NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Modeling Notification

Model Usability and Accuracy Testing for MOD-026-1 and MOD-027-1
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This Modeling Notification provides Transmission Planners with recommendations and guidance for effective testing of dynamic models received as part of the MOD-026-1 and MOD-027-1 model verification activities. The guidance provides some clarity to the applicable standard requirements, describes recommended methods for stress testing the dynamic models, and also discourages the misuse of some methods that have led to industry challenges and miscommunication with Generator Owners.

Primary Interest Groups

Transmission Planners (TPs), Planning Coordinators (PCs), Generator Owners (GOs), MOD-032 Designees

Background

NERC MOD-026-1[1] and MOD-027-1[2] are the dynamic model verification standards for volt/var control (generator excitation control or plant-level voltage control) and active power-frequency control (turbine-governor, load control, or plant-level active power control), respectively. The purpose of these standards, working in concert with each other and with the other NERC MOD Reliability Standards, is to ensure that the dynamic models provided for generating resources accurately represent generating resources response to system disturbances.

Requirement R2 of both standards requires that a verified set of dynamic models, including documentation and data (refer to Requirement R2.1 of each standard), is provided to the TP in accordance with Attachment 1 of each standard. The NERC Power Plant Modeling and Verification Task Force (PPMVTF)[3] has developed Reliability Guidelines related to model verification and testing for both synchronous generation[4] and inverter-based resources.[5] These guidelines are primarily focused on the verification activities relevant to Requirement R2 of both standards, and only briefly touch on the model testing from the TP perspective.

Requirement R6 of MOD-026-1 and Requirement R5 of MOD-027-1 then require the TP to provide a written response back to the GO that the model is usable or not usable within 90 calendar days of receiving the verified model per Requirement R2 of both Reliability Standards. Requirement R3 of both standards provides the option for the TP to monitor the performance of the model, and instigate a model review if issues elaborated in Requirement R3 are identified.

[1] NERC MOD-026-1. Available: HERE.
[2] NERC MOD-027-1. Available: HERE.
[3] https://www.nerc.com/comm/PC/Pages/Power-Plant-Modeling-and-Verification-Task-Force-.aspx.
[4] Reliability Guideline: Power Plant Model Verification and Testing for Synchronous Machines, July 2018. Available: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_-_PPMV_for_Synchronous_Machines_-_2018-06-29.pdf.
[5] Reliability Guideline: Power Plant Model Verification for Inverter-Based Resources, September 2018. Available: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/PPMV_for_Inverter-Based_Resources.pdf.

Requirement R6 of MOD-026-1 and Requirement R5 of MOD-027-1 focus on the usability of the model, and include three elements:

- The dynamic model initializes without error
- A no-disturbance simulation results in negligible transients
- For an otherwise stable simulation, a disturbance results in the dynamic models exhibiting positive damping

Requirement R3 of both standards includes a requirement of the GO to provide a written response to the TP upon receiving any of the following:

- Written notification from its TP (in accordance with Requirement R5/R6)[6] that the dynamic model(s) is not usable
- Written comments from its TP identifying technical concerns with the verification documentation related to the dynamic model(s)
- Written comments and supporting evidence from its TP indicating that the simulated dynamic response of a model did not match the recorded response to a transmission system event

The written response from the GO back to the TP must then contain either a technical basis for maintaining the current model, model changes, or a plan to perform model verification (in accordance with Requirement R2 of each standard).

This Modeling Notification describes the recommended dynamic model usability testing for TPs to employ when receiving a newly verified dynamic model or checking the accuracy or usability of the existing dynamic models.

Modeling Notification

All recipients of this Modeling Notification should review the following sub-sections that describe recommended practices for model usability and accuracy testing. TPs should adhere to these recommendations when performing model reviews, and GOs should expect this type of model verification review for the applicable standard requirements in MOD-026-1 and MOD-027-1. The majority of recommendations in this modeling notification are focused on usability testing performed by the TP upon receiving verified models per MOD-026-1 and MOD-027-1. Note that some of these concepts are also described in the NERC Reliability Guideline: Power Plant Model Verification and Testing for Synchronous Machines.[7]

Model Initialization

The dynamic models are tested to ensure that the interconnection-wide (or localized) study case initializes properly for dynamic simulation. Using a case that successfully initializes, the dynamic models are added to the case to ensure successful initialization is again achieved. Any modifications to the active and reactive

[6] Requirement R5 in MOD-027-1 and Requirement R6 in MOD-026-1.

