NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Dynamic Modeling Recommendations

Recommended Modeling Practices and List of Unacceptable Models

Primary Interest Groups

This document applies to Transmission Planners (TP), Planning Coordinators (PC), and MOD-032 designees. The recommendations are also relevant to Generator Owners (GO), original equipment manufacturers (OEM), consultants, and any other organization performing bulk power system (BPS) reliability studies.

Scope and Intended Use

This document replaces the NERC Acceptable Model List, which has historically been used to establish requirements and criteria for the creation of Interconnection-wide base cases by MOD-032 designees. The intent of this paper is to provide clear and more comprehensive recommendations regarding the use of dynamic models for different types of reliability studies. This paper particularly focuses on models used for dynamic stability analyses but does incorporate recommendations for other types of studies as well. MOD-032 designees shall incorporate the recommendations contained herein for their Interconnection-wide case creation processes; TPs and PCs are strongly encouraged to review and incorporate these recommendations in their modeling and study processes.

Recommended Dynamic Modeling Practices

NERC strongly recommends the following framework for dynamic models used in BPS reliability studies:

- All models should be detailed and accurate representations of expected or as-built facilities on the BPS, including during interconnection studies and throughout the lifecycle of a project.
- It is the responsibility of each TP and PC to establish clear, consistent, sufficiently detailed, and comprehensive modeling requirements. These requirements should include model quality checks and updates when needed.
- It is the responsibility of each project developer and GO to meet the modeling requirements established by the TP and PC and to provide adequate proof of conformance to the requirements. It is the responsibility of each GO to maintain an accurate model throughout the lifecycle of the project. GOs shall notify the TP and PC of any expected changes or updates (per NERC FAC-002) for in-service equipment and submit updated models accordingly.
- All TPs and PCs should require all of the following for each generator connected (or seeking interconnection) to the BPS to ensure that sufficient models and supporting documentation are provided:
  - A positive sequence library model that is on the list of unacceptable models found in **Appendix A** should not be provided. This model is often used by the MOD-032 designee for Interconnection-wide base case creation, and it is often used in studies to represent facilities outside of the TP/PC study area.

  - A positive sequence user-defined model (UDM)[1] should be used for system impact studies during the interconnection process and for local stability studies within the TP or PC footprint.
  - An electromagnetic transient (EMT) model is used to study specific BPS reliability issues in detail, specifically the interconnection of inverter-based resources. These types of analyses are becoming increasingly prevalent and necessary for systems with increasing levels of inverter-based resources.
  - All of the aforementioned models should be verified by the OEM to be accurately parameterized[2] to represent site-specific[3] controls, settings, and protections with supporting documentation and attestations. They should also be validated against actual product performance according to NERC Reliability Standards and local TP and PC requirements.[4]
  - A model benchmarking report should be prepared that compares all the aforementioned models against each other and documents any discrepancies across the models, including those due to software platform limitations. The benchmark reports should be available among neighboring PCs.
- MOD-032 designees have the responsibility of developing the Interconnection-wide base cases that are used as the starting point for TP and PC reliability studies.
- As required by the TP, PC, or MOD-032 designee, model packages, meeting operating requirements, and model acceptance criteria should be accompanied by detailed documentation. This should include user manuals, equipment manufacturer attestations, mapping between the model parameters, installed or to-be-installed facility settings, and benchmark reports that show matching performance between the models.
- Industry-approved standard library models are sufficient for use in Interconnection-wide base case creation but should be validated by the OEM and benchmarked against the equipment-manufacturer-verified EMT model or equipment-manufacturer-verified user-defined positive sequence model with the as-left or to-be-commissioned setting at the facility.

Dynamic models are used in reliability studies throughout the life cycle of a project. The recommended use of dynamic models across these studies varies based on the type of study being conducted, such as facility design studies, plant interconnection studies (feasibility studies, system impact studies, etc.) as references for the facility commissioning process,[5] annual transmission planning assessments, local reliability studies, large grid Interconnection-wide base case creation and studies, operational planning analysis, and real-time assessments. **Figure 1** illustrates how the different types of positive sequence models can be applied across the spectrum of studies. For all studies (including but not limited to those listed in **Figure 1)**, EMT models

[1] Also referred to "user-written model," the term "user-defined model (UDM)" is used throughout this document for uniformity.
[2] The default parameters listed in the library model software manuals are provided only as a starting point to prevent model initialization issues. Those parameters are not suitable replacements for site-specific parameters. Documentation showing how the library model was parameterized and compared to inverter and plant-level controller settings should be provided.
[3] While finalized plant settings are not available at this stage of the interconnection process, the models should be parameterized with control modes and parameters that are as reflective of the intended final design as possible. Model submitters should leverage publically available regional performance requirements and ensure appropriate parameters are reflected in the model to the best of their ability.
[4] "Model validation" involves comparing the simulated response against actual product performance; "model verification" refers to ensuring that model settings and parameters match the actual equipment installed in the field.
[5] The model used throughout the interconnection study process can be a reference for commissioning the facility will help close gaps between the modeled facility performance and the performance of the actual facility.

should be used if positive sequence simulation platforms or models are insufficient, or if high accuracy is desired.

