DETERMINING AN ECONOMICAL APPROACH TO ACHIEVING NERC MOD-026 AND MOD-027 COMPLIANCE

How to evaluate the upfront and hidden costs of generator model validation

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Executive Summary

In response to the 2003 blackout that impacted an estimated 50 million people in the northeast United States and parts of Canada, the North American Electric Reliability Corporation (NERC) created standards designed to achieve greater power grid reliability and resilience to system disturbances. One such mandate requires generation plants to validate the generator models that are reported to the Transmission Planner. Accurate models of the equipment connected to the power grid are required to ensure that the system-wide dynamic models and databases used by the Transmission Planner in grid simulations are realistic and up to date.

The NERC Modeling, Data, and Analysis (MOD) standards MOD-026 and MOD-027 outline the requirements for validating generator models against actual generator dynamic control system responses. MOD-026 pertains to the exciter voltage and reactive power response and MOD-027 pertains to the generator real power and frequency response. The purpose of both standards is to verify that the modeled response closely represents the actual generator responses to real system voltage and frequency excursions.

With the impending deadline of these standards, generating facilities must decide how to efficiently and economically demonstrate compliance. Many factors, including unit type, plant configuration (such as multiple generating units), fuel costs, business model, and operating schedule will impact these decisions. In this white paper, we explore the upfront and hidden costs of demonstrating compliance with the reliability standards and presents real-world case studies from generating facilities. These case studies weigh out the costs and benefits of both staged testing and online disturbance recording methods, and present an approach that a Generator Owner (GO) can use to evaluate these costs.

Model Validation Workflow

The workflow of the generator model validation process for either standard can be broken into four basic parts:

1. Build a generator model, including exciter and/or speed governor controls, in a commercially available software modeling package.

2. Create a recording of system voltages and currents using a dynamic disturbance recorder (DDR) or other suitable data acquisition system. This is a recording of root mean square (RMS) values over several seconds. This recording can be created during either of the two industry-established validation methods for creating a data recording: staged testing or online disturbance recording.

3. Place the modeled response over the actual recorded data and compare the plots.

4. Document and report the findings to the Transmission Planner as outlined in the MOD standards.

Throughout the validation process, the GO has choices to make regarding how to complete each task, and each stage of the model validation workflow has upfront and hidden costs. By using a thoughtful approach, the GO can select the course of action most operationally and economically prudent to their specific plant. In the larger context of a GO's entire portfolio of generating facilities, a more cost-effective long-term plan can be developed when the real cost impacts and deadlines are considered.

Methods of Testing

There are two industry-accepted testing methods that help GOs demonstrate compliance with MOD-026 and MOD-027 or effectively meet the requirements set forth in the standards. Historically, the most common method is staged testing that is mostly performed while the generator is offline. The newer method is online disturbance recording.

Method 1: Staged Testing

In this method, the generator is maneuvered through a series of staged tests. These tests might include introducing step changes to the automatic voltage regulators (AVR), partial load rejection tests, or other such tests to incite voltage and frequency changes from the unit's control systems.

Method 2: Online Disturbance Recording

In the second method, recording equipment is used to capture actual generator responses to real dynamic voltage and frequency disturbances on the power grid while the generator is in normal service mode and producing power.

Equipment Considerations

In either the staged testing or disturbance recording method, some form of recording equipment is required to capture at minimum the three-phase voltages and currents. In some cases, such recording equipment will already be available. For example, some modern digital exciters and AVRs have built-in recording capabilities. There are even some regions within the Western Electricity Coordinating Council (WECC) where the Transmission Planner has provided recording equipment at their remote substation for disturbance recording in order to assist plants with model validation and WECC certification.

Some sites may not have a DDR and will require one to be furnished for capturing generator voltage and frequency responses during either the staged testing or online disturbance recording test methods. These recordings can be created by installing either a temporary portable recording unit or a permanent mounted recording unit.

Benefits and Drawbacks of Testing Methods

Staged testing and online disturbance validation methods each have economical benefits and drawbacks. Staged testing can be performed at the owner's convenience. However, it may require an outage and possibly coordination with the Transmission Planner and local environmental authorities.

