protection system performance analysis now has to account for the fault response characteristics of inverters, and studies should use measured inverter behavior during faults wherever it is available. The effect will vary with local system conditions, the concentration of inverters at a substation, and the relay settings in place.

Chapter Summary

Existing protection systems were designed on the assumption that faults would announce themselves with high, sustained fault current from synchronous resources. The limited and controlled fault current from IBRs can affect the ability of protection to detect faults reliably, clear them in time, stay selective, and stay coordinated. Assessing those effects requires accurate dynamic models of IBRs and of the system topology around them, and that need grows as IBR adoption grows.

> **From the Field**
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> Protection schemes were calibrated to synchronous fault current. Inverter fault current is lower, shaped by controls, and different in character. Same algorithm, different input, different outcome. A protection misoperation on an inverter-dominated circuit is, in my view, not a setting error. It is a category error: the settings were correct for a system that is no longer there. The protection engineer who has not reset those assumptions for IBR is, in my view, where the next misoperation findings will come from.

6 Modeling, Studies, and System Analysis Considerations

6.1 Models Built for Machines

Models are how planners and operators predict reliability. They are used in planning studies and in operational analysis, across normal conditions, contingencies, and extreme weather. Existing power system models were built with the synchronous machine as the foundation. Inertia, exciter, governor, and protection models are all tied to the synchronous generator.

IBRs bring a different set of modeling problems, because their behavior is defined by control algorithms, not by the mechanics of a rotating machine. IBR models need to represent phase-locked loop behavior, current limits, voltage control, frequency response logic, and the protection functions that cause tripping. Generic and simplified models may be adequate for some analyses, but they can miss how inverters behave and interact during disturbances. At high penetration, small model inaccuracies can produce misleading results.

6.2 Steady-State and Dynamic Studies

Inverter modeling matters in both steady-state and dynamic analysis. In power flow, an IBR is usually represented as a controlled injection of real and reactive power within limits. That is adequate for some purposes, but it says nothing about dynamic behavior during transient events. Dynamic simulation has to complement steady-state power flow to confirm that inverter control strategies will perform as intended, and for weak grid conditions positive-sequence dynamic models may not be enough.

Dynamic IBR models are hard to build well. The difficulty is less the technology than the proprietary nature of control implementations, which differ from one manufacturer to another. Limited disclosure of proprietary control details has been a recurring barrier to accurate planning and operations studies. The positive development is the move toward a small number of standard model structures and defined procedures for validating IBR dynamic models.

6.3 Validation Against Real Performance

Model validation and verification are central to system analysis. Models should be checked against actual system performance whenever data allow, particularly after significant disturbances. The disturbance record has shown repeated mismatches between modeled and actual IBR behavior. NERC's May 2025 Level 3 Alert stated that NERC studies were not able to replicate the system and resource behavior that occurred during the major IBR events since 2016, and it called that a systemic deficiency in industry's ability to represent IBR performance.

The standards have responded. MOD-026-2, Verification and Validation of Dynamic Models and Data, became effective April 1, 2026, and its implementation plan retires MOD-026-1 and MOD-

027-1. Order No. 901 also directed standards on model validation and data sharing for registered IBRs, unregistered IBRs, and IBR-DERs in the aggregate. Chapter 10 has the status.

6.4 The Aggregate Is Not the Sum

Modeling the aggregate of many IBRs is not straightforward. The behavior of the group may not equal the sum of individual behaviors, particularly when resources respond to the same control signal, such as voltage. NERC's event analyses have documented aggregate IBR behavior distinctly different from what any single plant's model predicted.

Restoration and blackstart modeling has become important as well. IBR behavior during energization, islanding, and restoration differs from that of synchronous machines, and the controls that govern it under low voltage and low frequency conditions need to be represented. Planning criteria, study assumptions, and validation methods all need to be re-examined as the resource mix changes.

Chapter Summary

Inverter-based resources require different modeling approaches than synchronous machines because their behavior is governed by controls, in both static and dynamic analysis. The disturbance record has shown that modeling, validation, and aggregation of IBRs have to be done well for system studies to be trusted. As the IBR share grows, modeling practice, and now the validation standards, have to keep pace.

7 Operational Visibility and Real-Time Considerations

7.1 What the Operator Sees

Reliable real-time operation depends on accurate situational awareness and timely operator response. Control centers work from measurements, telemetry, and analytical tools that monitor system performance and support recovery after a disturbance. IBR integration has created new challenges for that situational awareness.

