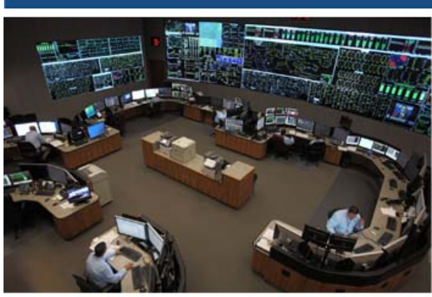
NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

NERC Modeling Improvements Initiative Update

Technical Report

May 2018

RELIABILITY | ACCOUNTABILITY

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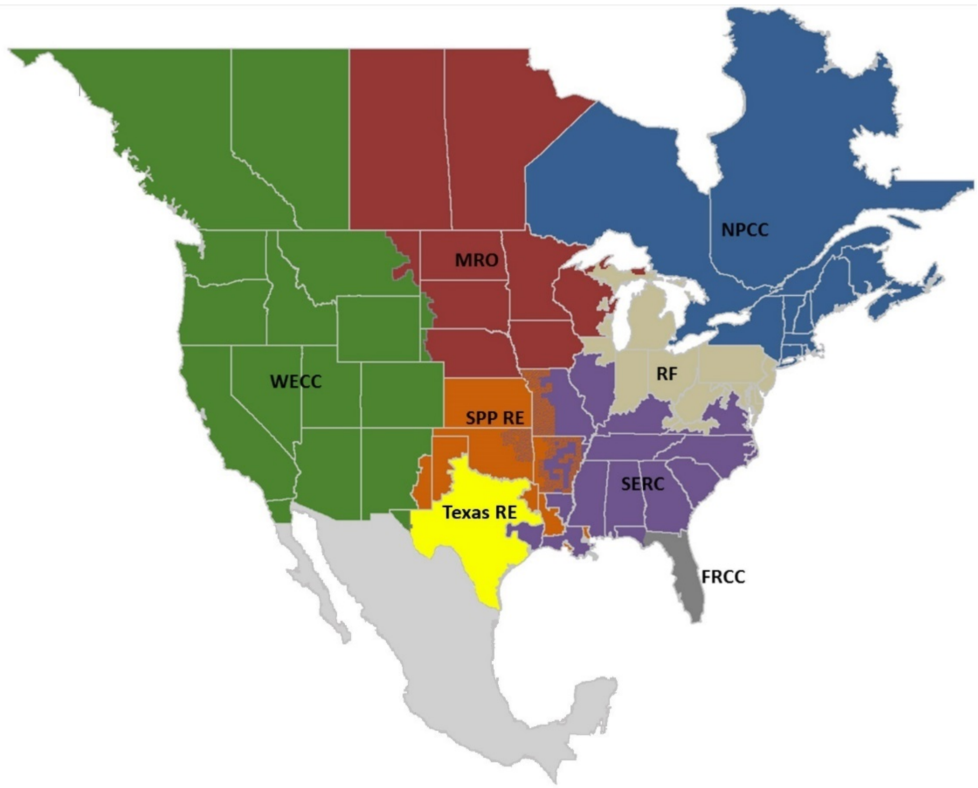
Preface

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to assure the reliability of the bulk power system (BPS) in North America. NERC develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the BPS through system awareness; and educates, trains, and certifies industry personnel. NERC's area of responsibility spans the continental United States, Canada, and the northern portion of Baja California, Mexico. NERC is the electric reliability organization (ERO) for North America, subject to oversight by the Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada. NERC's jurisdiction includes users, owners, and operators of the BPS, which serves more than 334 million people.

The North American BPS is divided into the eight Regional Entity (RE) boundaries, as shown in the map and corresponding table below.



The Regional boundaries in this map are approximate. The highlighted area between SPP and SERC denotes overlap as some load-serving entities participate in one Region while associated transmission owners/operators participate in another.

FRCC	Florida Reliability Coordinating Council
MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	Reliability First
SERC	SERC Reliability Corporation
SPP RE	Southwest Power Pool Regional Entity
Texas RE	Texas Reliability Entity
WECC	Western Electricity Coordinating Council

Executive Summary

The electric industry continues to undergo rapid changes in generating resource composition, which presents new challenges to planning and operating the bulk power system (BPS). Innovative new technologies continue to be introduced to the market to address these challenges. Throughout this process, BPS reliability and resilience continues to be of paramount importance. One aspect of maintaining reliability is the assurance that the mathematical models used to assess the future and past performance of the BPS are an accurate representation of equipment installed. These models are included in base cases used for steady-state and dynamic simulations. The interconnection-wide cases are created by the designees identified by NERC ("MOD-032 Designees") under Reliability Standard MOD-032-1, *Data for Power System Modeling and Analysis*. NERC has embarked on a modeling improvements initiative to ensure that the interconnection-wide cases have a high degree of accuracy and fidelity. This initiative includes close coordination with industry stakeholders, modeling experts, software vendors, and the MOD-032 Designees. This report provides an overview of the various NERC modeling improvements efforts and also describes each of the milestones reached. These efforts are to support the electric industry related to the following standards:

- **MOD-025-2:** Verification and Data Reporting of Generator Real and Reactive Power Capability and Synchronous Condenser Reactive Power Capability
- **MOD-026-1:** Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions
- **MOD-027-1:** Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions
- **MOD-032-1:** Data for Power System Modeling and Analysis
- **MOD-033-1:** Steady-State and Dynamic System Model Validation

Recommendations

As NERC continues to support model improvements and advance modeling practices across the industry, the following recommendations are for NERC efforts moving forward:

- NERC should continue strengthening the feedback loop with the MOD-032 Designees. This includes continuing to track the case improvements of the MOD-032 Designees and their efforts to improve processes and procedures to effectively create and maintain the interconnection-wide cases.
- NERC should continue working closely with industry to develop Modeling Notifications for specific modeling issues deserving industry attention. NERC should ensure that these notifications are widely disseminated to the industry for their awareness.
- NERC should continue performing the annual Case Quality Metrics Assessments to track the effects of the NERC MOD-026-1, *Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions*, and MOD-027-1, *Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions*, standards implementation as well as efforts of the MOD-032 Designees.

The following areas should be a primary focus for NERC and the electric industry in the near term to ensure sufficient and effective models and modeling practices:

- As technology continues to evolve, the dynamic models used to represent actual physical equipment will need to evolve as well. This includes ensuring that the generic models used in interconnection-wide cases are able to accurately represent inverter-based resources.

- Software vendors should ensure that implementation of the available models occurs in a timely and effective manner such that planners and operators of the BPS can use these models in their reliability assessments.
- As the penetration of distributed energy resources (DERs) continues to grow in multiple regions, the capability to model DER becomes a prominent focus. Many software platforms have limited capability to model DER, and this poses a potential reliability risk. Software vendors, working closely with industry stakeholders and NERC technical committees, should prioritize uniform implementation of DER models to account for these resources.
- While turbine-governor models are fairly mature and capable to capture the dynamic behavior of these systems, many resources on the BPS operate in a different mode or have plant-level controls that override the governor response. While governor response may be verified by test as part of MOD-027-1, the on-load response of the resource does not match the modeled response. Continued focus on improving the model representation of on-load behavior of turbine-governors should be a high priority for NERC, Generator Owners, Transmission Planners, and Planning Coordinators.
- Large disturbance response of resources is typically not testable and therefore not captured as part of the performance-based NERC Reliability Standards. Conventionally, synchronous resource response was driven by physics that could be mathematically modeled with sufficient accuracy. However, the response of inverter-based resources is predominantly driven by the controls programmed into the inverters. These controls are not well understood and some aspects are not captured by the current state of generic models for inverter-based resources. For example, this includes the various aspects of momentary cessation the recovery from momentary cessation. Industry should continue improving the generic renewable energy system models based on the studies and findings developed by industry and NERC.
- Load modeling continues to be a challenge, and continued focus on improving load models and modeling practices should continue in the NERC Load Modeling Task Force (LMTF). This includes ensuring the models are flexible to represent different types of end-use loads, understanding how the aggregate end-use load behavior is changing with new technologies, and developing verification techniques to ensure that the models reasonably match actual performance.