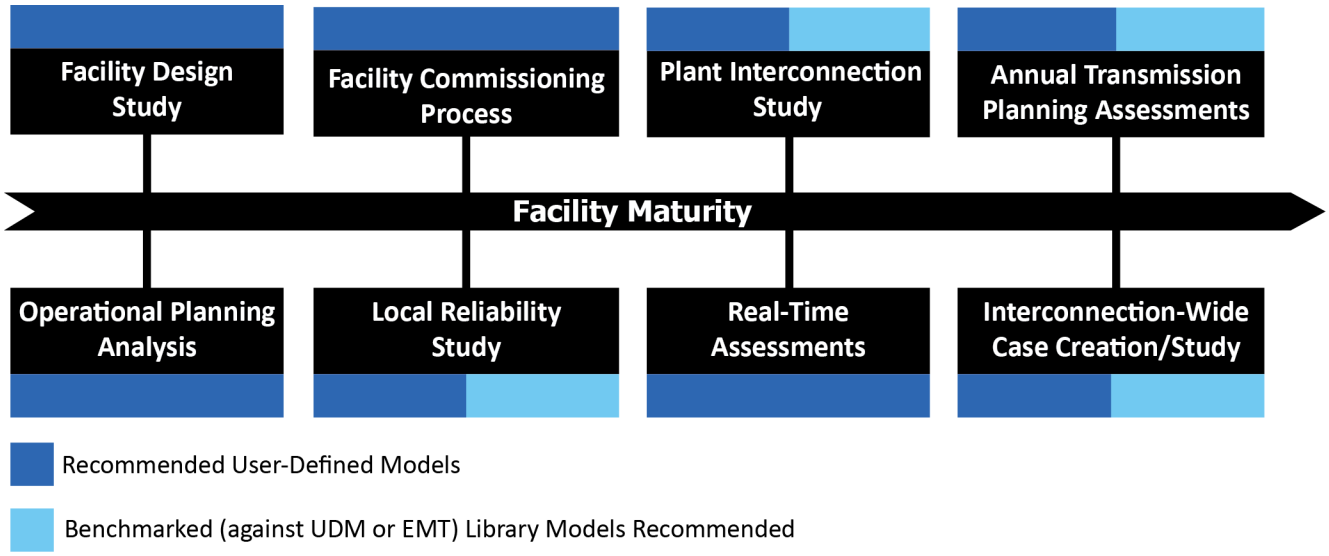

Figure 1: Recommended Dynamic Modeling Practices[6]

Positive Sequence User-Defined Models

Accurately parameterized, manufacturer-verified, and user-defined models should be used for detailed reliability studies, such as during interconnection system impact studies, as references during the facility commissioning process and local reliability studies. For example, a PC modeling the resources in their footprint during their TPL-001 annual planning assessment should use the more detailed UDMs in their area (and neighboring footprint(s)) while the rest of the Interconnection would be represented with library models from the Interconnection-wide base case. UDMs should be used for any studies or parts of the network that require accuracy and fidelity and that are not available in library models.

Equipment manufacturers should provide both UDM and library models for the equipment installed or to be installed at a facility. Included in the model packages, the equipment manufacturers should clarify the differences across models in terms of model accuracy and fidelity as well as to provide justification regarding when each model should be used. With both model types available as well as a detailed description of the limitations and best uses of each model, GOs, TPs, and PCs should have enough information to use engineering judgement to determine which model is most appropriate for each study. Additionally, once a facility is accurately represented with a UDM, the library model can then be benchmarked against the site-specific UDM performance by the GO or their third-party consultant.

[6] NERC recommends using user-defined models; when unavailable or when the library model has been sufficiently benchmarked, the library models may be acceptable.