Operators are used to conventional hydro, gas, coal, and nuclear units whose dynamic responses are well understood and broadly similar. IBRs can respond very quickly, and how they respond is determined by plant-specific control settings. As IBR penetration grows, the system dynamics operators are used to seeing can change substantially.

7.2 Visibility Gaps

NERC has identified visibility gaps associated with IBRs: missing real-time, high-resolution data; delayed or poor-quality status information; and little insight into control modes and states. During significant events, a lack of high-resolution data can make it impossible to see what IBRs actually contributed. The real and reactive output, voltage control status, frequency response mode, and protection state of each plant determine how it interacts with the grid, and operators increasingly need to know them in real time.

Voltage response is a good example. For a conventional synchronous generator, reactive behavior follows from first principles and can be predicted with confidence. For an IBR, reactive response is set by the inverter's operating logic. Two similar plants can respond quite differently to the same system conditions because of control settings, firmware versions, and operating restrictions. That uncertainty about how many plants will behave weakens the operator's ability to anticipate the outcome of a disturbance.

Many fast IBR events, such as momentary cessation, current limiting, or a brief loss of synchronization, do not show up in conventional SCADA data at all. Without a visible trigger, it is hard to connect them to the frequency and voltage deviations, the response of reactive devices, or the failure of other resources to perform. That obscures root cause analysis and delays the mitigation that should follow. PRC-028-1, effective April 1, 2025, addresses part of this by requiring disturbance monitoring and recording capability at IBRs, with compliance phased in under its implementation plan.

7.3 Coordination, Alarms, and Training

Operational coordination among Transmission Operators, Balancing Authorities, and Generator Operators becomes more important as inverter penetration rises. Knowing each plant's

capabilities, limits, and expected response improves that coordination. Data specifications and information sharing are part of it, and with Category 2 registration, Category 2 Generator Operators became subject to standards such as TOP-003-6.1 and IRO-010-5 on May 15, 2026.

Alarm management and operator training also have to change. Faster system behavior and different response characteristics call for changes to operating procedures, training programs, and simulator models, so that operators can recognize IBR-related alarms and practice the contingencies they imply.

7.4 Restoration and Reconfiguration

System restoration and reconfiguration continue to surface operating challenges with IBRs that differ from those of synchronous generation: voltage recovery, islanding, and resynchronization. Limited visibility into inverter status after a significant event can affect restoration timing and stability. Operational visibility is a technical and a non-technical challenge, running from data availability and communication protocols to how well operators understand inverter operation. As more IBRs interconnect, NERC and the industry are pushing for the visibility that reliable BES operation requires.

Chapter Summary

Operational visibility is essential to reliable real-time management of the bulk power system. The control-driven nature and fast response of IBRs make visibility and predictability harder. NERC's work has documented gaps in telemetry, situational awareness, and operator knowledge that can affect real-time decisions. Visibility, coordination, and operator training all have to keep pace with growing inverter levels.

> **From the Field**
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> The operator runs the system on what the SCADA reports. If IBR telemetry is incomplete, the operator is running on partial information, in real time, with consequences. Since May 15, 2026, Category 2 IBR operators have carried data obligations under the operations standards NERC's compliance-dates supplement lists, including TOP-003-6.1 and IRO-010-5. An IBR fleet the operator cannot see, cannot dispatch, and cannot curtail in real time is a contingency, and the system has to be planned around a contingency it cannot see.

8 System Strength, Stability, and Inverter Interactions

8.1 What System Strength Means

System strength describes the ability of the system to keep voltage and frequency stable through disturbances. Historically it has been tied to the presence of synchronous machines, which provide inertia, fault current, and voltage support through direct electromechanical coupling with the grid. With high synchronous generation, voltage tends to be stiff and stable, fault currents are high, and excitation systems hold voltage tightly. With high IBR penetration, short circuit levels and voltage stiffness may be lower, especially in electrically remote parts of the transmission system.

IBRs use measurements taken from the grid to regulate their output. In a weak grid, voltage and frequency measurements are less stable, and that degrades inverter control performance. Interactions between inverters and weak grids can show up as oscillations, slow recovery, and unexpected tripping. How an inverter affects the grid depends heavily on the strength of the system at its point of interconnection.