Online disturbance recordings can be created while the generator is online in normal power producing mode, but this method of validation requires sufficient planning and forethought to allow enough time to capture system disturbances, perform analysis, and compile the report in order to meet the NERC specific Implementation Plan deadlines.

Technical Considerations

In addition to the logistical and economic aspects of each method, there are also technical advantages and disadvantages. Online disturbance recording provides a better quality of validation. By capturing a variety of real generator responses to real system conditions, online disturbance recordings provide a more realistic validation of the model. Comparatively, the results obtained from staged testing are less comprehensive because they cannot fully simulate real-world conditions. Again, either method is acceptable by the Regional Entity to demonstrate compliance with the Reliability Standard.

In the application of either a temporary or permanent DDR, the generator must be offline in order to safely make connections and test the connections to the recording equipment. At minimum, the current transformer (CT) and potential transformer (PT) secondary circuits must be connected to the recorder. In some cases, exciter field voltage and currents may also be included.

In the case of a temporary recorder, the unit must be taken back offline to remove the CT and PT connections from the recorder after testing is completed. This additional required outage must be taken into consideration when determining the real cost impacts for each method of testing.

For seasonal units that plan far enough in advance, the modifications to existing equipment or installation of a DDR can be performed during the scheduled downtime. For a base load plant with a fast approaching NERC deadline, a dedicated outage may be needed for the purpose of installing the recording equipment.

Staged testing of a generating unit can typically be performed in a day. The unit is removed from normal power producing service and subjected to a series of tests. These tests are designed to produce a response from the unit's voltage and frequency control systems that mimic how the unit would respond to a similar voltage or frequency event as predicted by the system model. The excitation system and speed governor responses can be tested by introducing step response voltages into the control units or by partial load rejection tests.

In many cases, settings and control parameters in the AVR, power system stabilizer (PSS), and speed governor must be manipulated while the unit is maneuvered through these tests. While the testing is being performed, the unit's outputs are recorded and then compared with the modeled response. Once the testing is complete, care must be taken to return the control system to the original conditions and as-found settings.

Online disturbance recording, on the other hand, requires more forethought and planning. Due to the rate of occurrence of grid disturbances, the generator must be online continuously for a sufficient period of time in order to obtain recordings of generator responses to the system disturbances as they occur. This is subject to how often disturbances occur on the grid. Typical events that result in a qualifying disturbance include loss of generation elsewhere on the system, gain/loss of load, and remote transmission faults. The data recorder should be configured to record an event when voltage or frequency moves outside of the programmed window.

Although model validation has been required in the WECC region since 1997, it is only now being required in the other NERC regions via MOD-026 and MOD-027. With a history of disturbance recording already established in the WECC, there is some data available regarding the rate of occurrence of qualifying grid disturbances. One paper reports that during its research, five events occurred in seven months which were suitable for model validation. With this data, a reasonable assumption can be made that in six months of continuous monitoring, a DDR can capture a sufficient number of dynamic disturbance events suitable for model validation. This is an important aspect to consider when evaluating the impending deadlines of the MOD-026 and MOD-027 standards.

Re-validation Considerations

Another aspect to consider when determining the best way to achieve compliance with the standards is how often a plant is required to perform model validation. NERC requires generator models to be re-validated every 10 years. The WECC requirement is every five years. In this white paper, these re-validation periods are referred to as testing cycles. The first cycle is the first time the unit is validated and “future cycles” refers to each time the unit will be re-validated per the standards’ implementation plan requirements. It is important to differentiate between the first and future MOD testing cycles because the real costs discussed in this paper will vary between them.

For example, when a DDR is permanently installed the cost in the first testing cycle might be high, but during the next testing cycle, the recording equipment will already be in place and the only action required is to download the recent events from the recorder. However if a temporary DDR is used to obtain the recordings, then this will be a recurring cost because the GO will need to rent the recording equipment during each testing cycle.

This and other re-validation costs can impact a plant’s bottom line and careful evaluation of them helps when designing a cost effective plan to meet the NERC generator model validation requirements. Factors such as these that affect long-term planning and budgeting are highlighted in this paper’s case studies.