Introduction

The bulk power system (BPS) is represented in simulation tools as mathematical models of individual components and their control systems. These models form the foundation of power system studies performed in the planning and operations horizons. Ensuring accurate models is critical to a range of reliability studies including transmission planning assessments, setting Interconnection Reliability Operating Limits (IROLs), performing Real-Time Assessments (RTAs), and state estimation. As the BPS is operated with tighter margins and with greater variability, it is increasingly important that the models used to perform these assessments provide accurate steady-state and dynamic representations of BPS performance. Typically, planning models are separated into the steady-state powerflow representation and an accompanying dynamics model database for stability assessments.[1]

The State of Modeling Report is intended to provide an overview of the power system modeling, modeling improvement initiatives, and system analysis activities that are ongoing at NERC. Many of these activities are collaborative with industry members, modeling experts, software vendors, academic institutions, national laboratories, and research institutes. The NERC System Analysis and Modeling Subcommittee (SAMS) serves as the technical stakeholder group that facilitates many of these activities to move the industry forward collectively. On the other hand, some of the activities described in this report are driven through NERC's independent assessment of interconnection reliability. These assessments may focus on a range of topics, from frequency response to short circuit strength to inverter behavior during transient grid conditions. They help inform industry and policymakers of potential trends in grid performance, as well as possible mitigating actions to ensure reliability. In addition, these assessments have proved to shine a light on additional modeling improvements and assessment techniques that may be needed by industry. In essence, they further inform future model improvements working collaboratively with industry.

The NERC MOD Standards set the foundational requirements for power system modeling in North America. The following standards are particularly related to the creation of interconnection-wide models and the accuracy of these models:

- **MOD-025-2:** Verification and Data Reporting of Generator Real and Reactive Power Capability and Synchronous Condenser Reactive Power Capability
- **MOD-026-1:** Verification of Models and Data for Generator Excitation Control System or Plant Volt/Var Control Functions
- **MOD-027-1:** Verification of Models and Data for Turbine/Governor and Load Control or Active Power/Frequency Control Functions
- **MOD-032-1:** Data for Power System Modeling and Analysis
- **MOD-033-1:** Steady-State and Dynamic System Model Validation

Much of the work described in this report focuses on the interconnection-wide powerflow and dynamics cases developed for industry. These models are created as part of NERC Reliability Standard MOD-032-1. These cases are developed in each interconnection by a "MOD-032 Designee", which are the Regional Entities[2] for each of the three interconnections. NERC coordinates closely with the MOD-032 Designees to ensure that the available models are used appropriately and that the interconnection-wide cases are created accurately. The MOD-032 Designees are also critical in many assessments performed by industry, and in ensuring that model improvements are made to the interconnection-wide cases over time.

[1] Other models (e.g., for resource adequacy or electromagnetic transient studies) also exist and are used for specific purposes. However, these are not the focus of the steady-state and dynamics models discussed in this report.

[2] In the Western Interconnection, this is WECC. In the Texas Interconnection, this is Texas RE. In the Eastern Interconnection, this is the Eastern Interconnection Reliability Assessment Group (ERAG), which consists of the Regional Entities of the Eastern Interconnection.

Chapter 1: Interconnection-Wide Case Creation

Efficient and effective processes for interconnection-wide case creation are crucial to developing models that are high quality and accurately reflect performance of the BPS. NERC Reliability Standard MOD-032-1 establishes a framework for "consistent modeling data requirements and reporting procedures for development of planning horizon cases necessary to support analysis of the reliability of the interconnected transmission system". MOD-032-1 establishes the concept of a "designee" (referred to herein as "MOD-032 Designee") that NERC can designate to fulfill the role of creating the interconnection-wide planning cases. The MOD-032 Designees develop these cases, working collectively with their Planning Coordinator stakeholders. To ensure an effective and efficient process, NERC has signed Designee Agreements with each of the selected MOD-032 Designees that describe the functions and attributes that shall be carried out by the MOD-032 Designee. The Planning Coordinator[3] and equipment owner[4] activities are specified in MOD-032-1. A high-level overview of the case creation process, and MOD-032-1, is shown in Figure 1.1.

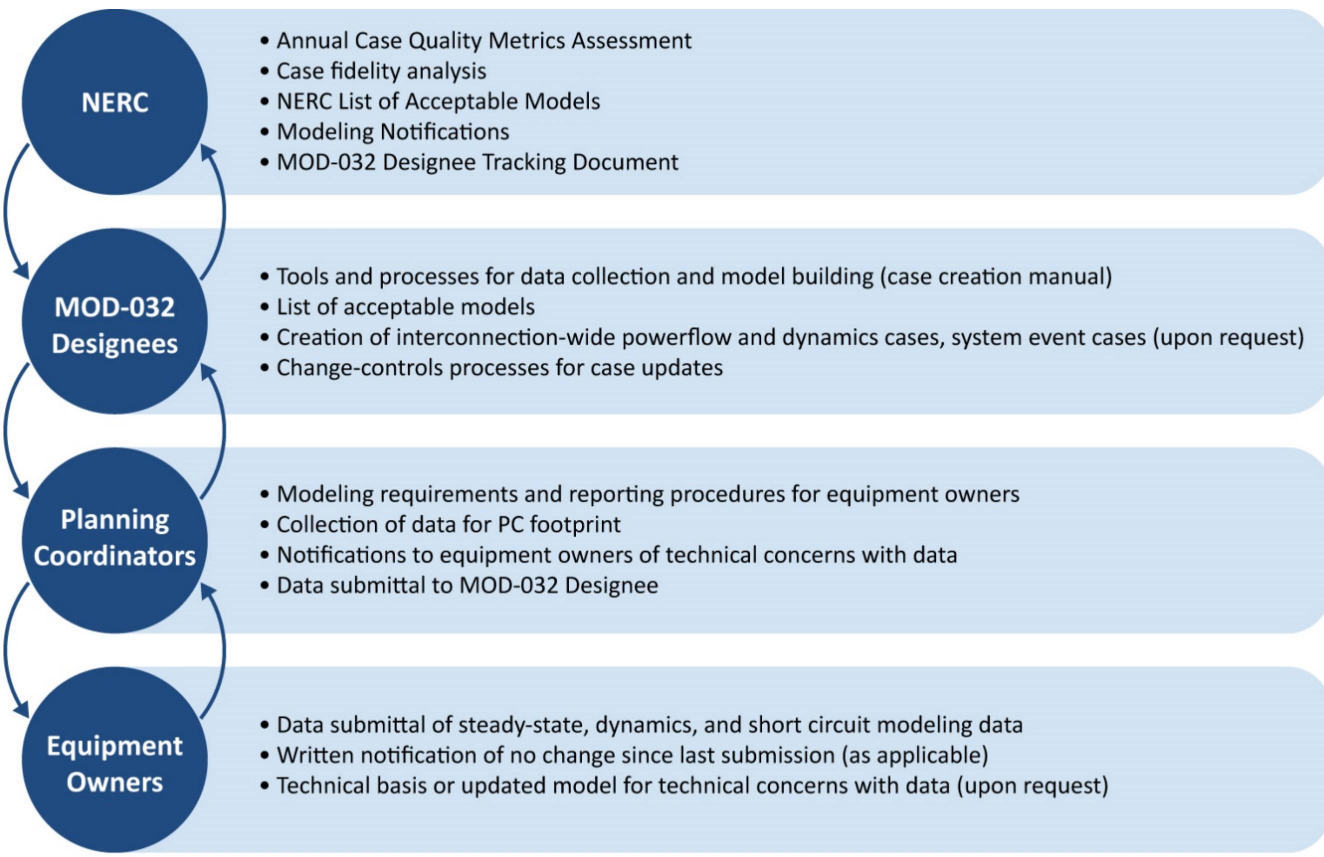


Figure 1.1: MOD-032 Designee Coordination

This chapter describes some of the activities underway and recent milestones in developing feedback loops between NERC, the MOD-032 Designees, and the Planning Coordinators. The overall goal is to improve the processes and tools used to create the interconnection-wide cases, which will effectively ensure higher quality cases in the future.

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[3] Some of the functions pertaining to the Planning Coordinator also relate to the Transmission Planner. Refer to MOD-032-1 for specific details.
[4] The applicable entities related to MOD-032-1 are the Balancing Authority, Generator Owner, Resource Planner, Transmission Owner, and Transmission Service Provider.

