



USING LOADABILITY STUDIES TO COMPLY WITH NERC PRC-025

How to streamline the assessment
process and benefit from early adoption

Executive Summary

An August 2003 electric power blackout across the northeast United States and Ontario, Canada, affected an estimated 50 million people. An analysis of this and other major disturbances over the last 25 years revealed that generators tripped for conditions that did not pose a direct risk to those generators and associated equipment. In many cases, this tripping was found to have expanded the scope and/or duration of these disturbances.

As a result, the North American Electric Reliability Corporation (NERC) created reliability standard PRC-025-1—Generator Relay Loadability. The purpose of the standard is to “set load-responsive protective relays associated with generation facilities at a level to prevent unnecessary tripping of generators during a system disturbance for conditions that do not pose a risk of damage to the associated equipment.”

The standard, which outlines multiple options for achieving compliance, applies to generating plants connected to the Bulk Electric System (BES), including those identified as Blackstart Resources in the transmission operator’s system restoration plan.

PRC-025-1 is currently enforceable, so facilities will need to assess their compliance immediately and develop a plan of action. Non-compliant facilities may need to budget for system modifications or incorporate changes during a planned system outage, which can take considerable time. To avoid potential fines, demonstrated compliance must be completed by October 2019.

This white paper and other Vertiv™ resources aim to help generator owners (GOs) and generator operators (GOPs) reap the benefits of early adoption. In fact, Vertiv’s Electrical Reliability Services (ERS) team developed a tool to streamline the process of assessing the settings for generation unit protection relays. Wherever a facility is in the process of achieving compliance, using the assessment tool will help organizations better plan the effort, time, and cost needed to meet the NERC standard’s requirements.

Determining Needed Engineering Resources

The competitive nature of a deregulated bulk energy system has driven GOs and GOPs to find ways to reduce their overall operational costs while still increasing their reliability and availability to produce. This strategy often results in operating with limited engineering resources. Under typical conditions, this approach is economic and appropriate. However, as new regulatory requirements such as PRC-025-1 are instituted, meeting them with limited engineering resources can be difficult.

Because regulatory requirements governing operations continue to change, single generation sites that have a lean workforce will likely need to rely heavily on external or outsourced engineering resources, such as contractors. Multi-site generation entities often already utilize an engineering team specializing in matters pertaining to NERC compliance. However, they may also need additional assistance if their engineering team is focused on disseminating new standards to the fleet and preparing for audits, rather than the highly technical tasks needed to meet new regulatory requirements.

As these requirements for system stability and loadability are enacted, a surge in demand for engineering support of a much more technical nature becomes apparent. It is common practice for a GO to contract with a GOP and remain relatively removed from the day-to-day operations of the facility. In this arrangement, the GOP is often better positioned to ensure that a facility complies with new standards using either internal or external resources. However, it is usually the GO that is financially responsible for any fines assessed for noncompliance.

Addressing Misoperations Along with Compliance

Generation facilities that qualify as the BES, according to the NERC definition, are required to conform to PRC-025-1. This standard is designed to increase grid stability during system disturbances by reducing the number of nuisance trips due to incorrect settings. Thirty-one percent of all misoperations resulting in unplanned hours (UH) or forced outage hours (FOH) were due to incorrect settings, logic, or design errors. More than 20 percent of all misoperations in 2013 and 2014 were due to microprocessor relays with incorrect settings, logic, or design errors.

The Federal Energy Regulatory Commission (FERC) has approved specifications designed to reduce misoperations by 25 percent, including implementation of standardized setting methodologies as defined by PRC-019-2, PRC-024-2 and PRC-025-1, all of which are currently enforceable.

Early adoption of these standards helps generation sites remain competitive in the energy market and attractive to investors. By avoiding UH or FOH due to misoperations, and subsequently reducing the equivalent forced outage rate (EFOR), facilities can achieve increased revenues, as well as lower operational, maintenance, and repair costs.