8.2 Inverter-to-Inverter Interactions

Control interactions among multiple IBRs are a separate stability factor. When many inverters respond to the same signal, they can amplify system oscillations or damp them. Uncoordinated controls can produce unstable control oscillations and erode stability margins even when each plant individually meets its interconnection requirements.

Grid-following inverters rely on a voltage reference from the grid and are not always stable on weak grids. Grid-forming inverters create their own voltage and frequency reference and can support weak areas, but their performance is still being evaluated across operating conditions and in coordination with other protection and control systems.

8.3 New Sources of Instability

Small-signal and transient stability analysis is increasingly shaped by inverters. For decades, stability studies centered on rotor angle dynamics and synchronous machine excitation control. Now instability can come from interactions among inverter control loops, phase-locked loop dynamics, and current limits. Stability study methods have to adapt, and in weak areas that may mean electromagnetic transient studies rather than positive-sequence simulation alone.

8.4 A Planning Constraint

System strength is now a factor in transmission planning and resource siting. Low system strength occurs in areas with weak transmission connections or high IBR concentration. The

remedies discussed in planning studies include additional transmission, synchronous condensers, and grid-forming capability. System strength is not an on-off switch. It is a range of conditions that varies with location, with time, and with which resources are online. Because it touches planning, operations, and protection at once, system strength is where those disciplines meet.

Chapter Summary

System stability and adequacy have classically rested on the characteristics of synchronous generation. Systems with more IBRs need to rethink what system strength and stability mean. Weak system conditions affect inverter performance and ride-through. Disturbance analyses and planning studies have shown the effect of new control interactions, lower short circuit levels, and new stability phenomena. The response has to be system-level: one that recognizes what has changed about system strength and plans for it explicitly.

> **From the Field**
>
> System strength used to be a byproduct of how many synchronous machines were online. Now it is a planning constraint, and IBR penetration limits are how the constraint shows up in real decisions. Two well-designed inverters in close electrical proximity can interact in ways that appear in neither of their individual studies. The interaction is the new reliability question, and many studies still do not ask it.

9 Disturbance Events and Reliability Lessons Learned

9.1 What Disturbances Teach

Disturbances show how the bulk electric system actually performs under stress, and they expose the gap between planned and actual performance. As IBRs have grown, NERC has made analysis of their behavior during disturbances a priority.

The pattern is consistent. NERC has reported events in which large numbers of IBRs reduced output, entered momentary cessation, or tripped in response to normally cleared faults and routine voltage or frequency excursions, producing generation losses that planning and operations staff had not anticipated. In these events the IBR losses were not caused by the fault damaging the plants. They came from control strategies and protection settings inside the resources. NERC's May 2025 Level 3 Alert put the total at more than 15,000 MW of unexpected generation reduction across major events since 2016, documented in 10 major event reports and four Level 2 Alerts.

9.2 The Named Events

Event	Date	What happened
Blue Cut Fire, Southern California	August 16, 2016	About 1,200 MW of solar PV interrupted by transmission faults (NERC/WECC report, June 2017)
Canyon 2 Fire, Southern California	October 9, 2017	About 900 MW of solar PV interrupted; momentary cessation a major cause (NERC/WECC report, February 2018)
San Fernando, Southern California	July 7, 2020	About 205 MW and then about 1,000 MW of solar PV reduction across two transmission faults (NERC/WECC report, November 2020)
Odessa, Texas	May 9, 2021	1,112 MW of solar PV reduction, plus 192 MW at the faulted combined-cycle plant and 36 MW of wind (NERC/Texas RE report, September 2021)
Odessa, Texas	June 26, 2021	Second Odessa-area solar tripping event (same report)
Odessa, Texas	June 4, 2022	2,555 MW of synchronous and IBR generation lost; frequency to 59.7 Hz (NERC/Texas RE report, December 2022)

Order No. 901 lists these among thirteen documented IBR events, along with Angeles Forest, Palmdale Roost, Victorville, Tumbleweed, Windhub, Lytle Creek, and the Panhandle Wind disturbance.

9.3 The Whole Is Larger Than the Parts

A common theme in NERC's analyses is aggregate behavior. Each plant may respond within its own limits and still, combined with many others, pose a significant risk to the system. Those effects do not appear in one-plant-at-a-time analysis. They emerge only when the system is examined as a whole.

The analyses also show how much model assumptions mattered. Models built before the events did not capture the dynamic response of inverter controls, and detailed post-event modeling with measured data confirmed it. That points to an urgent need for model validation and data sharing.

