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Substation Interface Readiness for Renewable Energy Projects Through a Proposed Standardized Turnover Package Framework

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Abstract

In renewable energy projects, the transition to energization and operation of the substation interface must be managed and documented through a coordinated engineering record, commissioning evidence, and formal approval. This paper offers a standardized framework for these records in the turnover package and their application, without replacing utility-specific requirements. The framework is compiled from published interconnection research and select official technical sources, such as Lawrence Berkeley National Laboratory's Queued Up: 2026 Edition, which projects roughly 8,200 Transmission Interconnection Requests for projects in the U.S. at the end of 2026, including 1,312 GW of generation and approximately 749 GW of storage. The schema consists of 10 modules, 42 core record classes, four readiness gates, and metadata linking each record to the governing source or clause, revision, applicability, owner, evidence location, and approving status of the deliverables. It is important to explicitly record the document edition and project context, as illustrated in the example PJM source document and in ISO projects 1, New England, ERCOT, AEP, IEEE, and NERC. This framework is a design proposal, not an empirical study. No claims are made about prevalence, inter-coder agreement, validation coverage, or reducing rejection or improving the schedule for the requirement. The paper suggests evaluation based on the final project product, first pass, re-submissions, deficiencies, and review time. Project teams need to check the applicability of the governing documents before implementation.

Keywords: Substation interface readiness; renewable energy interconnection; standardized turnover package; utility turnover requirements; inverter-based resources

1. Introduction

Utility-scale renewable energy generation and storage facilities continue to advance toward transmission access in the United States. By the end of 2025, the Queued Up: 2026 Edition report by Lawrence Berkeley National Laboratory (LBNL) shows there are about 8,200 transmission interconnection requests (TIQs) active, totaling 1,312 GW of generation and roughly 749 GW of storage. This dataset includes data from seven ISO/RTOs and 50 non-ISO balancing areas, representing about 98 percent of all installed U.S. generating capacity; it excludes load requests and distribution-connected or behind-the-meter projects (Rand, et al., 2024). At this scale, a substation interface is an important boundary in project delivery. Utility readiness requires drawings, SCADA data, dynamic models, protection settings, metering records, commissioning records, test results, and approvals to be in place, current, and

traceable. FERC Order No. 2023 modified generator interconnection processes and agreements administered by public utility transmission providers (Federal Energy Regulatory Commission,, 2023).

The reason behind the late-stage turnover problems is not reflected in the queue stats. Documentation of deadlines and deliverables for each utility must be provided in the applicable tariff, interconnection agreement, commissioning process, or current technical standard. Sponsorship matters because, along with the model, it shows how to achieve competitive project development for PJM Interconnection's transmission construction projects and demonstrates the need to build competitive projects in PJM Interconnection (Herling, Koza, & P. McGlynn, 2016). ISO New England's Major New Equipment Commissioning Checklist Procedure, revision 7.1, dated 19 December 2024 and valid through 19 December 2026, outlines the requirements for monitoring and completing the checklist (ISO New England, 2024). ERCOT has a formal Resource Integration page with Reference Materials that include a Commissioning Plan Template and ERCOT New Generator Commissioning Checklist (ERCOT). PJM refers to the AEP connection standard as detailed in the accompanying document, revision 7 (American Electric Power). These examples show one way to use a source-centered schema without specifying the frequency of utility needs.

Four key objectives are presented in the paper: (1) specifying a feasible structure for describing utility-specific turnover requirements; (2) defining a set of record families that a turnover package should be able to process; (3) formulating a schema that includes 10 modules and 42 classes, including attributes such as requirement status and readiness gates; and (4) defining an approach for testing this schema at the project level for future studies. This paper is a technical framework paper and is not meant to assess cross-utility requirement frequencies, schema coverage, rejection rates, or schedule effects.

The proposed framework applies to transmission and sub-transmission interfaces at utility-scale solar PV, wind generators, battery energy storage systems, hybrid plants, collector substations, and points of interconnection. It supports detailed design, synchronization, energization, commercial operation, commissioning, and final turnover to the utility. Record classes should be viewed only as suggested delivery components of the schema and should not be considered a formalized set of mandated supplies.

This study has been divided into several sections. Section 2 investigates the literature on the interconnection context and technical sources. The scope and the framework-development approach are contained in Section 3. Section 4 provides the proposed scheme for turnover and the readiness gate. Section 5 examines implementation issues, their constraints, and a future evaluation design. Section 6 concludes with a summary of the results and outlines directions for further research.

