UTILITY-SCALE RENEWABLE ENERGY ENGINEERING

Solar, Wind & Storage

engineered to clear the grid, not just the queue

Engineering support for utility-scale solar, wind and battery storage — from POI studies and IEEE 2800 compliance through grid integration, plant electrical design and NERC reliability support.

The hard part of a renewable project stopped being the equipment. It is now the model, the ride-through performance and the compliance record behind them.

Keentel Engineering supports utility-scale solar, wind, storage and hybrid projects across the full electrical scope — interconnection studies and EMT models, collector and POI substation design, plant electrical and protection design, IEEE 2800 capability demonstration, and the NERC registration and compliance obligations that now attach to inverter-based resources from the day they register. One team from the queue position to the compliance handover.

30+	4	8	4
YEARS ACROSS TRANSMISSION, GENERATION & STORAGE	TECHNOLOGIES — SOLAR, WIND, BESS AND HYBRID	ISO / RTO MARKETS PLUS THE NON-RTO FOOTPRINT	U.S. OFFICES — TAMPA, AUSTIN, SACRAMENTO, BALTIMORE

TECHNOLOGIES | **Utility-scale solar PV** | **Onshore & offshore wind** | **Standalone BESS** | **Solar + storage hybrid** | **Wind + storage** | **Synchronous condensers**

WHERE WE PLUG INTO THE PROJECT

01
Site screen
POI selection, capacity and grid strength screening before a deposit is at risk.

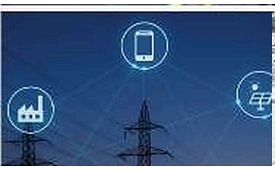
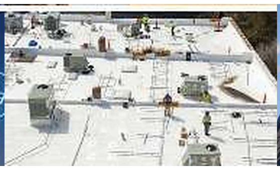
02
Queue entry
Models, data forms and readiness package into the governing cluster process.

03
Studies & EMT
Interconnection studies, EMT model build and usability testing to the ISO checklist.

04
Plant design
Collection, substation, protection and plant electrical through IFC.

05
Compliance
IEEE 2800 capability, NERC registration and standard-by-standard applicability.

06
Energization
Commissioning, model validation, as-built handover and ongoing support.



START A SCOPE ›› Send your POI, MW, technology, OEM and the queue you are in — we return a scoped fee and schedule, and can start from a partial data set.

NSPE | D·U·N·S REGISTERED | IEEE SENIOR MEMBER | BBB ACCREDITED A+

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THE LANDSCAPE, AS OF AUGUST 2026

What Changed for IBR Projects

Four shifts have moved the risk on a renewable project from construction into engineering and compliance.

1 IEEE 2800 moved from paper to practice

- **The standard itself is voluntary.** IEEE 2800-2022 sets uniform minimum technical requirements for inverter-based resources at transmission and sub-transmission — but it binds only where the interconnection authority adopts it.
- **Adoption is now real.** More than twenty utilities and system operators have adopted it in some form, and adoption is spreading through interconnection requirements rather than through a federal mandate.
- **PJM is a live example.** A first phase of IEEE 2800 adoption — definitions, voltage and frequency ride-through, protection settings and primary frequency response — moved through the PJM stakeholder process in 2026, with a mid-2027 effective date and a new interconnection-requirements attachment to the governing manual.
- **And there is now a way to prove it. IEEE 2800.2-2026**, published in mid-2026, gives the plant-level test and verification procedures — type test, design evaluation, commissioning and post-commissioning validation. Capability claims can now be assessed against a defined method.

2 NERC obligations now attach earlier and reach further

- **Registration reached down to non-BES resources.** A second registration category captures inverter-based resources at 20 MVA or more in aggregate behind a single point of interconnection at 60 kV or above, with the registration date reached in **May 2026**.
- **Ride-through became a standard, not a study assumption.** Performance-based frequency and voltage ride-through obligations for inverter-based resources reach enforcement on **1 October 2026**, with non-BES resources phasing in from January 2027.
- **Events now trigger a formal process.** An unexpected real-power change above the defined threshold starts a fixed analysis and corrective-action-plan clock.
- **Monitoring is a design item.** Disturbance recording, time synchronization and retention build out on a schedule ending in 2030 — and are far cheaper to install than to retrofit.

3 Model quality became the schedule risk

- **EMT models gate the queue.** Across the major markets an EMT model is now required at a defined decision point, screened by system strength, or required outright for every inverter-based request — with standardized usability test sets behind it.
- **A rejected model costs a cycle.** Not a revision — a cycle, because the study phase moves on without you.
- **Verification does not end at commercial operation.** As-built tuned models, periodic revalidation and resubmission after equipment or settings changes are standing obligations.

4 The commercial clock tightened — unevenly

- **Solar and wind face a hard federal deadline** under the 2025 tax legislation, tied to beginning construction by mid-2026 or being placed in service by the end of 2027.
- **Storage does not face the same cliff.** Standalone and co-located storage keeps a materially longer runway, which is a large part of why storage and hybrid configurations now dominate new interconnection requests.
- **Foreign-entity sourcing rules now have cost thresholds** that projects beginning construction from 2026 must meet, with different thresholds for generation and for storage.
- **Beginning-of-construction guidance is unsettled**, having been revised and then vacated in court during 2025–2026.