A UDM should only be considered acceptable by a TP and PC if the following usability requirements are met:

- A model validation report is provided that compares the actual equipment performance against the EMT, positive sequence UDM, and library models.[7]
- A model benchmarking report is provided that compares the response of models across each platform.
- The UDM should include compiled .dll files such that no additional compiling is required by the end-user.
- The UDM should be accompanied by sufficient documentation[8] for the TP and PC:
  - Properly integrate the facility model(s) into network model
  - Understand control modes and applicable parameter functions
  - Understand the facility ratings and capabilities
  - Initialize models appropriately in reliability studies

Portions of UDM may be "black boxed" to protect intellectual property. This is generally considered acceptable so long as sufficient documentation is provided and applicable control settings are exposed to the end-user so that they can be parameterized appropriately.

Positive Sequence Library Models

Library models should generally not be used for detailed reliability studies, particularly in and around the study area due to a lack of model accuracy and fidelity to represent the actual equipment controls and protections. Unique situations may exist where equipment manufacturers attest that the library models sufficiently represent the actual installed equipment controls and protections; however, most equipment manufacturers advocate that UDMs are more appropriate for these detailed studies. This is particularly applicable for BPS-connected inverter-based resources.

Library models are often used by the MOD-032 designees to create the Interconnection-wide base cases, so TPs and PCs should require submittal of a positive sequence library model in conjunction with a UDM for all facilities. The models should be benchmarked by the GO against actual facility or site-specifically parameterized EMT or UDM model. Models used as the benchmark for the library should be parameterized to match the commissioned facility such that the resulting benchmarked library model is as representative of the facility as possible. Gaps between the library model and UDM performance should be documented and mitigated if possible.

[7] Performance differences between real equipment, user-defined EMT, and user-defined positive sequence models should be minimized as manufacturer-verified models and these models should provide the highest accuracy and fidelity. Performance differences between the manufacturer-verified models and the library models display the limitations of the library models.

[8] Model validation test reports, user manuals, capability curves, etc. may also be supplemented with block diagrams; however, block diagrams are highly proprietary and may not be applicable to real-code integrated user-defined models.

Models for MOD-032

The MOD-032 designees are responsible for establishing model requirements[9] for the Interconnection-wide base cases that include defining models considered acceptable and/or recommended. These requirements must account for and incorporate[10] the NERC list of unacceptable models (provided in **Appendix A**). The MOD-032 designee, working with their respective TPs and PCs, will determine appropriate modeling requirements for the Interconnection-wide base case that include whether UDMs will be deemed acceptable in the base cases. Practices vary across each Interconnection for legitimate reasons that include model usability and interoperability across entities.

As modeling practices evolve, some models may transition from acceptable to unacceptable. GOs will be responsible for adhering to changes to the TP, PC, and MOD-032 designee modeling requirements and may need to update their models accordingly, as needed. MOD-032 designees should have a change management process in place for model updates to reflect as-built facilities for these changes.

All applicable entities should ensure they remain compliant with all MOD-032 designee requirements as well as any local TP and PC modeling requirements established.

Electromagnetic Transient Models

Conventional positive sequence simulation tools used by TPs, PCs, TOPs, and RCs may be inadequate for identifying reliability risks in certain systems with high penetrations of inverter-based resources. Electromagnetic transient simulations are needed to accurately identify possible reliability risks when integrating inverter-based resources. All EMT models used to represent actual installed (or planned) facilities should be an accurate representation of site-specific controls and protections and comprise of validated equipment EMT models.

TPs and PCs should establish EMT model quality requirements that define the acceptability of submitted EMT models. EMT models should meet the quality criteria as follows:

- Include a complete, full, and accurate representation of the inverter-based resource
- Represent all pertinent controls and protections that affect the electrical output of the facility
- Include attestations from the equipment manufacturer(s) and GO that the model matches site-specific equipment, controls, and protection
- Accompanied by reports on unit model validation, plant model verification, and benchmarking against corresponding positive sequence model

[9] WECC maintains an approved dynamic model list for the Western Interconnection, the Eastern Interconnection Reliability Assessment Group Multiregional Modeling Working Group maintains an approved dynamic model list for the Eastern Interconnection, and the Texas RE coordinates with the Electric Reliability Council of Texas to maintain an approved dynamic model list for the Texas Interconnection.

[10] The MOD-032 designee must incorporate the NERC unacceptable model list in their model requirements. The MOD-032 designee's unacceptable model list can be more prescriptive than the NERC unacceptable model list. Furthermore, the MOD-032 designees may develop phase out plans for models deemed unacceptable.

