Joint Review of Protection System Commissioning Programs

2021 FERC, NERC and REs Report

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FEDERAL ENERGY REGULATORY COMMISSION

NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

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I. Executive Summary

In April 2020, the Federal Energy Regulatory Commission (FERC or the Commission), the North American Electric Reliability Corporation (NERC) and the Regional Entities (collectively, joint staff review team initiated a joint review to assess certain registered entities' (hereinafter, participants) protection system[1] testing or protection system commissioning (PSC) programs[2] and procedures.[3] The joint staff review team was initiated after a review of a sample of the Misoperation Information Data Analysis System (MIDAS) data indicated that an estimate of between 18 percent and 36 percent of misoperations in MIDAS, on January 1, 2019, can be attributed to issues that should have been detected through PSC. The goal of the review was to reduce misoperations attributable to PSC by identifying opportunities for improvement and developing recommendations and best practices for registered transmission and generator owners' PSC programs. The joint staff review was not a compliance or enforcement initiative.

In conducting this review, the joint staff review team gathered information and examined PSC programs from a representative sample of eight participants with diverse Bulk-Power System geographical locations and one contractor entity with experience aiding registered entities with their PSC programs. The joint staff review team assessed the existence and thoroughness of various elements of each participant's PSC program. Specifically, the joint staff review team focused on the following elements of each participant's PSC program:

- Stated goals and objectives
- Well-defined plans to perform commissioning
- Clearly identified lines of responsibility
- Authority given to responsible parties
- Feedback methods to improve the plan

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[1] "Protection System" is defined in the NERC Glossary as: (1) protective relays which respond to electrical quantities; (2) communications systems necessary for correct operation of protective functions; (3) voltage and current sensing devices providing inputs to protective relays; (4) station DC supply associated with protective functions (including station batteries, battery chargers, and non-battery-based DC supply); and (5) control circuitry associated with protective functions through the trip coil(s) of the circuit breakers or other interrupting devices. NERC Glossary of Terms Used in NERC Reliability Standards (June 28, 2021) (NERC Glossary).

[2] PSC program refers to a management program that serves as the source and means for executing PSC plans. This includes identifying the responsible parties for both managing and performing commissioning tasks.

[3] PSC procedure or plan refers to the sequence of steps required to carry out the stated purpose and goals of the PSC program. The PSC procedure or plan supplies a complete task list for testing every piece of equipment. The documentation defines the necessary scope for each organization involved in the project.

The joint staff review team also assessed the participants' PSC procedures. In particular, the joint staff review team assessed how well they conformed with the Institute of Electrical and Electronics Engineers (IEEE) WG I-25 guide *Commissioning Testing of Protection Systems.*[4]

The joint staff review team identified best practices and opportunities for improvement in the participants' programs/procedures and developed associated recommendations, which are discussed in this report. These recommendations and best practices are voluntary; they do not impose any obligations beyond those required by the relevant Reliability Standards. Thus, to obtain the intended benefits from this report, transmission owners, generator owners, and distribution providers are encouraged to assess their own PSC programs and procedures and implement relevant recommendations and best practices where appropriate.

The joint staff review team observed the following issues in most of the participants' programs. The JSRT believes that these common issues could have a significant adverse impact on misoperations rates:

- Lack of independent review of protection system designs by the commissioning group prior to construction;
- Lack of centralized overarching PSC programs that serve as a tool for the execution of PSC procedures; and/or
- Lack of feedback controls to prevent repeated problems in future PSC projects.

Other opportunities for improvement highlighted in this report, if implemented, could also improve misoperations rates.

A. Recommendations and Related Opportunities for Improvement

These voluntary recommendations apply to all Transmission Owners, Generator Owners, and Distribution Providers (collectively, Entities).

PSC Programs

1. **Entities should document a formal PSC program.** Having a formal documented program in a central location allows easy reference to all the elements of the program in a single document.

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[4] IEEE PSRC, WG I-25, *Commissioning Testing of Protection Systems*, (2017) https://www.pes-psrc.org/kb/published/reports/WG%20I-25%20Commissioning%20_Testing%20of%20Protection%20Systems%205-10-2017.pdf (IEEE WG I-25 guide).

