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Energy Storage and Grid Reliability

BESS as a reliability resource class. Operational characteristics, compliance, and risk.

Battery energy storage does not fit cleanly into the reliability categories the Bulk Electric System was built around. It charges like load, discharges like generation, and does both through power electronics. This reference walks through what that means for balancing, voltage, adequacy, protection, visibility, planning and event analysis, and where the NERC standards now reach storage directly.

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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've spent more than thirty years on every side of the bulk electric system. I've operated control centers as a Reliability Coordinator, Transmission Operator, and Power System Operator. I've audited grid facilities and signed off on findings as a senior compliance auditor. I've worked enforcement matters from inside the regulator's process. For the last several years I've 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, but reliability is something a system either delivers or doesn't. They prepare for audits by building programs that survive real questions, not binders that look thick.

That's 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's been told that compliance and reliability are the

same thing and suspects they aren't. And for the new compliance hire who got handed a binder and told good luck.

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

Energy Compliance exists because, in my view, most of the consulting offered to registered entities today is structured for billable hours rather than outcomes. Every engagement is overseen by a senior practitioner. We don't bring five people to a meeting that needs one. We automate the work that should be automated. We apply senior judgment to the work that requires it. If that approach matches what you're 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's 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

Battery Energy Storage Systems do not fit cleanly into the reliability categories the Bulk Electric System was designed around. They are not generation in the traditional sense, because they consume energy when they charge. They are not load in the traditional sense, because they produce energy when they discharge. They do not provide passive system support the way transmission lines do. And they keep getting larger, faster and more consequential to operations. The reliability framework is adjusting, and as of October 2026 it has caught up in several places: NERC now defines storage as an Inverter-Based Resource, registers smaller IBR plants as Category 2 Generator Owners and Operators, and enforces IBR-specific ride-through, disturbance monitoring and event mitigation standards.

The chapters that follow take storage one reliability function at a time. The short version:

- A 100 MW battery isn't a 100 MW solar plant with a battery attached. The compliance scope is different. The operational behavior is different.
- Adequacy for storage is a two-variable problem: power rating and duration. In my view, models that treat storage like thermal over-credit it, and the next stress event is where that shows up.
- Protection schemes were calibrated to synchronous fault current. Storage faults look different, and protection-related standards already sit near the top of NERC's most frequently reported noncompliance.
- A storage asset the operator can't see in real time is a contingency the operator can't plan for.
- Storage is past the demonstration phase. The next reliability conversation isn't whether to integrate it. It's how to keep integration ahead of the standards that now apply to it, which Chapter 9 lays out.

1 Energy Storage as a Reliability Resource Class

1.1 Neither Generation, Load, nor Transmission

Battery Energy Storage Systems (BESS) bring a different kind of resource to the bulk electric system, one that does not line up with traditional reliability definitions. A BESS does not produce primary energy the way a thermal, hydro or wind plant does. It is not a consuming load like a pump or a heater. And it cannot support the transmission system passively the way lines, transformers and switches do, whose contribution does not depend on their own operating state.

Instead, a BESS is state dependent and works through a power electronic interface. Its reliability contribution depends heavily on system configuration, control strategy and operating conditions.

1.2 Two Operating Modes

From a reliability perspective, the main difference between storage and most other resources (pumped hydro being the closest exception) is that storage operates in two modes. A storage system can act as load at one moment and as generation the next. Batteries can cycle between charging and discharging several times in a single day, depending on what they are dispatched to do.

That alternating behavior complicates the classical methods used to determine a resource's availability and its ability to perform when called. In discharge mode, a BESS functions much like conventional generation. In charge mode, it behaves like load, but it can be charging, and therefore adding load, at exactly the moments when grid stability is a concern.

The traditional reliability tools were built for assets with stable characteristics. Generators were known by the physical limits of their machines. Loads were largely uncontrollable in aggregate, and demand response came later as the exception. Storage breaks those assumptions. It is highly controllable in power, injecting or absorbing real power very quickly, but it is limited in energy. Fast response does not guarantee energy capability, so reliability analysis has to account for both steady-state capability and time-limited capability.

1.3 Power Electronics Instead of Machines

The first distinguishing feature of a BESS is that it connects through power electronics rather than a synchronous machine. That changes its behavior with respect to inertia, short-circuit current and voltage control. Controls can be set to mimic some synchronous behavior, but the result depends on the control strategy chosen. It is not supplied natively by the electromagnetic

interaction between a machine's field and armature. The dynamic response observed during a disturbance therefore does not always match the nominal values on the equipment data sheet.

1.4 Aggregation, Flexibility and Use

Aggregation raises its own issues. Individual battery systems can be small compared with conventional generation, but large numbers of them under centralized control or responding to the same market signals can add up to a real reliability concern. The aggregation issues are visibility, control and correlation. Many similar storage resources connected in parallel react to the same grid event, and together they can move frequency or power flow significantly.

BESS flexibility is often presented as a reliability benefit. Flexibility alone does not deliver reliability. It has to be used in a way that fits the real-time condition of the system, the operating needs of utilities and grid operators, and the system's reliability performance goals. A storage resource dispatched mainly for economic value may have little energy left when an emergency arrives. Reliability assessments of BESS have to look closely at how the resource is scheduled, reserved and prioritized.