Why an engineering firm raises the tax clock at all

Because it sets the engineering schedule. Physical work tests, equipment procurement and placed-in-service dates all depend on design packages being finished and equipment being specified. We are not tax advisors and nothing here is tax advice — but we plan the engineering around the dates your tax counsel gives us.

DATES WORTH MARKING

May 2026 — IBR registration date reached for the non-BES category	**1 Oct 2026** — IBR ride-through and event mitigation enforcement begins	**Jan 2027** — non-BES ride-through design requirements phase in	**2027** — first phase of IEEE 2800 adoption takes effect in PJM
Through 2028 — modeling data standard versions phase in	**1 Jan 2030** — full disturbance monitoring coverage required	**Ongoing** — interconnection requirement adoption spreading market by market	**Project-specific** — the tax and placed-in-service dates your counsel confirms

AS OF August 2026. Interconnection requirements, reliability standards, product codes and federal policy in this area all change continuously. Every engagement starts with a check of the governing requirement, code edition and standard revision actually in force for the project.

SCOPE

What We Deliver on a Renewable Project

The electrical scope end to end — grid side, plant side and the compliance record that ties them together.

Grid Side

- **POI screening & queue strategy.** Candidate interconnection points screened for headroom, short-circuit strength and constraint exposure before a deposit is committed.
- **Interconnection studies.** Power flow, contingency, transient and voltage stability, short circuit, and independent shadow analysis of the ISO's own result.
- **EMT modeling & usability.** OEM model integration, initialization, weak-grid and ride-through testing, and the usability report in the ISO's template.
- **Reactive capability & POI compliance.** Demonstration at the point of interconnection, not at the inverter terminals.
- **Affected system & cluster review.** Restudy response, cost allocation review and decision-point support.

Plant Side

- **Collector system design.** MV collection topology, cable sizing and ampacity, losses, and the trade between circuit count and conductor size.
- **Collector & POI substation.** Full electrical design through Issued-for-Construction, including main power and step-up transformers.
- **Protection & control.** Plant and POI protection, transfer trip, anti-islanding, and settings written to the transmission owner's fault model.
- **Auxiliary & station service.** AC and DC auxiliary systems, battery and charger sizing, and the loads a storage plant actually carries.
- **Grounding & lightning.** IEEE 80 grounding design, step and touch potential, and array or turbine grounding and bonding.
- **SCADA & telemetry.** Plant controller interface, ISO telemetry and metering to the market's data and interval requirements.

Facility Studies

- Arc flash, coordination, load flow and short circuit for the plant
- Harmonics and power quality at the point of common coupling
- Insulation coordination and surge protection
- Cable ampacity, thermal analysis and losses

Grid Code & IEEE 2800 Compliance

- **Capability assessment.** The plant's reactive capability, ride-through, frequency response, power quality and protection capability assessed clause by clause against the governing requirement.
- **Gap analysis at procurement.** Establishing what the inverter and plant controller actually deliver, before the equipment is bought rather than after.
- **Verification support.** Type test evidence, design evaluation, commissioning tests and post-commissioning validation aligned to the published verification practice.
- **Compliance matrix.** Clause, requirement, how it is met, and the evidence that proves it — in a form a reviewer can follow.

NERC Reliability Support

- **Registration assessment.** Whether the facility registers, in which category, and what attaches on that date.
- **Ride-through compliance.** Programmed parameters reconciled with the standard's envelope and with the model that was studied.
- **Model verification.** Step-response test planning, oscillography-to-model comparison and recalibration.
- **Disturbance monitoring.** Recording, time synchronization, retention and reporting designed in at the POI.
- **Event analysis.** Unexpected-event investigation and corrective action planning within the standard's clock.
- **Data submittal & facility ratings.** Modeling data packages and ratings support to the Transmission Planner and Planning Coordinator.

Owner's Engineer & Diligence

- Independent review of another firm's study, model or design
- Technical diligence for lenders, acquirers and tax equity
- OEM proposal and warranty technical review
- Second-opinion restudy on a stalled queue position

APPLIES TO Utility-scale solar PV · Onshore and offshore wind · Standalone BESS · Solar-plus-storage and wind-plus-storage hybrids · Repowering and augmentation · Co-located and behind-the-meter configurations · Synchronous condensers

TECHNOLOGY — PART ONE

Utility-Scale Solar PV

DC System & Array

- **String sizing & voltage window.** Maximum system voltage at record low temperature, MPPT window at record high, and the module datasheet coefficients that decide both.
- **Source-circuit current.** Maximum current established by the code's calculation basis — noting that the 2026 code edition removes the plant-size threshold that previously limited industry-standard calculation methods to larger systems.
- **Bifacial modules.** Rear-side gain treated with manufacturer data rather than a blanket derate, using the highest applicable short-circuit rating.
- **Overcurrent protection & fusing.** Fused and fuseless architecture, the string fuse constraint window, and reverse-current backfeed under fault and mismatch.
- **DC collection & combiners.** Combiner and recombiner architecture, DC cable sizing, voltage drop and losses.
- **Arc fault, ground fault & rapid shutdown.** Detection, protection architecture and the disconnect and labeling requirements that follow.
- **Tracker electrical interface.** Power, control and grounding for tracker rows, and stow behavior interaction with the plant controller.

