Unlocking India’s Renewable Grid

Policy-Driven Solutions to CON4 delay

Prepared by: Kumar M
19 April 2025

This publication purely reflects the personal views and professional observations of the author. The content herein is independent and does not represent the official position or viewpoint of Armax, Smart Grid Analytics Pvt. Ltd., or any affiliated organization or any references mentioned.

CHAPTER 1: INTRODUCTION

Given the ambitious aspirations of India being the global leader in renewables integration, maintaining grid stability becomes more complicated as the proportion of variable renewable energy (VRE) rises, particularly in transitory and fault circumstances. Integrating solar, wind, hybrid systems, and BESS calls for not just real-time control but also strong pre-connection testing, dynamic behavior modeling, and grid-friendly operational settings; they all fall under appropriate research and compliance.

This report looks at systematic, technological, and procedural causes of such delays, points out market-level knowledge gaps, and contrasts them with worldwide best practices, including AEMO's pre-approved model framework. It supports organized changes such as a national library of verified models and required field implementation alignment with study results.

Regulatory Evolution

Grid compliance was first established by the CEA (Central Electricity Authority) Technical Standards for Connectivity to the Grid (2007). Early editions, however, were vague on dynamic responses, fault ride-through, and inverter-based resources (IBRs). Fast forward to 2019–2025: India's grid code has been changed several times, finally reaching the IEGC 2023 and CON4 submission criteria under CERC GNA Regulations 2022.

These requirements currently call for thorough technical data comprising RMS (PSS®E) and EMT (PSCAD) simulation models benchmarked against certified type test results (Central Electricity Authority [CEA], 2023).

Through this regulatory maturity, actual execution encounters systematic constraints. Across India's RE projects, CON4 delays are currently the main cause of commissioning problems.

This study looks at the underlying reasons, contrasts India's strategy with that of Australia's AEMO DMAT framework, and offers a methodical solution comprising pre-approved model libraries, improved field-study alignment, and national training standards.

Reference:

Central Electricity Authority. (2023). *Technical Standards for Connectivity to the Grid (Rev. 0)*. Retrieved from https://cea.nic.in/

CHAPTER 2: ROOT CAUSES OF DELAY IN CON4 COMPLIANCE

2.1 Observations

A large share of project delays stem from incorrect or incomplete or quick simulation submissions. Models submitted in PSS®E or PSCAD formats often lack

- Correct SCR (Short Circuit Ratio) used at the POI.
- Voltage dips or reactive power profiles as per CEA's benchmarking guidelines.

Further complicating this issue is the **lack of a centralized model certification or validation system in India along with a coordinated vision of developers as well.** Developers frequently press for project-specific submissions using new or customized inverter and PPC models. Without a national registry or set of pre-approved models, **every submission becomes a fresh exercise in validation**, regardless of whether the same OEM and firmware version has already been tested for another project.

This approach leads to **redundant simulation efforts, increased regulatory burden, and growing approval timelines**. Instead of leveraging standardized, verified models—as practiced by AEMO through its pre-approved model registry—India currently processes each new model in isolation (Australian Energy Market Operator [AEMO], 2023).

. This has become a major bottleneck in the CON4 workflow, not due to the grid code itself, but due to **a fragmented and reactive modeling ecosystem**.

Key lessons from Chapter 3 demonstrate that AEMO mitigates these delays through

- A publicly maintained pre-approved model registry.
- Structured ownership and maintenance of models by OEMs.
- Submission templates that align with grid authority validation tools.
- Mandatory alignment between validated model parameters and field implementation.

India's absence of such mechanisms exacerbates modeling inefficiencies, with multiple projects using slightly altered models for the same OEM products, none of which are version-controlled or pre-certified.

2.2 Study-to-Field Implementation Gap

In many cases, studies are conducted accurately, but their recommendations are not implemented on site. This includes inverter control settings (Id/Iq during LVRT), PPC ramp rates, enabling of different modes transformer tap positions, and protection configurations.