1.5 Adequacy Assumptions Start Here

Storage also raises planning, adequacy, deliverability and performance assumptions. Existing resource adequacy metrics were built for resources with predictable output profiles. Storage differs in two ways that matter:

- Many of the assumptions about its availability depend on how the resource was charged and cycled beforehand.
- It carries capacity and duration constraints, including limits on charge and discharge cycles and minimum and maximum state of charge.

How those constraints affect storage's ability to supply energy through extended stress, meaning multi-hour or multi-day events, is still being worked out. Chapter 4 takes this up in detail.

> **Chapter Summary**
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> Two operating modes, power electronic conversion, limited duration and high controllability make BESS its own resource category. Evaluate it as one.

> **From the Field**
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> A battery is a different resource class with different obligations, and the framework is still catching up. Apart from pumped hydro, storage is the only resource on the grid that takes in its own energy and gives it back minutes later. The reliability framework was not designed around that profile. Calling a BESS a "generator" is convenient. It is also wrong often enough to matter, because the classification drives which requirements apply and which ones an auditor will test.

2 System Balancing and Frequency Response Considerations

2.1 Fast Response

Maintaining system balance and frequency is a fundamental reliability function. It depends on matching supply and demand in real time across time frames from seconds to hours. Storage interacts with these functions differently from conventional resources because of how fast it responds and how long it can sustain that response.

A BESS can change real power output very quickly in response to frequency deviations or dispatch signals. Properly designed, configured and enabled, it can provide primary and secondary frequency response. Fast frequency response matters most in the seconds right after a disturbance, when frequency is least stable and most in need of arrest.

2.2 Sustainability and State of Charge

Frequency response capability has to be weighed against sustainability. A synchronous generator's ability to hold output depends on fuel supply and mechanical capacity. A battery's depends on state of charge and discharge duration. Storage can deliver strong response at the start of a disturbance and still be unable to hold it if frequency does not recover before the energy runs out. That matters most for large contingencies and prolonged system stress.

2.3 Charging Dynamics

Charging creates its own reliability question. A battery that is charging during a low-frequency event is adding load at the wrong moment, which can make the event worse unless its controls stop or reverse the charge. In a high-frequency event, charging helps by absorbing the surplus. Reliability planning for grid-scale storage has to consider both discharge behavior and charging behavior, including when charging happens and how much flexibility exists to suspend or adjust it when frequency is unstable.

2.4 Regulation, AGC and Cycling

Storage that participates in regulation service under automatic generation control can accumulate a high cycle count, and managing state of charge becomes a concern because it governs availability. The reliability question is not whether storage can provide regulation. It is whether a resource providing regulation still has the capability to respond to an unplanned event.

2.5 Settings, Not Physics

BESS frequency response is set by control settings and operator instructions, not by the inherent physics that governs a synchronous machine. Response can vary from one BESS to the next, which means it is a modeling assumption in reliability studies, not a given.

Many storage systems responding to the same frequency deviation within a short window can produce large changes in frequency. Well-coordinated response speeds recovery. Poorly coordinated or uniformly tuned controls can produce oscillations or other unwanted interactions.

Chapter Summary

Storage supports balancing and frequency control with a fast, controllable response that conventional plants cannot match. It can supply primary frequency response in the short term, but limited energy means its contribution needs dedicated analysis. Interconnection studies have to make explicit assumptions about storage dynamics, state of charge and coordination with other control functions.

From the Field

Balancing the system around storage is different from balancing it around thermal. Storage responds in milliseconds. Most operating practices were written for resources that respond in minutes. The fast response is not all upside. A storage resource that depletes mid-event becomes the new contingency the BA has to plan around. Frequency response from storage is real, measurable, and increasingly relied upon. It is also conditional on state of charge. That conditionality is what operating practice and the standards are still working through.

3 Voltage Support and Reactive Power Behavior

3.1 Reactive Capability Through the Inverter

Voltage control is a basic reliability function. It requires coordinated management of reactive power, voltage levels and network configuration under both normal and fault conditions. A BESS takes part in voltage control through its power electronics, which behave very differently from a synchronous machine.

A BESS typically connects through an inverter that can supply reactive current within a defined range. Properly configured and authorized, storage can help manage voltage. That gives engineers more options, especially in areas with little or no synchronous generation nearby.

3.2 Real Power Competes With Reactive Power

Reactive capability is bounded by inverter ratings, thermal limits and control priorities. Real power dispatch, charging or discharging, eats into the reactive reserve. Reliability analysis has to account for that trade-off, particularly after a contingency, when the system may need both functions at once.

3.3 Dynamic Behavior During Disturbances

Inverter-based resources respond to voltage disturbances very differently from synchronous machines. A synchronous machine follows known physical characteristics governed by its excitation system. An inverter-based storage resource follows its programmed control strategy: voltage ride-through, reactive current injection, or output reduction based on set points or protection. Those differences can change system-wide dynamics significantly.

Faults add more. Inverter-based resources typically contribute much less fault current than synchronous generation, and lower fault current can affect relay operation and fault detection. The impact grows as inverter-based resources, storage included, make up a larger share of connected capacity. Chapter 5 covers protection.