The mismatch and backfeed problem

Fourth-quadrant reversal, shading, soiling and cell damage can drive reverse current into a string well beyond what the array's nominal rating suggests. The fuse has to sit inside a four-sided window — above the nuisance floor, below the module's maximum series fuse rating, inside the enclosure's thermal derating and above its clearing capability. That window is narrower than most people expect.

AC System & Plant

- **Inverter selection & configuration.** Central versus string architecture, DC:AC ratio, clipping, and the reactive capability the inverter can actually deliver across its operating range.
- **MV collection.** Feeder topology, cable sizing and ampacity with soil thermal resistivity, losses, and the trade between conductor size and circuit count.
- **Transformers.** Inverter step-up sizing and impedance, main power transformer specification and tap range, and the reactive consequences of both.
- **Reactive compensation.** Capacitor banks, reactors or dynamic devices where the inverters alone cannot meet the POI requirement across all operating points.
- **Plant controller.** Voltage, VAr and power-factor control loops, coordination with inverter local control, and the hunting and interaction failure modes.
- **Auxiliary load.** Tracker, HVAC, lighting and control load, and station service sized for night-time and outage conditions.

Codes & Standards Applied

- **NEC Articles 690, 691, 705 and 706** for PV, large-scale PV, interconnection and storage — against the code edition actually adopted in the jurisdiction, which for most of the country is still the previous edition.
- **IEC 61215 and 61730** for module qualification and safety, and **IEC 62548** for array design.
- **IEC 62446** for commissioning tests, inspection and system documentation.
- **UL 1741** for inverters, with the current supplement basis for certification to the DER interconnection standard.
- **IEEE 1547** where the plant interconnects at distribution, and **IEEE 2800** where it interconnects at transmission.

STUDIES A SOLAR PLANT ACTUALLY NEEDS

Interconnection power flow and stability	EMT model usability and ride-through	Weak-grid and system strength screening	Reactive capability at the POI
Collector short circuit and equipment duty	Protective device coordination	Arc flash and label program	Ground grid to IEEE 80
Harmonics at the point of common coupling	Cable ampacity and losses	Insulation coordination and arrester duty	Auxiliary and station service loading

DELIVERABLES DC and AC one-lines · String and combiner schedules · Cable and conduit schedules · Protection settings and coordination · Arc flash study and labels · Grounding design · Commissioning test plan · IFC package

TECHNOLOGY — PART TWO

Onshore & Offshore Wind

Electrical Balance of Plant

- **Collection system design.** Radial and looped MV feeder layout, circuit loading, cable sizing and ampacity with burial depth and thermal backfill, and loss optimization across the array.
- **Cable-intensive system behavior.** Charging current, reactive balance, resonance and harmonic amplification — the issues that separate a long cable collection system from an overhead one.
- **Turbine transformer & interface.** Pad-mount or nacelle transformer specification, protection interface and grounding at each turbine.
- **Substation & POI.** Collector substation design, main power transformer, reactive compensation and the POI protection package.
- **Grounding & lightning.** Turbine and array grounding, and lightning protection design against the IEC wind lightning standard.
- **Offshore-specific.** Export cable, offshore substation interface and onshore landfall coordination where the project is offshore.

What makes wind models different

Turbine models are type-specific rather than generic, and the OEM's own model must be integrated, initialized and validated in the ISO's environment. On cable-intensive collection systems the resonance and harmonic behavior is a genuine study question, not a formality — and it changes as the array builds out in phases.

Grid Performance & Models

- **Type-specific dynamic models.** WTG type models and plant controller assembled and flat-run verified for the positive-sequence case.
- **EMT models.** OEM EMT models integrated and tested against the governing usability checklist, including weak-grid and ride-through cases.
- **Sub-synchronous interaction.** Screening and EMT confirmation on series-compensated and long radial systems — a specific and well-documented wind exposure.
- **Power quality.** Flicker, harmonics and voltage fluctuation assessed against the applicable measurement and assessment standard.
- **Ride-through & frequency response.** Verified against the governing interconnection requirement and the reliability standard.

Standards Applied

- **IEC 61400-1** design requirements, as amended, and **61400-3-1** for fixed offshore turbines.
- **IEC 61400-21-1** for measurement and assessment of electrical characteristics, with the newer parts of that family where the project calls for them.
- **IEC 61400-24** lightning protection, as amended.
- **IEC 61400-27-1 and -27-2** for generic electrical simulation models and model validation.
- **IEEE 2800** for the transmission interconnection requirement, and the applicable NERC reliability standards for the operating obligations.