Interconnection-Wide Modeling Framework

The creation of interconnection-wide powerflow and dynamics cases for use in the planning horizon revolves around the MOD-032 Designees and their process working with the Planning Coordinators. Powerflow and dynamic models are provided to Planning Coordinators by the equipment owners, and the MOD-032 Designee has established processes and procedures to handle the aggregation of these models and development of the base cases. Those cases are used by the Transmission Planners and Planning Coordinators, as well as NERC staff in Planning Assessments, regional planning studies, and interconnection-wide system analysis. An illustrative flowchart of the overall process of case creation, and its related activities, is provided in Figure 1.2.

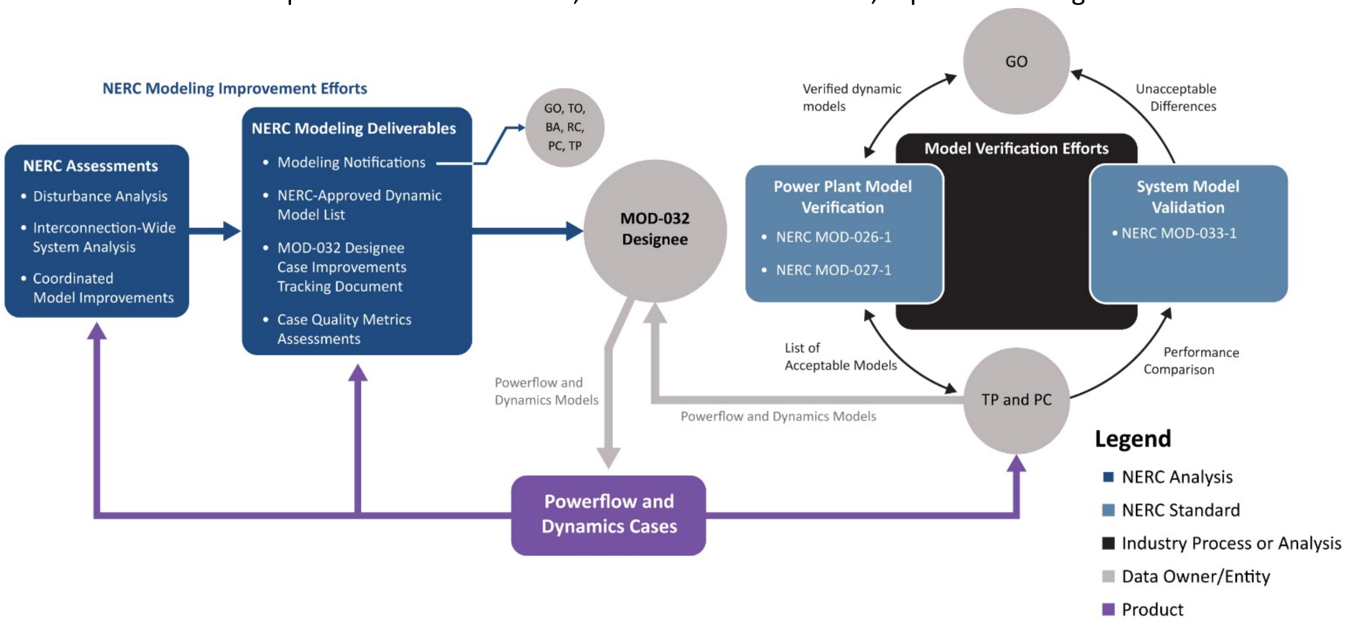

Figure 1.2: Flowchart of MOD-032-1 and the Interconnection-Wide Case Creation

NERC performs a number of assessments that support continuous improvement of industry modeling practices. This includes analysis of large disturbances (which includes a modeling aspect to develop a sequence of events and to benchmark the model against the actual disturbance); forward-looking assessments of system stability, frequency response, and other interconnection-wide phenomena; and coordinated model improvement simulations with industry. These assessments feed into key deliverables that NERC produces on a regularly or semi-regular basis. The deliverables are provided to the MOD-032 Designee and also made publicly available to industry on the NERC website for reference and future use. Deliverables created by NERC to support interconnection-wide modeling improvements include:

- New Modeling Notifications to share important modeling aspects with specific entities
- Updates to the NERC Approved Dynamic Model List
- Updates to the MOD-032 Designee Case Improvements Tracking Document
- Annual NERC Case Quality Metrics Assessment

Equipment owners provide data to the Planning Coordinators and Transmission Planners, per their data requirements and reporting procedures, as described in MOD-032-1. The MOD-032 Designee then gathers the data submitted to the Planning Coordinators. Generator Owners ensure accurate dynamic models based on the requirements of MOD-026-1 and MOD-027-1, and provide those models to the Transmission Planner. The Transmission Planner provides the Generator Owners with a list of acceptable models and also provides oversight for identifying potential modeling issues or errors in the data submitted. The Planning Coordinators also perform system model validation to ensure that models in their footprint can accurately recreate system disturbances.

This process may identify potential generator models, or other dynamic models, that may need to be revisited to achieve a match between modeled versus actual response.

MOD-032 Designee Coordination and Case Improvement Tracking

To develop and strengthen a feedback loop between NERC and the MOD-032 Designees, all parties have created a working document that captures the efforts underway to improve the quality and fidelity of the interconnection-wide cases. This document includes the following items:

- MOD-032 Designee and NERC contacts for case improvements
- NERC Case Quality Metrics documentation
- NERC Case Quality Metrics Assessment results
- NERC case fidelity findings and recommendations for MOD-032 Designee improvements
- NERC Approved Dynamic Model List
- MOD-032 Designee Approved Model Lists
- MOD-032 Designee tracking of case quality improvements

Many of these topics are described in more detail throughout this report. As NERC continues to develop its tracking metrics and support industry modeling improvements, NERC will continue to coordinate with the MOD-032 Designees in an effort to ensure these improvements are acted upon.

The MOD-032 Designee Case Improvement Tracking document can be found here.

NERC Approved Model List

Mathematical models of power system elements used in the simulation tools for planning and operating the BPS have evolved over the many decades since their early inception. The models that are available in the commercial software tools commonly used for these purposes are of different vintage, capability, and purpose. For example, some models were developed over forty years ago with limited computational capability while others have been developed for very detailed representation of equipment for specific reasons. While the manuals and instruction guides for these tools do cover some of these aspects, it is not expected that each tool fully track the applicability, accuracy, and preferred usability of each model. Furthermore, while some models would be considered obsolete in the North American system, they may be applicable in other parts of the world and are therefore kept in the standardized model libraries.

The NERC System Analysis and Modeling Subcommittee (SAMS) has developed a *NERC List of Acceptable Models for Interconnection-Wide Modeling* to aid TPs and PCs in the creation of their portion of the interconnection-wide models developed by the MOD-032 Designees. The list focuses on dynamic models across multiple software platforms and identifies:

- Models that are not recommended: Other models may be more appropriate for use. While existing models in the cases may still use these models, their future use is discouraged. Resubmission of models as per MOD-026-1 and MOD-027-1 for existing resources should convert the existing model to a more representative model.
- Models that should be prohibited: Use of these models for new resources or resources re-certifying their models as per MOD-026-1 and MOD-027-1 should be prohibited, unless specifically acceptable by the Modeling Designee for interconnection-wide base case creation. Known modeling issues, errors, or deficiencies exist with this model. Modeling Designees should consider proactive actions to move towards more representative and accurate models.

While the list developed and maintained by NERC is not directly enforceable, the PCs and TPs have the ability to set steady-state, dynamics, and short circuit modeling data requirements and reporting procedures pursuant to MOD-032. It is recommended that the PCs and TPs incorporate the *NERC List of Acceptable Models for Interconnection-Wide Modeling* into their modeling requirements or their own acceptable model lists.

The *NERC List of Acceptable Models for Interconnection-Wide Modeling* can be found here.