3.4 Local Support, Visible Control

Voltage support from storage is largely local. Reactive power effects weaken with electrical distance, so a storage unit mainly affects voltage near its point of interconnection. That has to be considered together with how storage capability is coordinated and how the transmission network is planned as the area's resource mix changes.

Operational visibility and control are critical to whether storage voltage support actually helps. Operators need to understand how storage reactive output will behave across operating

scenarios. Under stressed conditions, not knowing a unit's control mode or state of charge makes voltage management harder.

Chapter Summary

Storage supports voltage through inverter-based reactive capability that behaves very differently from a synchronous machine. Its contribution is limited by inverter ratings, operating conditions and settings, and it is highly local and programmable. Voltage control studies have to account for those characteristics. Treat storage voltage support as a complement to other voltage control resources, not a replacement for them.

From the Field

A storage resource provides voltage support through power electronics, not through a machine's excitation system. The two are not equivalent, and the protection scheme has to know the difference. Reactive support from storage is dispatchable. That sounds like an advantage. It's also a control gap if the dispatch logic isn't tied to the operator's voltage strategy. Voltage performance from storage looks fine in steady state. The reliability question is what happens during the disturbance, when the controls are doing the work the exciter used to do.

4 Resource Adequacy and Duration Limitations

4.1 Power Rating Is Only Half the Answer

Resource adequacy asks whether existing and planned resources can serve load across a range of scenarios: peak load, contingencies and extended stress. Storage adequacy is different because a BESS is not defined by its power rating alone. It has finite energy and limited charge and discharge capability.

Conventional generation is typically evaluated on installed capacity and forced outage rates. Storage has to be evaluated on both instantaneous capability and sustained performance. A storage resource sized to meet a short peak may add little in a longer event once its energy is gone.

4.2 State of Charge as an Adequacy Variable

State of charge is a key variable in adequacy assessment. Whether a BESS is available when needed depends on earlier operating and scheduling decisions, market outcomes and charging opportunities. An unknown initial state of charge adds uncertainty about availability during unusual conditions or extended outages.

4.3 Duration Against Event Length

Duration matters most during extended high-risk periods lasting hours or days: extreme weather, fuel supply shortfalls, transmission constraints. Storage can help early in such an event, but once its duration is spent it may not replace the capacity that conventional or long-duration resources provide. Adequacy studies have to compare storage duration directly with the length of the events that drive risk.

4.4 Aggregation Eases Duration Constraints but Not the Energy Limit

A portfolio of storage resources can be sequenced to cover a longer window than any single unit, which gives some flexibility against duration limits. It does not change the underlying energy constraint. How much longer the portfolio can serve depends on system conditions, charging availability and how well the resources are coordinated. Any analysis that relies on aggregated storage needs specific, validated assumptions.

4.5 Modeling Storage in Adequacy Studies

Modeling storage in adequacy studies is still evolving. Historical loss-of-load and adequacy models assumed resources with relatively stable output. Storage requires additional variables to represent charge and discharge performance, cycle life and technology-specific operating limits. The modeling approach chosen can change the adequacy result materially.

Accreditation methods already differ by market. PJM accredits storage through Effective Load Carrying Capability (ELCC) class ratings that depend on duration; its preliminary ratings for the 2027/2028 delivery year put 4-hour storage at 52 percent and 10-hour storage at 74 percent, with the 4-hour rating declining in later years. In MISO, FERC accepted a direct loss of load (DLOL) accreditation method in October 2024 that MISO will apply to all Capacity Resources other than External Resources, Electric Storage Resources included, beginning with the 2028/2029 Planning Year.

4.6 Conditional Contribution

Storage can serve as a capacity resource and contribute to adequacy, but its contribution is always conditional. Short-term and long-term reliability evaluations are both needed, because storage plays different roles and shows different characteristics across those horizons.

Chapter Summary

Storage contributes short-duration capacity, limited by finite energy and by how much charge it holds when the event starts. Unlike conventional generation, its contribution depends on how it was used beforehand and on how long the event lasts. Adequacy assessments must model those effects to value storage correctly.

From the Field

A storage resource is a power rating times a duration. Either side of that product alone tells you nothing useful for adequacy planning. ELCC for storage is not a fixed number. It's a function of the portfolio. The same battery accredits differently in PJM than it will under MISO's direct loss of load method, and that's not a calculation error.

5 Protection Systems and Fault Response Implications

5.1 Protection Built on Synchronous Fault Current

Protection systems detect abnormal conditions and isolate faults, both to keep the system reliable and to keep individual components from being damaged. They are designed around known electrical behavior during faults, especially the magnitude and direction of fault current. Storage changes those assumptions. Its power electronics and switchgear can be sources of failure, and the fault current it contributes is small.

A synchronous generator delivers fault current whose magnitude and waveform follow from its design and size. An inverter-based BESS delivers controlled, limited fault current determined by its design, control strategy and protection settings, not by electromagnetic characteristics. Fault current levels and signatures in systems with high storage penetration will differ from what protection engineers are used to.

5.2 Where Legacy Schemes Struggle

Low fault current can cause problems for protection functions that depend on current magnitude or directional elements. Many newer protection functions account for inverter-based resources. Legacy schemes were not designed for such low fault current. The issue grows as storage replaces or supplements synchronous sources.