WHERE WIND PROJECTS LOSE TIME

- **OEM model availability and version.** The turbine model, its version and its support obligations are a supply-agreement item — requested afterward, they arrive late and in the wrong format.
- **Cable-intensive resonance found late.** Collection-system resonance and harmonic amplification identified after the cable schedule is fixed leaves filter design as the only remaining lever.
- **Phased build-out treated as one case.** The array's electrical behavior changes materially between phases; a single study of the final configuration misses the intermediate conditions.
- **Sub-synchronous exposure not screened early.** Series compensation or a long radial connection is knowable at site selection, not at the facility study.
- **Turbine grounding and lightning left to the OEM.** The interface between turbine grounding and the array grounding system is a design responsibility that falls between scopes.
- **Power quality measured against the wrong basis.** Assessment written to a general standard rather than the specific measurement and assessment method the reviewer expects.

Onshore utility-scale wind | Offshore fixed-bottom | Repowering and partial repowering | Wind plus storage hybrids

DELIVERABLES Collection system design and cable schedules · Loss and reactive studies · Resonance and harmonic assessment · Turbine and plant models · Protection settings · Grounding and lightning design · POI compliance demonstration

TECHNOLOGY — PART THREE

Battery Energy Storage & Hybrid

The converter is the grid asset, not the battery — but the battery is what the fire code, the insurer and the AHJ will ask about first.

Electrical Design

- **DC block & PCS architecture.** Container and DC block configuration, PCS sizing, DC:AC ratio, and the round-trip efficiency and auxiliary load that follow.
- **MV collection & step-up.** Feeder topology, cable sizing, transformer specification and the reactive behavior of the collection system.
- **Auxiliary load.** HVAC, fire system, controls and lighting — a materially larger and more continuous load than on a solar plant, and one that has to be served during outages.
- **Protection.** DC and AC protection, arc flash, ground fault detection on the DC side, and POI protection with current-limited fault contribution.
- **Metering & isolation.** Auxiliary load isolation and idle-mode designation so retail station load is not commingled with wholesale charging energy.
- **Augmentation planning.** Electrical provisions for capacity augmentation across the project life, designed in rather than retrofitted.

Hybrid & Co-Located Configurations

- **DC-coupled versus AC-coupled.** Trade-off analysis on clipping recapture, efficiency, controllability and interconnection treatment.
- **Shared interconnection.** Capacity sharing at the POI, control coordination, and how the market treats the combined resource.
- **Charging source restrictions.** Design and metering to support whatever charging restriction the tax or market position depends on.
- **Co-location with large load.** Configuration analysis where a data center or other large load sits alongside the generation.

Grid Behavior & Modeling

- **State-of-charge-aware dynamics.** Storage-specific electrical control models with SoC logic, so the dynamic case reflects how the plant actually behaves at the ends of its range.
- **Current-limited fault contribution.** Fault behavior that looks nothing like a synchronous machine, with the protection consequences worked through.
- **Negative-sequence and phase-angle behavior.** The converter behavior that drives distance and directional element misoperation risk.
- **Harmonics and resonance.** Distortion at the point of common coupling and resonance with collection-system capacitance, reassessed as the site builds out in phases.
- **Grid-forming capability.** Assessment against the applicable functional specification where the market or the owner requires it.

Safety, Fire Code & Listing

- **NFPA 855.** The 2026 edition makes hazard mitigation analysis the default for essentially all in-scope installations, tightens explosion control toward prevention systems, and ties large-scale fire testing to the listing test method. Design to the edition the AHJ has adopted, and to the one they are about to adopt.
- **UL 9540 and UL 9540A.** System listing and the thermal runaway fire propagation test method that supports separation and siting decisions — the test method was revised again in 2026.
- **UL 1973** for the battery, and **UL 1741** for the power conversion equipment.
- **IEC 62933** series for grid-integrated electrical energy storage safety where the project design basis is IEC.
- **Emergency response and commissioning.** Response plan content, detection design, and commissioning evidence the AHJ and the insurer will both ask for.

THE STORAGE-SPECIFIC QUESTIONS WE GET ASKED

How much auxiliary load, really?

Enough that station service sizing, outage behavior and metering separation all become real design questions rather than boilerplate — and enough to matter to the revenue meter.

What does augmentation cost later?

Far less if the electrical provisions, spare capacity and space are designed in at the start than if the plant is opened up in year seven to add DC blocks.

Will the AHJ accept the layout?

That depends on the fire code edition adopted locally, the listing and test evidence behind the product, and the hazard mitigation analysis — which is why it belongs early in design.

NOTE Fire protection engineering, hazard mitigation analysis and large-scale fire testing are performed by qualified fire protection specialists and test laboratories. Keentel provides the electrical engineering, the plant design and the coordination interface with that scope.

THE INTERCONNECTION PERFORMANCE STANDARD

IEEE 2800 Compliance

A capability claim is worth what the evidence behind it is worth — and since 2026 there is a published method for producing that evidence.