2. Literature Review

2.1 Renewable Energy Interconnection Backlogs and Project Readiness

Research on interconnection barriers has been published, as well as papers on queue-management strategies, transmission-system co-ordination, and lead times for renewable-project development (Gorman, et al., 2025); (Ostler, Li, & L. Dale, 2024). Although these studies contribute to understanding the complexity of interconnection delivery, they do not indicate that a lack of documentation causes queue withdrawals or delays. Readiness for turnover is a different engineering-management activity in which the project team identifies the controlling utility requirement, revises it, determines what evidence is needed, assigns a

responsible owner, and verifies approval of each deliverable item (Zahraoui, Pokhrel, Oleinikova, & S. N. Gros, 2025).

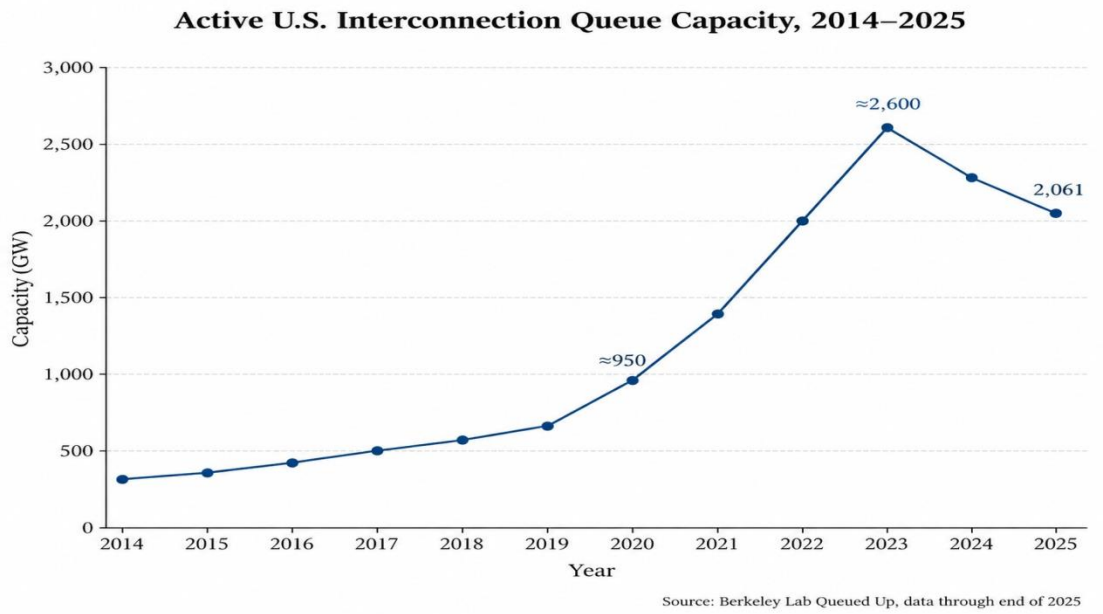


Figure 1: Trend in active U.S. interconnection queue capacity from 2014 to 2025, highlighting sustained backlog growth.

Figure 1 shows the forecasted path of potential U.S. generation and storage resources connected to the grid and under development that will be online and need connections between 2014 and 2025. The interconnection backlog has increased steadily and quickly and is expected to reach a low of approximately 2,061 GW total by the end of 2025, a 10 percent reduction from 2024. The diagram shows how grid readiness becomes more critical as renewable projects progress through construction, commissioning, and commercial operation.

2.2 Substation Interface Readiness and Utility Turnover Requirements

Substation interface readiness is the point at which a renewable facility and interconnection assets have the engineering evidence, approved settings, operating data and records, and approvals the receiving utility or system operator needs to proceed to the next stage of operation. Grid-code certification by simulation is one example of technical evidence that may contribute to readiness where required by the applicable connection rules (B. Yondjin Ngamy, 2026). This is an organizing definition for this paper rather than a claim that the term is universally standardized. Readiness does not equate to physical completion: installed equipment may still lack required testing, configuration, documentation, or acceptance.

Project delivery can involve physical completion, mechanical completion, electrical completion, pre-energization readiness, initial synchronization, commissioning completion, commercial-operation readiness, and final as-built turnover. Project-development lead-time research and work on blackstart strategies provide complementary context for distinguishing the development process from technical and operational milestones (Clapin & T. Longden, 2024); (Galeela, Fawad, Chakravorty, Javid, Li, & J. Liang, 2026). Commissioning

milestones must be mapped to the applicable utility procedure rather than assumed to be universal.