[7] Reliability Guideline: Power Plant Model Verification and Testing for Synchronous Machines, July 2018. Available: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability_Guideline_-_PPMV_for_Synchronous_Machines_-_2018-06-29.pdf.

power limits in the steady-state base case should be coordinated between the TP/PC and the GO. The TP and PC should ensure that the model is dispatched within the defined active power, reactive power, and terminal voltage limits prior to initialization. All log files should be checked to ensure that no errors occur during initialization, and that reasonable initial conditions are achieved and limits are not exceeded. If not, the TP should check to ensure that the unit is dispatched within its MW capability, temperature limits (e.g., Ldref), head level (e.g., hydro units), voltage limits, etc. Case initialization errors may be caused by either errors in the newly added model, or previously unidentified errors in the base case that now manifest with the addition of the new model. It is the responsibility of the TP to identify and deduce which is the case.

No Disturbance Flat Run Test

Successful execution of a no-disturbance simulation in which a new dynamic model is added to an existing power system model is a necessary condition for acceptance of the new model. A successfully initialized dynamics case should be able to remain at equilibrium during a dynamic simulation when no disturbance is applied. A no-disturbance "flat run" simulation should be performed to ensure that the added dynamic models produce no or negligible transients. This simulation is typically run for at least 20 seconds to capture any potential small signal or control interaction instabilities that could arise over this time period. Worst signal deviations for the entire case should be analyzed. Voltage angle and active power output (for MOD-027-1 test) and field voltage E_{FD} and reactive power (for MOD-026-1 tests) of the unit being assessed should be plotted to show that the no-disturbance simulation results in negligible transients.

Any unsteady or unstable behavior of the dynamic simulation with the new generating unit added to the existing system model is not necessarily grounds for rejection of the new dynamic model. The addition of a new dynamic model to the existing data set may uncover erroneous generator or other dynamic model data that may have existed in the data set for a long time. If any issues are identified during the flat run test, further analysis is needed by the Transmission Planner to identify the root cause of these issues. This may be identification of a modeling issue with the new plant or an existing modeling issue newly uncovered (which should be addressed in coordination with the GO of that facility).

Positive Damping Test

An otherwise stable system should exhibit positive[8] damping before and after the new model is added to the case. This requires an understanding of the stability of the case prior to adding the model. For MOD-026-1 testing, a three-phase, normally cleared fault at the high side of the generator step-up (GSU) or point of interconnection (POI) is typically applied in simulation. For MOD-027-1 testing, a disturbance that creates a sustained frequency deviation larger than the governor deadband is typically used.[9] In some cases, a different type of contingency may represent the worst case stability conditions, and may be tested to ensure model robustness as well. The simulation should be at least 30 seconds, typically 60 seconds, to capture any potential small signal or control interaction instabilities that could arise over this time period.

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[8] Some TPs may require positive damping, while other TPs may use a damping ratio criteria above some threshold value. This criteria may be applied using numerical curve fitting techniques (e.g., Prony analysis) or by observation of a reduction in oscillation amplitude over time.

[9] Simulating the loss of a single generator may be insufficient of a frequency excursion for MOD-027-1 positive damping and stable response testing. A larger contingency may be needed to sufficiently test the active power-frequency response of the resource. Typically, the Resource Loss Protection Criteria (RLPC) should be used as the largest credible contingency test to ensure stable operation under large yet possible frequency deviations. Refer to NERC BAL-003 Reliability Standard for more information.

To ensure positively damped dynamics from generating resources, speed (for synchronous generators), active power, and reactive power[10] are monitored in the simulation.

If damping issues are identified, then the TP should determine if the poor damping is due to an actual stability issue or due to errors with the new model being added to the case. Note that identification of damping issues indicative of a stability-related issue is not part of the assessment of model usability. The TP may perform the same test for both usability and performance assessment, but these concepts need to be differentiated. Usability testing should not focus on whether or not the model performance is adequate.

When the dynamic model of a generating plant is questioned, the model should be tested in situations where its behavior is not affected by other dynamic models external to itself. Test situations need to be able to readily recognize the behavior as correct or incorrect. In many cases, a “single machine infinite bus” test simulation is satisfactory for these types of tests. Behavior of the new dynamic model should be tested with a Thevenin impedance (Z_{sys}) for the outgoing transmission system at its lowest and highest expected values at the high-side of the GSU. Test disturbances can include step changes of the voltage regulator reference setting (or other applicable voltage control), step changes of turbine speed-load reference (or other applicable active power control), changes in the value of the 'system' impedance, and switching of active and reactive load at the high-side of the GSU. Setup of test simulations is accomplished in the commercial simulation programs using scripting techniques. The following sub-section describes issues with using built-in tests under isolated conditions, which are not suitable for usability testing.