THE CAPABILITY AREAS WE WORK THROUGH

CAPABILITY AREA	WHAT THE PLANT HAS TO DEMONSTRATE	WHERE IT USUALLY GOES WRONG
Reactive power & voltage control	Reactive capability across the active power range, at the point of interconnection, with voltage, power factor and reactive power control modes	Capability demonstrated at the inverter terminals, with collector and step-up losses unaccounted for
Voltage ride-through	Continuous operation through defined voltage excursions, with current injection behavior and recovery ramp specified	Programmed protection settings that trip inside the required no-trip envelope
Frequency ride-through & response	Operation through frequency excursions and defined active power-frequency response	Response disabled, mis-tuned, or defeated by a plant controller setting nobody documented
Power quality	Harmonic and interharmonic limits, flicker, DC injection and unbalance at the point of interconnection	Assessed for one build phase and never reassessed as the site expands
Protection	Protection coordination with the transmission system for a current-limited, negative-sequence-deficient source	Settings derived from a source model the transmission owner's database does not reproduce
Modeling & validation	Positive-sequence and EMT models that reproduce the plant's real behavior, validated against test data	A model that runs locally but will not initialize in the reviewer's environment
Measurement & monitoring	Disturbance monitoring and data capability at the required resolution and retention	Treated as a commissioning afterthought rather than a procurement specification

The standard is voluntary. The requirement usually is not.

IEEE 2800 binds only where the interconnection authority adopts it — but adoption has spread across more than twenty utilities and system operators, and it increasingly arrives through the interconnection requirements attached to your agreement rather than through a code. The practical question is never "does the standard apply" but "which clauses has this transmission provider adopted, in what form, from what date."

Adoption is phased, and partial

A provider may adopt definitions, ride-through and protection requirements first and defer others entirely. Designing to the full standard when only part of it is adopted wastes money; designing to the old requirement when a phase has landed costs a retrofit.

How We Run a Compliance Scope

- **Establish the governing requirement.** Which clauses the transmission provider has adopted, in what version, effective when — in writing, before design decisions are made.
- **Assess capability at procurement.** What the inverter, turbine and plant controller actually deliver across the full operating range, established from OEM evidence before the equipment is bought.
- **Close the gap by design.** Reactive compensation, control tuning, protection settings or equipment change — whichever closes the gap at least cost.
- **Verify to the published method.** Type test evidence, design evaluation, commissioning tests and post-commissioning validation, structured to the recommended verification practice published in 2026.
- **Hand over a compliance matrix.** Clause by clause: the requirement, how it is met, and the document that proves it.

DELIVERABLES Governing requirement matrix · OEM capability assessment · Gap analysis with mitigation options and cost · Reactive capability demonstration at the POI · Verification test plan · Clause-by-clause compliance matrix with evidence register

THE TECHNICAL GATE ON THE QUEUE

Interconnection Studies & Model Quality

Studies We Run

- **Power flow & contingency.** Base case rebuilt from ISO and transmission owner models; N-1 and N-1-1 thermal and voltage screening.
- **Transient & voltage stability.** Fault clearing, critical clearing time, voltage recovery, damping, and PV/QV reactive margin at the POI.
- **Short circuit & equipment duty.** Fault duty for breaker adequacy and equipment specification, with a current-limited source correctly represented.
- **Weak-grid & system strength.** Short-circuit ratio, weighted and composite screening, and controller stability at low grid strength.
- **Sub-synchronous interaction.** Screening and EMT confirmation on series-compensated and long radial systems.
- **Overvoltage.** Load-rejection and ground fault overvoltage, grounding configuration at the step-up, and arrester energy duty.
- **Harmonics & resonance.** Frequency scans, resonance with collection-system capacitance, and filter design where needed.
- **Protection performance.** Distance and directional element behavior with an inverter-based source behind them.

What the Model Gate Tests

- **Initialization and flat start.** The model reaches setpoint and stays there, in the reviewer's environment, at the reviewer's time step.
- **Step response.** Active power, reactive power, voltage and frequency steps, damped and settling inside the stated window.
- **Fault ride-through.** Balanced and unbalanced faults at defined depth and duration, with recovery ramp and repeat-fault behavior.
- **System strength sweep.** Stepped reduction of short-circuit ratio to find where the controller becomes unstable, not merely whether it survives one case.
- **Phase-angle jump and ROCOF.** Phase-locked-loop and control behavior through the disturbances that expose converter interaction.
- **Protection representation.** All plant and inverter protections modeled, so the model trips when the plant would.
- **Operating range coverage.** Accurate from minimum stable output to full capacity — and, for storage, across the state-of-charge range.
- **Cross-validation.** Agreement between the EMT and positive-sequence cases, with any divergence explained.

Model quality is a procurement issue

By the time an OEM model is in your hands, its quality is fixed. The leverage is in the supply agreement — model deliverables, format, version, usability criteria, support obligations and update commitments specified before the order is placed, not requested afterward.

MODEL DELIVERABLES TO SPECIFY AT PROCUREMENT

Positive-sequence generic model, named version	Stability-tool user-written model	EMT model, named tool version	Plant controller model
Storage state-of-charge control logic	Model quality test results	Benchmark report against test data	Documented parameter set
Usability acceptance criteria	Support obligations during ISO review	Update commitment after settings changes	As-built tuned model after commissioning

Each of these is cheap to require in a purchase order and expensive to obtain afterward. We write this list into the equipment specification as a matter of course, and we review the OEM's response before the order is placed.