NERC LIST OF ACCEPTABLE MODELS FOR INTERCONNECTION-WIDE MODELING		
Last Updated: February 2017		
Use of this model is not recommended. Other models are more suitable.		
Future use of this model should be prohibited. Modeling limitations or discrepancies known.		
Machine Models		
Model Description	**Siemens PTI (v. 33)**	**GE PSLF (v. 19)**
Round Rotor Generator Model (IEEE Std 1110 §5.3.2 Model 2.2)	GENROU	genrou
Salient Pole Generator Model (IEEE Std 1110 §5.3.1 Model 2.1)	GENSAL	gensal
Round Rotor Generator Model (IEEE Std 1110 §5.3.2 Model 2.2)	GENROE	--
Salient Pole Generator Model (IEEE Std 1110 §5.3.1 Model 2.1)	GENSAE	--
Round Rotor Generator with DC Offset Torque Component	GENDCO	gensdo
Cross Compound WECC Type F	--	gencc
Generator Type F	--	gentpf
Generator Type J	GENTPJU1	gentpj
Classical Generator Model (IEEE Std 1110 §5.4.2)	GENCLS	gencls
Third Order Generator Model	CGEN1	--
Transient Level Generator Model	GENTRA	--
Salient Pole Frequency Changer Model	FRECHG	--
"Two-cage" or "One-Cage" Induction Generator	CIMTR1, CIMTR3	genind

Figure 1.3: Illustration of NERC List of Acceptable Models

Chapter 2: Case Quality and Fidelity

Case Quality Metrics Assessments

In 2015, NERC developed a Case Quality Metrics Assessment and initiated Phase 1 of this assessment, which sought to analyze the interconnection-wide models developed for planning the BPS in terms of the quality of the case. The quality metrics focus on the reasonableness of the models and parameters used to represent elements on the BPS. For each metric, a performance score (%) is used to track how each case scores in each area. These scores are then reviewed to identify any possible trends in data issues and develop recommendations for the MOD-032 Designees to consider and implement during the case creation process. NERC has continued this assessment on an annual basis, and will continue to seek improvements in the performance scores across all interconnections.

Phase 1 Case Quality Metrics Assessment

Phase 1 focused primarily on powerflow metrics, ensuring reasonable and consistent modeling of BPS elements as well as reasonable development of an operating condition to be studied. Introductory dynamics metrics were also developed that considered generator modeling, load netting, and machine reactance values. The Phase 1 metrics illustrated that each of the interconnections have overall good quality, but also have areas for improvement that are provided in detail in the assessment.

Phase 1 Case Quality Assessment can be found here.

Phase 2 Case Quality Metrics Assessment

Phase 2 added some more powerflow metrics, but most metrics added were focused on improving the quality of the dynamics data. Dynamics data checks, particularly for generating resources, were added to improve the quality of transient stability simulations. The results of the Phase 2 assessment demonstrated a few areas where significant improvements is needed, in addition to demonstrating consistent performance with the Phase 1 assessment. More detailed findings and recommended are provided in the assessment.

Phase 2 Case Quality Assessment can be found here.

Phase 3 Case Quality Metrics Assessment

The 2017 Case Quality Metrics Assessment continued the quality checks from Phase 1 and Phase 2 assessments. This assessment also identified some corrections to the assessment scripts, and improvements to the previous years' metrics to keep the threshold values aligned with industry practices. This resulted in significant improvements in some metric scores. However, other metrics observed major improvements due to industry improvements in MOD-032-1 case creation process improvements and potentially continued MOD-026-1 and MOD-027-1 verification testing as these standards come into effect.

Phase 3 Case Quality Assessment can be found here.

MOD-033 Reference Document – NATF

MOD-033-1 establishes consistent validation requirements to facilitate the collection of accurate data and building of planning models to analyze the reliability of the interconnected transmission system. PCs develop and implement a data validation process that includes both steady-state and dynamic system model validation. The validation activities seek to ensure that the models used for planning the system are a realistic and accurate representation of actual system behavior. The studies performed with these models may be used for determining transmission reinforcements, generation interconnections, system operating limits (SOLs), and other reliability measures. Therefore, using models that appropriately represent the static and dynamic nature of the system is a critical step to ensuring reliability.

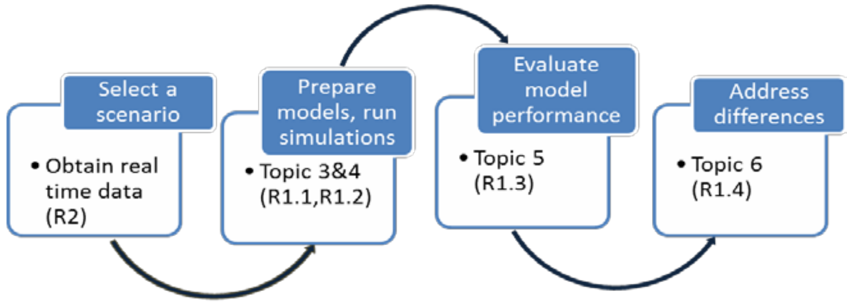

Figure 2.1: MOD-033 Process from NATF Document

With MOD-033-1 now effective, utilities are developing processes, procedures, and tools to perform system model validation. To support these efforts, NATF developed a MOD-033-1 reference document that provides technical discussion and recommendations around the MOD-033-1 standard and how entities may develop their processes and tools. The intended audience for this reference document is PCs with responsibility for conducting the various studies called for under MOD-033-1. The document will be made publicly available here, and was also endorsed by the ERO as Compliance Implementation Guidance, which can be found here.

Playback Models and Disturbance-Based Power Plant Model Verification

Playback models allow simulation tools to play back actual grid conditions to observe how the models will respond to these types of conditions. The playback models, and accompanying tools, can be used to verify that modeled performance matches actual performance, and can be used by GOs and TPs to comply with MOD-026-1 and MOD-027-1. While the playback model has been available for many years in some software platforms, the lack of consistent playback tools across software platforms has hindered the ability to use the capability across all interconnections in North America. NERC worked closely with software vendors to ensure some form of playback capability is available in the commonly used software platforms used by industry. Today, industry now has the tools needed to perform disturbance-based model verification using high resolution data (e.g., synchrophasor data from Phasor Measurement Units (PMUs)). Figure 2.2 shows an illustration of the setup for performing disturbance-based verification, where some form of dynamic disturbance recorder (DDR) monitors the response of a generating unit(s) which can then be used by the playback model in the simulation tools.

The NERC Synchronized Measurement Subcommittee (SAMS) developed a Reliability Guideline on using PMU data to perform disturbance-based power plant model verification (PPMV). This guideline provides a detailed walkthrough of how to functionally perform disturbance-based model verification and also provides useful reference material for the various tools in each software platform. This guideline can be found here.

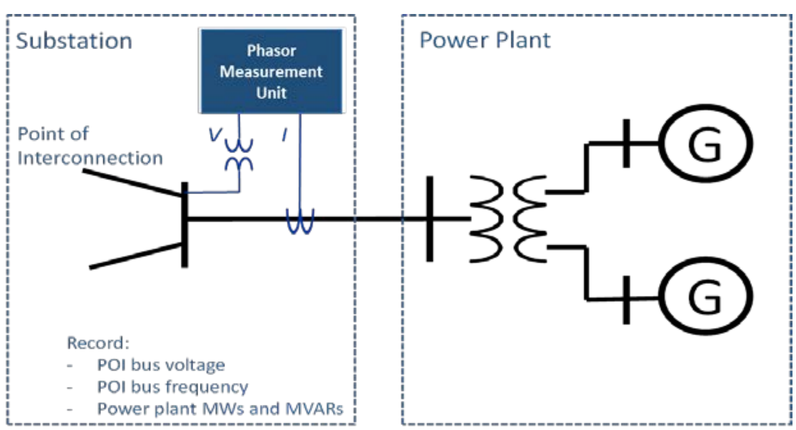

Figure 2.2: Example Monitoring Setup for Disturbance-Based PPMV

Chapter 3: Modeling Notifications

As the resource mix and BPS continue to evolve, power system engineers need to be equipped with, and be utilizing, the most applicable and effective tools, and models within their power system studies. The Modeling Notification process was developed to support the dissemination of useful modeling information relevant to the standardized component models in the commercial software tools used for running these studies. The NERC System Analysis Modeling Subcommittee (SAMS), under the direction of NERC Planning Committee, facilitates this process to inform the industry of obsolete models, model errors, and relevant updates to the current models that best represent the physical elements on the BPS. While it is not expected that the software tools remove these models, this information needs to be tracked, documented, and shared across the industry. This process bridges the gap where users of analytic and simulation tools can be particularly vulnerable to analysis result discrepancies where models do not accurately reflect true component behavior due to modeling issues.