2.3 Protection, Control, SCADA and As-Built Documentation

Protection, control, SCADA, and final drawing records can help confirm that the installed substation matches the design reviewed by the utility. Candidate schema fields include final one-line diagrams, three-line diagrams, AC and DC schematics, relay-setting calculations, as-left setting files, breaker and control-circuit drawings, transformer information, communication diagrams, RTU/SCADA point lists, metering configuration, teleprotection information, and test reports.

Table 1 presents technical evidence required for the installed renewable substation to meet the utility-approved design, setting, and operational requirements before energization and commercial operation, which can be provided by the protection, control, SCADA, and as-built documentation.

Table 1: Protection, Control, SCADA and As-Built Documentation Requirements for Renewable Substation Turnover

Documentation Category	**Required Records / Evidence**	**Purpose in Substation Readiness**
Protection System Documentation	Protection philosophy, relay setting calculations, as-left relay settings, relay configuration files, protection coordination records	Confirms that installed protection systems match the approved utility design and operating requirements
Electrical Drawings and Schematics	Final one-line diagrams, three-line diagrams, AC schematics, DC schematics, breaker and control circuit drawings	Demonstrates that the constructed substation configuration corresponds with the reviewed engineering design
Relay Testing and Verification	Relay testing reports, protection commissioning records, functional test results	Provides evidence that protection devices operate correctly under required conditions before energization
Inverter and Plant Control Documentation	Inverter control testing records, plant controller settings, control configuration files	Verifies that renewable plant controls are correctly configured for grid-support functions and utility requirements
Equipment Data and Technical Records	Transformer data, equipment ratings, manufacturer information, equipment specifications	Ensures that installed equipment characteristics align with approved studies and utility requirements
SCADA and Communication Records	SCADA point lists, RTU configuration, communication architecture, telemetry records	Confirms that the utility can monitor and operate the renewable facility through required communication interfaces
Metering and Teleprotection Documentation	Metering configuration, protection communication links, teleprotection records	Supports accurate measurement, protection coordination, and secure utility system operation
Testing and Commissioning Evidence	AC/DC circuit testing documentation, commissioning reports, final test records	Provides traceable evidence that systems have been inspected, tested, and accepted before operation

Documentation Category	Required Records / Evidence	Purpose in Substation Readiness
Configuration Control Records	Approved drawings, revision history, final as-built documentation, change records	Prevents discrepancies between studied designs, installed systems, and operational configurations

These are proposed record classes, not a claim that every utility requires every item. Literature on inverter-based resource interconnection standards and protection methods highlights the need to check the behavior of protection schemes against the characteristics of inverter-rich systems (Hoke, et al., 2024); (Gui, Lei, & B. K. Johnson, 2024) ; (Lopes, Davi, Oleskovicz, Hooshyar, Dong, & A. A. Neto, 2024).

2.4 Inverter Based Resource Models, Controller Settings and Commissioning Evidence

Drawings and relay test sheets may be insufficient on their own for projects that rely on digital controls and dynamic models. IEEE Std 2800-2022 addresses voltage and frequency ride-through, active and reactive power control, dynamic support, power quality, and protection requirements for transmission-connected inverter-based resources (IEEE, 2022). NERC materials address disturbance monitoring and reliability concerns for inverter-based resources (North American Electric Reliability Corporation); (North American Electric Reliability Corporation, 2025). Research on inverter-model validation, negative-sequence current behavior, and validation across simulation domains further supports linking applicable model files and settings to commissioning evidence (Biswas, Tuffner, Follum, & T. Wall, 2024); (Nasr & Hooshyar, 2023). Depending on the governing interconnection requirements and project design, candidate turnover records may include positive-sequence models, electromagnetic-transient models, inverter settings, plant power-controller settings, field-validation results, and updated as-built models. A record should only be deemed mandatory if the governing documents applicable to the utility are current and meet the as-built requirements of the applicable model.