Shadow the ISO before the decision point

Reproducing the study result independently is the only way to know whether a network upgrade allocation is worth accepting, challenging or walking away from.

Screen grid strength at site selection

Short-circuit ratio at a candidate POI is knowable before a deposit is committed, and it predicts most of the EMT scope, schedule and remediation cost that follows.

Plan for the restudy

Neighbouring withdrawals move cost allocations between phases. Projects that budget the Phase 1 number and nothing else are the ones caught out.

PLATFORMS PSCAD/EMTDC · Siemens PTI PSS® E · GE PSLF · DIgSILENT PowerFactory · ASPEN OneLiner · ETAP — selected by the question the study has to answer and by the format the governing market requires

RELIABILITY COMPLIANCE

NERC Registration & Standards

Registration converts study assumptions into auditable obligations — and the evidence has to be created during design and commissioning, not reconstructed later.

Bulk electric system resources

The traditional Generator Owner and Generator Operator thresholds follow the bulk electric system definition — an individual unit above 20 MVA, or a plant aggregating above 75 MVA, connected at 100 kV or higher, including dispersed power producing resources such as solar, wind and storage.

Inverter-based resources below that threshold

A second registration category captures non-BES inverter-based resources at **20 MVA or more in aggregate** behind a single point of interconnection at **60 kV or above**. Aggregation is by gross nameplate rating across all inverter-based resources at the facility — ownership structure and operating limits do not change the test. The registration date was reached in **May 2026**.

THE STANDARDS THAT ATTACH

STANDARD	WHAT IT OBLIGATES	TIMING
PRC-029 IBR ride-through	Performance-based obligation to remain connected and continue operating through defined voltage and frequency excursions, with a documented exemption path for genuine hardware limits	Enforcement **1 October 2026** for bulk-system IBRs; non-BES design requirements phase in from **January 2027**
PRC-030 Unexpected events	Analysis of an unexpected real-power change above the defined threshold within 90 days, a corrective action plan within a further 60 days, and notification of the Reliability Coordinator	Enforcement **1 October 2026**
PRC-024 Protection settings	Frequency and voltage protection set to avoid tripping inside the defined envelope — scope now narrowed to synchronous machines, synchronous condensers and older wind types	Current version enforceable; inverter-based ride-through moved to PRC-029
PRC-028 Disturbance monitoring	High-resolution disturbance and sequence-of-event recording with precise time synchronization, retention and submission on request	Phased build-out with full coverage by **1 January 2030**; non-BES obligations phase in from 2027
MOD-026 Model verification	Dynamic models whose behavior reasonably reflects actual facility performance — controller verification, validation against disturbance data, periodic review, EMT where required	Consolidated version in force, absorbing the separate turbine-governor standard; requirement compliance phases in through the end of the decade
MOD-032 / 033 Modeling data	Steady-state, dynamics and short-circuit data to the Transmission Planner and Planning Coordinator, and validation of the interconnection-wide model against actual response	Applicability attaches on registration, with the current standard version phasing in through 2028
FAC-008 Facility ratings	A documented facility ratings methodology, with the facility rated to its most limiting element and consistent with the as-built configuration	In force from registration

Registered facilities also inherit obligations across operations, voltage control, real-time data, event reporting, protection maintenance and, where applicable, cyber security — a set most owners of a 20 MVA plant had not previously carried.

Registration follows the facility

Aggregation at the point of interconnection decides registration, not corporate structure — and a phased build-out can cross the threshold mid-project.

Regional variances are real

Standards apply nationally, but variances, interpretations and audit approach differ by Regional Entity. Confirm which Region governs before assuming a requirement.

Settings drift is the usual finding

What is programmed on site, what was modeled and what the standard requires diverge quietly. Reconciling the three is a commissioning deliverable, not an annual chore.

NOTE Standard numbers are shown without version suffixes because versions change. Dates reflect the position as of August 2026 and must be confirmed against the current standard, the implementation plan and your Regional Entity before being relied on.

THE NEXT CAPABILITY REQUIREMENT

Grid-Forming & Advanced Capability

No U.S. standard requires it yet. One market already pays for it, and the standards work is underway — which makes it a procurement decision now.

Where Grid-Forming Actually Stands

- **No national mandate.** There is no U.S. standard or federal rule requiring grid-forming capability on an inverter-based resource as of August 2026.
- **Standards work is in progress.** A recommended practice for grid-forming functional capability and performance is under development, along with an amendment to remove grid-forming barriers in the transmission interconnection standard. Neither is published.
- **Published guidance already exists.** Functional specifications from the reliability organisation for bulk-system-connected storage, a federally funded specification set, and international working group material give a usable functional definition today.
- **ERCOT moved first and moved hard.** Advanced grid support requirements for new inverter-based storage resources were approved in late 2025 and now sit in the operating and planning guides, with model quality demonstration attached — and a funded incentive programme was established in 2026 to retrofit the legacy storage fleet, paying per MW with a fixed deployment window.
- **Other markets are specifying rather than mandating.** Utility and system operator specifications and test requirements are appearing without becoming tariff obligations.