9.4 Protection, Visibility, and Integration

Disturbance analysis has also highlighted the protection side: reduced fault current combined with fast, controlled inverter response changes how faults are detected and how the system recovers. Communication and coordination problems surfaced too. In many events, the lack of real-time visibility into inverter operating states made it hard to manage the immediate effects and hard to find the root cause afterward. NERC has put additional effort into telemetry, event reporting, and data availability so that utilities can determine the impact of inverter-related disturbances quickly and accurately.

NERC has characterized many of these problems as integration issues rather than flaws in inverter technology. IBRs can provide reliable service when their integration is managed properly: through protection and control settings, accurate models, operating procedures, and Reliability Standards. The lessons are flowing into guideline revisions, reliability studies, outreach, and, since 2023, mandatory standards.

Chapter Summary

The disturbance record is the clearest evidence of how IBRs perform under stress. Events in California and Texas showed aggregate IBR responses that planning models did not predict, limited visibility into plant behavior, and recovery problems after normally cleared faults. The conclusions are consistent: system-wide studies, more accurate models, better visibility of IBR operation, and better integration of IBRs into system operations.

> **From the Field**
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> Every IBR disturbance event of the last decade has revealed a different gap. Read the post-event reports as a curriculum, not a punishment. Blue Cut. Canyon 2. Odessa. The names are shorthand for control settings, ride-through profiles, and protection logic that did not behave the way the planning model said they would.

10 Reliability Frameworks and Oversight Considerations

10.1 A Framework Built for Synchronous Machines

The North American bulk power system is governed by a reliability framework that defines performance criteria, applies consistent rules, and provides for continuous improvement. NERC develops and enforces Reliability Standards under FERC oversight pursuant to Section 215 of the Federal Power Act. That framework was developed on a system dominated by synchronous generation, and it has had to adapt as IBRs have grown.

NERC Reliability Standards are written to be technology-neutral, specifying performance outcomes rather than designs, materials, or technologies. Technology-neutral does not mean technology-blind. How a resource type behaves is a necessary input to any reliability analysis, and IBRs affect compliance, performance analysis, and risk assessment in ways the original standards did not anticipate.

10.2 Where IBRs Touch the Existing Standards

Planning standards for modeling, contingency analysis, and transfer capability all depend on predicting system performance under assumed conditions, which makes accurate IBR modeling essential. Operating standards for frequency, voltage, and event response apply at the system level, and IBRs tend to affect those system-level characteristics as a group. Protection standards cover coordination, maintenance, and misoperation analysis. As IBRs change fault current, protection performance can change even when relay settings do not.

NERC also publishes Reliability Guidelines and other reference material that support the standards without being mandatory. Its IBR guidelines cover dynamic modeling practice, performance recommendations, and lessons learned from disturbances. The Level 2 Alert findings cited in NERC's 2025 Level 3 Alert are blunt about what happened to those voluntary recommendations: many Generator Owners had not implemented them. Order No. 901 reached the same conclusion in 2023: current actions were insufficient, and the new IBR rules had to be mandatory.

10.3 Order No. 901

FERC issued Order No. 901, Reliability Standards to Address Inverter-Based Resources, on October 19, 2023, in Docket No. RM22-12-000 (88 FR 74250, October 30, 2023). It directed NERC to develop new or modified standards in four areas: data sharing, model validation, planning and operational studies, and performance requirements. It set three filing deadlines:

Deadline	What NERC had to file
November 4, 2024	IBR performance requirements (frequency and voltage ride-through, post-disturbance ramp rates, phase-locked loop synchronization, other causes of tripping or momentary cessation), plus disturbance monitoring data sharing and post-event performance validation for registered IBRs
November 4, 2025	Data sharing, and data and model validation, for registered IBRs, unregistered IBRs, and IBR-DERs in the aggregate
November 4, 2026	Planning and operational studies for registered IBRs, unregistered IBRs, and IBR-DERs in the aggregate

10.4 The IBR Standards in Effect, October 2026

Standard	Subject	Effective
PRC-028-1	Disturbance monitoring and reporting requirements for IBRs	April 1, 2025, with phased compliance
MOD-026-2	Verification and validation of dynamic models and data (retires MOD-026-1 and MOD-027-1)	April 1, 2026
PRC-024-4	Frequency and voltage protection settings, now limited to synchronous generators, Type 1 and Type 2 wind, and synchronous condensers	October 1, 2026
PRC-029-2	Frequency and voltage ride-through requirements for IBRs (replaces PRC-029-1)	October 1, 2026, with phased compliance
PRC-030-1	Unexpected IBR event mitigation	October 1, 2026
EOP-004-5	Event reporting, adding an IBR loss event type for Balancing Authorities	October 1, 2027