Case Study Methodology

Three case studies of actual generating plants are described in this paper. In each case study, the following three approaches are considered in order to determine the real cost impact of obtaining generator response data:

- Performing staged tests with a temporary DDR.
- Installing a temporary DDR and leaving it in place for a period of six months.
- Installing a permanent DDR.

The real cost impact includes upfront costs, as well as any hidden costs. The upfront costs might include the cost of the DDR, testing company fees, and engineering fees. The hidden costs might include fuel consumed during startup and testing, or the revenue lost due to the outage time required for staged testing, shutdown with lockout/tagout (LOTO), DDR installation, and startup.

Assumptions

For purposes of the case studies, only fossil fuel plants were considered. It was also assumed that the data retrieved from the DDR will in fact validate the model and that no follow-up investigation or tests were required to demonstrate compliance with the standards. Another assumption is that within six months of online disturbance recording, a sufficient number of usable disturbances will have been captured to satisfy the reporting requirements. Lastly, it was assumed that a means for recording the dynamic response of the voltages and currents was not available in the plant. The cost for acquiring recording equipment was taken into consideration.

Case Study #1 – 700 MW Base Load Coal Plant

Upfront Costs

To perform staged testing, the cost of hiring a testing company consultant ranges from $20,000 to $35,000. This would typically include the temporary recording equipment, consultant-led testing script, engineering analysis, and report. The consultant's report would be the final documentation submitted to the Transmission Planner or an auditor. This cost would be a recurring cost during each testing cycle. For the purpose of this paper, an average cost of $28,000 will be used for staged testing.

To perform validation through online disturbance recording, this plant must budget for a data recorder as no recorder is presently available. The cost for renting a DDR from a contractor is $20,000. This includes the engineering preparation work, equipment, and setup. The cost for hiring a contractor to install a permanent recorder is $60,000. This also includes the engineering preparation work, equipment, installation, setup, and creation of as-built system drawings.

Once the online disturbance recordings have been created, they can be analyzed. The engineering fee for this analysis is $15,000 which covers both MOD-026 and MOD-027 and includes building the generator model, analyzing recorded events against the model, and reporting documentation.

For the first MOD testing cycle, the disturbance recording method by means of a temporary DDR comes to $35,000 ($20,000 rental DDR + $15,000 engineering fees). When a permanent DDR is installed, the cost in the first cycle is $75,000 ($60,000 install permanent DDR + $15,000 engineering fees).

If the same engineering consultant is used for future model validation of the same generator, the engineering cost will be $8,000 for each future testing cycle assuming no system modifications have been made. This is because the model is already built in the modeling software and need only be compared with new disturbance recordings. The upfront costs for all future testing cycles for a temporarily installed DDR and permanently installed DDR would total $28,000 and $8,000, respectively. The upfront costs are summarized in the table below.

CASE STUDY #1 - UPFRONT COSTS PER TESTING CYCLE		
Validation Method	**First MOD Testing Cycle**	**Future MOD Testing Cycles**
Staged testing	$28,000	$28,000
Disturbance recording (temporary DDR)	$35,000	$28,000
Disturbance recording (permanent DDR)	$75,000	$8,000

At first glance, it would appear that staged testing would be the obvious choice simply due to the lower overall cost. However, hidden costs should now be considered.

Hourly Net Revenue

The plant in this case study is a base load plant and does not have a planned maintenance outage scheduled in time to meet the NERC deadline for performing model validation. This means that in order to perform staged testing a dedicated outage is required. During this outage, the plant is not able to sell power and this lost revenue will be considered. First, the hourly net revenue is calculated.

Coal Delivered	=	$20/ton
Coal Heat Rate	=	20 MMbtu/ton
Wholesale Rate	=	$27/MWH
Plant Heat Rate	=	10,000 btu/KWH

Hourly Revenue	=	(Unit Rating) x (Wholesale Rate)
	=	700 MW x $27/MWH
	=	~ $19,000

Hourly Costs	=	$\frac{\text{(Unit Rating) x (Heat Rate) x (Price)}}{\text{(Coal Heat Rate)}}$
	=	$\frac{\text{700 MW x 10,000 btu/kWH x \$20/ton}}{\text{20 MMbtu/ton}}$
	=	$7,000/hour

Hourly Net Revenue	=	(Hourly Revenue) - (Hourly Costs)
	=	$19,000/hour - $7,000/hour
	=	$12,000/hour

Real Cost of Staged Testing

Once the hourly net revenue has been calculated, it can be factored into each of the three scenarios to determine lost revenue for each. Now the timeline for staged testing must be understood to determine how long the plant must be out of service and thus not selling power.