Do Not Evaluate Model Usability under Isolated Conditions

Some TPs have historically used the governor performance initialization activity available in PSS®E, GSTR/GRUN, for checking governor performance and for governor data verification by simulating the response of individual units in isolation. Figure 1 shows an example of accessing the GSTR/GRUN in PSS®E. This test is described as a “governor performance checking” tool. The tool uses a hypothetical test system where the generator and the turbine-governor models are connected to an isolated load and a step change to the load is simulated. However, this test does not consider the dynamics of the rest of the BPS and may actually show an otherwise stable unit having marginal stability or unstable conditions due to how it is tuned for normal operation. Units often have different settings for when operating in isolation that do not apply to interconnection stability studies. Therefore, the use of GSTR/GRUN for MOD-027-1 Requirement R5 is not recommended and should not be used for model usability verification.

The same concept described above regarding GSTR/GRUN also applies to the activity ESTR/ERUN. There are two tests under ESTR/ERUN in PSS®E: response ratio and open circuit step response. The response ratio test, if properly used, can provide an assessment of rated field voltage/current and ceiling field voltage.[11] The open circuit step response test can be used to compare verification test reports with simulation

[10] While reactive power may not be a good measure of damping, it can help reveal excitation system oscillation issues. Depending on the configuration and status of the AVR, some synchronous machines may not have a simulated EFD value.

[11] Errors in the excitation system model limits may lead to incorrect ceiling field voltages, which if higher than reality can lead to an optimistic excitation system model regarding transient stability. Also, errors in generator data (e.g., reactance or saturation values) can lead to higher rated field voltage/current than reality. Rated field voltage/current is a fundamental parameter if modeling over-excitation limiters (OELs). All limiters are set based on rated field voltage/current (usually current). It is hard to discern modeling problems with the OEL without this information. Again, this is outside the scope of conventional usability testing performed by the TP. If issues are identified by the TP, then the GO may be required to correct these issues.

results.[12] However, both of these aspects are outside the scope of conventional usability testing performed by the TP. The GO, often working with a generator testing consultant, may perform these types of simulations to ensure reasonable modeling.

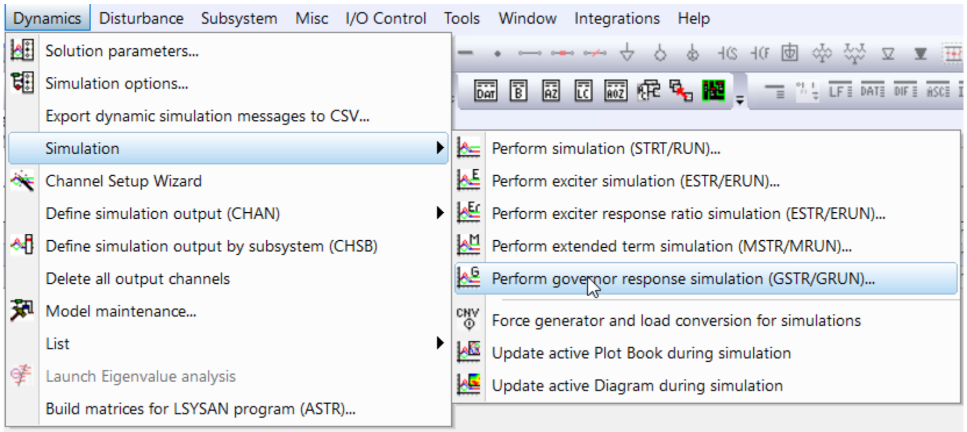

Figure 1: Screenshot of Dynamic Simulation using GSTR/GRUN

Verification Documentation Review

After the verification has been performed and the TP has tested the usability of the models, the TP should thoroughly review the verification documentation for the excitation control system (or plant volt/var control function) per MOD-026-1 or the turbine governor-control and load control system (or active power-frequency control function) per MOD-027-1. Requirement R3 of each standard states that if the TP identifies technical concerns related to the verification documentation (and accompanying data) for these models, they can inform the GO who has 90 calendar days to provide a written response containing either the technical basis for maintaining the current model, the model changes, or plans to perform model verification again.

This step is under-utilized[13] by TPs and should be further expanded in many cases. The TP should review each model provided and ensure that the provided models reasonably represent the actual equipment installed in the field, including:

- Are the correct models being used for this type of resource?
- Is a complete list of model parameters provided? Are there any gaps in the data?
- Are the provided models identified on the list of acceptable models specified by the TP, the MOD-032 Designee, or the ERO as unacceptable or not recommended? If so, other models should be used.