For instance, during one project in Rajasthan, the approved CON4 submission specified a voltage dip response wherein inverters were expected to inject reactive current at a rate of 1.0 pu/s during LVRT conditions (50% voltage dip for 300 ms). However, on-site inspection revealed that the inverters had not been updated from factory defaults and were operating with a flat reactive current response curve. As a result, during a real grid fault observed in April 2024, the plant failed to support voltage recovery at the POI, triggering a full inverter trip event.

To mitigate this, India must adopt best practices seen in AEMO's DMAT, where developers must submit:

- Screenshots of active inverter control settings.
- PPC ramp rate profiles as configured.
- Time-stamped protection relay setting files.
- Confirmation from OEMs on successful deployment.

Without such auditable processes, the cycle of repeated approvals and retests will continue to delay India's renewable energy pipeline and undermine grid stability during dynamic events.

This illustrates a systemic problem: no field-level enforcement mechanism currently exists to verify that the modeled settings are uploaded and active in the actual devices. This disconnect results in failed validations, delayed energization, and regulatory penalties. (AEMO, 2023).

2.3 Fragmented Coordination Among Stakeholders

Projects often involve multiple vendors—OEMs, PPC vendors, relay integrators, EMS providers, and SCADA teams. Without a single-point ownership model, accountability for applying CON4 study settings is diluted. SLDCs are left unsure who implemented what.

In a 150 MW hybrid project in Gujarat, the simulation studies were approved with well-tuned PPC behavior, ramp limits, and LVRT settings. However, during final testing, grid disturbance events did not trigger the expected reactive support. It was discovered that the field team had not activated the respective Voltage Control Mode when they were supposed to, and PPC was only operating in Active Power Mode, and hence it did not respond.

In another 200 MW solar project, the vendors submitted their models separately without coordination. Each assumed the other would manage the overall control coordination logic. During commissioning, a frequency drop event led to both systems injecting power simultaneously in an uncoordinated manner, causing overshoot, followed by inverter trips. The SRLDC observed instability and withheld approval pending clarification and retesting.

Such examples highlight a **glaring need for unified project governance**, where a designated compliance coordinator ensures:

- All parties (OEM, SCADA, PPC, EMS, relay) adhere to the final approved settings.
- Final settings are locked and validated before energization.
- Responsibility is assigned for every control logic implementation (Parashar & Singh, 2021)

To reduce this fragmentation, India must adopt practices such as

- Appointment of a project-wide Technical Compliance Coordinator (TCC).
- Mandatory final settings validation checklists signed by all vendors.
- Integrated CON4 readiness audits with participation from SLDC, OEMs, and EPCs.

Without these structural reforms, even the best-designed studies and models will be rendered ineffective due to **misaligned stakeholder execution**.

2.4 Power System Knowledge Gap in the Market

One of the most fundamental challenges contributing to CON4 delays is the **lack of adequate power system modeling knowledge** across many consultants, EPC contractors, and field integrators. While India has built significant capacity in solar and wind deployment, the number of professionals with **specialized training in grid code compliance, EMT simulations, and real-time control behavior** remains very limited. (IEEE PES India Chapter & National Skill Council, 2022).

Many consultants rely on template-based RMS models, with little or no adjustment for site-specific characteristics such as transformer impedance, network short-circuit ratios, or dynamic load interactions. In some submissions, relay logic diagrams were lifted directly from OEM brochures rather than tailored to grid authority specifications. This lack of critical understanding not only leads to non-compliant submissions but also results in **delays in responding to revision requests from RLDCs or CTUs**.

This reflects a broader ecosystem issue where large-scale renewable projects are being executed without a core team of professionals trained in grid behavior modeling. Further, field teams often lack the interpretive ability to translate approved study documents into on-site inverter or relay configurations.

These issues are compounded by the absence of a national certification program or standardized training for:

- Dynamic modeling using PSS®E and PSCAD.
- Fault ride-through behavior and testing.
- Real-world inverter control calibration.

To resolve this, India must urgently:

- Establish mandatory certification programs under POSOCO or CEA.
- Develop a national consultant/engineer registry with levels of technical validation.
- Mandate that every CON4 submission must list a certified modeling engineer or models approved with the national library.

Until this knowledge gap is closed, India's ambition of advanced compliance enforcement will be undermined by **sub-par modeling quality and weak field adaptation**, irrespective of how strong the regulations are on paper.