Defining Compliance Options

PRC-025-1 provides multiple options for setting load-responsive protective relays, as outlined in Attachment 1, Table 1 of the application guidelines. Each relay may have up to three options available—A, B and C. Figure 1 illustrates the requirements for the phase distance relay (21), including three compliance options.

PHASE DISTANCE RELAY (21) - DIRECTIONAL TOWARD THE TRANSMISSION SYSTEM

Option	Bus Voltage	Pickup Setting Criteria
1A	Generator bus voltage corresponding to 0.95 per unit of the high-side nominal voltage times the turns ratio of the generator step-up transformer	The impedance element shall be set less than the calculated impedance derived from 115% of: (1) Real Power output – 100% of the gross MW capability reported to the Transmission Planner, and (2) Reactive Power output – 150% of the MW value, derived from the generator nameplate MVA rating at rated power factor
		or
1B	Calculated generator bus voltage corresponding to 0.85 per unit nominal voltage on the high-side terminals of the generator step-up transformer (including the transformer turns ratio and impedance)	The impedance element shall be set less than the calculated impedance derived from 115% of: (1) Real Power output – 100% of the gross MW capability reported to the Transmission Planner, and (2) Reactive Power output – 150% of the MW value, derived from the generator nameplate MVA rating at rated power factor
		or
1C	Simulated generator bus voltage coincident with the highest Reactive Power output achieved during field-forcing in response to a 0.85 per unit nominal voltage on the high-side terminals of the generator step-up transformer prior to field-forcing	The impedance element shall be set less than the calculated impedance derived from 115% of: (1) Real Power output – 100% of the gross MW capability reported to the Transmission Planner, and (2) Reactive Power output – 100% of the maximum gross Mvar output during field-forcing as determined by simulation

Figure 1: Setting options for load-responsive protective relays

This white paper will focus on two options. The first is Option A, which is the simplest to apply, but generally results in a less accurate assessment. The second, referred to as “software simulation” (and either Option B or Option C in the application guidelines), is more accurate because it models the machine’s reactive power capability using field-forcing simulations. GOs need to understand the benefits and detriments of each, which are summarized in Figure 2.

	OPTION A DERIVE REACTIVE POWER RATING FROM CONSERVATIVE CALCULATIONS	SOFTWARE SIMULATION USE FIELD-FORCING TO DETERMINE REACTIVE POWER RATING
Benefits	<ul style="list-style-type: none"> The process of assessing compliance can be automated Requires the least amount of effort to demonstrate compliance if all settings comply 	<ul style="list-style-type: none"> Majority of the settings that fail Option A pass software simulation In some cases, all settings assessed are compliant, requiring no setting changes Fewer setting changes compared to Option A Fully modeled machines are better protected
Detriments	<ul style="list-style-type: none"> High probability that generation unit will not be capable of producing calculated reactive power Increasing settings to comply may sacrifice protection Changing settings requires coordination with upstream devices and may include transmission Implementing relay setting changes requires a maintenance outage and testing to comply with PRC-005 	<ul style="list-style-type: none"> Complete system modeling can be challenging for older machines and sites with poor document control or lack of OEM support Modeling software is expensive Requires more engineering resources to complete assessments Requires the most amount of effort to demonstrate compliance

Figure 2: Benefits and detriments of Option A and software simulation

PRC-025-1 Option A analysis is a conservative approach that is relatively easy to execute once all system data is gathered and parsed. In simplified terms, Option A applies to all load-sensitive relays in service during normal operations (e.g., 21, 51, 51C, 51V, 67). It requires setting these relays greater than 115 percent of the calculated capacity of the machine. This calculated machine capacity is based upon 100 percent of the gross megawatt (MW) capability as reported to the transmission planner, and the calculated reactive power capability of the machine derived from 150 percent of the MW value at rated megavoltampere (MVA) and power factor (based on generator nameplate values). While Option A is relatively easy to execute, it may not be most appropriate for the needs of the facility.