5.3 BESS Behavior During Faults

Storage fault behavior includes ride-through and protection requirements, and the way inverter controls respond to low voltage and protection thresholds: reducing output current, injecting reactive current, or ceasing output. Those choices affect post-fault voltage recovery and stability. A complete reliability analysis of storage covers how the system is expected to behave both during and after a fault.

Ride-through is no longer only a design preference. NERC PRC-029-2, effective October 1, 2026, sets frequency and voltage ride-through requirements for Generator Owners of BES Inverter-Based Resources and Category 2 IBRs, and its voltage ride-through table that covers solar, BESS and hybrid solar-plus-storage facilities applies directly to storage. The obligations phase in. The design-based parts of R1 to R3 for non-BES (Category 2) IBRs start on the later of January 1, 2027 or the PRC-029-1 effective date, and the performance-based parts start only once the entity has the PRC-028-1 disturbance monitoring capability for that IBR. PRC-024-4, effective the same date, now covers synchronous generators, Type 1 and Type 2 wind and synchronous condensers, so storage ride-through is tested against PRC-029-2, not PRC-024.

5.4 Coordination Between Plant and System Protection

Storage protection and system protection have to be coordinated. Poor timing between inverter protection functions and transmission or distribution relays can cause unwanted trips or delayed fault clearing. This reference does not address protection design or settings directly, but the reliability consequences of coordination cannot be ignored.

Many inverter-based resources reacting the same way to a fault can affect the system in ways no single-facility study would show. One example is the voltage effect of many storage resources reducing output simultaneously, which shifts power flows during fault recovery.

Chapter Summary

Storage can limit fault current sharply, depending on inverter performance. That differs substantially from synchronous generation and can affect fault detection, relay coordination and post-fault recovery. Those effects belong in reliability analysis as more systems add storage.

From the Field

Protection schemes were designed around the predictable behavior of synchronous fault current. Storage faults look different, and "different" is what causes Misoperations. A protection setting that worked for the synchronous era can underperform on a storage feeder. PRC-005, PRC-019, PRC-024 and PRC-025 all made NERC's list of the ten most frequently reported O&P noncompliance areas for 2025. The report does not break these out by resource type, and PRC-024-4 has since moved IBR ride-through to PRC-029-2, but the maintenance and coordination discipline behind those findings applies to a storage plant's protection too. If your protection engineer has not specifically studied storage fault behavior, your protection system is not yet properly coordinated for it. That's not a criticism of the engineer. It's the state of the practice.

6 Operational Visibility, Control, and Coordination

6.1 What the Operator Needs to See

Operational visibility and control are fundamental to reliable bulk power system operation. They supply the information needed for planning and operations in normal and disturbed conditions. Storage creates new visibility and control issues because its state, availability and ability to respond to commands can change frequently with its control strategy and state of charge.

Knowing whether a BESS is online or offline is not enough. From a reliability standpoint, operators need state of charge, charge or discharge mode, active and reactive power capability, and control mode. Without that information, operators can misjudge storage availability and capability during peak demand.

6.2 Who Controls the Resource

Storage control arrangements vary widely. Some resources are dispatched directly by the grid operator. Others respond to market signals or automated and aggregated controls. The degree of direct operator control affects whether the resource can be relied on for reliability services after a system event. A resource that is not directly controlled will respond to the regime it was designed for, price signals or automated logic, and not necessarily to reliability needs as they arise during a disturbance.

Coordination has to scale as storage grows and aggregates to compete in energy markets. Aggregation can hide individual unit behavior and produce unexpected local effects. The control and response of an aggregated storage fleet matter because storage can move the system very quickly and in a highly coordinated way.

6.3 State of Charge Across Time Frames

State of charge management is a coordination problem across time frames. Decisions made hours ahead rest on forecast load and assumptions about when storage will charge and discharge. If storage has been fully cycled before the tightest hours, it may have little left to support real-time operations when a reliability event hits. The reliability framework has to address the link between normal-condition scheduling and emergency-condition availability.

6.4 Communications and Data Quality

Communications and data quality also shape storage's reliability contribution. Delayed, inaccurate or lost telemetry undermines operator confidence and complicates decisions, especially during fast-moving events. This will matter more as storage takes a larger role in real-time operations.

The reliability value of a highly capable resource is limited if the operator does not understand its state at the moment it is needed.

Chapter Summary

Reliable storage integration requires visibility and control. State of charge, control mode, level of aggregation and communications performance all determine whether storage can be relied on during grid events. Reliability studies need to account for the coordinating functions of the grid, not only the inherent capability of the resource.

From the Field

The control center sees what SCADA tells it. If state of charge isn't telemetered, the operator is dispatching a resource whose remaining capability is unknown. Visibility into storage is not a nice-to-have. It is the precondition for coordinated reliability operation. Without it, the resource is a black box dispatched on faith.

7 Planning Assumptions and System Modeling Considerations

7.1 Charge and Discharge Assumptions

Planning studies drive decisions on transmission development, resource adequacy and contingency performance. Storage is hard to represent in planning models because its contribution is conditional and time dependent, and because its operational controls are often not captured in existing models and frameworks.

A key modeling decision is how to represent charge and discharge. Traditional generation can be modeled without reference to its previous operating state. Storage cannot. The study has to assume when the battery charges, when it discharges and how it moves between states. Those assumptions can change the result materially, particularly when the battery is stressed for an extended period or the study covers many contingencies.