Shutdown, LOTO:	6 hours
Setup temporary DDR:	2 hours
Remove LOTO, startup:	6 hours
Staged testing:	16 hours
Shutdown after testing, LOTO:	6 hours
Remove temporary DDR:	2 hours
Remove LOTO, hot startup, sync to full load:	6 hours
TOTAL TIME	**44 hours**

The lost revenue due to an outage to perform staged testing is now calculated.

Lost Revenue = (Hourly Net Revenue) x (Total Time)
= $12,000 x 44 hours
= $528,000

Additional hidden costs also include the cost of coal and diesel used during testing. The cost of coal is estimated at $20,000. The cost of diesel to heat the boilers during startup is estimated at $20,000.

Startup Fuel Cost = (Coal Cost) + (Diesel Cost)
= $20,000 + $20,000
= $40,000

The lost revenue and the startup fuel costs represent the total hidden costs of staged testing when a dedicated outage is required.

Hidden Costs = (Lost Revenue) + (Startup Fuel Cost)
= $528,000 + $40,000
= $568,000

Now that the hidden costs are known, they can be added to the upfront testing organization fees to determine the real cost impacts for each of the three scenarios. This results in a staged testing real cost impact which includes the testing company fees with the hidden costs.

Real Cost Impact = (Upfront Costs) + (Hidden Costs)
= $28,000 + $568,000

= $596,000

In this case study, a maintenance outage had not been previously scheduled which would allow sufficient time for disturbance event recording and completion of the engineering analysis and reporting documentation. However, with a 10-year re-validation requirement, plans can be made to perform staged testing in future MOD testing cycles that will meet the NERC deadlines. Therefore, the lost revenue is not included in the hidden cost of staged testing in future cycles. Lost revenue will be $0, and the fuel costs for a single startup will be $10,000.

Hidden Costs	=	(Lost Revenue) + (Startup Fuel Cost)
	=	$0 + $10,000
	=	$10,000

The real cost impact of staged testing for future cycles in now calculated.

Real Cost Impact	=	(Upfront Costs) + (Hidden Costs)
	=	$28,000 + $10,000
	=	$38,000

Real Cost of Disturbance Recording with a Temporary Recorder

If online disturbance recording is to be performed, it should be planned for the generator to be in service for a minimum period of six months. A conservative addition of three months is budgeted for analysis and reporting efforts. This would mean that in the scenario of achieving compliance through online disturbance recording, either a temporary or permanent DDR should be installed and the unit returned to normal online service no later than nine months prior to the deadline. In this case study, there is no scheduled outage prior to this time which requires a dedicated outage be taken for the DDR installation.

A temporary recording device can be installed with minimal engineering preparation. Once the CT and PT circuits are determined, the connections to a portable recording device are straight forward. The PT circuits can be connected directly to the device. A current clamp can be installed on the CT secondary circuit leads. This will minimize installation effort and risk of errors by not breaking the CT secondary circuit. This is particularly important if protection CTs are to be used for the recorder. The timing for this installation is as follows.

Shutdown, LOTO:	6 hours
Install temporary DDR:	2 hours
Remove LOTO, hot startup, sync to full load:	6 hours
TOTAL TIME	**14 hours**

The lost revenue due to installation of a temporary DDR installation is now calculated.

Lost Revenue	=	(Hourly Net Revenue) x (Total Time)
	=	$12,000/hour x 14 hours
	=	$168,000

Additional hidden costs also include the diesel consumed during startup. This hidden cost is the same for both temporary and permanent equipment installations. The cost of diesel to heat the boilers during startup is estimated at $20,000. The lost revenue and the out-of-pocket costs represent the total hidden costs of installing a temporary DDR when a dedicated outage is required.