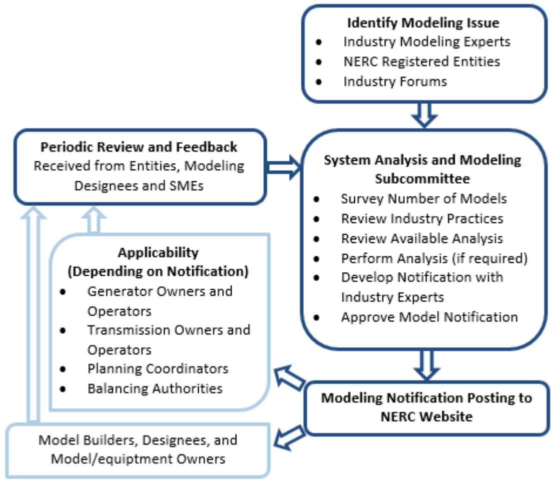

Figure 3.1: Modeling Notification Process

The Modeling Notification process is illustrated in the figure. NERC SAMS[5] acts as a user forum to discussion potential modeling issues and determines whether these issues should be elevated to a Modeling Notification. Utility planners and modelers bring these topics to SAMS and SAMS works directly with equipment manufacturers, software vendors, utility members, and other subject matter experts to address the modeling discrepancies and develop a concise notification on the topic.

The MOD-032 Designees, Planning Coordinators, Transmission Planners, and other applicable entities are encouraged to adopt the recommendations provided in the Modeling Notifications. NERC is coordinating with the MOD-032 Designees and Planning Coordinators to help facilitate this process as a feedback loop to the interconnection-wide model development process.

The NERC Modeling Notifications can be found on the NERC SAMS webpage.

EX2000 Excitation System Model

EX2000, EX2100, and EX2100e are excitation systems for synchronous generators manufactured by GE. In the Siemens PTI PSS/E power system dynamics simulation software package, the dynamic component model EX2000 is intended to represent this excitation system. However, the field current limiter reset action modeled in the EX2000 exciter model in PSS/E is based on the information that was provided when the model was first written and is not how the actual equipment works. Specifically, once the Latch 2 gate in the field current limiter portion of the model is set, it will never reset, even if the field current falls below the value IFDREF2.

[5] The NERC Modeling Working Group (MWG) was disbanded and MWG activities were consolidated into the NERC SAMS activities to increase efficiency and effectiveness. Previous MWG members were encouraged to continue participating in SAMS to provide modeling expertise.

The notification advises users of the EX2000 model in PSS/E to be aware that the representation of the field current limiter within this model is suspect. For situations that do not involve overexcitation limiters (OEL) action (i.e., ICON (M) = 0), the EX2000 model can be used without any issue, or the EX2000 model may be replaced with the AC7B model from the IEEE 421.5 standard. However, if it is necessary to represent over-excitation limiter (OEL) action of an EX2000, EX2100, or EX2100e excitation system in PSS/E[6], a user-written model (EX21BR) may be downloaded for PSS/E versions 32 and later from the Siemens PTI PSS/E user support web page.

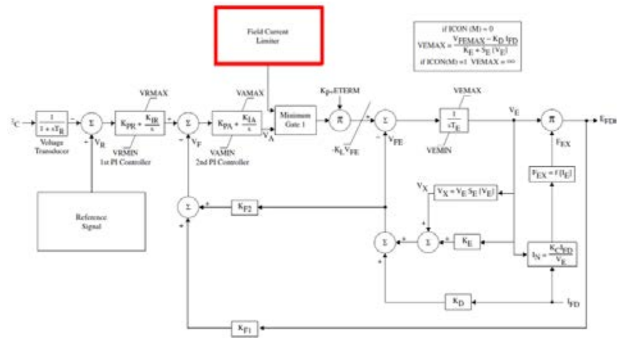

Figure 3.2: EX2000 Modeling Notification

This notification can be found here.

Use of GENTPJ Generator Model

This Modeling Notification describes using the GENTPJ generator model as a replacement of the GENSAL model for representation of salient pole generators. The GENTPJ model recognizes that the inductance coefficients that characterize a generator are affected by load current to a greater extent than is embodied in the GENSAL model. Treatment of magnetic saturation in GENTPJ allows it to provide more accurate simulation of required field current than is given by the GENSAL model. It is recommended to use the GENTPJ model for new modeling of salient pole generators and future (re)verification of salient pole generator models. The GENTPJ model may also provide improved calculation of field current in comparison with the GENROU model in the simulation of round rotor machines. It is noted that it can be appropriate to use GENTPJ in place of GENROU in situations where overexcitation limiter action, and hence accurate estimation of field current, is an important factor in system performance.

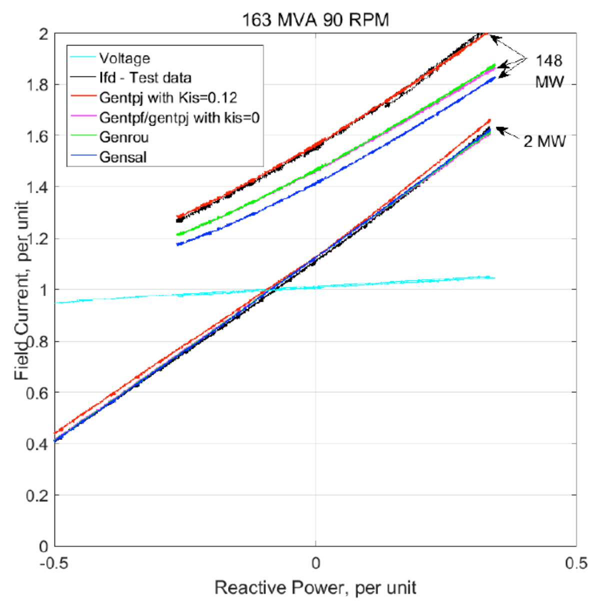

Figure 3.3: GENTPJ Modeling Notification

This notification advises those using the *GENSAL* salient pole generator model or the *GENROU* round rotor generator model to consider using the *GENTPJ* model for new generators and where generator data is to be newly verified or (re)verified. The notification also provides some appendix material related to these models and testing that illustrates the potential deficiencies in these models and the recommendation to use the *GENTPJ* model.

This notification can be found here.

[6] Until and no later than such time as a standard model has been implemented in PSS/E.

Gas Turbine Governor Modeling

This Modeling Notification recommends reviewing application of the GAST, GAST2A, GASTWD, GFT8WD, and WESGOV turbine-governor models to gas turbine generators with modern digital controls. These models do not have the capabilities and flexibility of more recently developed models, and should not be used in the future. Default manufacturer data for the more flexible GGOV1 model is provided as a starting point for verification of the updated model using GGOV11. Considerations when transitioning to GGOV1 are also provided.

A significant number of generating resources are represented using, for example, the GAST model. Industry is advised to use more representative and accurate models of gas turbine-governor systems in the interconnection-wide base cases.

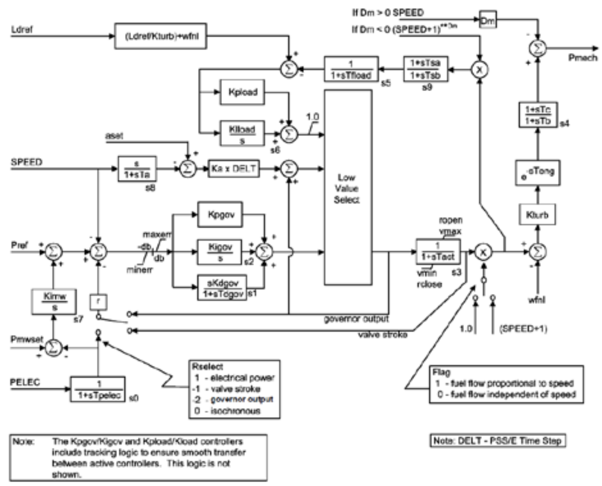

Figure 3.3: Gas Turbine Governor Modeling Notification

This notification can be found here.

Second Generation Renewable Modeling

NERC is developing a Modeling Notification focusing on use of the second generation renewable energy system models, in an effort to support the transition from the older first generation models which have limited capability and possible numerical issues. The notification will advocate a reasonable and effective transition away from the first generation models and timely verification of the model accuracy using the second generation models.

This notification is expected to be published in Q2-Q3 2018.

Modeling Momentary Cessation

Event analysis of recent disturbances involving BPS-connected solar PV generating resources, such as the Blue Cut Fire and Canyon 2 Fire disturbance, have led to the finding that the vast majority of solar PV resources use an operating strategy called momentary cessation during low voltage conditions. Momentary cessation[7] involves a "zero current injection" into the point of connection with the grid at the inverter terminals where both active and reactive current (and subsequently power) go to zero output because the power electronic firing commands are blocked such that the inverter does not produce current. The NERC IRPTF is developing guidance around inverter-based resource performance. While the guideline explicitly recommends that momentary cessation should not be used for BPS-connected inverter-based resources, existing resources may need to use this control mode as an equipment limitation. In these cases, the equipment controls need to be accurately modeled and are currently not captured in the models currently used to represent these resources. NERC IRPTF is coordinating with NERC SAMS on the development of a modeling notification to describe how and when to model this.