2.5 Standardization, Digital Handover, and Readiness Gates

File-based turnover brings the challenge of keeping names, revisions, approvals, ownership, conditional requirements, and submission timing in sync. For a structured information-management approach, background studies on version-controlled construction information, common data environments, digital asset information, digital twins, handover information loss, and digitalized quality-document management can support the research study described in this paper (H. Yin, 2026). The proposed schema is a common organizational layer, not a replacement for any particular utility's rules. The four readiness gates provide a planning framework that must align with the specific utility gates and approvals for each project.

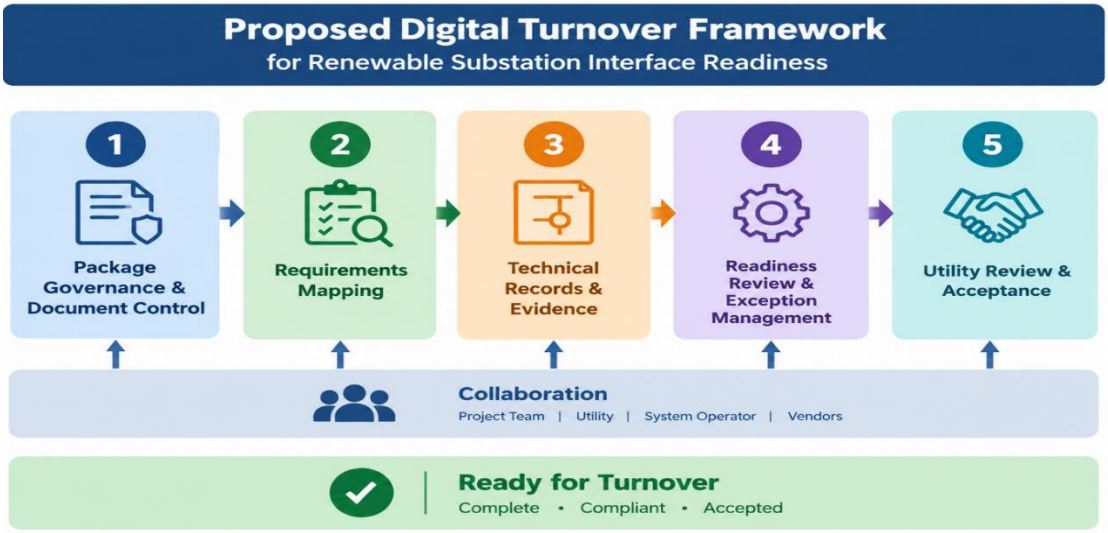


Figure 2: Proposed Digital Turnover Framework.

Figure 2 presents document control, requirements mapping, technical records and evidence, readiness review, and utility acceptance as the five stages in the proposed five-stage turnover framework for renewable substation projects. Successful, complete turnovers are achieved through collaboration among project teams, utilities, system operators, and vendors.

2.6 Research Gaps and Limitations in the Literature

Past interconnection studies have focused on queue duration, project upgrade costs, and withdrawals during the project, but these results do not, by themselves, prove a deficiency in delivery during the project turnover stage (S. E. Culver, 2023). Technical frameworks also influence performance and compliance, but do not offer utilities a consistent, plug-and-play framework. In addition, the requirements may be referenced in tariffs, facility connection manuals, commissioning checklists, operating procedures, and project agreements. The national queue dataset used in this paper does not provide information about the number of projects that were not accepted due to incomplete, missing, inconsistent, or turnover packages. This paper discusses a more constrained engineering-management problem: organizing documentary evidence of readiness at the substation interface.

3. Methods and Techniques

3.1 Scope and Source Use

This paper proposes a framework for information governance based on three types of material: (1) national interconnection context published by Lawrence Berkeley National Laboratory; (2) selected documents published by organizations and standards bodies that contain official technical or procedural text; and (3) general principles of document control, configuration management, and engineering handover. The use of a real-time simulation and protective relays for commissioning research can be used as an example of how test evidence can be applied to the equipment and settings being considered (Piesciorovsky, Hink, Werth, Hahn, Lee, & Y. Polsky, 2023). Data from the national queue are used only to depict the extent of transmission interconnection activity. It is not considered a measure of rejection rates or the framework's effectiveness.

The sources cited in this paper are examples, not a systematically coded or comprehensive list of utility requirements in the United States. The framework does not assert

that the listed records would be required by all utilities, nor does the framework assert a common frequency of requirement. A project team is required to specify the controlling interconnection agreement, tariff, facility-connection requirement, commissioning procedure, technical standard, and any approved project-specific instruction for each actual project in the project plan. The status of a requirement must be assigned after noting the applicable revision, clause, effective date, and any exceptions.