- Participants lacked a central document containing the five key elements of an effective PSC program.[5] Some participants had the required elements but did not combine those pieces within a single program or house them in a central location.

2. **Entities should include goals and objectives in their formal PSC program.** Having a formal program that clearly states the commissioning goals and objectives provides employees clear direction as to what commissioning activities are intended to do.

    - Participants did not document their PSC programs' overarching goals and objectives.

3. **Entities should review whether their PSC programs include adequate detail regarding commission testing plans.** Consideration should be given to developing details on how to perform the commission tests required for each specific project.

    - The majority of the participants' programs would have benefitted from better defined plans for performing commissioning on protection system projects.

4. **Entities should separate the commissioning agent[6] from the design and installation processes**. An independent commissioning agent review is instrumental to uncovering and correcting errors introduced by the designer. As the IEEE WG I-25 guide points out, an independent commissioning review provides an additional layer of review because the agent is not directly a part of the design and installation and thus is more likely to detect errors introduced by others.

    - Some participants did not have the commissioning agent perform a separate review of the design.

5. **Entities should have well-documented training requirements that include both classroom and on-the-job training coupled with a proficiency assessment to ensure that commission testing personnel are well qualified.**

    - A few participants solely rely upon on-the-job training and years of experience and have no objective measures to determine if an individual is qualified to implement a PSC program and/or procedures.

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[5] IEEE WG I-25 guide, section 2.1.

[6] The term "commissioning agent" describes a person, or group of persons, responsible for executing the process in a commissioning program. The commissioning agent is typically the employee, or designee, that performs on-site inspections, collects test data, provides technical guidance, consults on developing the affected switching orders and ultimately takes responsibility that the substation commissioning performed meets all company requirements. IEEE WG I-25 guide, section 2.3.1.

6. **Entities should use internal controls to find, track and correct issues in their PSC programs.** Entities should implement controls to ensure that lessons learned are documented and fed back into future project design and commissioning processes.

   - Some participants did not have controls in place to include issues encountered in prior projects in the feedback loop for future project teams.

PSC Procedures

7. **Entities' individual technicians should use a consistent and complete PSC test checklist that identifies specific tasks and deliverables/objectives in the commissioning procedure.** Checklists ensure a comprehensive commissioning process and that the installed design meets the engineer's intent.

   - One participant had an optional checklist to ensure that an installed design meets the engineer's intent; however, technicians could use their discretion to determine which checklists were appropriate for any given job.

8. **When using third-party contractors, Entities should ensure the contract requires a design review by the commissioning group prior to the start of construction and/or commissioning activities**. Design review is even more important in instances where the project involves multiple owners and separate design groups. The independent design review allows for error correction with the concurrence of the design groups while keeping the objectivity of the commissioning group.

   - One participant reported it only performs a design review if the contract it has with an entity explicitly requires it.

9. **Entities should compare their acceptance testing practices to those listed in IEEE WG I-25 section 3**. This section addresses commissioning testing of protection schemes and incorporates practices for process improvement. Thorough acceptance testing can help ensure that the right equipment is provided in good working order and functions as designed.[7]

   - Participants reported performing acceptance testing on all five elements of a protection system.

10. **Entities should maintain an isolation log.** The contents of the isolation log should be standardized and include at a minimum: (1) the repositioning of test switches, temporary jumpers, and shorting blocks; (2) who made the changes; (3) time and date of the change; and (4) when the equipment was returned to normal. Entities that use an isolation log

[7] Acceptance testing requires the commissioning agent to: (1) verify that the work is completed adequately; (2) be physically present for certain tasks; and (3) to verify that all manufacturer-required or owner/operator-required testing is completed.

minimize the risk of potentially leaving temporary system configuration changes in place, which may result in misoperations. The IEEE WG I-25 guide considers use of isolation logs as a necessity to manage these types of errors.

- Some participants did not require a documented isolation log in their commissioning procedures.

11. **Entities should perform both functional and in-service tests, for robust wiring/setting/logic error prevention.** Thorough functional testing is critical to verify that the circuit is wired correctly and that no unintended circuit paths exist that may impact the overall performance of the protection and control scheme.