This notification can be found here.

[7] Momentary cessation is sometimes referred to as "blocking" for this reason.

Chapter 4: Dynamic Load Modeling

NERC formed the Load Modeling Task Force (LMTF) to improve the state of the art of dynamic load models and modeling practices by bringing together industry efforts and expertise in the area of load modeling. The group is focusing on improving the implementation of dynamic load models, particularly the composite load model, and developing technical reference material and guidance around applying these models for system studies. The following are key highlights and relevant topics being addressed by the NERC LMTF.

Dynamic Load Modeling Technical Reference Document

NERC held a technical workshop on Dynamic Load Modeling and Fault Induced Delayed Voltage Recovery (FIDVR) in September 2015, which highlighted the current state-of-the-art in dynamic load modeling and the motor testing and simulation studies performed that provide the technical basis for the current dynamic load models. In particular, the workshop focused on the composite load model and the physical nature of end-use loads that drive the various components of the model including induction motor load. The newly formed NERC LMTF then developed a technical reference document that provided a detailed overview of the material covered in the workshop that serves as a useful reference for TPs and Planning Coordinators (PCs) in understanding dynamic load models and modeling practices. The report highlights the changing nature of end-use loads, testing programs of motors and electronically-coupled loads, electromagnetic transient simulations, composite load model data, and system studies using this model.

The workshop presentations can be found here.
The technical reference document can be found here.

Load Model Benchmarking

NERC LMTF has benchmarked the performance of the composite load model across four major transient stability software programs used by industry – GE PSLF, Siemens PTI PSS/E, PowerWorld Simulator, and Powertech TSAT. EPRI played a significant role in performing the benchmark tests, along with close coordination from all involved software vendors. Benchmark tests were developed to put the models through rigorous testing. Figure 4.1 shows an example of one of the tests, and different performance identified during the tests. Many iterations of testing were performed, and the software vendors helped identify the causes of any discrepancies as well as solutions to get consistent performance results.

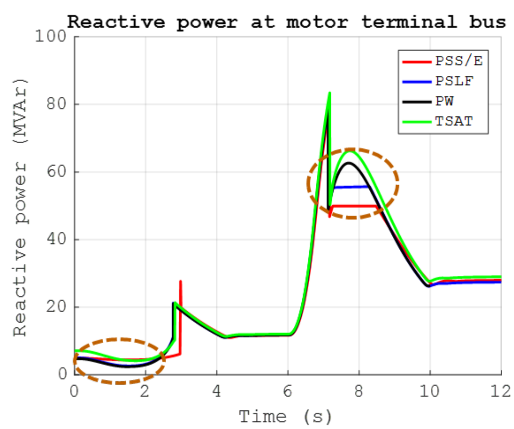

Figure 4.1: Load Model Benchmarking

The benchmark tests have been completed and all composite load models are expected to perform nearly identically across software platforms. NERC LMTF is planning to continue benchmarking activities, focusing on any new model functionality as well as the inclusion of the distributed energy resource (DER) component in the model.

NERC LMTF has completed these tasks under the Phase I portion of the benchmarking and has moved onto Phase II, which is to encapsulate each model to look like that of the generator models currently used.

Composite Load Model Data Defaults

NERC LMTF has compiled a set of model data that allows the users of the Composite Load model to navigate the default settings of the model. This encourages the users to utilize all portions of the model and provides a default setting for the parameters that the user may not be as familiar with. This allows the model to be flexible for all users who wish to model certain load behaviors based off the default settings.

The Data Sets can be found here.

Reliability Guideline: Developing Load Model Composition Data

The NERC LMTF developed a reliability guideline that provides Transmission Planners (TPs) and Transmission Owners (TOs) with insights into end-use load behaviors and how to capture them in the composition of dynamic load models. Load composition aspects of dynamic load modeling are the primary focus but other aspects of dynamic load modeling such as motor performance, protection modeling, or performing sensitivity studies are also incorporated. Examples of how to develop aggregate load model composition data from various data sources, classify that data, and convert that information into suitable load model parameter values are provided for references. The guideline also provides technical guidance and reference material for how to apply the load composition data to develop reasonable and suitable dynamic load models used in stability simulations.

This Reliability Guideline can be found here.

Reliability Guideline: Modeling DER in Dynamic Load Models

To begin addressing the modeling aspects of increasing penetrations of distributed energy resources (DER), the NERC LMTF developed a reliability guideline to provide a common framework for entities to consider when modeling DER in transient stability and powerflow simulations. The framework is intended to be useful for interconnection-wide studies where a reasonable approximation is made regarding the aggregate behavior of these resources across a large footprint. Modeling practices described in the guideline can be modified to meet the needs of particular systems or utilities, and are intended as a reference point for interconnection-wide modeling practices. The guideline establishes definitions used for modeling purposes that supplement the definitions created by the NERC Distributed Energy Resources Task Force (DERTF) in their task force report. The new definitions used specifically for modeling purposes help differentiate between Utility-Scale DER (U-DER) and Retail-Scale DER (R-DER). Each type of DER has unique characteristics that ideally should be modeled separately to capture sufficient detail in the models.

This Reliability Guideline can be found here.

Reliability Guideline: DER Modeling

To build upon the guideline described above, NERC LMTF continued their efforts in providing guidance for TPs and PCs regarding DER modeling by developing another Reliability Guideline focused specifically on the dynamic modeling aspects. This guideline includes an overview and useful industry references regarding the latest dynamic models that can be used as part of the load model as well as stand-alone DER models. In particular, the guideline highlights the *pvd1* models as the best model for DER modeling with current software tools. It also highlights the upcoming release of the *der_a* model, which will include improvements to the *pvd1* model. Reasonable default values for model parameters are provided as a starting reference, with guidance to explore updates to these model parameters based on actual data collected.

This Reliability Guideline can be found here.

Chapter 5: Power Plant Modeling

NERC formed the Power Plant Modeling and Verification Task Force (PPMVTF) to focus on developing technical reference and guidance material related to power plant modeling, testing, and model verification. These activities center on the MOD-025-2, MOD-026-1, MOD-027-1, and relevant PRC standards. This work is very relevant, with these standards coming into effect and implementation currently. The NERC PPMVTF is developing a guideline that covers a wide array of testing, verification, and modeling practices and will serve as an industry reference as well as provide recommended practices in some areas. The following are key highlights and relevant topics that will be addressed in detail in the guideline.

Power Plant Model Verification and Testing Workshop

In early 2017, NERC PPMVTF hosted an informational workshop for Generator Owners and other stakeholders concerning the modeling standards. The team went over MOD-025-2, MOD-026-1, MOD-027-1, MOD-032, and MOD-033 standards, and their applicability to the Bulk Electric System entities. Entities in the NERC PPMVTF then presented how they have performed their testing and model validation as it pertains to the applicable modeling standards. Topics such as disturbance monitoring, modeling verification, and power plant performance were the primary focus of the workshop.

The aggregated presentations can be found here.

Variable Energy Resource Modeling Workshop

In addition to the above workshop, NERC PPMVTF has also hosted a Variable Energy Resource (VER) workshop to depict the issues and solutions for the modeling of VERs in powerflow and dynamic studies. This workshop focused on inverter-based resources connected to the BPS. Industry presenters highlighted their respective challenges with modeling and implementing VERs into their portion of the Bulk Electric System as well as supplying their solution to the issue. A few presentations were reserved for updates on current renewable technologies and control systems available for these generation resources.

The zip archive of all presentations can be found here.

Reliability Guideline: Power Plant Model Verification Testing for Synchronous Machines

The NERC PPMVTF is developing a reliability guideline focusing on the testing and model verification activities of synchronous generating resources related to meeting the requirements set forth in the NERC MOD Standards, namely MOD-025-2, MOD-026-1, and MOD-027-1. This guideline provides useful reference material related to the various tests that are performed in deriving or verifying many of model parameters of the dynamic models used to represent the equipment installed in the plant. This guideline focuses solely on synchronous generating resources.

This draft guideline is intended to be published in Q3 2018, and the draft can be found here.