- Include detailed documentation sufficient for end-users to understand control loops and associated parameter functions necessary to functionally use the model and to incorporate equipment models into aggregate facility models[11]

Geomagnetic Disturbance Modeling

NERC TPL-007 intends for MOD-032 to be used for gathering adequate modeling data for geomagnetic disturbance (GMD) studies.[12] TPs and PCs should leverage MOD-032 Attachment 1 for collecting GMD data and should require supporting information to conduct GMD vulnerability assessments that include, but are not limited to, the following:[13]

- Winding and phase configuration
- Terminal voltages
- DC system model equivalents
- Thermal and electrical limits of the transformer windings
- Supplemental or known Earth conductivity of the grounded transformers
- Substation grounding

Contact Us

Feel free to contact the NERC Advanced System Analytics and Modeling department (advancedsystemanalyticsmodeling@nerc.net) with any questions or to discuss any dynamic model concerns.

[11] TPs and PCs are expected to use the models as submitted and are not expected to tune or otherwise make changes to the models submitted by GOs. Any issues observed should be communicated to GOs.

[12] https://www.nerc.com/pa/Stand/Project201303GeomagneticDisturbanceMitigation/Consideration_of_Comments_GMD_TPL-007-1_10292014.pdf

[13] https://www.nerc.com/pa/RAPA/GMD/RefDocs/GMD_Data_Reporting_Instruction.pdf

Appendix A: NERC Unacceptable Model List

Table A.1 is a list of models deemed unacceptable due to proven modeling errors, numerical issues, or those that have been phased out of use for other reasons. The known unacceptable model name column is provided only for clarity in major commercial software programs, and it is not intended to be an exhaustive naming list across all software platforms. The model description column provides a name of each associated model for reference.

Table A.1: Unacceptable Model List

Known Unacceptable Model Name	Model Description
Renewable Energy Models	
WT3G1,WT3G2, wt3g	Generic Type 3 WTG Generator/Converter Model - Doubly-fed induction generator
WT4G1,WT4G2, wt4g	Generic Type 4 WTG Generator/Converter Model - Variable speed generator with full converter
WT3E1, wt3e	Generic Type 3 WTG Electrical Control Model
WT4E1,WT4E2, wt4e	Generic Type 4 WTG Electrical Control Model
WT3T1, wt3t	Generic Type 3 WTG Turbine Model
WT3P1, wt3p	Generic Type 3 WTG Pitch Control Model
WT12A1, wt1p,wt2p	Generic Type 1 and 2 WTG Pitch Control Model
WT4E1, wt4t	Generic Type 4 WTG Power Converter Model
wt4p	Generic Type 4 Pitch Control Model
REECB1,REECBU1, reec_b	Generic Phase 2 PV Electrical Controls Model
genwri	Vestas Model of Wound-Rotor Induction Generator (with Variable External Rotor Resistance)
exwtg1	Vestas Model of Rotor Resistance Control for Wound-Rotor Induction WTG
wndtge	GE Wind Turbine Control Model - Doubly Fed Induction Generator (DFIG) and Full Converter (FC) Models
gewtg	GE Wind Turbine Generator/Converter - DFAG and FC Models
exwtge	GE Wind Turbine Excitation (converter) Control Model for DFAG Generators
wndvar	GE Wind Turbine Plant-Level Supervisory Voltage/VAR Control
Machine Models	
GENSAL, gensal	Salient Pole Generator Model (IEEE Std 1110 §5.3.1 Model 2.1)
GENCLS, gencls	Classical Generator Model (IEEE Std 1110 §5.4.2)
GENTRA	Transient Level Generator Model
Excitation System Models	
texs	General Purpose Transformer Fed Excitation System
SEXS, sexs	Simplified Excitation System
EX2000	GE EX2000 Excitation System
Current Compensation Models	
COMPCC, ccomp	Cross and Joint Current Compensation Model
Turbine-Governor Models	
lm2500	LM 2500 Aero-Derivative Gas Turbine Governor Model
lm6000	LM 6000 Aero-Derivative Gas Turbine Governor Model
URGS3T, gast	WECC Gas Turbine Governor Model

Table A.1: Unacceptable Model List	
GAST	Gas Turbine-Governor Model
GAST2A	Gas Turbine-Governor Model
GASTWD	Gas turbine-governor
IEEEG2	1981 IEEE Type 2 General Approx. Linear Ideal Hydro Model
WESGOV	Westinghouse Digital Governor Model for Gas Turbines
Load Models	
motorc	Phasor Model of Single-Phase Air-Conditioner Compressor Motor
Protection and Other Models	
mslr1	Mechanically Switched Line Reactor

Appendix B: Revision History

Table B.1: Revision History		
Version	**Comments**	**Approval Date**
1.0	Initial Release	July 2023