Table 2: Sources and Scope of the Proposed Framework

Source Category	**Purpose**	**Limitations / Application**
National interconnection data (LBNL)	Describe the scale of transmission interconnection activity.	Not used to measure turnover rejection rates or framework effectiveness.
Official technical and procedural sources	Inform the framework using selected grid-organization and standards-body requirements.	Illustrative examples, not an exhaustive survey of utility requirements.
Document control and engineering handover principles	Guide information governance, configuration management, and technical handover.	Applied as general principles within the proposed framework.
Project-specific requirements	Identify applicable agreements, tariffs, technical standards, commissioning procedures, and approved instructions.	The controlling document, revision, clause, effective date, and exceptions must be recorded for each project.
Framework application	Organize and manage substation turnover information consistently.	Does not assume that every record is required by every utility or establish requirement frequency.

3.2 Design Principles

The five design principles were organized into the schema. The first is traceability, whereby every deliverable should be linked to a controlling source and clause. The second is configuration control, meaning the submitted revision should be different from draft, superseded, approved for construction, and as-built revisions. These principles align with existing information-management guidelines for organizing, versioning, and monitoring project information across an asset's life cycle (International Organization for Standardization, 2018). The third is accountability: each record should have an owner, review date, due date, and status. The fourth is applicability, which requires the condition to be recorded when the requirement is conditional. The fifth is lifecycle alignment, where records should be linked to the readiness gate they should be used at, but not to the point of saying that the proposed gate structure takes the place of the utility's own authorization process.

3.3 Requirement Status and Applicability

A project register can be used to classify each requirement as mandatory, conditional, recommended, informational, and not identified for implementation. These labels are only to be given after careful consideration of the relevant source documents. The "Not identified" option should not be used if the reviewed and relevant sources do not identify a requirement, and cannot be used if the document is missing, not accessible, or of uncertain currency. If the source is not available or the source is not clear, then the status should NOT be inferred, but should be noted as "unverified" or "source clarification required." Identify the appropriate

technical requirements based on the governing interconnection standards and the project-specific utility documentation. They should not be presumed to match those proposed in the framework (IEEE, 2018).

3.4 Validation Status and Boundaries

The framework has not been validated with a set of completed projects, and a systematic source-coding study is not reported in this paper. No organization-by-record matrix, calculation of the prevalence of requirements, validation, inter-coder agreement statistic, or project-level performance analysis is claimed. The results presented are not those of the present paper. They may be eligible for inclusion in a later assessment if an auditable source register and appropriate project records are available. The suggested schema may be deployed using a spreadsheet, database, common data environment, or document-management platform. Whatever it is implemented as, it should contain its source citation, applicability logic, revision history, evidence location, approval status, and exceptions that have not been resolved. This design provides for an auditable workflow, but is not used to certify technical compliance or energization.

4. Standardized Turnover Package Schema for Renewable Substation Interfaces

4.1 Standardized Schema Architecture

The proposed standardized turnover structure comprises 10 modules and 42 core record classes. The package governance and master index consist of four records that are intended to cover the following: document control, deliverables control, requirements ownership, and package status. The proposed schema has six classes for final as-built drawings and design records; four classes for equipment data and ratings; five classes for protection and control; four classes for metering and power quality; five classes for SCADA, telecom, PMU and cyber interfaces; four classes for inverter-based resource models and plant controller settings; five classes for inspection, testing and commissioning evidence; three classes for operational, compliance and safety documentation; and two classes for final acceptance, exceptions and archive records. These are design allocations and not frequencies found in the utility documents.

The proposed 42 record classes form a controlled superset that enables organizations to include other requirements without modeling every project for each record. The proposed structure is based on a modular approach whereby evidence of technical, operational, commissioning, and acceptance properties is also included within a shared, controlled register. While conceived as a tool for traceability and review, it includes no assessment of its effect on review completeness, review time, or acceptance.