12. **In-service tests provide an overall check of current and potential circuits to verify that these circuits are properly connected and that measured levels of voltage and current are as expected.**

    - One participant reported that it does not require functional testing for minor modifications to control circuits.[8] Other participants noted that DC functional test may not be performed in some circumstances (e.g., for setting reach changes or for minor changes that affect only non-critical functions and alarms).

13. **Entities should implement end-to-end testing for all communication-based protection schemes as recommended by IEEE WG I-25.** Communication failures are one of the top three causes of misoperation.

    - For traditional directional comparison blocking schemes, one participant noted that it does not perform end-to-end testing in cases where it owns both ends of the line.

14. **Entities should perform testing for all phase to ground, phase-to-phase, and 3-phase faults.** This ensures that logic for all fault scenarios is tested.

    - One participant noted that it performs testing only for A-phase to ground and 3-phase faults. An issue could remain undetected if the B-phase to ground, C-phase to ground, and phase-to-phase tests are not performed.

15. **Entities should perform a final walk-down after the in-service testing is completed and use a checklist to document the visual inspection.** Performing a final walk-down in the commissioning process provides an extra layer of controls that can prevent misoperations.

[8] Functional testing of protection systems involves testing the individual components of the protection system and each subsystem as one cohesive unit to validate overall performance.

- Only a few participants reported that they use a walkdown checklist to document their final visual inspection. A visual inspection without documentation can result in some steps being missed in the final walkdown.

16. **Entities should update the PSC procedure documentation as necessary to accurately reflect field activities and conditions**. Entities should pay particular attention when copying documentation from other procedures.

    - One participant's documented protection system commissioning process did not reflect the procedures actually followed by the commissioning team; in fact, if the participant used the documented commissioning process, it could have allowed unapproved design changes to be implemented—leading to errors and omissions.

B. Observed Best Practices for Consideration

Observed best practices go beyond the recommendations and may not apply to all Entities.

<u>PSC Program Observed Best Practices for Consideration</u>

1. **One participant included with every project a unique detailed commission testing plan developed specifically for that project.** This participant designed a unique plan to perform the tests; had checks to meet the goals and objectives; and treated each project as unique in depth, scope, type of equipment involved, and level of complexity.

2. **Some participants had senior management from different departments of the company collectively responsible for approval of the PSC program**. These departments included system protection, station apparatus, communications, and metering.

3. **Some participants included the cyber security experts as participants in the commissioning process**. The cyber security group identified and mitigated vulnerabilities introduced by digital protection systems.

4. **One participant performed all commission testing with in-house company personnel.** In-house personnel typically have more in-depth knowledge of the entity's system and are often more accessible than a third-party contractor.

5. **When using contractors, some participants used oversight personnel involved in the project to evaluate the contractor in the areas of project management, construction management, quality performance, and safety performance**. Participant(s) used evaluation rankings to guide decisions to award future work.

6. **Some participants have their oversight personnel have frequent meetings with the contractor to review work performance**. Frequent contacts allowed for prompt resolution of issues.

7. **One participant reported that during contractor selection, it uses a multi-layer selection/vetting process.** Under this practice, the participant initially vetted contractors for required qualifications. The participant's protection and control staff then vetted the contractor's personnel performing commission testing. Thoroughly vetting the individual personnel working in the participant's substations ensured qualified third-party contractors.

8. **One participant reported it attempts to minimize the number of contractors working on a project.** Minimizing the number of contractors helped ensure consistency and prevented omission of steps.

9. **One participant explained that, when engaging a new contractor, it starts off with simpler projects and gradually increases the complexity to assure that the contractor has adequate knowledge and experience.**

10. **One participant reported it does not allow third-party contractors to make changes to the design or installation of the equipment being commissioned.** This practice required that all changes have approval of participant personnel. This ensured that the participant was aware of any changes and agreed with those changes.

11. **One participant reported that when using a third-party contractor, it requires a company subject matter expert to review the commission test results before placing the equipment in-service.** Such reviews of the test results were more likely to find installation errors and/or equipment deficiencies that might have been missed by the contractor.

12. **Some participants used a standardized form to document lessons learned. The lessons learned form was made accessible through a network application and the review of the form was included in a documented scope development process for new projects.** Some participants also regularly exchanged lessons learned information with external industry groups.

