Using Loadability Studies to Comply with NERC PRC-025-1

How to Streamline the Assessment Process & Benefit from Early Adoption

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The competitive nature of a deregulated bulk energy system has driven many generator owners (GOs) and generator operators (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 from the North American Electric Reliability Corporation (NERC) are instituted, meeting the new requirements 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 the GO that is financially responsible for any fines assessed for noncompliance.

This paper discusses methods to reduce the effort and resources required to assess compliance; provides guidance to manage noncompliant protective systems; and identifies the benefits of early adoption of the NERC PRC-025-1 Generator Loadability Standard.

Addressing Misoperations Along with Compliance

Generation facilities that qualify as the Bulk Electric System (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 misoperations due to incorrect settings, logic or design errors. 31 percent of all misoperations resulting in unplanned hours (UH) or forced outage hours (FOH) were due to incorrect settings/logic/design errors, and 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 unplanned hours or forced outage hours 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
NERC 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, Option A, Option B and Option C. Table 1, below, illustrates the requirements for the phase distance relay (21), including three compliance options.

<table>
<tr><th colspan="4">Table 1. Relay Loadability Evaluation Criteria</th></tr>
<tr><th>Relay Type</th><th>Option</th><th>Bus Voltage</th><th>Pickup Setting Criteria</th></tr>
<tr><td rowspan="5">Phase distance relay (21) – directional toward the Transmission system</td><td>1a</td><td>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</td><td>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</td></tr>
<tr><td colspan="3">OR</td></tr>
<tr><td>1b</td><td>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)</td><td>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</td></tr>
<tr><td colspan="3">OR</td></tr>
<tr><td>1c</td><td>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</td><td>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</td></tr>
</table>

Table 2: Comparison of Option A to Software Simulation

In this paper, we 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" in this paper (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 Table 2 below.

	Option A *Derive Reactive Power Rating from Conservative Calculations*	**Software Simulation** *Use Field-Forcing to Determine Reactive Power Rating*
Benefits	■ The process of assessing compliance can be automated ■ Requires the least amount of effort to demonstrate compliance if all settings comply	■ Majority of the settings that fail Option A pass software simulation ■ In some cases, all settings assessed are compliant, requiring no maintenance outage or testing ■ Fewer setting changes compared to Option A ■ Fully modeled machines are better protected ■ Models can be verified through testing MOD-25
Detriments	■ High probability that generation unit will not be capable of producing calculated reactive power ■ Increasing settings to comply sacrifices protection ■ Changing settings requires coordination with upstream devices and may include transmission ■ Implementing relay setting changes requires a maintenance outage and testing	■ 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

Table 2: Comparison of Option A to Software Simulation

NERC PRC-025-1 Option A analysis is a conservative approach that is relatively easy to execute once all of 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 in order 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 needs 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
The NERC 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 Emerson's Electrical Reliability Services (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. GOs can download the tool at any time to help with their compliance efforts.

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 1).

Once the generation system protective relays have been sorted into the appropriate options as seen in Figure 1, 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.