Given the conservative nature of the criteria in Option A, which may not be achievable by all generating units, an alternative method—software simulation—was created to determine the reactive power capability. The rationale for this option which appears in the technical application reads as follows:

The simulations confirmed, for units operating at or near the maximum real power output, that it is possible to achieve a reactive power output of 1.5 times the rated real power output when the transmission system voltage is depressed to 0.85 per unit. While the simulations demonstrated that all generating units may not be capable of this level of reactive power output, the simulations confirmed that approximately 20 percent of the units modeled in the simulations could achieve these levels. On the basis of these levels, Table 1, Options 1a (i.e. 0.95 per unit) and 1b (i.e. 0.85 per unit), for example, are based on relatively simple, but conservative calculations of the high-side nominal voltage. In recognition that not all units are capable of achieving this level of output, Option 1c (i.e. simulation) was developed to allow the generator owner, transmission owner, or distribution provider to simulate the output of a generating unit when the simple calculation is not adequate to achieve the desired protective relay setting.

To summarize this portion of the technical application, Option A requires less engineering effort, yet may not provide the most accurate assessment of generator capability. While this option does help to improve grid stability, it is less accurate than software simulation and may not provide optimal generator unit protection. In these cases, the thresholds of the load-sensitive relays typically need to be increased, which requires coordination with the transmission system prior to implementation. This coordination effort may take as much or more time than what would be needed to simply perform software simulation from the start. Additionally, any changes made to protective relay settings must be fully tested at the time of implementation, which generally requires the generation site to take a maintenance outage.

For the average single-site plant with limited engineering resources, the process of assessing how close a system is to compliance can be quite a challenging task without assistance. Even for the multi-site owner with a dedicated NERC team, the task of analyzing tens, or even hundreds of sites, is a significant effort without a systematic process and supportive tool for making initial assessments. While some might try to centralize engineering resources, this typically translates to less familiarity with each site and limited data gathering capacity.

Using a Systematic Process & Support Tool

PRC-025-1 application guidelines carefully detail the steps necessary to check compliance with Option A. This process must be performed for each site and requires a significant amount of effort to manually perform each time. A quality assessment tool will automate tasks of the process that require little supervision and are repeatable from project to project, reducing the time, effort, and energy needed to accomplish these tasks.

While engineering teams could create their own tool, this work has already been done by the engineers of ERS in hopes of helping GOs simplify the assessment process and subsequently encourage early adoption. This no-cost tool reduces the compliance-checking steps to the most essential components and makes the assessment process scalable for all generation site configurations.

The following seven step procedure, using the ERS tool, will guide an owner through the generator loadability process beginning with data gathering and initial assessments to corrective actions and final reporting.

Step 1: Gather generation unit data.

A minimum amount of information should be collected prior to performing assessments of the relay settings. This basic generation unit information is used throughout the assessment process. Required information can be found in the following documents: one-line drawings, three-line drawings, protective relay settings, relay test reports, and component nameplates.

Each document will contain key information such as the following:

- Maximum rated MVA for the generator
- Rated power factor
- Rated voltage
- Maximum MVA for generator step up (GSU) and unit auxiliary transformer, and associated impedances
- Rated primary and secondary voltages at the set tap position for the GSU
- Utility voltage
- MW reported to the transmission planning coordinator

Step 2: Determine which load-sensitive protective relays within the generation unit will require study for generator loadability.

PRC-025-1 application guidelines illustrate an example protective relay scheme for a generation unit. This scheme is comprehensive in order to assist the user in determining how the standard applies to a given plant, however not all relays illustrated will necessarily exist in every system (See Figure 3).

Once the generation system protective relays have been sorted into the appropriate options as seen in Figure 3, the remaining protective device information is gathered to assess each protective relay's compliance. This information is also found within the documentation gathered in Step 1.