<u>**PSC Procedures Observed Best Practices for Consideration**</u>

13. **Some participants have defined processes to qualify personnel involved with and leading commissioning projects.** This defined process involved a combination of classroom learning and on the job training, a proficiency test, and interviews with supervisors before becoming a commissioning lead ready to head projects.

14. **Some participants issued a checklist and expected deliverables for third-party contractors.**

15. **Some participants maintained a document that outlined recommendations for when human performance tools and techniques should be employed during commissioning activities.** Field test crews used the following tools: (1) pre-job briefings; (2) two-minute rule that requires workers to take time before starting a job to assess risks

and ensure proper defenses are in place for hazards that are present; (3) stopping when unsure and seeking help; (4) self-checking; and (5) adherence to procedures.

16. **Some participants employed a peer review process to assess test results and avoid possible bias**. The person tasked with performing a test was different from the person responsible for reviewing test results and determining whether they were acceptable to certify the equipment for service.

17. **As part of the commissioning process on tie lines, some participants employed back-to-back relay testing (i.e., testing in a laboratory environment) and end-to-end testing onsite.** Back-to-back testing was also performed when installing unfamiliar relay models, configurations, and or firmware editions. This practice increased confidence in relay settings and quality checking on the tests and measurements to the corresponding work scopes.

18. **One participant required the commissioning group to review the settings and logic issued by the design engineering group.** The commissioning group referred any issues discovered back to the engineering group. Relay settings were placed on relays of the same model and tested prior to installation against an expected outcome. Logic was validated against DC schematics for accuracy. The relays settings and logic were also used to develop the commissioning test procedure for the project.

19. **One participant reported an independent review by the commissioning group.** After the engineering group issued the construction print package, a commissioning technician was assigned to review the package and bring any discrepancies found by the commissioning technician to the attention of a supervisor and the engineering group.

20. **One participant ensured that the engineering drawings package identified all equipment that needed to be isolated or shorted to ensure adequate in-service protection throughout all stages of the project**. The participant also required the commissioning group to perform a peer-check of the isolations and shorted equipment on drawings, and the commissioning group reviewed any discrepancies and/or questions prior to the outage.

21. **In addition to maintaining an isolation log, some participants also tagged the circuits at the point of isolation for equipment isolation.** Uniformity in documentation and procedures for equipment isolation provided consistency in the level of detail in isolation procedures.

22. **One participant reported it verifies the correct phasing, ratios, and polarity through performing de-energized 3-phase primary injection testing on all CT circuits.** This verified the entire circuit from the CT primary, through the secondary conversion, and to the relay.

23. **Several participants did not short or lift one phase to force current flow through the neutral of differential circuit, as this practice introduced unnecessary risk and safety hazards.** As circumstances allowed, the practice of shorting or lifting one phase to force current flow through the neutral or differential was best performed with de-energized equipment, using test equipment to inject current.

II. Introduction

In 2021, staff from FERC, NERC, and the Regional Entities surveyed the PSC programs of a representative sample of eight registered entities with diverse Bulk-Power System geographical locations. The survey also included one contractor with experience aiding registered entities with their PSC programs. Participation in this survey was voluntary and was explicitly not designed as a compliance activity. Based on the survey results, the joint review team prepared this report to share recommendations and observed best practices in an effort to improve programs across industry. The report also compares the survey results to the recommendations in the IEEE WG I-25 guide for PSC programs. The joint staff review team anticipates that increased awareness of the IEEE WG I-25 guide and the dissemination of these recommendations and observed best practices will improve the reliability of the Bulk-Power System by reducing misoperations attributable to commissioning protection systems.

A. Background

1. NERC Activities to Address Protection System Commissioning and Testing

On July 13, 2011, NERC's Event Analysis and Investigations Group recommended the initiation of a new standard development project to develop a Reliability Standard addressing protection system commissioning and testing.[9] The recommendation was based on an event where an entity did not perform in-service testing as part of commissioning a new protection system. Without in-service testing, the entity failed to detect a defect that resulted in a relay incorrectly operating during the event, thereby increasing the magnitude and scope of the disturbance.[10] On December 27, 2011, the NERC Standards Committee issued a request for research to confirm the problem's existence and mitigation options.[11]

On March 5, 2013, in response to the research request, the NERC System Protection and Control Subcommittee (SPCS) issued the Response to Standards Committee Request for Research report (the SPCS report).[12] The SPCS report suggested improving commissioning practices through: (1) analysis of protection system misoperations; (2) sharing of lessons learned; and (3) IEEE development of an industry reference document on protection system commissioning practices.[13]

[9] *North American Electric Reliability Corp.,* Comments, Docket No. RM13-7-000, at 4 (filed Sept. 23, 2013) (NERC Comments).