What this means commercially

Grid-forming capability is far cheaper specified at procurement than retrofitted after commissioning — and in at least one market it is now a revenue line rather than a cost. The decision belongs in the OEM negotiation, not in a later compliance project.

What We Do With It

- **Requirement screening.** Whether the governing market, the transmission provider or the interconnection agreement asks for grid-forming behavior, and in what form.
- **Grid strength assessment.** Whether the site's short-circuit ratio makes grid-forming an engineering necessity rather than a preference.
- **OEM capability evaluation.** What the vendor's grid-forming mode actually does, across what operating range, and with what limitations — assessed against a published functional specification rather than a datasheet claim.
- **EMT demonstration.** Grid-forming versus grid-following comparison, islanded and weak-grid behavior, synthetic inertia response and control interaction with adjacent plants.
- **Black start and islanded operation.** Where the project has, or is pursuing, a black start or islanding role.
- **Specification language.** Capability, test and evidence requirements written into the equipment specification before the order is placed.

Adjacent Advanced Capability

- **Fast frequency response** and synthetic inertia, where the market has a product for them.
- **Synchronous condensers** as a system strength remedy, including conversion of retired machines.
- **Dynamic reactive support** sizing where inverter capability alone will not hold the POI requirement.
- **Black start sequencing** for storage-supported restoration paths.

GRID-FOLLOWING VERSUS GRID-FORMING — WHAT ACTUALLY DIFFERS

BEHAVIOR	GRID-FOLLOWING	GRID-FORMING
Voltage reference	Follows the grid voltage measured through a phase-locked loop	Establishes its own internal voltage source behind an impedance
Weak-grid behavior	Stability degrades as short-circuit ratio falls; control interaction risk rises	Remains stable at much lower system strength; can support other resources
Disturbance response	Responds after measuring the disturbance	Responds inherently and immediately, providing synthetic inertia-like behavior
Islanded operation	Cannot form an island alone	Can energize and hold an island, enabling black start roles
Study implication	Standard EMT and RMS model set	Requires demonstration against a functional specification and additional EMT cases

NOTE Grid-forming requirements, incentives and specifications are moving quickly and differ by market. The position above is as of August 2026 and is confirmed project by project.

THE DESIGN BASIS

Codes & Standards We Work To

REFERENCE	WHAT IT GOVERNS	NOTE
IEEE 2800	Interconnection and interoperability of inverter-based resources on transmission and sub-transmission — capability, ride-through, power quality, protection, modeling and monitoring	2022 edition; voluntary, and binding only where the interconnection authority adopts it
IEEE 2800.2	Test and verification procedures for inverter-based resources — type test, design evaluation, commissioning and post-commissioning validation	Published 2026; the conformity assessment method behind an IEEE 2800 capability claim
IEEE 1547 family	Distribution-level DER interconnection, its amendment, conformance test procedures and the storage application guide	Applies where the plant interconnects at distribution rather than transmission
UL 1741	Inverters, converters, controllers and interconnection system equipment, with the supplement that certifies to the DER interconnection standard	3rd edition, most recently revised in 2026
UL 9540 / 9540A	Energy storage system listing, and the thermal runaway fire propagation test method that supports siting and separation	9540A revised again in 2026; the test basis the fire code now leans on
UL 1973 / UL 3741	Batteries for stationary applications; PV hazard control systems	Both current and recently revised
NFPA 855	Installation of stationary energy storage — hazard mitigation analysis, explosion control, detection, separation, commissioning and emergency response	2026 edition released late 2025; design to the edition the AHJ has actually adopted
NEC / NFPA 70	Articles 690, 691, 705 and 706 for PV, large-scale PV, interconnection and storage; plus MV grounding and arc flash marking	2026 edition published, but most states remain on the previous edition — adoption is the governing question
IEC 61400 series	Wind turbine design requirements, offshore, power quality measurement, lightning protection, and electrical simulation models	Several parts recently amended
IEC 61215 / 61730 / 62446 / 62548	PV module qualification and safety; system commissioning, documentation and inspection; array design	Equipment certification and IEC-basis projects
IEC 62933 series	Electrical energy storage systems — vocabulary and safety requirements for grid-integrated electrochemical storage	Safety part updated in 2025
IEEE 80 / 519 / 1584 / C37	Grounding; harmonics; arc flash; equipment duty and protection — the facility-side standards behind the plant design	Applied on every plant regardless of technology
NERC PRC / MOD / FAC	Ride-through, disturbance monitoring, event mitigation, model verification, modeling data and facility ratings	See the reliability page — several reach enforcement in late 2026

Adoption beats publication

A newly published edition changes nothing until the jurisdiction or the interconnection authority adopts it. We design to the adopted requirement and flag what is coming.

Two clocks run at once

Interconnection requirements attach at the agreement; reliability obligations attach at registration. They are different dates with different evidence, and both have to be planned for.

Evidence is created early

Type test records, model validation, commissioning data and settings records are produced during the project. An audit years later cannot recreate them.

NOTE Editions and adoption status reflect the position as of August 2026. The governing edition, the adopted clauses and the jurisdiction's adoption status are confirmed project by project before design decisions are made.