7.2 Duration Modeling

Storage is usually described by a power rating for charge or discharge plus a discharge duration. The duration assumed has a material effect on reliability results, especially in adequacy and contingency studies. Assume a duration longer than the resource can actually deliver and the study overstates storage's ability to supply long events. Assume a conservative duration and the study can understate its value at peak.

7.3 Storage and Transmission Constraints

Storage interacts with transmission constraints differently from existing generation, because its effect on flows reverses with its mode. Discharging storage can relieve congestion. Charging can add congestion on the same path, sometimes by as much as discharge relieved. Planning models that miss that reversal can misjudge system conditions.

7.4 Inverter Models

Inverter behavior has to be modeled too. The stability and short-circuit models the industry has long relied on were built for synchronous machines. They do not translate directly to power electronic resources, which have different control responses, different fault behavior and their own interactions with other inverter-based resources, especially where storage penetration is high.

Model validation is now a compliance obligation, not just good practice. MOD-026-2, effective April 1, 2026, requires verification and validation of dynamic models for BES Inverter-Based Resources and Category 2 IBRs, including electromagnetic transient (EMT) models for IBRs (for legacy facilities, only where the Transmission Planner identifies them).

7.5 Uncertainty and Transparency

Even with better forecasting, storage planning carries many uncertain parameters. Operating practices, market design and control strategies may change several times over the life of a storage project. Planners have to balance the level of detail needed to assess storage's future role, the number of uncertainties formally considered, and the judgment applied in the analysis. Every assumption should be stated as an assumption, and every conclusion should be presented with its basis and limits.

Chapter Summary

Storage is hard to plan around because its operation is conditional, it is limited in duration and charge time, and it can reverse power flow. Assumptions about charging, duration, inverter dynamics and uncertainty must be explicit so that every study that includes storage rests on information whose validity can be established.

From the Field

Planning models that don't represent storage controls accurately will produce planning results that don't match operations. The mismatch shows up the day the model assumed something the controls didn't actually do. Generic storage models are improving, but generic isn't accurate. Project-specific models matter for reliability studies, especially as storage scales. The hardest planning question for storage isn't capability. It's correlation: when the system needs storage most, will all the storage in the portfolio be available? The model has to ask that question.

8 Event Analysis and Disturbance Performance

8.1 Response Set by Controls

Event analysis is how the industry learns what happened on the system, how disturbances develop and how resources performed. Storage complicates event analysis because it does not behave like synchronous generation or static load.

A BESS's dynamic response to a disturbance is set by its control strategy, protection settings and operating mode at the time. A conventional plant's response follows physical laws. A storage system can respond instantly, limit its response, or behave unexpectedly when its set points change. Storage can shape how an event unfolds even when it did not cause the initial disturbance.

8.2 Pre-Event State

State of charge at the time of the event is a key input to analyzing storage performance. A fully charged unit, a partially charged unit and an empty unit will behave differently. Analysts need the battery's pre-event operating condition to judge whether its response was what its design and known performance characteristics predict.

8.3 Analyzing Inverter Behavior

Many disturbance performance criteria were written with synchronous machines in mind. With more inverter-based resources on the system, event analysis has to allow for different ride-through behavior, different reactive current response and different recovery characteristics. Assuming the wrong inverter behavior leads to wrong conclusions about the event and misreads the data.

Several storage resources with similar controls can respond to the same disturbance simultaneously, with a combined effect far larger than any single unit's. In that case the analysis has to be done at the system level.

8.4 Data Quality

Data volume and resolution heavily influence what can be learned about storage behavior. Fast inverter dynamics and control actions are hard to capture with conventional monitoring. Without insight into inverter and aggregated control behavior, a detailed understanding of the event is out of reach.

8.5 The Standards That Now Govern IBR Event Data

The standards have moved on this point. PRC-028-1, effective April 1, 2025, sets disturbance monitoring and reporting requirements for Inverter-Based Resources. PRC-030-1, effective October 1, 2026, requires Generator Owners of applicable IBRs to identify unexpected changes in Real Power output of at least 20 MW and at least 10 percent of gross nameplate within a four-second period, analyze them and mitigate them. And EOP-004-5, effective October 1, 2027, adds an IBR loss event type that the Balancing Authority reports when IBR output loss after a Disturbance crosses the Interconnection's threshold.

Chapter Summary

Storage shapes system events dynamically, engaging quickly and in ways set by its operating mode and controls. Event analysis that accounts for aggregation and data limitations is needed to understand storage behavior during major disturbances and its effect on the power system.

From the Field

A storage resource that trips during a disturbance leaves the system without the contingency reserve it was counted on for. That's not a routine forced outage. It's a reliability event. Disturbance analysis on storage requires data the asset owner has and the operator usually doesn't. PRC-028-1 now requires the owner to record that data, PRC-030-1 requires the owner to analyze unexpected output changes, and EOP-004-5 has the BA report IBR loss from its own telemetry. If the post-event analysis can't reconstruct what the storage did and why, the lesson is incomplete and the next event will be the same.