[10] *Id.*

[11] *Id.* at 5.

[12] NERC, *SPCS Response to Standards Committee Request for Research*, (Mar. 5, 2013), https://www.nerc.com/comm/PC/System%20Protection%20and%20Control%20Subcommittee%20SPCS%2020/SPCS%20Commissioning%20Testing%20Response_Final.pdf.

[13] *Id.* at 3-4.

On May 10, 2017 IEEE Power System Relaying and Control Committee (IEEE PSRC) completed the industry reference document (IEEE WG I-25 guide) on PSC testing.[14] On September 20, 2017, NERC submitted its last informational filing, including the IEEE WG I-25 guide, satisfying the Commission's directive in Order No. 793.[15]

NERC also issued multiple NERC Lessons Learned related to protection system misoperations.[16] The NERC Lessons Learned cover a variety of misoperations stemming from protection system commissioning and testing failures, as well as remediation steps, over the last several years. For example, the misoperations in NERC Lessons Learned LL20200702 resulted from equipment being placed in service with incorrect CT ratios and missing connections in a residual current circuit, and it recommended effective commissioning tests, including functional and in-service tests. In NERC Lessons Learned LL20110805, misoperations were due to unused relay equipment that was left in service after the relay equipment was replaced. Also, in NERC Lessons Learned LL20200401, the commissioning team did not conduct a complete review of the engineering package prior to the start of construction.

2. IEEE WG I-25 Guide

The IEEE WG I-25 guide is as an industry reference document specific to protection system commissioning testing practices. The IEEE WG I-25 guide describes commissioning testing as the evaluation of the "condition of protection equipment after installation, but before final energization, to verify that equipment is installed and wired properly; to verify that correct settings and configurations are applied; and to observe interaction with other power apparatus."[17]

The IEEE WG I-25 guide explains that an effective program includes: (1) stated goals and objectives; (2) well-defined plans to perform commissioning; (3) clearly identified lines of responsibility; (4) authority given to responsible parties; and (5) feedback methods to improve the plan.[18] The guide recommends that an entity's PSC procedures contain eight core elements, including: (1) planning and sequencing; (2) print and technical review; (3) preparing installed equipment for modification; (4) equipment and device acceptance testing; (5) equipment isolation; (6) functional testing; (7) operational (or in-service load) checks; and (8) documentation.[19]

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[14] *North American Electric Reliability Corp.* Informational Filing, Docket No. RM13-7-000, at 4 (filed Sept. 20, 2017).

[15] Order No. 793, 145 FERC ¶ 61,253 at P 42.

[16] *See* NERC, *Lessons Learned Quick Reference Guide*, https://www.nerc.com/pa/rrm/Documents/Lessons_Learned_Quick_Reference_Guide.pdf (providing brief summaries and links to all current NERC Lessons Learned).

[17] IEEE WG I-25 guide at 5.

[18] *Id.* at 6.

[19] *Id.* at 7.

3. MIDAS Data

The Misoperation Information Data Analysis System (MIDAS) is a web-based system used to report and collect protection system misoperations data. Quarterly reporting is mandatory for all NERC registered Transmission Owners, Generator Owners, and Distribution Providers. This information is used to identify protection system misoperation trends and to support the statistical analysis of risk to the reliability of the Bulk-Power System.

In 2019, Commission staff reviewed data on U.S. registered entity misoperations contained in MIDAS to determine whether the cause was attributable to commissioning and testing.[20] Staff focused on the root cause to determine whether a misoperation was preventable through better commissioning testing practices. If, in staff's engineering judgement, the root cause of a misoperation could have been detected using the commissioning and testing methods identified in the IEEE WG I-25 guide, then staff considered the misoperation to be preventable through commissioning testing. For example, if a relay failure was the root cause of a misoperation, then the commissioning test would likely not detect the issue because it may not have existed at the time. On the other hand, if a mis-wired CT was the cause of a misoperation, then having a comprehensive commission testing process and procedures, as recommended by the IEEE WG I-25 guide, should have detected the issue.