Table 3: Proposed 10-Module and 42-Record Renewable Substation Turnover Schema

Module	Core Record Classes	Number of Records	Purpose
Package Governance and Master Index	Document control, deliverable tracking, requirement ownership, package status	4	Establishes overall turnover management, accountability, and traceability

Module	Core Record Classes	Number of Records	Purpose
Final As-Built Drawings and Design Records	Final drawings, design documentation, revisions, engineering records, approved changes, as-built updates	6	Confirms that installed facilities match approved designs
Major Equipment Data and Ratings	Equipment specifications, ratings, technical data, manufacturer records, asset information	4	Provides verified equipment information for utility acceptance
Protection and Control	Protection philosophy, relay settings, configuration files, control records, testing documentation	5	Ensures protection and control systems align with approved requirements
Metering and Power Quality Documentation	Metering records, power quality information, measurement documentation, test evidence	4	Supports accurate monitoring, compliance, and operational verification
SCADA, Telecommunications, PMU and Cyber Interface Records	SCADA data, communication systems, PMU records, cyber/interface information	5	Enables reliable monitoring, communication, and utility operational control
IBR Models and Plant Controller Settings	Dynamic models, inverter settings, plant controller data, validation records	4	Ensures renewable resource models and controls represent installed conditions
Inspection, Testing and Commissioning Evidence	Inspection records, test reports, commissioning documents, functional verification, performance evidence	5	Demonstrates technical readiness before energization and operation
Operational, Compliance and Safety Records	Operating procedures, compliance records, safety documentation	3	Supports safe operation and regulatory requirements
Final Acceptance, Exceptions and Archive Records	Final approvals, exceptions, waivers, archived turnover records	2	Provides formal closure and long-term record retention

Table 3 shows the proposed ten phases, based on the documentation, technical requirements, commissioning evidence, and acceptance process classification of the substation turnover, presented as evidence classes. This provides a standardized way to manage information and a flexible approach that lets project teams tailor records to different utilities and project scenarios.

4.2 Minimum Metadata and Document Control Fields

The typical presentation of each record, associating technical evidence with the governing requirement and project phase, is suggested in the form of well-structured metadata. Fields suggested include Project Identifier, Substation/Asset, POC, Utility/Engineered system, Document Identifier, Document Title, Responsible Engineer, Requirement Source, Requirement Clause, Status of the requirement, Apply requirement, Lifecycle Phase Gate, Responsible Organization, Planned Due Date, Actual Due Date,

Revision, As-built, Approved Status, Approving Engineer, Evidence Location, Open comment, Exception Waiver Reference, and Final accepted date.

These fields clarify current ownership, change assignments, and required approvals, but they do not technically validate the process. A controlled Excel/CSV might help to get started, but the register could also be a database, common data environment, document management system, JSON manifest, or another project information management system within a wider programme.

4.3 Stage Gated Utility Readiness Logic

The study collected all this information and incorporated it into the required readiness gates in the schema. At Gate 0, the processes were Design Freeze and Pre-Backfeed. This included Approved Drawings, Approved Equipment Specifications, Protection Studies, Basic Network/Inverter models, and End Protection Designs. Gate 1 included energization, completion inspections, protection testing (PFMC), metering checks, SCADA checks, communications checks, collated electrical safety documentation, and formal documentation for energization authorization (Sayed & H. A. Gabbar, 2017). Gate 2 was using early synchronization. It verified controls, telemetry, correlation with models and settings, and readiness of the automatic voltage regulator and reactive power capability, and authorized the operator for frequency-control functions.

Gate 3 included commercial work and turnover. This included performance testing, set-list testing of the relay and control as-left, and acceptance documentation (K. S. Manoj, 2021). This included all documentation required for performance testing since all relays and controllers were changed as-left, models were validated, all punch-list items were addressed, exception paperwork was completed, and acceptance paperwork was finalized. Overall technical readiness was acceptable because it was staged across 4 gates rather than on a single date.