2.5 Mandatory Validation of Settings Implemented in Field Devices

One of the most critically overlooked aspects of CON4 compliance is the absence of a structured verification system to ensure that the settings defined in simulation studies are **accurately implemented in field equipment** such as inverters, BESS controllers, PPCs, and protection relays.

While regulatory bodies such as the CEA mandate detailed LVRT, HVRT, and frequency response behavior in PSS®E and PSCAD studies, there is **no formal process that requires evidence of these settings being applied at the device/field level**. This creates a dangerous discrepancy: a study may pass simulation validation, but the installed plant may not respond correctly during real grid events (CEA, 2023).

For example, in a hybrid project in Madhya Pradesh, HVRT testing indicated inverter survivability at 1.3 pu for 0.2 seconds. However, due to a misconfigured overvoltage shutdown parameter (set at 1.2 pu), the inverters tripped prematurely during a real overvoltage event, negating the validated model response (Parashar & Singh, 2021).

Best practices from AEMO's DMAT process mandate that OEMs must submit evidence of field-level configuration. These include:

- Screenshots or exported configuration files of LVRT/HVRT settings.
- Verification of frequency, LVRT & HVRT settings implemented at the site.
- Matching of parameters in the device or least nearby values and also enabling all modes in PPC/EMS.
- Digital signatures and time-stamped confirmations by commissioning engineers (AEMO, 2023)

India currently lacks such enforcement. Often, the field engineers are unaware of the exact values approved in the simulation. Even when provided, **there is no centralized repository or audit system** to match study parameters with physical implementation.

To bridge this gap, the following must be made mandatory in the CON4 FTE checklist:

1. OEM-validated configuration reports (PDF/JPEG/CSV).
2. Time-stamped screenshots of all critical control and protection parameters.
3. Cross-verification sheet signed by the study consultant and site commissioning team.
4. Post-implementation bench test results to confirm dynamic response compliance.

Until such a system is put in place, grid events will continue to reveal gaps between compliance on paper and real-world performance, thereby undermining the intent of CON4 and grid code enforcement.

2.6 Overloaded Approval Pipeline

Another major contributor to delays in the CON4 process is the **overburdened and under-digitized approval workflow within** the regulatory and system operator ecosystem. While the CEA, CTU, and RLDCs have shown commendable initiative in defining comprehensive grid code requirements, the volume of project submissions has outpaced the capacity of the current review process.

Each CON4 submission involves multiple layers of scrutiny, including

- Verification of PSS®E and PSCAD model structures.
- Comparison with type test reports.
- Benchmarking of RMS and EMT dynamic responses.
- Alignment of simulation assumptions with actual POI parameters.
- Review of relay coordination settings and PPC logic.

Due to the absence of a centralized digital portal and automation tools, much of this evaluation remains manual, requiring line-by-line validation by technical officers who are often handling dozens of concurrent submissions. This leads to extended processing times, inconsistent reviewer feedback, and rework cycles that further burden the system.

Moreover, each region operates semi-independently, without shared access to validated models, test libraries, or version-controlled documentation. This creates duplication of effort when similar or identical components are submitted across multiple projects.

In addition, the lack of a dedicated queue management system or real-time submission tracking results in opaque timelines for developers. Many developers are unaware of the current status of their submissions, leading to premature site activities or mismatched project coordination.

To address this bottleneck, India must implement the following institutional and digital reforms:

- Develop a national **CON4 digital compliance portal** integrated with CEA and RLDC workflows.
- Introduce automated simulation validation engines to flag non-compliant settings and test deviations.
- Establish **model banks** and pre-approval shortcuts for verified components.
- Create **dashboard access for developers** to monitor approval stages, timelines, and reviewer feedback.
- Standardize submission formats and eliminate consultant-specific variations.