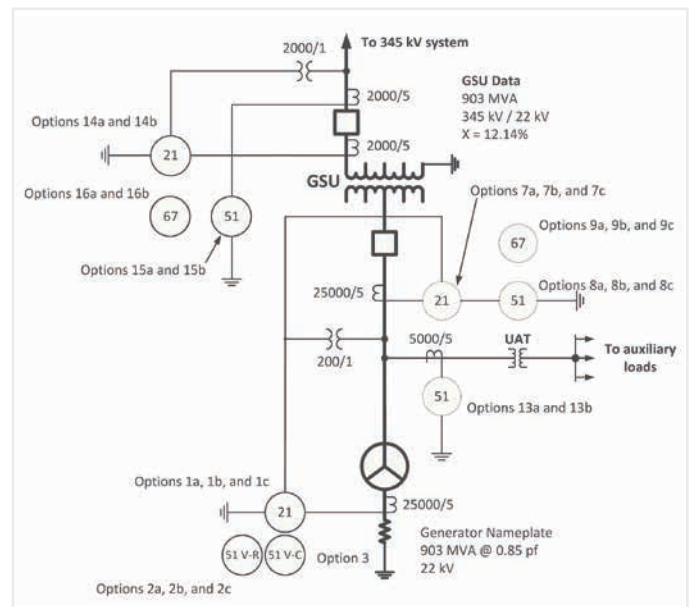


Figure 3: Synchronous generator protective relay scheme

Step 3: Begin populating tool with nameplate data.

Once the basic generation unit information has been gathered in Step 1, it should be entered into the nameplate tab of the assessment tool as shown in Figure 4. While more data has been gathered to support the assessment, this tool has distilled the information to the minimum requirements.

DEMO - NERC PRC-025, Table 1 Calculation

Instructions | Nameplate Data | 21-Option 1a | 51V-Option 2a | 51C-Option 3 | 21-Option 7a | 51/67-Option 8a or 9a | AUX XFMR-Option 13a | 21-Option 14a | 51/67-Option 15a or 16a | Contact

Generator Nameplate Data

Generator Name:

Maximum Unit MVA:

Power Factor:

Generator Rated Voltage [kV]:

MW Reported to the Transmission Planning Coordinator (MW):

GSU Transformer Nameplate Data

GSU MVA Rating:

GSU Reactance at MVA Rating [%]:

GSU in Service TAP:

Secondary Voltage:

Primary Voltage:

GSU High Side Nominal Voltage [kV]:

Calculated Ratio:

In order to verify compliance with NERC PRC-025-1 (Generator Relay Loadability) populate ALL fields to the left prior to moving to other tabs.

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Below is the data required to populate the tool and where that data can usually be found:

- Generator's Nameplate Rating (generator's nameplate, 3-line drawings, 1-line drawings)
- Generator Step Up (GSU) Transformer's Nameplate Rating (transformer's nameplate, 3-line drawings, 1-line drawings)
- Megawatts [MW] Reported to the Transmission Planning Coordinator (plant documentation)
- Auxiliary Transformer's Nameplate Rating (transformer's nameplate, 3-line drawings, 1-line drawings)
- Current Transformer (CT) Ratio, Potential Transformer (PT) Ratio (3-line drawings, 1-line drawings)
- Type of Utilized Protective Relays (single line diagram, maintenance records, commissioning report)
- Protective Relay Settings (generator protection study, maintenance records, commissioning report)

Figure 4: Example of how to enter generation unit parameters into the assessment tool

Step 4: Continue inputting data for each protective relay requiring study.

Compare Figure 3 to the site being assessed in order to determine the pertinent options. The protective relays subject to the requirements of generator loadability identified in Step 2 are selected from the remaining tabs of the tool. Each assessment for Option A will require protective relay specific information such as instrument transformer ratios, and protective relay pickup and/or tap values. This tool delivers a “compliant or not-compliant” assessment for each synchronous generator relay by comparing the protective relay settings with Option A of the standard. Additionally, the minimum settings required to become compliant with Option A are also calculated and presented. This gives the user valuable information indicating how close each load-sensitive relay setting is to Option A compliance.

Figure 5 illustrates an example of the results of an assessment of an overcurrent relay applied at the utility interconnection point. As indicated, the initial assessment fails the Option 15a compliance check. As-found settings were 5 amps secondary pickup but the minimum required to comply with Option 15a is 5.83 amps, a differential of .83 amps.