[12] The open circuit step response corresponds to the full-speed, no-load (FSNL) tests performed during verification testing. Simulation results from this test can be comparable to those given in a MOD-026-1 report. If the simulation results do not resemble the FSNL tests documented in the test report, there are likely issues in the generator or excitation system models. Again, this is outside the scope of conventional usability testing performed by the TP.

[13] Refer to the annual NERC Case Quality Metrics Assessment, which identifies errors or potential errors in the interconnection-wide base cases. A number of the metrics flag data that is numerical wrong or physically impossible yet still makes it into the interconnection-wide case after inspection by the TP. Available: http://www.nerc.com/comm/PC/Pages/System-Analysis-and-Modeling-Subcommittee-(SAMS)-2013.aspx.

- Are the provided models not listed on the list of acceptable models specified by the TP, the MOD-032 Designee, or the ERO? If so, what is the technical justification for using the model provided?
- Do the model parameter values make logical sense and pass a sensibility check (e.g., are they physically possible (e.g., reactance values) or do they reasonably represent the expected control settings (e.g., power factor versus voltage control))?
- Do the model parameter values match other forms of data provided by the GO regarding expected plant performance (e.g., use of momentary cessation in inverter-based resources)?
- If revised parameter values significantly change the response of an existing unit or negatively affect the usability of the model, what is the justification[14] for the parameter value change(s) and what is the source of this change?

The TP should use these questions as a guideline for checking the usability (R6 of MOD-026-1 and R5 of MOD-027-1) and verification documentation (R3 in both standards) of the submitted data, not necessarily as additional requirements imposed on the GO for every submittal. The goal is to ensure that sufficient information and technical justification is provided by the GO to have necessary confidence in the model parameters. In particular, the last point is key to comprehensive model verification. Each model parameter should have, either through test or explanation, a justification as to why that value was selected, calculated, or determined. Many models are submitted by GOs, perhaps unknowingly, that use default data parameters provided by the OEM. Often, those default values change upon commissioning but are not updated in the reported models, and pass through the testing and verification unnoticed. The GO should be diligent in ensuring that the model parameters reflect the actual installed equipment performance, and do not include default values where not appropriate.[15]

Comparison with Disturbance Recordings

The TP, upon identifying that a simulated dynamic response does not match the recorded response to a disturbance on the BPS, can instigate a model review by the GO by providing written comments and supporting evidence.

The NERC Synchronized Measurement Subcommittee (SMS)[16] published a Reliability Guideline[17] on performing power plant dynamic model verification using phasor measurement unit (PMU) data or other high resolution measurement data. This guideline is particularly useful for transmission entities that have the simulation tools and models needed to effectively perform verification using event playback, yet can also be useful for GOs who have the data and either have access to the simulation tools or who are working

[14] Newly verified models may show worse performance than the unverified models that were previously used. System performance issues relating the model parameters can be addressed in interconnection studies (i.e., FAC-002-2) or system planning studies (i.e., TPL-001-4), and are not a usability issue. However, abnormally large changes in response at least warrant a question regarding model usability. This is also true in some cases for updated models upon commissioning versus the models used in system impact studies.

[15] Some model parameter values are expected to use default values, and can be explained and justified accordingly. For example, physical machine characteristics or controls that are known to not be easily tested will often use default values. However, widespread use of default parameter values is not warranted. Adjustable control parameters, for example, that are likely different at each generating facility, should not use default values.

[16] https://www.nerc.com/comm/PC/Pages/Synchronized-Measurement-Subcommittee-(SMS)-Scope.aspx.

[17] Reliability Guideline: Power Plant Dynamic Model Verification using PMUs, September 2016: https://www.nerc.com/comm/PC_Reliability_Guidelines_DL/Reliability%20Guideline%20-%20Power%20Plant%20Model%20Verification%20using%20PMUs%20-%20Resp.pdf.

with a third party consultant or vendor who is using the tools for verification purposes. Refer to that guideline as a useful reference on the mechanics of executing disturbance-based dynamic model verification.

While according to MOD-026-1 and MOD-027-1, a single mismatch between simulated and actual response can be used to instigate a review, it is recommended that multiple events be used to demonstrate a mismatch. This helps mitigate any potential issues related to operating at limits or operating in a different or abnormal control mode. With multiple events demonstrating a mismatch between simulated and actual response, the TP should provide this information to the GO, and can often support the GO in identifying potential issues (depending on if the mismatch is related to active power or reactive power response). Figure 2 shows an example of a simulated response that poorly matches the actual response on the left, perhaps in part due to inadequacy of the model. Conversely, a very good match is demonstrated between the simulated and actual responses on the right. It is important that the PMU being used for verification be calibrated and reporting accurate measurements. Errors in the PMU data while assuming it is properly calibrated can lead to inaccurate models.