Hidden Costs	=	(Lost Revenue) + (Startup Fuel Cost)
	=	$168,000 + $20,000
	=	$188,000

Real Cost Impact	=	(Upfront Costs) + (Hidden Costs)
	=	$35,000 + $188,000
	=	$223,000

The above estimates are for the first testing cycle. We will now look at cost impacts for future testing cycles, and assume that the plant has a scheduled maintenance outage before the next NERC deadline in which a temporary DDR can be installed. This leaves only a brief outage required to remove the DDR after a sufficient number of disturbance events have been recorded. The timeline for the removal of the temporary recorder is shown below.

Shutdown, LOTO:	6 hours
Install temporary DDR:	2 hours
Remove LOTO, hot startup, sync to full load:	6 hours
TOTAL TIME	**14 hours**

The lost revenue due to DDR installation in future testing cycles is now calculated.

Lost Revenue	=	(Hourly Net Revenue) x (Total Time)
	=	$12,000/hour x 14 hours
	=	$168,000

The hidden cost in future testing cycles includes the same diesel startup as in the first testing cycle.

Hidden Costs	=	(Lost Revenue) + (Startup Fuel Cost)

	=	$168,000 + $20,000
	=	$188,000

Real Cost Impact	=	(Upfront Costs) + (Hidden Costs)
	=	$28,000 + $188,000
	=	$216,000

Real Cost of Disturbance Recording by Installing a Permanent Recorder

A permanent installation of a DDR requires more planning and installation labor. Much of the work for the installation such as drawings, determining layouts, panel preparation, and pulling secondary circuit wiring can be done in advance which will minimize the installation time during the outage. When outage time results in significant lost revenue, the installation can be performed with back-to-back day and night shifts to minimize the lost revenue. Due to the short outage time required for permanent DDR installation, the coal plant can perform a warm start of the plant which further minimizes the overall outage time. The timeline for installation of the permanent DDR is as follows.

Shutdown, LOTO:	6 hours
Install permanent DDR:	20 hours
Remove LOTO, warm startup, sync to full load:	8 hours
TOTAL TIME	**34 hours**

The lost revenue due to the outage time required for the DDR installation is now calculated.

Lost Revenue	=	(Hourly Net Revenue) x (Total Time)
	=	$12,000 x 34 hours
	=	$408,000

Hidden Costs	=	(Lost Revenue) + (Hidden Costs)
	=	$408,000 + $20,000
	=	$428,000

The real cost impact includes the upfront costs ($60,000 DDR installation and $15,000 engineering fees) and hidden costs. The real cost impact is now calculated for the first testing cycle.

Real Cost Impact	=	(Upfront Costs) + (Hidden Costs)
	=	$60,000 + $15,000 + $428,000
	=	$503,000

Because recording equipment was installed during the first testing cycle, there is no cost in future testing cycles for recording equipment. The only cost will be the engineering fees. The real cost impact of future cycles is now calculated.

Real Cost Impact	=	(Upfront Costs) + (Hidden Costs)
	=	\$8,000 + \$0
	=	\$8,000

Discussion of Scenarios

A summary of the costs associated with each approach to MOD testing is summarized in the following table.

CASE STUDY #1 - REAL COSTS PER TESTING CYCLE		
Validation Method	**First MOD Testing Cycle**	**Future MOD Testing Cycles**
Staged testing	\$596,000	\$38,000
Disturbance recording (temporary DDR)	\$223,000	\$216,000
Disturbance recording (permanent DDR)	\$503,000	\$8,000

Prior to considering hidden costs, the cost of staged testing was significantly less than disturbance recording. However, once the hidden costs are considered, installing a temporary DDR and performing validation with disturbance recordings turns out to have a significantly less real cost than staged testing. The hidden costs are influenced by many factors: cost of fuel, the wholesale rate of electricity, and outage time required for setup, installation, and testing. Any change to any of these factors would impact the real costs.

In this case study, a dedicated outage was required in order to perform the model validation. The plant was placed back into service as soon as possible after the work was complete. In order to increase overall plant reliability, there may be cases where extending the outage window beyond the time required for DDR installation would be beneficial in order to perform other facility repairs or maintenance work not related to MOD-026 and MOD-027. These instances would need to be evaluated on a case by case basis to determine how much of the lost revenue should be included in the real cost of generator model validation.