FERC approved PRC-029-1 and PRC-024-4 in Order No. 909 on July 24, 2025, and directed NERC, within 12 months, to determine whether and how to account for the equipment limitations of HVDC-connected IBRs with choppers and the long lead time between design specification and in-service date, and to clarify the documentation needed for legacy-equipment exemptions. NERC answered with PRC-029-2, which FERC approved and which replaced PRC-029-1 on the same October 1, 2026 effective date. Under the PRC-029-2 implementation plan, the performance-based portions of the ride-through requirements do not apply to an IBR until its PRC-028-1 disturbance monitoring capability is in place. Ride-through compliance and disturbance monitoring compliance are tied together. Plan them together.

PRC-029-2 and PRC-030-1 apply to Generator Owners with BES IBRs and with non-BES IBRs that meet the Category 2 thresholds.

10.5 Category 2 IBR Registration

The second half of IBR oversight is registration. NERC's Rules of Procedure, Appendix 5B (Statement of Compliance Registry Criteria, Revision 8, effective June 27, 2024), extended the Generator Owner and Generator Operator functions to owners and operators of non-BES inverter-based resources that have or contribute to an aggregate nameplate capacity of 20 MVA or more, connected through a system designed primarily for delivering that capacity to a common point of connection at 60 kV or higher. These are the Category 2 GO and Category 2 GOP. The NERC Glossary definitions of Generator Owner and Generator Operator now carry the same two categories.

Category 2 registrations entered the NERC Compliance Registry with an effective registration date of May 15, 2026. NERC's compliance-dates supplement lists May 15, 2026 as the Category 2 compliance date for BAL-001-TRE-2, IRO-010-5, MOD-032-2, PRC-012-2, PRC-017-1, TOP-003-6.1, VAR-001-5, and VAR-002-4.1, while other standards, including the CIP family, are listed as requiring modification before they apply to Category 2 assets. Check the current revision of that supplement before you settle any applicability question. NERC updates it in step with its quarterly IBR work plan filing to FERC, so check the revision history.

10.6 Reliability Rules Are Not Resource Policy

Standards compliance is only part of IBR oversight. NERC also runs reliability assessments, technical conferences, and outreach to understand the risks, and the RTOs and ISOs run their own technical forums on regional needs and lessons learned. Reliability oversight and resource policy are different things. NERC and FERC's reliability authority does not decide what power plants get built or which technologies are used. It exists to make sure that whatever connects to the bulk power system connects in a way that supports reliability.

The framework is being refined, not rewritten from first principles. The underlying principles of reliability have not changed.

Chapter Summary

Reliability Standards for the bulk electric system are technology-neutral, but effective compliance requires understanding how inverters affect system operation. Since this paper was first written, that understanding has been written into mandatory standards: disturbance monitoring, ride-through, event mitigation, and model validation are now in effect, and Category 2 IBR owners and operators are registered.

> **From the Field**
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> The reliability framework was developed for a system whose composition was stable. IBR changed the composition faster than the framework could revise, and the standards spent a decade chasing the system. Order No. 901 is not the final answer to IBR oversight. It is the beginning of one. Expect more cycles of registration, study requirements, and ride-through specifications.

11 Restoration, Blackstart, and Extreme Operating Conditions

11.1 Restoration Built Around Synchronous Machines

Restoring the system after a large outage is one of the most complex reliability tasks there is. It means re-energizing transmission, restarting generation, and resynchronizing islands while voltage and frequency are outside normal bounds. Restoration practice has historically been built around synchronous machines, and it is now evolving to account for IBRs and extreme operating conditions.

Blackstart Resources are, in NERC's definition, generating units that can start without support from the system, or remain energized without connection to the rest of the system, and can energize a bus while meeting the Transmission Operator's restoration plan needs. Historically they have been synchronous units. A grid-following IBR needs an energized system to operate, so it cannot meet that definition.

11.2 Inverters Early in Restoration

Early in a restoration, the system typically has low short circuit capacity, low inertia, and large voltage swings. Grid-following inverters operating in that environment may become unstable or trip on their own protection limits. A common practice is to leave IBRs offline, or run them in a reduced mode, until conditions improve.