This type of verification is particularly useful if the TP has disturbance monitoring data from the Point of Interconnection (POI) of the generating resource. Again, it is worth reiterating that the GO can also coordinate with the TP regarding disturbance data sharing and identifying model mismatches. This has proved to be an effective means of identifying and correcting modeling errors by multiple entities across North America.

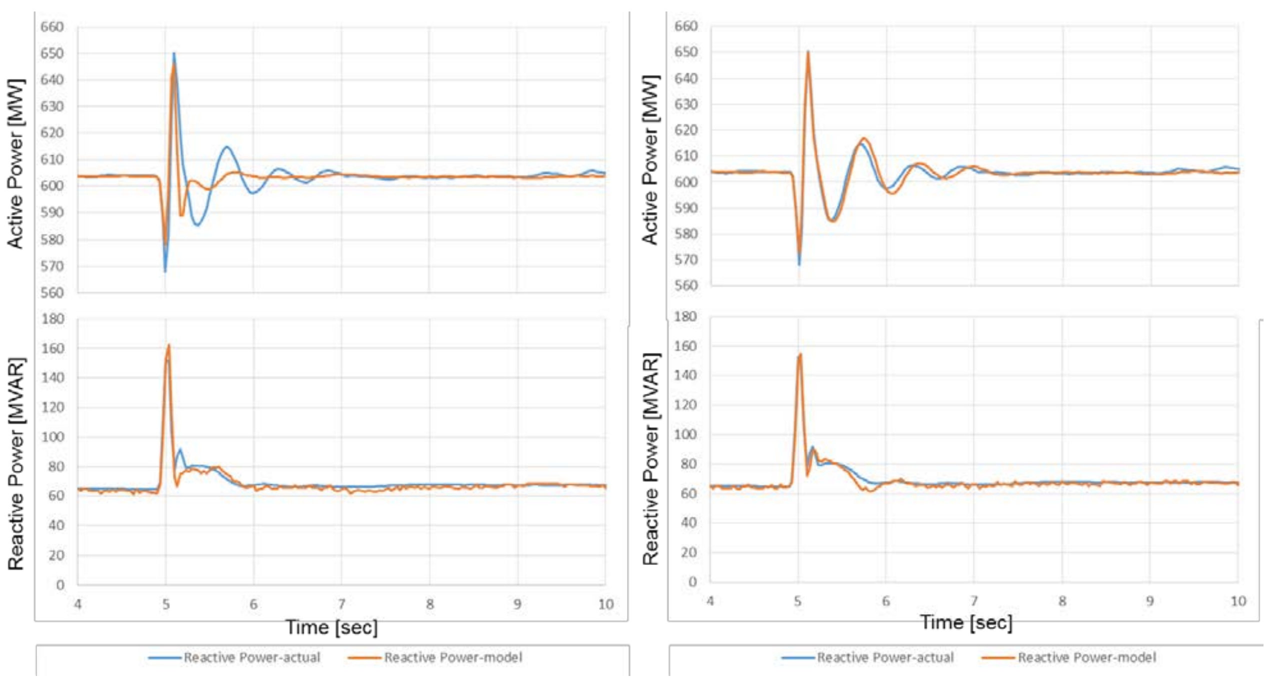

Figure 2: Example of Mismatch (left) and Good Match (right) – Simulated versus Actual

Written Notifications from Transmission Planners

When a written notification is provided by the TP to the GO regarding usability of the model, the following information[18] should be provided to the GO so they have sufficient information to identify the source the model usability issues:

- Models and model parameter values for affected units[19]
- Unit powerflow data and powerflow initial conditions
- Plots of key variables that reveal related technical concerns
- Description of simulation(s) performed (e.g., no disturbance “flat run”, disturbance simulation with type of fault (3-phase fault))
- Information regarding test system used (system-wide model or single machine infinite bus system)
- Progress window or log file showing modeling errors, initial conditions, and change of states[20]
- Examples of mismatch between simulated and actual (for disturbance-based verification)

[18] In some cases, not all this information may be necessary to address the modeling issues. But all the described information is very useful in identifying model issues.

[19] DOCU in PSS®E

[20] DSTATES in PSS®E