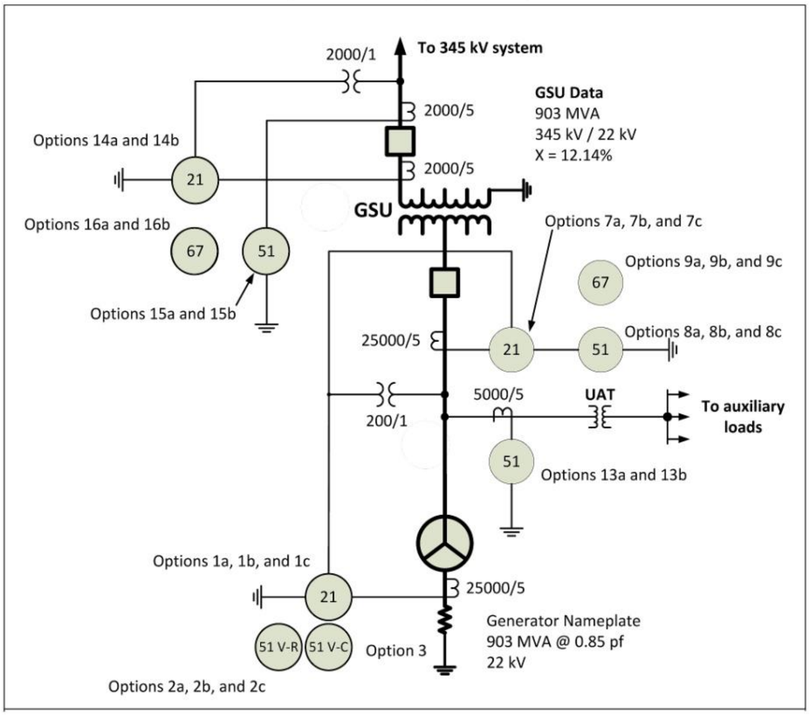

Figure 1: Example of a synchronous generator protective relay system

Step 3: Begin populating the 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 2. While more data has been gathered to support the assessment, this tool has distilled the information to the minimum requirements.

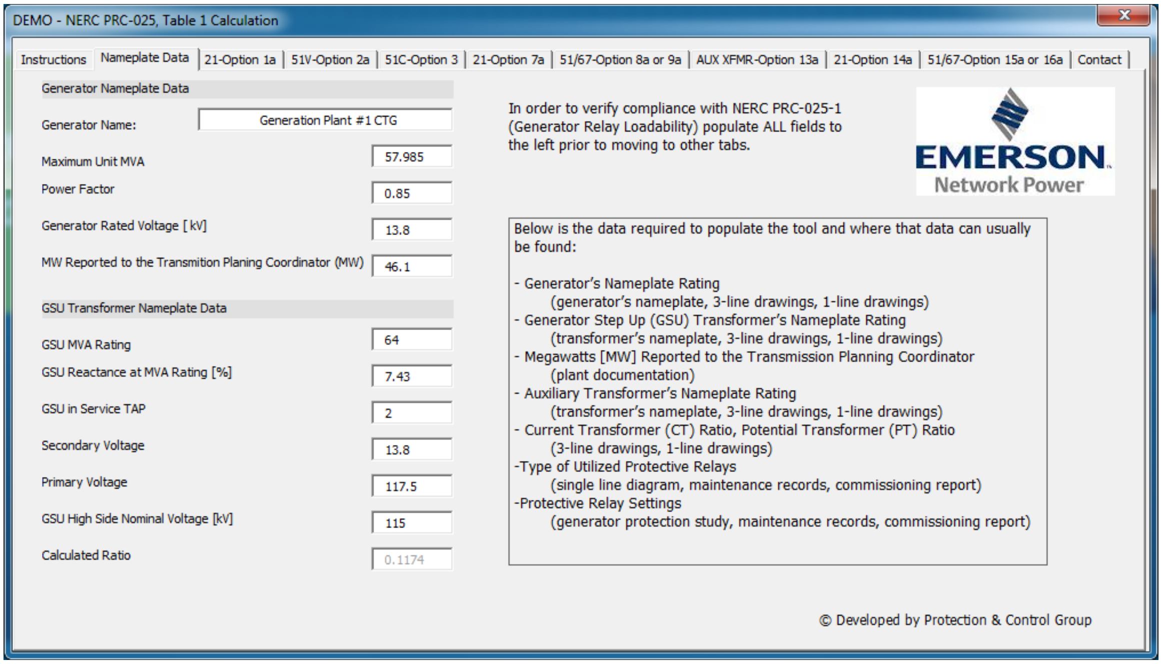

Figure 2: Example of how to enter generation unit parameters into the assessment tool

Step 4: Continue inputting data for each protective relay requiring study. Compare Figure 1 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 3 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 6.37 amps, a differential of 1.37 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 reactive power capabilities of the machine.