How an IBR behaves during energization depends on its measurement of voltage, frequency, and phase angle. Phase-locked loops and voltage control algorithms can perform differently during restoration than in normal operation, and if those control strategies are represented incorrectly or incompletely, restoration studies and the assumptions behind restoration plans can be wrong.

Grid-forming inverters come up most often in the context of restoration and islanded microgrid operation. They set their own local voltage and frequency rather than tracking a reference supplied by other resources. That capability may bring real benefits, but its value at grid scale depends on how grid-forming resources are coordinated with each other and with traditional restoration methods.

11.3 Later Stages and Shared Responsibility

IBRs also affect the later stages of restoration, including synchronization and load pickup. The timing and ramp rate of IBRs returning to service can affect voltage and frequency recovery, and uncoordinated return of IBRs can complicate resynchronization and load restoration.

Restoration remains a coordinated effort among Transmission Operators, Balancing Authorities, Reliability Coordinators, and Generator Operators. Planning it requires knowing what each resource can and cannot do, including where inverters can recover on their own and where they still need support from synchronous resources. Higher IBR penetration calls for more restoration studies and drills that reflect actual system conditions.

Chapter Summary

System restoration and operation under extreme conditions have long relied on synchronous generation. IBRs bring new challenges: dependence on an energized grid, different control behavior during restoration, and different recovery characteristics. Accurate modeling, realistic restoration planning, and clear expectations for each resource are critical to restoring the system as the resource mix changes.

> **From the Field**
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> Blackstart on an IBR-heavy system is not a solved problem. It is an active research question. The grid that came back after the 1965 Northeast blackout is not the grid that has to come back today. Grid-following inverters need a reference voltage to start. Synchronous machines did not. A restoration plan that assumes synchronous blackstart units will carry the whole load is a plan the next major outage will test. If the plan has not accounted for the inverter dependency, the restoration will be slower than the plan estimates.

12 Future Reliability Outlook and Ongoing Industry Focus

12.1 The New Normal

Inverter-based resources are now a permanent and growing part of the North American power system. NERC, FERC, the Regional Entities, utilities, and other industry participants continue to focus on reliable grid performance as the mix changes. IBRs are no longer an emerging issue. They are the normal state of the system.

As IBRs become a larger share of connected resources, reliability will be driven less by the characteristics of individual pieces of equipment and more by the dynamics of the system as a whole. That requires a system view, coordination across teams and functions, and a common understanding among all participants of what is happening in real time, in normal and abnormal operations.

12.2 What to Watch

The standards will keep pursuing performance outcomes rather than prescribing technology or design, because technology and system conditions vary across regions. The near-term items to watch:

- **The final Order No. 901 filing.** Standards for planning and operational studies of registered IBRs, unregistered IBRs, and IBR-DERs in the aggregate are due at FERC by November 4, 2026.
- **Ride-through and disturbance monitoring implementation.** PRC-029-2 and PRC-030-1 took effect October 1, 2026, and PRC-028-1 compliance phases in under its own plan. The first compliance monitoring of these standards will show how well fleets documented their settings, exemptions, and event analyses.
- **Category 2 applicability.** The compliance-dates supplement for Category 2 GOs and GOPs: NERC updates it in step with its quarterly IBR work plan filing to FERC, so check the revision history.
- **IBR event reporting.** EOP-004-5 adds an IBR loss event type for Balancing Authorities effective October 1, 2027.
- **Guidelines, RTO and ISO publications, and post-event reports** on model validation and disturbance analysis, which continue to set expectations ahead of the standards.

12.3 Protection, Restoration, and Resilience

Advances in protection and control schemes, and the growing role of inverters in dynamic voltage regulation, will continue. Their effect on fault current, relay operation, and stability needs ongoing study, and disturbance findings should keep flowing into reliability studies and guideline revisions. Restoration capability and resilience under extreme conditions remain open topics.

For now, grid-following inverters participate in restoration only under suitable conditions, and synchronous resources remain the primary resources for blackstart and early restoration. The conversation is shifting toward how all resources work together to provide resilience.

12.4 Technology-Neutral, Performance-Driven

Reliability Standards address who is responsible for reliable operation of the bulk power system and what performance is required, not what form of generation is used. They do not favor or reject any particular technology. The requirement is that any resource connecting to the grid does so in a way that preserves reliability.