Another aspect to consider is the long-term return on investment (ROI). Model validation through disturbance recording with a temporary DDR is the most cost effective method through several testing cycles into the future. It is not until the third or fourth testing cycle into the future that installing a permanent recorder will have less accumulated cost than using a temporary recorder and performing validation through online disturbance recording. Even in WECC where re-validation is required every 5 years, this payback would be 15 or 20 years into the future. For a utility or non-utility generator (NUG) who holds on to its generating assets for a long period of time, this kind of ROI analysis might be an important factor to consider.

For an entity that does not intend to hold on to its generating assets long term, the ROI might not be an applicable consideration. Depending on the lifecycle, type of plant, ownership structure, and existing power purchase agreements (PPAs), looking far into the future could be irrelevant. For many plants it would only be prudent to look at the immediate costs at hand in order to meet the next MOD-026 and MOD-027 Implementation Plan deadlines.

Because all plants have many factors to consider when designing an implementation plan for performing MOD-026 and MOD-027 testing, performing an analysis of upfront and hidden costs as done in this case study will help a GO determine the best course of action.

Case Study #2 – 280 MW Combined-Cycle Gas Plant

Upfront Costs

In this case study, the plant operates on a seasonal schedule which correlates to hot and cold weather. The plant is typically online during December, January, and February (cold winter months), as well as June, July, August, and part of September (hot summer months). During the shoulder months of March, April, May, October and November, the plant is typically offline. With this type of schedule, any testing or equipment installation can be performed during the offline months so as not to interfere with selling power during the online seasons.

CASE STUDY #2 - UPFRONT COSTS PER TESTING CYCLE		
Validation Method	**First MOD Testing Cycle**	**Future MOD Testing Cycles**
Staged testing	$28,000	$28,000
Disturbance recording (temporary DDR)	$35,000	$28,000
Disturbance recording (permanent DDR)	$75,000	$8,000

The staged testing cost includes the recording equipment, consultant-led testing script, engineering analysis, and report. As in the first case study, the staged testing method at first glance appears to be less expensive than disturbance recording. However, the hidden costs specific to this plant's type, operating mode, and business model should now be considered.

Staged Testing Real Cost

This seasonal plant is able to perform staged testing during its off season shoulder months. For this reason, the revenue lost due to the inability to sell power does not need to be included as a hidden cost or factored into the real cost impact of model validation. There are other hidden costs not seen in the previous case study. Regardless of when staged testing is performed, gas is still required. At this particular plant, the cost of fuel for startup is estimated at $5,000 and the cost of fuel for testing is estimated at $20,000.

Hidden Costs	=	(Gas for Startup) + (Gas for Testing)
	=	$5,000 + $20,000
	=	$25,000

This hidden cost will be the same in each testing cycle. When we add this to the testing company costs, we can determine the real cost impact of staged testing at the combined-cycle plant.

Cost Impact	=	(Testing Company) + (Total Gas Cost)
	=	$28,000 + $25,000
	=	$53,000

This will be the same recurring real cost in future testing cycles.

Real Cost of Disturbance Recording with a Temporary Recorder

As with the staged testing method, the DDR can be installed during the off season and the temporary recorder removed during the following off season. Therefore, revenue lost due to the inability to sell power during the installation period does not need to be factored into the real cost impact of model validation. This is why MW capacity of the plant is not important in this case study.

Additionally, the cost of gas for startup does not need to be considered because the DDR installation is performed during the shoulder months. The plant will undergo startup for the next seasonal service period and shutdown during the following shoulder months as originally planned. Therefore, the total hidden cost of a temporary and permanent DDR installation is the same. The total hidden cost is $0. The real cost impact of disturbance recording in the first testing cycle is now calculated for a temporary DDR.

Real Cost Impact	=	(Upfront) + (Hidden Costs)
	=	$35,000 + $0
	=	$35,000

For the disturbance recording method with a temporary DDR, the upfront costs in future cycles will be slightly less. The upfront cost of the recording equipment rental combined with the engineering fees is the same at $28,000 and the hidden costs are still $0 because of the plant's seasonal business model. The real cost impact of disturbance recording in future cycles is now calculated for a temporary DDR.