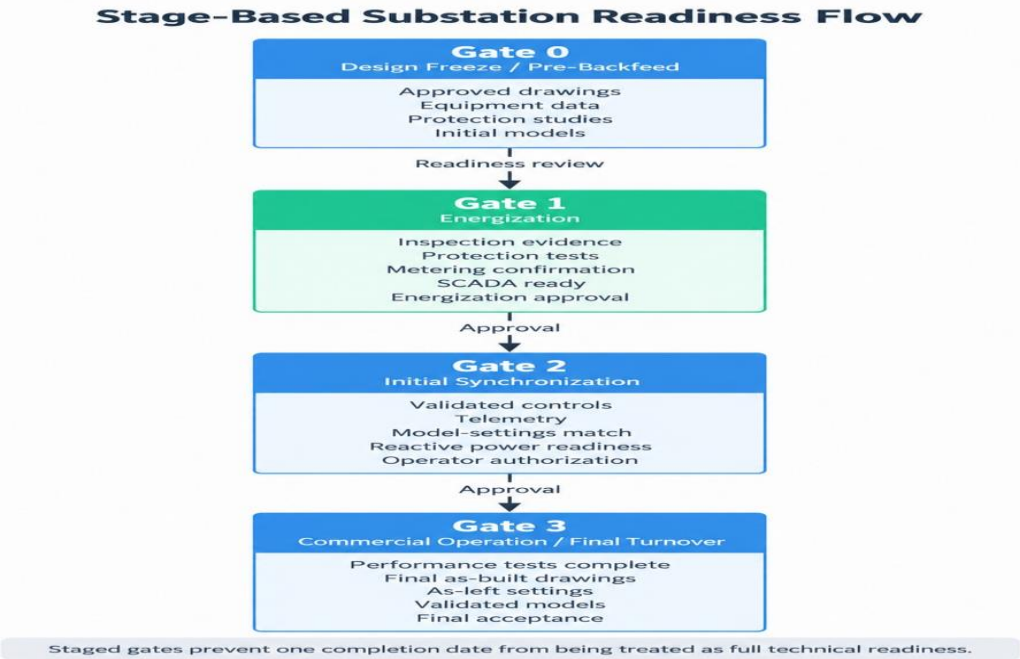


Figure 3: Stage-based workflow illustrating substation readiness gates from design freeze to final turnover.

Figure 3 shows the substation interface readiness workflow, including the specific allocation for each substation interface readiness workflow, technical records, and four operational gates. The framework sequence moves from design freeze to pre-backfeed, energization, initial synchronization, commercial operation, and final handover. Each gate is used to control and document the activities of testing, validation, and approval, which are completed as a path to technical readiness; each gate serves to transition to the next phase of the project.

4.4 Pre-submission Documentary Checks

The proposed package will look to mark documentary issues, prior to formal submission, such as missing records, revision conflicts, missing protection/commissioning test documentation, mismatch between approved and installed settings, lack of signatures or approval, items not addressed by punch list, incorrect file formats, late deliverables, and incomplete utility checklists. They are offered as checks that, in the writer's view, should precede submission but are not observed as rejection causes in this paper. The package's effectiveness in operation has not yet been proven, and it cannot replace any utility requirement or authorization.

5. Implementation and Discussion

5.1 National Context and the Limits of Queue Statistics

The national queue statistics provide a true understanding of the volume of interconnection activity. They do not measure substation turnover readiness, documentation rejection, or the effectiveness of the handover framework (Boff & S. E. Barrows, 2023). The proposed schema addresses the document organization problem only at the project interface and should not be taken as a remedy for queue congestion and interconnection delays in general.

5.2 Illustrative Utility and Standards Examples

The utility-specific examples above illustrate the need to track source, edition, clause, and applicability in requirements. They are illustrative and are not intended to be a universal checklist or common deadline. Project teams for individual projects are required to check existing governing documents and any applicable clauses for every project. Technical criteria and disturbance-monitoring criteria are not universal commercial turnover checks. The applicability and scope of a requirement on a particular project depend on the tariff to be regulated, the negotiated agreement, the adopted standard, the interconnection policy and requirements imposed, and the appropriate regulatory framework (Agupugo, Ajayi, Nwanevu, & S. S. Oladipo, 2022).

5.3 How the Proposed Schema Could Be Used

The governing documents should be identified at the project initiation stage, and the project team should create a requirements register (Dubey & D. D. Dubey, 2025). Each requirement should link to one or more record classes and include applicability, owner, due date, lifecycle gate, evidence file, revision, evidence review status, and any approved exception. The register should clearly distinguish between a requirement that applies to an absent document, a requirement that applies but is not triggered, and a requirement that is conditional but not triggered. The project team should review the updated document and decide whether the change impacts the deliverable, acceptance criteria, revision due date, or approval process.

The package coordinator can check the register before submitting it to the coordinator to ensure the required evidence is included, the changes are recorded correctly, there are no outstanding comments, and there are no discrepancies between installed and agreed-upon parameters, missing telemetry and metering information, or missing test records. These are suggested review checks and are not a list of rejection causes cataloged in a project sample based on logic in engineering document control. The utility's formal review and approval process still dominates.