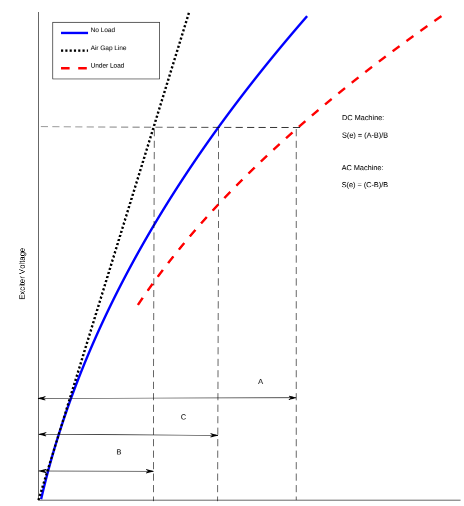

Figure 5.1: Model Verification Testing

Reliability Guideline: Power Plant Model Verification Testing for Inverter-Based Resources

The NERC PPMVTF is also developing a reliability guideline focusing on the testing and model verification activities of inverter-based (nonsynchronous) generating resources associated with the same NERC MOD Standards. This guideline is very similar to the other one in that it provides reference material for the various tests performed in deriving or verifying model parameters for inverter-based resources. The tests and considerations for these tests are quite different than that of a synchronous machines. Due to the differences between inverter-based and synchronous resources, the NERC PPMVTF decided to create two separate guidelines on the topic.

Reliability Guideline: MOD-032-1 Data and Data Requests

The North American Generator Forum (NAGF) provided a letter to NERC raising some questions and concerns with the MOD-032-1 standard, particularly related to the types of data collected and the processes associated with collecting that data. The NERC PPMVTF was tasked with developing guidance material specifically to address these questions. NERC PPMVTF is currently drafting a reliability guideline on this topic to provide clarity around MOD-032-1 data requests, the data requirements, and reporting procedures developed by the PC and TP, and the processes for sharing data among entities. The goal is to support consistency and effective development of the interconnection-wide case creation process for the purposes of planning the BPS.

This guideline is intended to be published in Q3 or Q4 2018.

Chapter 6: Plant-Level Controls and Protection Modeling

NERC formed the Plant-Level Controls and Protection Modeling Task Force (PCPMTF) to review the effects of plant-level turbine, boiler controls, and protection systems on the response of power plants and to what extent components may need to be modeled for interconnection-wide modeling cases. The PCPMTF consists of turbine manufacturers, Generators Owners, Generator Operators, and NAGF, subject matter experts in power system dynamics and control, and stability simulation software vendors. The PCPMTF collaborated on identification of models and modeling practices for plant-level turbine protection and control functions in order to identify any gaps in obtaining accurate stability study results.

The Task Force recommended the following actions to improve plant-level protection and controls modeling:

- Through Modeling Notifications,[8] advise the industry to use the most accurate model representation of their generator.
  - For instance, consider using models that represent PI controllers if such equipment is used in the plant. However, it is neither practical nor necessary to attempt to model all turbine and boiler controls.
- Encourage the commercial software vendors to adopt a model similar to gp1 (and gp2) in GE PSLF™ that can monitor and provide warnings of potential unit tripping due to the generator encroaching on possible trip-zones of protection systems.
  - The GP1 model should be revised or updated with additional functions that are outlined in the report (e.g., the power-load unbalance protection).
- NERC System Protection and Control Subcommittee (SPCS) engagement to review the reliability impacts of plant-level controls and protection on applicable NERC Reliability Standards.
- The data owners, PCs, and MOD-032 Designees should incorporate and monitor processes to include Volt/Hz, over excitation limiter, under excitation limiter, and reverse power dynamic models in future year planning cases.

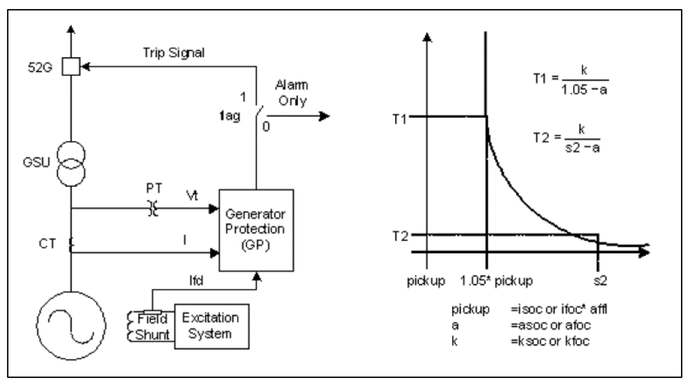

Figure 6.1: Plant-Level Controls and Protection Modeling

The approved PCPMTF report can be found here.

[8] The NERC Modeling Notifications are available on the NERC SAMS webpage.

Chapter 7: Interconnection-Wide System Analysis

In addition to the modeling improvements efforts described in the preceding chapters, NERC also conducts independent reliability assessments including interconnection-wide system analysis. The following sections describe the activities underway that NERC is focusing on from a system analysis perspective. These topics are based on identified issues through event analysis, the NERC Long Term Reliability Assessment (LTRA), or other emerging issues facing the North American bulk power system.

Eastern Interconnection Frequency Response Analysis

NERC has continued to highlight and assess the changing resource mix as part of its annual Long Term Reliability Assessment (LTRA). As synchronous generation retires and inverter-based resources continue to increase in penetration, NERC has begun studying the impacts this may have on interconnection frequency response. In particular, NERC has focused on assessing the impacts of various future scenarios in the Eastern Interconnection.

A light load Eastern Interconnection MMWG planning model was used as the starting point, and modified to more accurately actual frequency response behavior of the fleet. This included modifying, in coordination with ERAG MMWG assessments, the turbine-governor and load controller models for many of the units. This starting model, after some modifications for more realistic dispatch conditions, did not initialize correctly and a number of issues were documented and reported back to MMWG for case creation process improvements in the future. With some substantial effort, a root case was created from which sensitivity studies could be run.

This assessment evaluated the performance of Eastern Interconnection (EI) primary frequency response (PFR) during generation outages, with increasing penetration of inverter-based resources consisting primarily of wind and solar PV facilities. Studies compared model performance of EI grid frequency and power response for the generation fleet to actual event data for various levels of frequency responsive reserve levels (available frequency response power from online generation) and droop setting for resource loss events of 2,100 MW, 4,500 MW, and 6,800 MW. Characteristics of the frequency response were compared such as available margin to underfrequency load shedding (UFLS) and settling frequency. The study recommended operating characteristics for inverter-based resources to utilize frequency responsive capabilities moving forward for higher levels of inverter-based resources connected to the BPS.

NERC is continuing this effort by exploring grid stability and frequency response improvements by enabling frequency response capability from inverter-based resources with different droop setting and available headroom. Initial simulation results show improvements in interconnection-wide frequency response when the capability is enabled and the resources have operating reserve to move in the upward direction for underfrequency events. NERC is not advocating that this be a requirement. Rather, NERC is exploring the capability and any potential improvements it may have on BPS reliability.

The Eastern Interconnection Frequency Response Assessment report was filed with FERC in June 2017. The filing can be found here.

Short Circuit Modeling Coordination

NERC has expressed some concerns regarding short circuit modeling, particularly related to coordination of models and model performance around the seams between PC footprints. NERC has also questioned whether sufficient data verification processes exist today to ensure this coordination is taking place. NERC staff, in coordination with its technical stakeholder groups (e.g., NERC SAMS and SPCS), and possibly the North American Transmission Forum (NATF), is developing an action plan to examine this short circuit modeling coordination moving forward. Potential options include developing a *Reliability Guideline on Short Circuit Model Coordination*, hosting industry webinars, etc.

Stability Impacts of Momentary Cessation

The NERC IRPTF was requested[9] to perform an assessment of whether the impacts of momentary cessation (see Figure 7.1) warrant a modification to the Resource Loss Protection Criteria (RLPC) for the Western Interconnection. NERC IRPTF created a modeling and simulations sub-group consisting of modeling experts and Transmission Planners from the Western Interconnection to perform stability simulations to make this determination. The findings from this assessment proved that the Western Interconnection Resource Loss Protection Criteria (RLPC) did not require modification to account for impacts of momentary cessation of solar PV resources. However, the simulations did identify the following:

- The transient stability models that are currently used to model inverter-based resources in interconnection-wide studies do not sufficiently capture the effects of momentary cessation. A user-defined model was added to sufficiently capture all the effects of momentary cessation for the purposes of this study.
- For faults at critical locations in the Western Interconnection, a three-phase bolted fault could cause more than 9,000 MW of solar PV resources to enter momentary cessation. The voltage depression caused by a fault at a 500 kV bus has a widespread impact on grid voltage during on-fault conditions and can be felt by solar PV resources across a large geographic area.
- Two bus locations were identified as critical, where the studies showed that transient instability could occur based on the studied operating conditions and momentary cessation settings. The simulated transient instability was caused by excessive transfer of inter-area power flows during and after momentary cessation. The momentary cessation of inverter-based resources caused large inter-area angular separation resulting in system-wide uncontrolled separation.