The difference between the as-found setting and the minimum setting required by Option 15a is significant (27 percent). The calculation provides the GO or GOP enough information to make a choice regarding whether to pursue making changes to the existing protective system settings or to further study the loadability of the generator through simulations in order to derive the most accurate assessment of machine capabilities.

At this stage, using an assessment tool will have significantly reduced the effort required to check compliance with Option A of the standard versus manually performing the calculations found in PRC-025-1 application guidelines. This strategy frees up valuable engineering resources needed for other tasks. Because this process is scalable, an entire fleet can be quickly assessed so that engineers and management can make decisions based upon the whole rather than a small and potentially non-representative sample.

DEMO - NERC PRC-025, Table 1 Calculation

Instructions | Nameplate Data | 21-Option 1a | 51V-Option 2a | 51C-Option 3 | 21-Option 7a | 51/67-Option 8a or 9a | AUX XFMR-Option 13a | 21-Option 14a | 51/67-Option 15a or 16a | Contact

Please select if the 51 or 67 protection is utilized on the utility side of the GSU.

CT Ratio [XXX:1]

PT Ratio [XXX:1]

Generator Step Up Transformer

Each generator has its own GSU

Two generators are sharing the GSU

Existing Protective Relay Data

Manufacturer [Optional]

Model [Optional]

51 Pickup [A]

PRC-025, Table 1, Option 15a/16a Required Minimum Pickup [A]:

Setting is NOT in compliance with Table 1, Option 15a/16a.

[51-15a HELP](#) [67-16a HELP](#)




Figure 5: Assessment of overcurrent protective relay settings on the utility side of the GSU to Option 15a

Step 5: Decide whether to demonstrate compliance using Option A or software simulation.

If choosing Option A, GOs will need to make necessary adjustments to protective relay settings and create the reporting necessary to demonstrate compliance. If GOs want to ensure more accurate relay settings that improve generating unit protection, they should investigate further through field-forcing to model the machine's reactive power capability during a transient sufficient enough to lower utility voltage to 85 percent of steady-state values. Once the approach has been decided, any changes to the existing settings should be carefully reviewed by the original equipment manufacturer (OEM) and the protection engineers responsible for upstream coordination prior to implementation.

For sites utilizing software simulation to demonstrate compliance, engineering best practices call for reassessment of all load-sensitive protective relays based upon the reactive power capabilities derived from field-forcing.

Step 6: Perform corrective actions as needed.

Whether determining the reactive power rating through conservative calculation or through software simulation, corrective actions will likely need to be taken. Actions will include scheduling an outage for the implementation, testing, and documentation of the protective relays' setting changes.

Step 7: Compile all information to complete the demonstration report.

A thorough report for generator loadability will contain all information that was gathered during the assessment phase, supportive calculations from PRC-025-1 application guidelines, results from the software simulations (if performed), and documentation of any corrective actions and testing.

Assimilating reporting characteristics that make the auditing process efficient will contribute to a successful audit with the electric reliability organization (ERO). Reporting methods that support a searchable document such as an electronic format employing optical character recognition (OCR) conversions, a linked table of contents, bookmarking, and embedded links to supportive documentation should be an integral part of the demonstration report. These attributes allow an auditor to quickly navigate through the report to find critical information.

When reviewing reports, an auditor will be more likely to recognize formulas similar to those published in PRC-025-1 application guidelines, so all calculations should follow the guidelines as closely as practical. A high-level summary of all load-sensitive protective relays should be listed in a format to show the reader which relays were studied as part of generator loadability and which were not applicable.

Benefiting from Early Adoption

The benefits of being an early adopter of the generator loadability study are numerous and the potential costs for those that delay can be significant. GOs are subject to the same economic pressures that any industry faces when considering stiffer regulatory requirements and can be tempted to wait until the last moments to comply, in the hopes of realizing cost savings. As previously discussed, NERC designed the PRC-025-1 standard to directly reduce the number of misoperations reported and to increase the stability of the BES. This standard was designed to save effort, time and expense, and early adoption will maximize those benefits.