Commission staff found that between 18 percent and 36 percent of the misoperations were attributable to issues that effective commissioning testing could have detected. The findings of this review prompted the joint staff review team's assessment of industry PSC programs.

[20] Staff acknowledges that the Event Description and Corrective Action fields are free form and the accuracy of the review depends on how well these fields are completed.

III. Study Process and Data

A. Participant Selection

Staff from each Regional Entity proposed candidate responsible entities for participation based on either a relatively high misoperation rate or a relatively low misoperation rate as compared with other registered entities in the region. The joint staff review team reduced the list of participants to eight representative registered entities across the Regional Entities' footprints based on entity size, location, and events, and the joint staff review team added one independent contractor with experience working with NERC registered entities on protection system installation and commissioning.

B. Survey Questions

The joint staff review team designed survey questions for each participant to gain insight into the participants' PSC programs and PSC procedures. The joint staff review team organized the questions into sections that correlated to relevant sections of the IEEE WG I-25 guide.

C. Evaluation of Participants' Responses

The joint staff review team reviewed the responses using the IEEE WG I-25 guide as a benchmark to evaluate the PSC programs and procedures of the participants. Over several months, the joint staff review team analyzed the responses and organized the findings by area of the IEEE WG I-25 guide focusing on: (1) observations; (2) opportunities for improvement; (3) recommendations; and (4) observed best practices for consideration. The joint staff review team discussed and agreed upon each of the findings in this report. For each identified opportunity for improvement, there is a related recommendation. For those sections where all the participants' programs and procedures were sufficient, the report identifies no opportunities for improvement or recommendations.

IV. Assessment of Participants' Protection System Commissioning Programs

The survey of commissioning practices asked participants questions about five key elements of a formal PSC program to gauge whether the participants had a formal PSC program and how they addressed those elements. The joint staff review team used the responses to identify potential areas for improvement or best practices. This report evaluates each of the participant's programs against the five key elements[21] that make a PSC program effective: (1) stated goals and objectives; (2) well-defined plans to perform commissioning; (3) clearly identified lines of responsibility; (4) authority given to responsible parties; and (5) feedback methods to improve the plan.

A. Existence of a formal commissioning program

Observations

All participants but one had a formal commissioning program; however, none of the participants' programs were as comprehensive as the IEEE WG I-25 guide recommends. Specifically, no participant maintained a centralized document that contained all five key elements of an effective PSC program. In their responses, the participants described how their PSC programs contained these elements, but the program elements were not documented in a single centralized document that PSC program personnel could reference.

Opportunity for Improvement

The participants lacked a centralized document containing the five key elements that make a PSC program effective. Some participants had all the required elements but did not consolidate those pieces within a single documented-program or house them in a central location.

Recommendation

All Entities should document a formal PSC program. Having a formal, documented program in a central location (e.g., a single document) allows easy reference to all the elements of the program.

B. Stated goals and objectives

Documenting the goals and objectives of the commission testing program is an integral piece of the PSC program. Identifying goals and objectives in a document that commission testing personnel can reference and train on provides personnel with guidance on all of their PSC-related activities.

Observations

All participants documented the goals and objectives of their PSC program in some form, although three did not specifically document the goals and objectives in a program document. Rather, these participants

[21] IEEE WG I-25 guide, section 2.1.

embedded the goals and objectives in the procedures and activities outlined in their equipment commissioning processes.

Opportunity for Improvement

Three participants did not document their PSC program's overarching goals and objectives in their program document.