Without these systemic upgrades, even the most detailed grid code will continue to face implementation friction—not due to regulatory ambiguity, but due to process overload and under-digitization.
(CEA, 2023; CERC, 2022)

References

- Australian Energy Market Operator. (2023). *Generator Model Acceptance Guidelines*. Retrieved from https://aemo.com.au/consultations/current-and-closed-consultations/generator-model-guidelines
- Central Electricity Authority. (2023). Technical Standards for Connectivity to the Grid (Rev. 0). Retrieved from https://cea.nic.in/
- IEEE PES India Chapter & National Skill Council. (2022). *Technical Competency Framework for Smart Grid Engineers*. Retrieved from https://ieeepes.org/india-chapter/skill-grid-program
- Parashar, A., & Singh, S. (2021). Challenges in Grid Integration of Renewable Energy in India. *Energy Policy Journal*, 152, 112229. https://doi.org/10.1016/j.enpol.2021.112229

CHAPTER 3: INTERNATIONAL BEST PRACTICE—THE AEMO DMAT FRAMEWORK (AUSTRALIA)

3.1 Introduction to AEMO and Its Role

The Australian Energy Market Operator (AEMO) is the central body responsible for operating Australia's National Electricity Market (NEM). Recognizing the technical complexities associated with integrating large-scale renewable generation into a low-inertia power system, AEMO introduced a robust compliance and validation mechanism known as the **Dynamic Model Acceptance Test (DMAT)**.

This process is a cornerstone of AEMO's commitment to ensuring that all inverter-based resources (IBRs), including wind, solar, BESS, and hybrid systems, respond predictably and effectively to dynamic grid conditions (AEMO, 2023).

3.2 Key Features of the AEMO DMAT Process

3.2.1 Centralized Pre-approved Model Registry

AEMO maintains a public registry of pre-approved and validated RMS and EMT models for frequently used components such as inverters, BESS controllers, STATCOMs, and PPCs. Each model entry in this registry includes its operational envelope, benchmarked test results, and version history.

Developers using these models benefit from a faster review process, as the need for revalidation is minimized unless a change in control logic or configuration is introduced.

3.2.2 Structured Submission and Review Templates

The DMAT process mandates strict documentation protocols. Model submissions must include:

- RMS and EMT models in AEMO-specified formats.
- Test cases and simulated responses.
- Benchmark comparisons with type-tested curves.
- Model owner declaration (usually by the OEM).

This structure ensures that every submission is uniform, complete, and immediately traceable.

3.2.3 Ownership and Maintenance of Models

AEMO places the responsibility of model maintenance on the original equipment manufacturer (OEM). This prevents the proliferation of inconsistent or outdated versions of the same model. OEMs are required to notify AEMO of any changes in firmware, control logic, or model parameters and submit a revised model for validation. This guarantees consistency across all project deployments using a particular OEM platform.

3.2.4 Field Setting Validation and Auditability

Unlike India's current system, AEMO mandates that model compliance is validated against actual field implementation. The final project approval is contingent upon proof that the inverter, BESS, or PPC settings match those modeled. This is done through

- Time-stamped screenshots or exported setting files.
- Submission of firmware versions.
- Test reports comparing field response to modeled behavior.

This closes the loop between simulation and reality, ensuring system-wide stability.

3.3 Benefits Realized in the Australian Context

The DMAT framework has enabled AEMO to reduce project approval timelines, enforce consistent modeling quality, and maintain a growing repository of reusable and validated component models. Additionally, the approach fosters:

- Reduced regulatory rework cycles.
- Fewer field rejections during commissioning.
- Lower burden on system operators due to reduced duplication of effort.
- Increased accountability across developers and OEMs.

3.4 Relevance for India

India's scale of renewable deployment makes the need for a similar model registry and structured validation framework even more urgent. With over 200+ mandatory tests for RMS and EMT validation under CON4, the current project-specific and consultant-dependent approach is not scalable. By adopting AEMO's key principles—centralized model registration, OEM accountability, template-driven submissions, and post-installation audit enforcement—India can significantly reduce CON4 delays and elevate its grid readiness.

3.5 Summary of Actionable Learnings for India

AEMO Practice	Indian Gap	Suggested Reform
Central model registry	No national registry exists	CEA/NLDC-maintained model validation bank
OEM model ownership	Developer-submitted models dominate	Transfer validation responsibility to OEMs
Structured submission templates	Consultant-specific formats	Standardized digital templates via portal
Field-to-model consistency audit	No verification of site-level settings	Mandate audit with screenshots and reports
Reuse of validated models across projects	Redundant validations for same hardware	Enable project tagging of verified models

The AEMO DMAT framework provides a proven roadmap for scaling model compliance in complex, high-penetration renewable systems. By adapting its most effective elements, India can strengthen its CON4 enforcement ecosystem without reinventing its regulatory foundation.