To best illustrate the costs associated with a transient stability misoperation, consider two identical generation plants. Plant 1 uses the original design and OEM load-sensitive protective device settings, while Plant 2 has complied with the PRC-025-1 Generator Relay Loadability standard. Both plants are generating close to rated MW capacity at rated power factor when a transmission system transient requires each plant to produce enough reactive power to temporarily support the system through a 15 percent voltage sag. Plant 2 rides through the transient without activating any of the load-sensitive relays. Plant 1 senses the increased transient load at a load-sensitive relay as an overload and trips the unit offline. In this case, Plant 1 is considered the only affected entity.

While Plant 1 did not damage any equipment, recovery from this event is going to take substantial operational effort, including mechanical shutdown and cool down of the unit, while an investigation into the cause of the protective device trip is performed. Investigations are usually performed by maintenance staff or contract labor and mobilization times should be considered part of the recovery effort.

Depending on which load-sensitive relay in the system tripped, component testing may also need to be performed, further delaying the recovery. Once the cause of the relay misoperation has been identified, the transmission planner requires notification of the cause and corrective actions taken before scheduling a return service.

This process can take an entire day, resulting in lost revenue, increased costs, and a higher EFOR for the facility. This scenario can be considered the least impactful as no damage was caused to the unit as a result of the misoperation. The impact can only increase in magnitude for different scenarios.

Other considerations include planning and logistic factors. The economic laws of supply and demand dictate that as a deadline approaches and generation plants rush to seek out contract assistance (increasing demand) the available supply of those contractors and engineering firms will dwindle. This translates into higher costs and potentially lower quality. Early adopters will have access to greater engineering resources at lower costs.

For those generation sites that have completed the assessment and require changes to the load-sensitive protective relay settings, implementation and testing will need to be scheduled, requiring a maintenance outage. When the study has been performed earlier, rather than later, the chances of scheduling the implementation and testing during a planned outage, as opposed to scheduling a maintenance outage, is much greater.

Planned outages are typically part of a forecast and budget. Unplanned maintenance outages typically incur additional unexpected costs and are disruptive to normal operations. Early adopters will have a lower impact cost to the operations of the facility by implementing changes during previously scheduled planned outages.

Finally, in some instances, the existing relay system is not capable of accepting the settings required by PRC-025-1. In these special cases, the deadline for compliance is extended by two years to allow for retrofit of the existing protective relay system in order to comply with the generator relay loadability standard. This is a significant engineering effort which is best performed carefully with ample time and resources. Early adopters will have the benefits of adequate time to plan, budget, engineer, remove, install, and test the new protective relays.

Conclusion

NERC PRC-025-1 is currently enforceable and the GO is financially responsible for ensuring timely compliance. Regardless of the size of a generating entity, achieving compliance takes a concerted effort requiring ample time. GOs or GOPs will need to assess compliance immediately and develop a plan of action.

When developing a plan, the first priority should be to align needed engineering resources, whether internal or external. These resources are becoming scarcer as the compliance deadline nears. Qualified engineering resources are able to assist GOs and GOPs with determining which compliance option is best suited for each application. Whether choosing Option A, the more conservative approach, or deferring to the more accurate software simulation, several factors should be considered such as how much time, effort, and expense is needed to achieve compliance. GOs and GOPs should also consider the risks associated with non-compliance such as costly misoperation. Minimizing these operational interruptions and maximizing the benefits of compliance is best achieved through early adoption.

Using a systematic process and quality assessment tool, such as the user-friendly tool designed by ERS engineers, will speed up the time needed to evaluate initial compliance by reducing the effort required. This streamlining of the assessment process makes early adoption easier.

By starting now, generating entities will have better access to needed engineering resources, as well as more time to budget and plan for how to achieve compliance. A well-executed compliance plan rewards generating entities with a protected and more stable system and grid.

For more information about using loadability studies to comply with NERC PRC-025, visit VertivCo.com/NERCcompliance or contact a NERC specialist at NERCcompliance@VertivCo.com.