Recommendations

All Entities should have a formal company PSC program as recommended and outlined in the IEEE WG I-25 guide on commission testing that includes the goals and objectives of the program. Having a company-wide document that clearly describes the commissioning goals and objectives provides employees clear direction for their tasks. Entities should follow the IEEE WG I-25 guide and include the following goals in their PSC program:

- Identify and control temporary changes to pre-existing in-service station equipment and systems while verifying that the equipment, or the overall transmission and distribution system, are not compromised as changes are made.
- Validate the acceptability and functionality of the substation equipment being installed or modified through the application of a comprehensive list of appropriate tests and measurements.
- Uncover and correct errors introduced by the designer or installation crews.
- Prepare and retain sufficient documentation concisely reflecting that all acceptance, functional and operational (in-service) tests have been completed.
- Identify and control the energization sequence of new or modified equipment to reduce or limit risks to the electric system.[22]

C. Well-defined plans to perform commissioning projects

Well-defined plans to perform commissioning of protection systems are essential to a successful PSC program. Well-defined plans should detail all required individual tests and checks to meet the goals and objectives of the PSC program.

Observations

Every participant had some form of plan for commissioning projects. These plans ranged from standard form-type checklists to tests and forms for specific types and models of equipment. The joint staff review team observed a wide range of content in the participants' plans. For example, in response to a survey question asking if the participant had reference documents containing plans to perform commissioning, one participant provided a Regional Entity document that made minimum recommendations for installing, modifying, and maintaining protection systems. The document, however, did not include instructions on what the commissioning team should look for when performing a commissioning test on equipment. The participant provided test forms for specific equipment such as circuit breakers, but the equipment-specific

[22] IEEE WG I-25 guide at 6.

test forms also provided no guidance. In comparison, another participant responded to the same question by providing a detailed internally developed testing guideline listing the different tests to perform based on the equipment being commissioned. Only one participant reported that it did not develop any checklist; however, this participant indicated that it was beginning an initiative to create a PSC checklist. Overall, greater detail and specifics for performing commissioning projects would improve most of the participants' PSC programs.

Opportunity for Improvement

The majority of the participants' PSC programs would benefit from more detailed, well-defined plans for performing commissioning projects.

Recommendations

All Entities should review their PSC programs and determine whether their commissioning testing plans include an adequate level of detail. Entities should consider detailing how to perform the commissioning tests that are required for each specific project. All Entities should follow the guidance provided in the Annex A of the IEEE WG I-25 guide. For example, Entities should include the following checklist from the IEEE WG I-25 guide in PSC plans for a circuit breaker:[23]

- Verify breaker bushing #1 position agrees with prints and manufacture drawings.
- Verify Current Transformer physical position in breaker.
- Verify all auxiliary contacts used for project circuits, 52a and 52b contacts.
- Verify functionality of breaker; open/close when called upon and emergency trip.
- Verify all alarms agree with relay prints and are checked in to CEE relays.
- Verify that battery bank and chargers have been installed correctly with integrity checks performed and test results documented per standard procedures.
- Verify that battery ground detector circuit works correctly from initial battery installation. The use of a small fuse jumper can prove circuit.
- Proper identification labels installed to show circuit numbers and description.

Observed Best Practices for Consideration

One participant included with every project a detailed commission testing plan specific to that project in terms of depth, scope, type of equipment involved, and level of complexity. In addition to identifying and documenting different commissioning tests, the plan detailed how to perform those tests and checks (e.g., how to set up the equipment for phase angle readings, listing expected phase angle values, and developing a spreadsheet for entering the values that will highlight the cell in red if the reading is not as expected).

D. Clearly identified lines of responsibility and training

Each task covered by the program should have clearly identified lines of responsibility. This prevents gaps in commission testing by assigning every test, function or task to a responsible person or group. As part of

[23] IEEE WG I-25 guide, Annex A at 34.

the specified lines of responsibility, participants identified: the management responsible for approving the PSC program; the personnel positions involved in the development and execution of the program; the training or certification required for those personnel; and whether the installation personnel also performed the commission testing. The IEEE WG I-25 guide recommends that:

> [w]hen possible, utilizing a commissioning agent who acts as a technical resource separate from the design team, the construction groups and test technicians provides additional reviews since the agent was not directly a part of the design, installation or individual tests and is less likely to introduce errors or to miss detection of errors introduced by others.[24]

<u>Observations</u>

All participants provided organization charts and/or lists of employee positions for their PSC program and process. All participants detailed the role each position has in the process, and participants' responses indicated that there are varying levels of management charged with approving the PSC program. These levels ranged from vice presidents to area supervisors. For the seven participants with formal programs, director/manager was the most common level of management required for approval.