The evidence base keeps growing from real-time operations, event analysis, and research. Planners, operators, asset owners, and policymakers all need to understand where IBRs fit in that picture.

Chapter Summary

The integration of inverter-based resources into the bulk electric system is well underway. NERC and industry are focused on system-level performance, modeling, real-time monitoring, and visibility, and the Order No. 901 standards have moved much of that work from guidance into mandatory requirements. The framework will keep evolving with each new analysis and each new event.

Glossary

Term	Meaning in this paper
Balancing Authority	The responsible entity that integrates resource plans ahead of time, maintains Demand and resource balance within a Balancing Authority Area, and supports Interconnection frequency in real time (NERC Glossary).
Blackstart Resource	A generating unit that can start without support from the System, or remain energized without connection to it, and energize a bus to meet the Transmission Operator's restoration plan needs, and that is included in that plan (NERC Glossary, paraphrased).
Bulk Electric System (BES)	Unless modified by the inclusions and exclusions in the definition, all Transmission Elements operated at 100 kV or higher and Real Power and Reactive Power resources connected at 100 kV or higher, excluding facilities used in the local distribution of electric energy (NERC Glossary). The BES definition determines the applicability of most Reliability Standards.
Bulk-Power System	The Federal Power Act term: facilities and control systems necessary for operating an interconnected transmission network, and generation needed to maintain transmission system reliability, excluding local distribution (NERC Glossary). It is not an old name for the BES; the BES is the NERC-defined subset most standards apply to.
Category 2 Generator Owner and Generator Operator	The entity that owns and maintains (GO), or operates (GOP), non-BES Inverter-Based Resources that have or contribute to an aggregate nameplate capacity of 20 MVA or more, connected through a system designed primarily for delivering that capacity to a common point of connection at 60 kV or higher (NERC Glossary; ROP Appendix 5B).
Frequency Response	For equipment, the ability to react or respond to a change in system frequency; for the system, the change in demand plus the change in generation, divided by the change in frequency, in MW/0.1 Hz (NERC Glossary).
Grid-Following Inverter	An inverter control approach that synchronizes to an existing grid voltage, typically through a phase-locked loop, and injects current based on that reference. It depends on a sufficiently strong grid established by other resources.
Grid-Forming Inverter	An inverter control approach that establishes its own internal voltage and frequency reference and behaves as a voltage source, rather than tracking a reference provided by the grid.
Inertia	Stored kinetic energy in rotating mass that opposes changes in speed and so in system frequency. Inverter-based resources have none coupled to the grid, though their controls can provide fast frequency response.

Term	Meaning in this paper
Inverter-Based Resource (IBR)	A plant or facility consisting of individual devices that are capable of exporting Real Power through a power electronic interface, such as an inverter or converter, and that are operated together as a single resource at a common point of interconnection. Examples include solar PV, Type 3 and Type 4 wind, battery energy storage, and fuel cells (NERC Glossary).
Momentary Cessation	A mode of operation in which the inverter remains electrically connected to the Bulk-Power System but does not inject current during low or high voltage conditions outside its continuous operating range, so it produces no active or reactive power (FERC Order No. 901, citing NERC's 2018 IBR performance guideline).
NERC	The North American Electric Reliability Corporation, the Electric Reliability Organization certified by FERC under Section 215 of the Federal Power Act to develop and enforce Reliability Standards for the Bulk-Power System.
Phase-Locked Loop (PLL)	The control function a grid-following inverter uses to track the phase angle and frequency of the grid voltage so its output stays synchronized.
Reactive Power	The portion of AC power that establishes and sustains the electric and magnetic fields of AC equipment and supports system voltage. Measured in volt-amperes reactive (var).
Reliability Coordinator	The entity that is the highest level of authority responsible for the Reliable Operation of the Bulk Electric System, with the Wide Area view and the operating tools, processes, and procedures, including the authority to prevent or mitigate emergency operating situations in next-day analysis and real-time operations (NERC Glossary).
Ride-through	The plant or facility remains connected and continues to operate through voltage or frequency system disturbances (NERC Glossary, effective October 1, 2026).
Short Circuit Strength	The ability of the power system at a given point to supply fault current, usually expressed as short circuit capacity. It matters for protection design and for voltage stability.
Synchronous Generator	A rotating AC machine whose rotor turns in synchronism with system frequency. Its inertia, fault current, and reactive behavior follow from its physics and excitation system.
System Strength	An engineering term, not a NERC defined term, for the grid's ability at a location to hold voltage and frequency stable through disturbances.
Transmission Operator	The entity responsible for the reliability of its local transmission system, and that operates or directs the operations of the transmission Facilities (NERC Glossary).