Real Cost Impact	=	(Upfront) + (Hidden Costs)
	=	$28,000 + $0
	=	$28,000

Real Cost of Disturbance Recording by Installing a Permanent Recorder

As with a temporary recorder, performing model validation by way of installing a permanent recorder has no hidden costs in this plant due to its seasonal operation. The real cost impact of disturbance recording in the first testing cycle is now calculated for a permanent DDR.

Cost Impact	=	(Upfront) + (Hidden Costs)
	=	$75,000 + $0
	=	$75,000

The real cost impact of disturbance recording in future testing cycles is now calculated for a permanent DDR.

Real Cost Impact	=	(Upfront) + (Hidden Costs)
	=	$8,000 + $0
	=	$8,000

Discussion of Scenarios

While the cost of model validation through disturbance recording is significantly less in the second testing cycle, the cost of staged testing will remain the same in all future cycles. See the comparison in the following table.

CASE STUDY #2 - REAL COSTS PER TESTING CYCLE

Validation Method	First MOD Testing Cycle	Future MOD Testing Cycles
Staged testing	$53,000	$53,000
Disturbance recording (temporary DDR)	$35,000	$28,000
Disturbance recording (permanent DDR)	$75,000	$8,000

It can be seen that, as in first case study, disturbance recording with a temporary recorder is the most economical approach during the first testing cycle. Also similar to the first case study is that disturbance recording by way of installing a permanent recorder becomes economical in the third cycle. The dollar amounts are the same as disturbance recording with a temporary recorder. By the end of the third testing cycle, $159,000, $91,000, and $91,000 will have been spent on staged testing, disturbance recording with a temporary recorder, and disturbance recording with a permanent recorder, respectively.

Like in the first case study, a determination must be made whether looking three testing cycles in the future is relevant for the plant's expected lifecycle, business model, existing PPAs, and other such factors.

Further Cost Savings Opportunity

An opportunity to reduce disturbance recording costs exists if the GO were to perform the DDR installation internally. If the resources exist within the organization to design, install, test, commission, and create as-built drawings, the upfront costs can be reduced significantly. The cost of the DDR, test switches, and other materials can be estimated at $20,000. This will reduce the out-of-pocket costs of the permanent DRR installation from $60,000 to $20,000. In this situation, the total first testing cycle cost of disturbance recording can be re-calculated.

Real Cost Impact	=	(In-House DDR Installation) + (Engineering Fees) + (Hidden Costs)
	=	$20,000 + $15,000 + $0
	=	$35,000

If the resources exist internally to install recording equipment, the cost impact of installing disturbance recording equipment would be much less than staged testing even in the first cycle.

Case Study #3 – 280 MW Combined-Cycle Gas Plant with Existing Recorder

As discussed earlier, other components of a plant's existing control system may already have recording capabilities such as some modern exciters and AVRs. Whatever the recording hardware may look like, it must be capable of being configured to trigger a recording of frequency or voltage conditions per specific interconnection criteria. With this in mind, the real cost impact is taken from the second case study and modified to remove the DDR installation cost. The real cost impact of staged testing remains unchanged. However, the cost impact of disturbance recording is reduced significantly because recording equipment is already available.

Real Cost Impact	=	(DDR Installation) + (Engineering Fees) + (Hidden Costs)
	=	$0 + $15,000 + $0
	=	$15,000 (first cycle)

A comparison of staged testing and disturbance recording costs is shown in the following table.

CASE STUDY #3 - REAL COSTS PER TESTING CYCLE		
Validation Method	**First MOD Testing Cycle**	**Future MOD Testing Cycles**
Staged testing	$53,000	$53,000
Disturbance recording (existing DDR)	$15,000	$8,000

This case study shows that it is worthwhile for a plant to determine if existing equipment within their system is capable of creating data recordings. Care must be taken to confirm that the existing equipment is capable of creating data recordings suitable for use in the engineering analysis.

The existing recording equipment or devices might also require some level of setup or programming. If resources do not exist internally within the GO's organization to configure the equipment, then the cost of bringing in an outside contractor to perform this work needs to be included in to the real cost impact.