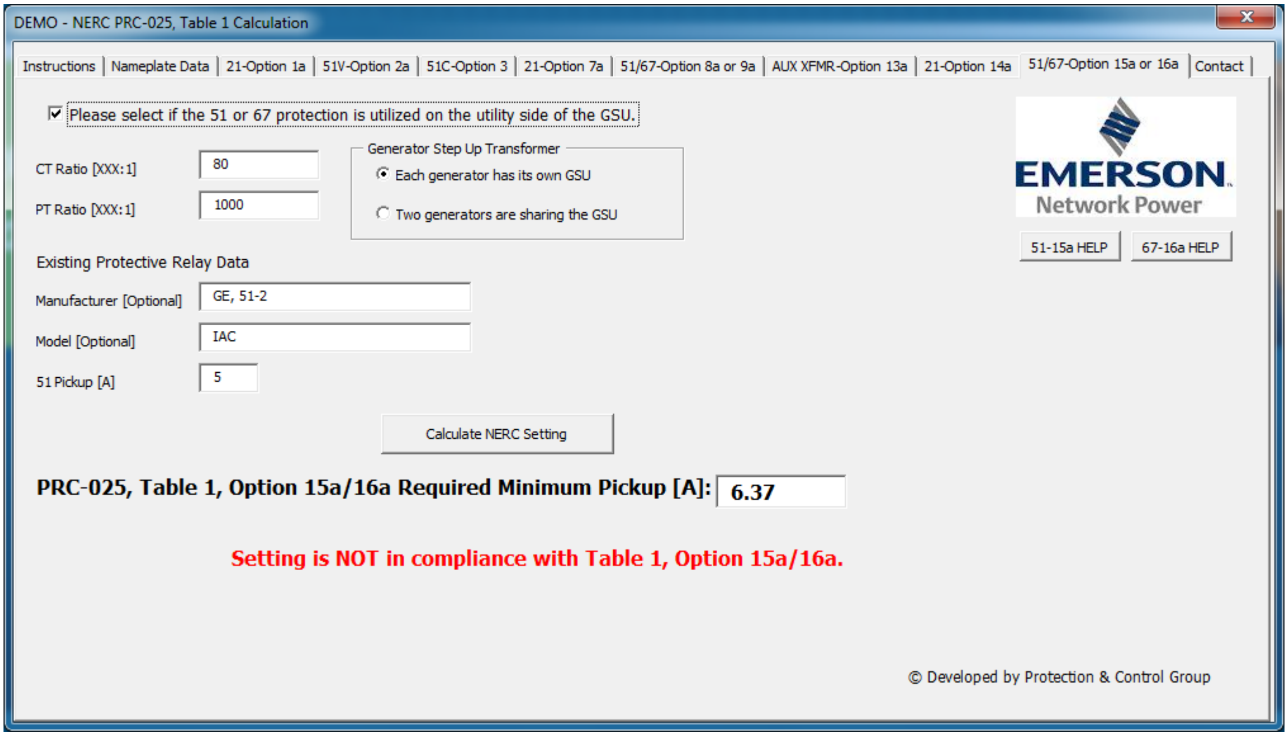

Figure 3: Assessment of overcurrent protective relay settings on the utility side of the GSU to Option 15a

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.

Step 5: Decide whether to demonstrate compliance to the standard using Option A or using 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 software simulations 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 simulations.

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 Electrical 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 the generator loadability and which were not applicable.

Benefiting from Early Adoption

The benefits of being an early adaptor 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 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 off line. 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 NERC 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 to comply with the generator 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.

Summary

Regardless of the size of a generating entity, achieving compliance with NERC PRC-025-1 requires a concerted effort. GOs or GOPs will need to rely heavily on either their internal or external engineering resources, especially when moving beyond the conservative calculations used in Option A to the more accurate software simulations. While these simulations take more time to execute, they ultimately require fewer setting changes for better protection.

Fortunately, Emerson’s Electrical Reliability Services team developed a downloadable tool and systematic process that can help engineering teams streamline their compliance assessment. This no-cost, user-friendly tool also encourages early adoption. 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.

Author Bio

In his role of supervising engineer for Emerson Network Power, Electrical Reliability Services (ERS), Steve Nollette draws on more than 20 years of experience performing and managing electrical testing, maintenance, and engineering services. Prior to joining ERS in 2001, Nollette was a nuclear engineer for more than 10 years with the U.S. Navy and most recently worked as a journeyman electrician for a global supplier of semiconductor products. Nollette also studied electronics management at Southern Illinois University, Carbondale and earned a Bachelor of Business Administration in management and operations from the University of Phoenix.