References

- Australian Energy Market Operator. (2023). *Generator Model Acceptance Guidelines*. Retrieved from https://aemo.com.au/consultations/current-and-closed-consultations/generator-model-guidelines

CHAPTER 4: PROPOSAL—NATIONAL LIBRARY OF PRE-APPROVED MODELS

To streamline the model submission and validation process, India must establish a **National Library of Pre-approved Models** under the purview of CEA or NLDC. This library would act as a centralized repository for verified and certified component models that meet the dynamic performance standards mandated in the CEA Technical Standards and the CERC GNA regulations.

The library should include:

- Validated RMS (PSS®E) and EMT (PSCAD) models for all major inverter, BESS, STATCOM, and PPC vendors
- Associated firmware documentation and operational documents.
- Benchmark validation results from DMAT-equivalent testing.
- Model ownership attribution to OEMs, not developers.

The benefits of this initiative are significant:

- Developers can reference pre-approved models and reduce CON4 test cycles.
- System operators avoid reviewing repeated models for identical components.
- Model traceability improves transparency and regulatory compliance.
- Updates to models (due to firmware or logic changes) can be controlled centrally.

Adopting this model-centric registry approach will address many of the inefficiencies outlined in Chapter 2 and support a scalable, reliable renewable integration framework.

CHAPTER 5: STRATEGIC RECOMMENDATIONS FOR INDIA'S GRID COMPLIANCE REFORM

India's grid compliance ecosystem is maturing, but requires structural enhancements to match the scale and pace of renewable deployment. The following strategic actions are proposed to strengthen CON4 implementation:

Action Item	Justification
Launch CEA/NLDC Model Registry	Avoids redundant model validations and improves standardization
Transfer Model Ownership to OEMs	Ensures technical accountability and model consistency across projects
Mandate Audit of Field-Level Settings	Aligns simulated and actual inverter/PPC responses; closes study-site gap
Certify Modeling Consultants and Engineers	Builds a national talent pool and enhances study quality and interpretability
Automate RMS/EMT Validation	Reduces review cycle time; flags errors early using software tools
Integrate CON4 Status Tracker and Submission Portal	Improves transparency and timeline certainty for developers and SLDCs
Standardize Submission Templates Across India	Eliminates consultant-based variation and improves review efficiency
Incorporate DMAT Logic in CON4 Approval Matrix	Enables pre-rejection of poor-quality submissions; matches AEMO's effectiveness

These strategic reforms would not only accelerate project commissioning but also ensure the Indian grid remains stable, resilient, and compliant with international technical benchmarks.

CHAPTER 6: CONCLUSION

India's transition to a renewable-powered grid hinges on its ability to implement regulatory frameworks with precision and accountability. The CON4 process is critical in this journey, yet it is undermined by repeated modeling errors, fragmented execution, planning, no proper coordination with vendors, developers taking decisions at the last minute, and a lack of digital transparency.

Drawing from international best practices—particularly AEMO's DMAT structure—this paper makes a strong case for creating a model-centric compliance ecosystem in India. The establishment of a national pre-approved model library, combined with automated validation systems and post-study implementation audits, will fundamentally enhance the reliability of inverter-based resources.

To realize this vision, policymakers must institutionalize digital tools, centralize data governance, and expand the nation's technical workforce through standardized certification programs.

In doing so, India will not only de-risk its renewable pipeline but also build a grid that is robust, adaptive, and truly future-ready.

References

- Central Electricity Authority. (2023). Technical Standards for Connectivity to the Grid (Rev. 0).

Retrieved from https://cea.nic.in/

- Australian Energy Market Operator (AEMO). (2023). Guide to Generator Model Acceptance—DMAT Requirements.

Retrieved from https://aemo.com.au/consultations/current-and-closed-consultations/generator-model-guidelines

- CERC. (2022). General Network Access Regulations.

Retrieved from https://cercind.gov.in

End of Document