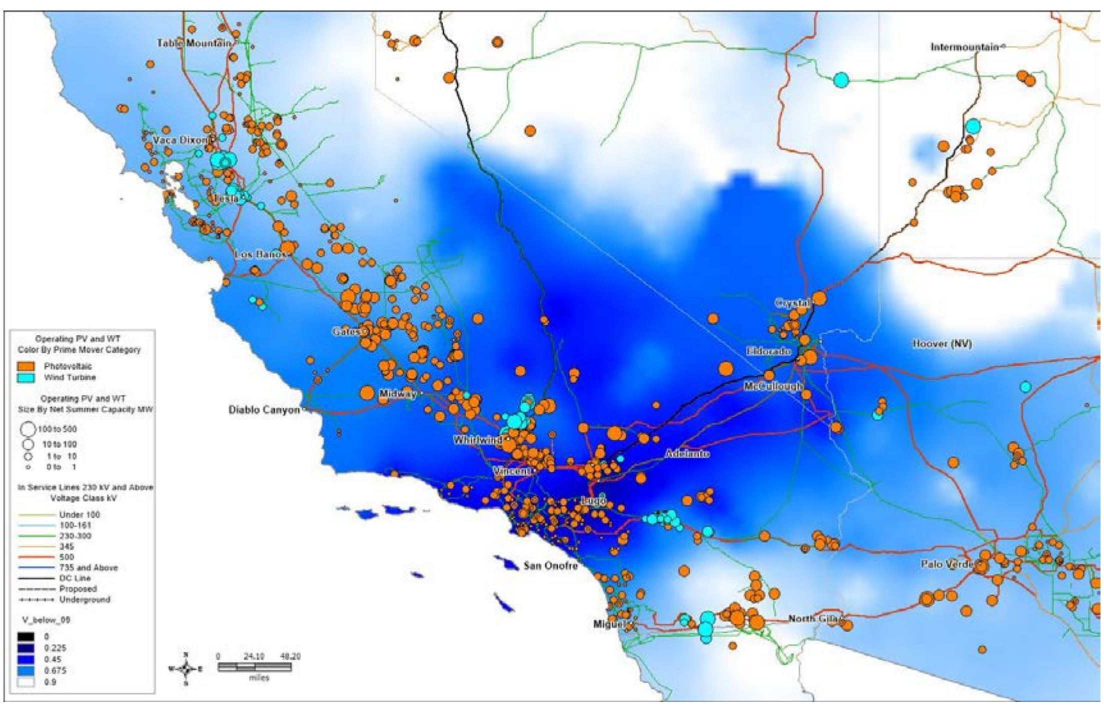

Figure 7.1: Widespread Voltage Depression during Fault Conditions

[9] This request came from the NERC Resources Subcommittee (RS).

Appendix A: Relevant Materials

NERC Reliability Guidelines

NERC Reliability Guidelines, particularly those related to modeling and system analysis, are provided in Table. A.1.

Table A.1: Reliability Guidelines Related to Modeling and System Analysis		
NERC Reliability Guidelines	**Date Approved**	**References**
NERC Reliability and Security Guidelines	N/A	Link
Reactive Power Planning	March 2017	Link
Developing Load Model Composition Data	March 2017	Link
Modeling DER in Dynamic Load Models	December 2016	Link
DER Modeling	September 2017	Link
Power Plant Dynamic Model Verification using PMUs	September 2016	Link
Forced Oscillation Monitoring and Mitigation	September 2017	Link
Integrating Inverter-Based Resources into Low Short Circuit Strength Systems	December 2017	Link

NERC Technical Reference Documents

NERC Technical Reference Documents are developed by the NERC technical committees and respective subgroups. Relevant reference documents to modeling and system analysis are provided in Table A.2.

Table A.2: Technical Reference Documents Related to Modeling and System Analysis	
Technical Reference Documents	**References**
Phase Angle Monitoring	Link
Primer on Phase Angle Monitoring	Link
Dynamic Load Modeling	Link
Plant-Level Controls and Protection Modeling	Link

NERC Modeling Notifications

NERC Modeling Notifications are developed by the NERC System Analysis and Modeling Subcommittee (SAMS), in coordination with industry experts. Published Modeling Notifications can be found at the references in Table A.3.

Table A.3: Technical Reference Documents Related to Modeling and System Analysis	
Modeling Notifications	**References**
Modeling Notifications	Link
Modeling Notification Process	Link
EX2000 Excitation System Model	Link
Gas Turbine Governor Modeling	Link
Use of GENTPJ Generator Model	Link
Webinar – EX2000 and GENTPJ Notifications	Link
Modeling Momentary Cessation	Link

NERC Technical Workshops and Webinars

Technical workshops related to power system modeling and system analysis are provided in Table A.4.

Table A.4: Technical Workshop Related to Modeling and System Analysis	
Technical Workshops	**References**
2008 Dynamic Load Modeling & FIDVR	Link
2009 Dynamic Load Modeling & FIDVR	Link
2015 Dynamic Load Modeling & FIDVR	Link
2016 NERC-NASPI Disturbance-Based PPMV Tools	Link
2016 Power Plant Model Verification & Testing	Link
2017 NERC-NATF Power System Modeling Conference	Link
2017 Variable Energy Resource Modeling Workshop	Link
2017 NERC-NASPI Forced Oscillation Technical Workshop	Link

NERC Webinars

NERC webinars related to power system modeling and system analysis are provided in Table A.5.

Table A.5: NERC Webinars Related to Modeling and System Analysis	
Technical Webinars	**References**
2016 Dynamic Load Modeling	Presentation Recording
2017 Reactive Power Planning	Presentation Recording
2018 Disturbance Analysis of Solar PV Events	Presentation Recording

Other Relevant Reference Materials

Other useful publicly available reference materials that are relevant to the discussions in this document are included here:

- NATF Public Documents can be found here.

Appendix B: List of Acronyms

Table B.1: List of Acronyms	
Acronym	**Description**
BA	Balancing Authority
BPS	Bulk Power System
DER	Distributed Energy Resource
ERAG	Eastern Interconnection Reliability Assessment Group
ERO	Electric Reliability Organization
FIDVR	Fault-Induced Delayed Voltage Recovery
GO	Generator Owner
GOP	Generator Operator
IROL	Interconnection Reliability Operating Limit
MMWG	Multiregional Modeling Working Group
NERC	North American Electric Reliability Corporation
NERC IRPTF	NERC Inverter-Based Resource Performance Task Force
NERC LMTF	NERC Load Modeling Task Force
NERC MWG	NERC Modeling Working Group (disbanded)
NERC OC	NERC Operating Committee
NERC PC	NERC Planning Committee
NERC PPMVTF	NERC Power Plant Modeling and Verification Task Force
NERC SAMS	NERC System Analysis and Modeling Subcommittee
NERC SMS	NERC Synchronized Measurement Subcommittee
NERC SPCS	NERC System Protection and Control Subcommittee
OEL	Over-Excitation Limiter
PC	Planning Coordinator
PPMV	Power Plant Model Verification

PV	Photovoltaic
R-DER	Retail-Scale DER
RC	Reliability Coordinator
RTA	Real-Time Assessment
TO	Transmission Owner
TOP	Transmission Operator
TP	Transmission Planner
U-DER	Utility-Scale DER
UEL	Under-Excitation Limiter

Appendix C: Contributors

NERC would like to express its appreciation to those who provided technical support and review of this report, including NERC technical stakeholder groups (Table C.1) and NERC Staff (Table C.2).

Table C.1: Contributors	
Stakeholder Group	**Names**
NERC System Analysis and Modeling Subcommittee	Michael Lombardi, NPCC Neeraj Lal, NPCC Bill Harm, PJM Rich Kowalski, ISO-NE Raj Nimbalkar, ISO-NE

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