9 Reliability Boundaries and Evolving Frameworks

9.1 Where Storage Tests the Categories

Reliability frameworks set the boundaries within which planners, operators and regulators work. They are meant to be durable, technology neutral and adaptable. Storage tests those qualities for two reasons. It does not fit neatly into generation, load or transmission. And its performance in each mode depends more on the operating scenario than on the inherent physical capability of the resource.

One boundary question is how to judge storage across several reliability functions at once. A storage resource can support one function while working against another at the same moment, depending on its mode and the system state. That is a multidimensional resource, and simple categories do not handle it well.

The growing attention to system strength, stability and resilience under high inverter-based penetration, storage included, sharpens the point. This reference does not propose new reliability metrics. It does argue that the conventional understanding of inertia, fault response and dynamic control will change with the resource mix, and storage sits at the center of that change.

9.2 Capability Versus Obligation

Another boundary runs between capability and obligation. A storage resource may be able to provide a reliability service without any assurance that it will provide it at the right time. That depends on market rules, operating rules and contracts. Reliability frameworks need to keep the theoretically possible separate from what the rules require.

9.3 Jurisdictional and Functional Boundaries

Storage can connect to transmission or distribution, participate in wholesale markets, and be controlled by entities outside a utility's traditional operating hierarchy. That raises visibility, coordination and accountability issues that reach beyond the individual asset into reliability governance as a whole.

As reliability modeling grows more complex, it needs clearer and more consistent expression. Changes to models, operating procedures or evaluation methods should be justified, with assumptions identified and supported by analysis of actual system behavior.

9.4 The Standards That Now Reach Storage

When this reference was first written, much of the IBR framework was still in development. As of October 2026, most of the pieces that touch storage are defined, approved or in force. FERC

Order No. 901 (October 2023) directed NERC to develop IBR Reliability Standards in three filing waves due November 4, 2024, November 4, 2025 and November 4, 2026, and the results are now arriving.

Item	What it does for storage	Status (October 2026)
Inverter-Based Resource (NERC Glossary)	Defines IBR to include battery energy storage systems	Effective April 1, 2025
Category 2 GO and GOP	Registers owners and operators of non-BES IBRs of 20 MVA or more aggregate, connected at 60 kV or higher	Definitions effective January 1, 2026; NERC registry effective May 15, 2026
PRC-028-1	Disturbance monitoring and reporting for IBRs	Effective April 1, 2025
MOD-026-2	Dynamic model verification and validation, including IBRs and EMT models	Effective April 1, 2026
PRC-029-2	Frequency and voltage ride-through for IBRs; replaces PRC-029-1	Effective October 1, 2026
PRC-024-4	Protection settings; now limited to synchronous units, Type 1 and 2 wind, synchronous condensers	Effective October 1, 2026
PRC-030-1	Identify, analyze and mitigate unexpected IBR output changes	Effective October 1, 2026
EOP-004-5	Adds an IBR loss event type reported by the Balancing Authority	Effective October 1, 2027

Two practical consequences follow. First, a storage plant below the BES thresholds is no longer automatically outside NERC's reach: at 20 MVA aggregate and 60 kV it meets the Category 2 criteria. Second, many compliance dates for Category 2 entities are phased, so the effective date of a standard is not always the date an obligation starts for a given facility. Check the NERC compliance dates for Category 2 GOs and GOPs and each implementation plan before you plan the program.

9.5 Applying Reliability, Not Redefining It

Storage is one of the areas where the link between reliability theory and practice and the real behavior of the system needs close examination. Storage does not redefine reliability. It tests how current reliability concepts are applied. The task is to understand the boundaries and assumptions behind reliability metrics, how they are interpreted, and how storage can be deployed to strengthen reliability rather than obscure it.

Chapter Summary

Storage acts as both generation and load, changes behavior with operating mode, and depends heavily on the surrounding system, all of which strain conventional reliability concepts. Those concepts still apply, but they need care: separating required capability from discretionary and optional capability, and understanding multidimensional resources. As the framework absorbs more storage, consistency and clarity matter, and the IBR standards now in force make many of those expectations explicit.

From the Field

Storage doesn't fit cleanly as generation, load, or transmission. The framework's response has been to treat it as a hybrid, which works until the hybrid framing produces a gap. The reliability framework is technology-neutral by design. Storage is a stress test of how neutral the design actually is. So far the neutrality is holding, but the seams are showing. Storage is the leading edge of how the framework will accommodate every emerging asset class. The lessons from storage will travel.

10 Reliability Risk, Resilience, and System Dependency

10.1 Dependencies Behind the Asset

Reliability risk assessment is about more than current conditions. It asks how the bulk electric system will perform across a wide range of stressed, uncertain or emergency conditions. Storage affects risk and resilience mainly through dependency, coordination and duration, rather than through the capability of an individual resource to meet a performance standard.

Storage cannot always deliver energy when it is most needed, and it depends on several things outside itself:

- Charging energy.
- Transmission access to deliver its output.
- Communications and information technology to carry control signals for both charging and discharging.
- Other external conditions needed for stable, efficient operation.

A particular concern is that storage and its supporting infrastructure can be rendered useless as emergency reserve during extended outages caused by catastrophic weather or widespread transmission failures. Assessing whether storage will perform when needed means assessing the readiness of everything it depends on, not just the battery.