DELIVERABLES, PLATFORMS AND THE FIRMS WE WORK FOR

What You Receive

- Queue application package — data forms, models, one-lines and readiness evidence to the specific market's checklist
- Native study files in the platform the market requires, delivered clean and library-clean
- Study report with assumptions, cases, plots and explicit pass/fail criteria against every requirement
- EMT model package with a usability test report in the ISO's own template
- Weak-grid, ride-through and control interaction results with waveform evidence
- Reactive capability curve and POI compliance demonstration
- IEEE 2800 clause-by-clause compliance matrix with an evidence register
- Plant electrical design package through Issued-for-Construction
- Collector and POI substation drawings, schedules and specifications
- Protection settings, native settings files and coordination records
- Arc flash results, mitigation analysis and print-ready labels
- Grounding design report with step and touch results
- NERC registration assessment and standard-by-standard applicability matrix
- Commissioning parameter and settings record, and the as-built model update

INDUSTRY-STANDARD ENGINEERING PLATFORMS

PSCAD · PSS®E · ASPEN · PSLF · SILENT DIG · etap

ENGAGEMENT MODELS

Single project, end to end

Screening through energization on one project — studies, models, plant design and compliance under one scope and one point of accountability.

Portfolio support

Retained support across a development pipeline in several markets — deadline tracking, model maintenance, restudy response and compliance calendar.

Diligence & second opinion

Independent review of another firm's study, model, design or compliance position — for a lender, an acquirer, tax equity or a board.

OUR CLIENTS

entergy · EDF power solutions · aps · AVANGRID · aypa · SIEMENS energy · octa DATA CENTER · PIKE ENGINEERING · RRC · FISHER ASSOCIATES · BRASSWATER · RISK WORK

- Utility-scale solar developers
- EPC contractors
- Wind developers and owners
- Utilities and cooperatives
- Standalone and hybrid storage
- Lenders and tax equity
- IPPs and asset owners
- OEMs and integrators

START HERE

Four Things and We Can Scope It

The project — technology, MW and MVA, OEM if selected

The POI — interconnection point, voltage and transmission owner

The queue — which market, which cycle, your position in it

The driver — the study requirement, comment letter or milestone date

WHY KEENTEL ENGINEERING

01 Grid side and plant side in one scope

Interconnection studies, EMT models, substation and plant design and the compliance record come from the same team — so the drawings, the model and the settings describe the same asset.

02 Every market, tracked as it changes

Eight ISO and RTO processes plus the non-RTO footprint, and the interconnection requirements that arrive with them — a portfolio in several markets is not several separate engagements.

03 Model quality as a discipline

Models built to survive someone else's environment and someone else's checklist, with cross-platform reconciliation documented for the reviewer rather than left to be discovered.

04 Compliance designed in

Registration, ride-through, monitoring, model verification and data submittal built into the design and commissioning record instead of reconstructed for an audit.

05 P.E.-sealed and defensible

Florida-registered firm (Reg. No. 36853) with multi-state licensure. Written to survive transmission owner, ISO, independent engineer and lender review.

06 We stay through energization

Comment response, settings, commissioning support, as-built model updates and compliance handover — not a report and a handshake.

PRIMARY AUTHORITIES BEHIND THIS FLYER

IEEE. IEEE Std 2800, Interconnection and Interoperability of Inverter-Based Resources Interconnecting with Associated Transmission Electric Power Systems; IEEE Std 2800.2, Recommended Practice for Test and Verification Procedures for Inverter-Based Resources; IEEE Std 1547 and its amendment, IEEE 1547.1 conformance test procedures and IEEE 1547.9 storage guide; IEEE 80, 519, 738, 1584 and the C37 series.

UL Standards & Engagement. UL 1741 and its supplements; UL 9540 and UL 9540A; UL 1973; UL 3741.

NFPA. NFPA 855, Standard for the Installation of Stationary Energy Storage Systems; NFPA 70, National Electrical Code, Articles 690, 691, 705, 706 and related articles; NFPA 68 and NFPA 69 as referenced by NFPA 855.

IEC. IEC 61400 series for wind turbines; IEC 61215 and 61730 for photovoltaic modules; IEC 62446 and 62548 for photovoltaic system commissioning and array design; IEC 62933 series for electrical energy storage systems.

NERC. Reliability Standards PRC-024, PRC-028, PRC-029, PRC-030, MOD-026, MOD-032, MOD-033 and FAC-008; Rules of Procedure registration criteria and the inverter-based resource registration initiative; NERC grid-forming functional specifications for bulk-power-system-connected battery energy storage.

FERC. Order No. 901 on inverter-based resource reliability standards; Order No. 2023 and 2023-A on generator interconnection procedures.

ISO / RTO. The governing interconnection procedures, business practice manuals, planning and operating guides and EMT model requirements of the market in which the project sits.

Other. Federally funded and international working group specifications for grid-forming inverter-based resources; and, for commercial timing only, the federal tax legislation of 2025 and the implementing guidance issued under it.

Standard editions, adoption status and regulatory positions described are current as of August 2026 and are provided for orientation only. Nothing here is legal, regulatory or tax advice. The governing interconnection requirement, code edition and standard revision in force for a given project control.

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