Additional Considerations

If recording equipment is already available in a plant, online disturbance recording can possibly be the most cost effective method to perform model validation. However, there are instances where performing model validation through disturbance recording might not be possible or make financial sense.

One example would be a peaker plant that is only online for short periods of time on a seasonal basis. These kinds of plants might not be online long enough to experience system disturbances as they occur on the grid. Model validation would need to be performed through staged testing. Another example where disturbance recording might not make sense is a plant that is scheduled to be decommissioned prior to the NERC deadlines for MOD-026 and MOD-027 model validation.

There are additional benefits of having a DDR permanently installed in a facility. The same recording equipment used to capture generator response data can often also satisfy the requirements for NERC's Disturbance Monitoring and Reporting Standard (PRC-002). A modern DDR can record many input channels at a time, create individual multi-hour recordings, export data for use with other software programs, and more. These features enable benefits beyond regulatory compliance. Benefits can also be realized for other purposes such as checking breaker opening times and similar predictive maintenance functions.

Another benefit is that disturbance recording provides a better quality of validation by capturing real generator responses to real system conditions. The results obtained from staged testing are only as good as the tests the machine is run through. They are not rigorous and are limited in scope. For this reason, staged tests cannot fully simulate real-world conditions.

Compliance Plan Development

The following outlines the process for determining how to apply MOD-026 and MOD-027 to a fleet of generating facilities within an organization.

1. Determine if MOD-026 and MOD-027 Reliability Standards are applicable to your fleet of applicable entities based on its location in the Eastern, Quebec, Western or ERCOT Interconnect and criteria found in Section 4.2 in the Reliability Standards related to individual generator or facility MVA rating.

2. Consider how the entity is configured for NERC registration. Is the entity a single registered entity with one or multiple generators or does the registered entity have multiple facilities and multiple generators? This information is needed in order to determine the phased-in percent completion dates based on NERC's MOD-026 and MOD-027 Implementation Plan.

3. Determine current and future planned outage schedules for the NERC MOD-026 and MOD-027 applicable facilities. This planning is an important consideration that must also be addressed in order to meet the phased-in NERC Implementation Plan as a temporary or permanent DDR will need to be installed for verification testing.

4. Schedule DDR installation for applicable facilities during planned outages to meet the phased-in NERC Implementation Plan and demonstrate compliance.

Conclusion

NERC's MOD-026 and MOD-027 Reliability Standards are currently enforceable and mandate generator model validation. In order to develop a compliance plan, GOs have many factors to consider that impact immediate and long-term expenses, as well as the bottom line.

The three case studies presented in this paper highlight a comprehensive, thoughtful approach that helps GOs evaluate the upfront and hidden costs of generator model validation testing. In each case, there were unique factors that played into the real cost impact. At first glance, the upfront costs of contractor and engineering fees would lead one to conclude that the staged testing was more economical than disturbance recording. However, when hidden costs such as lost revenue and startup fuel costs were taken into account, disturbance recording with temporary recorders were more economical. When the plants utilized existing resources the costs of disturbance recordings were further reduced.

Due to the many unique combinations of generator types, plant configurations, fuel costs, business models, and operating schedules for any given generating facility, there is no "one size fits all" solution for determining the most economical approach for generator model validation testing. However, as seen in this paper's case studies, determining the most economical approach to complying with MOD-026 and MOD-027 is best done with a comprehensive analysis of each individual plant and assessment of the GO's entire portfolio of assets.

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Biographies

Andrew Kaster earned his Bachelor of Science in Electrical Engineering from Oregon State University in 2002 with an emphasis in power systems. He has experience as a system design engineer, electrical equipment manufacturing, and electrical equipment sales. He joined Vertiv's Electrical Reliability Services in 2012 as a field engineer and currently works as a system protection engineer. His primary focuses are protection and control system design, power system studies, and NERC PRC/MOD compliance for generation plants. Andrew is a registered professional engineer in Oregon.

Steven Gaynier has worked 37 years in the power generation business. More specifically, he has 26 years of experience in power plant startup and operations, as well as operations and maintenance management. He also has 11 years of experience in design, development, and implementation of sustainable NERC compliance programs.