10.2 Short-Term Versus Long-Term Resilience

Storage provides short-term resilience during transient disruptions, offering near-instant support that limits the impact. Its contribution to long-term resilience is limited by its duration. Once a disruption outlasts the battery, long-term resilience depends on resources with sustained capability, fuel diversity and the restoration sequence. Storage may affect only the first phase of restoration.

10.3 Cyber and Communication Dependencies

Storage relies on digital controls, communication links and automation for availability, fast response and flexibility. Those features bring real benefits, including real-time monitoring. Lose the data or the systems, though, and the operator loses visibility and control during a disturbance, which can reduce or eliminate the asset's value at the moment it matters. That belongs in any reliability risk evaluation.

10.4 Correlated Performance

Resilience depends partly on diversity, the system's ability to absorb the variability or unavailability of individual resources. Storage fleets built on similar hardware, management

systems or operating practices can perform in a correlated way. Standardization brings lower acquisition cost, simpler administration, better integration and better support. It also raises exposure to common-mode failures, including malware, and to the same control action firing across many sites in response to different disturbances.

10.5 Markets and State of Charge

Market interaction is part of storage's dependency profile. Economic dispatch during high-demand periods drives state of charge. When market signals and reliability needs diverge, storage may be depleted exactly when it is needed most. That divergence has to be managed deliberately, so the system is not left leaning on other resources at the worst moment.

Chapter Summary

Storage affects reliability risk and resilience through its needs for charging energy, communications and control systems, and through correlated behavior. It can strengthen short-term reliability, but its effect in extended outages is limited by duration and supporting infrastructure. Risk assessments need to account for storage dependencies.

From the Field

Storage shifts the reliability risk profile. It removes some risks and creates new ones, and the entity that adds storage without re-running its risk assessment is operating with stale assumptions. Resilience from storage is real. So is dependency. The grid that leans hardest on storage is the grid most exposed to a coordinated storage failure. Asset owner risk and system risk are not the same risk. The asset owner sees revenue exposure. The system sees cascading exposure. Both views matter.

11 Integration Trends and Reliability Implications

11.1 Beyond the Individual Project

Storage continues to grow on the bulk electric system in size, location and application. Its reliability implications reach beyond any single project and reflect deeper changes in the makeup, operation and planning of transmission and distribution. Understanding these trends puts storage's reliability significance in context.

11.2 Co-Location and Hybrids

Storage is increasingly paired with other resources, especially inverter-based generation. Co-located resources may not be represented consistently to planners and operators, and the effect of each element on overall plant behavior may be unclear. Reliability depends on understanding how these combined resources perform in normal and disturbed conditions and how they can be called on to meet system needs.

11.3 Storage at Every Voltage Level

Storage is appearing at every voltage level: transmission-connected, distribution-connected and behind the meter. This reference focuses on high-voltage reliability, but distribution-connected storage can affect transmission reliability through aggregate effects. Reliability studies will need to account for distributed storage that traditional transmission analysis tools do not readily capture.

11.4 Market Participation

Storage now provides energy, capacity and ancillary services, often several at once. Serving multiple markets brings flexibility and revenue. It also adds uncertainty about which reliability services a resource is committed to at any given moment and how simultaneous commitments affect its availability in an unexpected event.

11.5 Geographic Concentration

Storage may cluster in particular regions for economic, transmission or regulatory reasons. Concentration cuts both ways. Coordinated response from concentrated storage can help local reliability. Correlated derates or outages across that same cluster can create local vulnerability.

11.6 Experience Is Still Accumulating

Storage operating practice is evolving as experience grows. Planning and operating assumptions shift as more is learned about storage reliability and performance. Changed

practices can make past performance a poor guide to the future, so historical performance data should be used with care and adjusted for changes in how storage is integrated.

Chapter Summary

Integration trends, including co-location, aggregation, market participation and geographic concentration, carry reliability implications well beyond the design of any single component. They change visibility, coordination and overall system behavior. Reliability assessment has to account for them.

12 Summary of Reliability Considerations for Battery Energy Storage Systems

12.1 A Material Resource

Storage is now a material resource on the Bulk Electric System and interacts with nearly every reliability function. Growing reliance on storage reflects changes in generation, in operations and in wholesale market participation. Storage belongs in reliability analysis on a system-wide basis, held to the same basic reliability principles as every other resource.

This reference has examined storage as a resource class whose behavior differs significantly from other resources. Its defining characteristics are two operating modes, limited energy duration, power electronic conversion and a high degree of automated control. Those characteristics shape how storage interacts with balancing, frequency response, voltage control, protection and resource adequacy.

12.2 Conditionality

One theme runs through every chapter: conditionality. The reliability contribution of storage varies with state of charge, operating mode, the level and type of control, whether units operate alone or in fleets, and the instructions grid operators and utilities give them. Having capacity does not guarantee that the capacity will be available, or used well, when the grid is under stress.

Assumptions about how storage is charged and controlled in normal conditions, dispatched during transients and prioritized during major disturbances drive the validity of planning studies, operating assumptions and the conclusions drawn from grid events.

12.3 Risk and Resilience

Storage adds reliability risk and new resilience considerations. Sustained operation requires charging energy, reliable communications and supporting hardware. Storage can respond quickly and flexibly to short transient events. Its support through long-duration stress and outages is limited by its duration and its dependencies.