Figure 4: Proposed Workflow for Managing Substation Turnover Requirements

Figure 4 illustrates the Project Turnover Requirements Workflow, which has 5 stages: Identify Requirements, Map Requirements, and Track Requirements for Evidence, Review Requirements for completeness, and Submit to the utility. The sequence is shown with blue icons, numbered circles, and arrows, and the key activities of each stage are explained with the subtitles.

5.4 Proposed Readiness Gates

The four proposed gates provide a planning structure only, and are not a replacement for formal utility milestones. Teams can reference approved drawings, design specs, protection studies, and network/inverter models at design freeze/pre-backfeed. Before energization, teams can confirm required inspections, protection trials, metering, SCADA, communications, safety documentation, and technical authorization (Anick & T. Kabir, 2022). At initial synchronization, the package can be correlated with the controls, telemetry, and evidence of model-to-setting correspondence and pertinent voltage-reactive power evidence. With commercial operation/final turnover, the register can also record any required performance tests, as-left configurations, changed models (if applicable), punch-list results, and final acceptance bookings. Project and applicable utility documentation must provide the actual prerequisites and authority for each gate to be released.

Table 4: Proposed Readiness Gates and Required Checks

Readiness Gate	**Key Checks**	**Required Evidence**
Design Freeze	Drawings, equipment specifications, protection studies, and models	Approved drawings and technical studies
Energization	Inspections, protection tests, metering, communications, and safety	Inspection reports, test results, and authorization
Initial Synchronization	Controls, telemetry, voltage, and reactive power	Control records and test results

Readiness Gate	Key Checks	Required Evidence
Commercial Operation / Final Turnover	Performance tests, final settings, updated models, and closure of outstanding issues	Final test reports, updated records, and acceptance documents

Table 4 provides a summary of four readiness gates that have been proposed: design freeze; energization; initial synchronization; and commercial operation. Each gate lists verification items and related documentation the project team must review to ensure they have the information needed for the gate review scientists and that all work is completed to specification, safe to use, and acceptable to move to the next stages.

5.5 Practical Implications and Evaluation Plan

The schema displays a document's ready state, revision history, source requirements, and ownership in one place. It enables development teams to coordinate output products and allows protection and control teams to link approved settings to test evidence, while commissioning and operations teams monitor open items and approvals. These are expected uses and not measured benefits. The paper does not necessarily indicate a decline in the number of papers rejected, or how many times the paper was submitted for review, or a shorter review timeline, or earlier energization.

The schema might be helpful for finished projects, then comparing before and after applying the schema, or comparing to other similar projects where possible. These measures include first-pass acceptance, number of resubmissions, number and type of deficiencies resolved through the decision gates between resubmissions, time from full submittal to decision date, and time from construction to energizing date. The evaluation should document the project size, technology, utility, requirements, and scope changes to avoid blaming the schema without supporting data. Documentary deficiencies should be coded as appropriate by the reviewer with pre-established definitions wherever possible, with preservation of the original comments attached to each deficiency.

6. Conclusions

This paper proposes a turnkey approach to standardizing renewable substation interfaces. The framework consists of four readiness gates, 42 core record classes, and 10 modules. It suggests metadata linking each deliverable to the governing source, clause, applicability, owner and responsible party, revision, where evidence is recorded, reviews, and the record of approval/exception. The main design intention is to make the technical proof more visible and more traceable, so that the requirements and authorization procedures for the different utilities are maintained.

The broad nature of U.S. transmission interconnection activity is reflected in the latest national queue statistics reported by Lawrence Berkeley National Laboratory, with examples of requirements varying at the tariff level, the procedure level, the connection standards level, and the technical standards level provided by PJM, ISO New England, ERCOT, AEP, IEEE, and NERC, respectively. These examples are offered with this understanding, and no attempt is made to be a fully or systematically coded comparison of utilities. The prevalence of the measured requirements, the extent to which they are covered by validated cross-utility, inter-coder reliability, or reduced utility reject rates are not provided in the paper.

The study's key contribution is that this structure utilizes a practical approach to organizing information in a way that caters to project-specific needs and fits well with

standard project information systems. Its drawbacks are that it is not based on completed turnover of project records and cannot be used to independently determine technical compliance or authorize energizing without completing the records. The framework should be further evaluated via project-level evidence with outcome measures such as first-pass acceptance, submission of repeats, unresolved deficiencies, and review/energization time. Until this evaluation is undertaken, the schema should be regarded as tentative engineering-management guidelines, not yet proven effective.

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