These definitions are for general information. Where a term is defined in the NERC Glossary of Terms Used in NERC Reliability Standards, the NERC Glossary controls.

How Energy Compliance Can Help

Inverter-based resources are now a compliance subject, not just an engineering one. The ride-through settings, the disturbance monitoring records, the event analyses, and the validated models this reference describes are the evidence an auditor will ask for. Three services fit the problems in this paper:

- **Registration and applicability analysis.** A clear answer on whether your plants meet the Category 2 GO or GOP thresholds, which standards apply on which dates, and what the BES and non-BES distinction means for each facility.
- **Operational and engineering reliability alignment.** Getting the inverter settings, plant controller settings, and protection settings your engineers own to line up with what PRC-029-2, PRC-030-1, PRC-028-1, and MOD-026-2 require, and documented so the evidence survives an audit.
- **Audit defense.** Audit preparation, RSAW production, and data request strategy for the IBR standards, led by the senior named on the engagement, with Notice of Penalty response and settlement posture if it comes to that.

WattOps Compliance

WattOps Compliance is EC's NERC compliance evidence platform (wattopscompliance.com). For IBR owners taking on PRC-028, PRC-029, PRC-030, and MOD-026 obligations, it is where the evidence for those programs is kept. EC will run one standard at one facility through WattOps at no cost (CIP standards excluded).

RenewOps

RenewOps is EC's renewable operations monitoring and analytics platform, with a Data Center module. For solar, wind, and storage fleets, it puts the operations data behind ride-through and event analysis in front of the people who have to explain what the plant did.

If your fleet registered as Category 2 this year, or your ride-through documentation is still a vendor data sheet, start there. Then call.

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About the Author

Rob Smith is the Founder and Principal of Energy Compliance, Inc., with more than thirty years in the industry on every side of the system. He began in control-room operations as a Reliability Coordinator, Transmission Operator, and Power System Operator across RTO/ISO and utility control centers. On the regulator side, he was a senior compliance auditor and subject matter expert for NERC Reliability Standards. He audited grid facilities, evaluated mitigation adequacy, participated in risk-based oversight of utility mitigation activities, and supported the development of violation notifications and settlements in FERC-directed enforcement actions. He conducted a regulatory audit in the Sultanate of Oman against the Sultanate's Sector Law and Grid Code.

He founded Energy Compliance, Inc. to deliver senior regulator-side compliance authority without the layered staffing and billable-hour overhead of larger firms.

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- MBA, Energy Management, University of Mary
- MSL, Compliance Law, Fordham Law University
- BAS, Energy Management, Bismarck State College
- BAS, Mechanical Engineering, Metallurgy minor, University of Florida
- BAS, Criminology, St. Petersburg College (State Law Enforcement Certification)
- AAS, Power Plant Technology, Bismarck State College
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About Energy Compliance, Inc.

Energy Compliance, Inc. is an independent consulting and advisory firm focused exclusively on electric reliability, cybersecurity reliability, and regulatory compliance for organizations connected to the North American Bulk Electric System. Our work supports Generator Owners and Operators, Transmission Owners and Operators, Reliability Coordinators, Balancing Authorities, and Distribution Providers. We work across NERC Reliability Standards, FERC orders, RTO/ISO market participation rules, Regional Entity oversight, and state regulatory frameworks.

We do this work differently than larger consulting firms. Engagements are overseen by a senior practitioner with regulator-side experience. We do not staff for billable hours. We staff for outcomes. Our deliverables are written to be operationally executable and audit-defensible, not to manufacture activity. Where automation can replace manual work, we build the automation. Where senior judgment is required, the senior is in the room. The practice is organized around four areas: **NERC Compliance** (program support, interpretation, and audit preparation), **Senior Advisory** (direct engagement on complex reliability questions), **Industry Engagement** (standards development and working-group participation), and **Audit Defense** (Notice of Penalty response and settlement posture). Services include, but are not limited to: NERC reliability and compliance advisory support; reliability governance and program assessments; registration and applicability analysis; operational and engineering reliability alignment; compliance program design and improvement; audit and enforcement support (non-advocacy); mitigation planning and Self-Report development; training and executive briefings on reliability frameworks; and regulator-perspective program reviews.

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