12.4 Discipline, Not New Theory

Integrating storage does not require a wholesale rewrite of reliability standards and practices. It requires disciplined application of those standards within well-defined boundaries, assumptions and interpretations, and the IBR standards now in force supply much of that discipline. Storage will test the flexibility of reliability categories, but the fundamental reliability goals stay the same.

Storage is not a drop-in substitute for traditional resources. Nor is it an exotic technology that needs a new reliability theory. Applying it successfully depends on understanding how its particular properties interact with established reliability concepts and system states.

Chapter Summary

Storage affects Bulk Electric System reliability in planning, in real-time operations and during disturbances. Its impact is conditional, state dependent, and shaped by how it is integrated and what it depends on. Traditional reliability analyses and metrics still apply, with care and with explicit assumptions and interpretations.

Glossary

Term	Meaning in this paper
Battery Energy Storage System (BESS)	A facility that stores energy in electrochemical batteries and supplies real and reactive power through power electronics. Limited by duration and charging capability; state dependent in operation.
Bulk Electric System (BES)	NERC Glossary: unless modified by the definition's inclusions and exclusions, all Transmission Elements operated at 100 kV or higher and Real Power and Reactive Power resources connected at 100 kV or higher. It does not include facilities used in the local distribution of electric energy.
Category 2 Generator Owner / Generator Operator	NERC Glossary: the entity that owns and maintains, or operates, 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.
Effective Load Carrying Capability (ELCC)	A probabilistic measure of a resource class's contribution to resource adequacy; PJM's storage accreditation method.
Frequency Response	NERC Glossary: (Equipment) the ability of a system or elements of the system to react or respond to a change in system frequency. (System) the sum of the change in demand plus the change in generation, divided by the change in frequency, expressed in MW/0.1 Hz.
Inverter-Based Resource (IBR)	NERC Glossary: a plant or facility of individual devices capable of exporting 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. Examples include solar PV, Type 3 and Type 4 wind, BESS and fuel cells.
Misoperation	NERC Glossary: the failure of a Composite Protection System to operate as intended for protection purposes.
Reactive Power	NERC Glossary: the portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. It directly influences electric system voltage and is usually expressed in kvar or Mvar.
Resource Adequacy	The ability of the system's resources to meet projected demand over a planning horizon, allowing for forecast outages.
State of Charge (SOC)	The energy stored in a BESS at a given moment, relative to its fully charged capacity.
Voltage Support	The reactive power and voltage regulating capability provided to keep transmission voltage within acceptable limits in normal and abnormal conditions.

How Energy Compliance Can Help

The engineering questions in Chapters 1 through 8 become compliance questions the moment an auditor asks for the evidence. That is where we work.

Registration and Applicability Analysis

We determine, facility by facility, whether your storage and hybrid plants fall under the BES definition, the Category 2 criteria, or neither, and which standards and dates follow.

Operational and Engineering Reliability Alignment

We line up what your protection settings, ride-through capability, telemetry and models actually do with what PRC-029-2, PRC-030-1, PRC-028-1 and MOD-026-2 require.

Compliance Program Design and Audit Defense

We build the program and evidence for a storage fleet's standards, write RSAW narratives tied to it, and stand with you through audits and data requests.

WattOps Compliance

WattOps Compliance is EC's NERC compliance evidence platform, at wattopscompliance.com, where a storage owner taking on the new IBR standards keeps the evidence for each requirement. We will run one standard at one facility through WattOps at no cost (CIP standards excluded).

RenewOps

State of charge, control mode, availability and alarm data are the operational facts behind every storage compliance position. RenewOps is EC's renewable operations monitoring and analytics platform, with a Data Center module.

Also From EC

- NERC compliance: program support, interpretation, and audit preparation
- Senior advisory: direct engagement on complex reliability questions
- Industry engagement: standards development and working-group participation
- Audit defense: Notice of Penalty response and settlement posture

If you own or operate storage and are not sure which of the standards in Chapter 9 apply to you yet, start there. Call or write, and we will work through it with you.

Website: energycomplianceinc.com · Email: rsmith@complianceforenergy.com

Phone: 763.438.4427

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.

Education:

- 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
- AAS, Electrical Transmission System Technology, Bismarck State College

Certifications: NERC Lead Auditor training; previously NERC-certified at the Reliability Coordinator level; 1st Class A Boiler Engineer License, Minnesota.

About Energy Compliance, Inc.

Energy Compliance, Inc. is an independent consulting and advisory firm based in Bloomington, Minnesota, focused exclusively on electric reliability, cybersecurity reliability, and regulatory compliance for organizations connected to the North American Bulk Electric System.

We support Generator Owners and Operators, Transmission Owners and Operators, Reliability Coordinators, Balancing Authorities, and Distribution Providers across NERC Reliability Standards, FERC orders, RTO/ISO rules, Regional Entity oversight, and state regulatory frameworks.

We do this work differently than larger consulting firms. A senior practitioner with regulator-side experience oversees every engagement, and we staff for outcomes, not billable hours. Deliverables are operationally executable and audit-defensible. Where automation can replace manual work, we build it. Where senior judgment is required, the senior is in the room. Learn more at energycomplianceinc.com.

Each engagement is scoped to the entity's role, function, and bulk system impact. Our 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
- Regulator-perspective program reviews

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