Training and certification requirements varied widely across the survey participants. Some participants had well-documented training provided in-house by the entity. In these cases, personnel were required to complete such training to qualify to perform commission testing. In contrast, some participants only required on-the-job training and gauged proficiency based on the number of years on the job. Two participants required a licensed professional engineer to lead the project commissioning process.

Four of the eight registered entity participants (i.e., excluding the vendor participant) permitted the same crew to install and commission a project. The other four registered entity participants did not have installation crews perform commission testing. This split suggests that there are advantages and disadvantages to each method. For example, when the installation crew performs commission testing, one advantage is that personnel are familiar with the project and schemes. However, using the same crew to install and commission a project could weaken the commissioning process because the crew may be inclined to assume that the installation was performed correctly. Conversely, having a separate crew perform commission testing, whether in-house or a third-party contractor, removes the risk of bias; but the crew would potentially be less familiar with the project than if the same crew were used.

<u>Opportunity for Improvement</u>

Some participants could improve personnel training for commission testing. A few participants relied solely upon on-the-job training and years of experience and had no objective measures to determine if an individual was qualified.

[24] IEEE WG I-25 guide at 9.

Some participants did not have the commissioning agent perform a separate review of the design as recommended by the IEEE WG I25 guide.[25] A separate review is instrumental in uncovering and correcting errors introduced by the designer.

Recommendations

All Entities should have well-documented training requirements that include both classroom and on-the-job training coupled with some type of proficiency assessment to ensure well-qualified commission testing personnel.

All Entities should consider the IEEE WG I-25 guide recommendation to separate the commissioning agent from the design and installation processes. As the guide points out, having this separation provides additional reviews since the agent is not directly a part of the design and installation and is more likely to detect errors introduced by others.

Observed Best Practices for Consideration

Some participants designated senior management from different departments of the company (e.g., system protection, station apparatus, communications, and metering) to collectively share responsibility for approval of the PSC program. Including senior managers from all relevant departments was more likely to result in adequate commission testing. Additionally, senior management involvement is likely to draw attention to and support commission testing programs.

Some participants assigned one manager as responsible for both the operation and maintenance of the installed equipment as well as commissioning that equipment. Thus, the manager had an interest in ensuring adequate commission testing because the same manager also handled the operation and maintenance after installation.

Some participants involved cyber security personnel in the commissioning process to identify and mitigate vulnerabilities introduced by digital protection systems. Cyber security is a critical element of protection systems connected to communications networks. Involving cyber security personnel in the commissioning process ensured that appropriate cyber security controls were included on protection systems.

E. Authority given to responsible parties

Many protection system misoperations are attributable to latent errors that commission testing should have discovered and prevented. In many instances, inadequate commission testing by third-party contractors failed to discover design and installation errors.

Observations

Seven of the eight registered entity participants used third-party contractors to perform PSC testing. The remaining participant responded that it "nearly always" used an in-house PSC testing department to perform the actual testing and commissioning of protection systems for its equipment. One participant used the same contractor to perform all its commission testing, and this contractor exclusively contracted with that

[25] *Id.*

one entity. This arrangement effectively mitigated the lack of familiarity and coordination issues with third-party contractors by mimicking the relationship that an entity would have with an internal department. In all but those two cases, the participants used third-party contractors to perform protection system commission testing in a traditional contractor arrangement.

In the six traditional contractor arrangements, the participants' employees performed oversight of the third-party contractor. In those instances where the same personnel performed installation and commission testing, a construction inspector/supervisor provided oversight. For those instances where the third-party contractor performed commission testing alone, either in-house local protection system personnel or a commissioning engineer/technician provided oversight. In most cases, this designated oversight position was the single point of contact for the third-party contractor. In all instances in which participants used third-party contractors for commission testing, oversight personnel assessed and evaluated performance of the contractor.

There were two common methods for soliciting, vetting, and selecting commissioning contractors: a company vendor selection process or competitive bid process. In most cases that used a company vendor selection process, the protection system department helped develop the criteria used to identify qualified contractors. One participant, upon selecting the contractor through the company's vendor selection process, then interviewed the contractor personnel that would be performing the work. Each individual contractor employee was classified according to work experience; response to oral technical questions; and overall protection system knowledge.

Most participants restricted the authority of contractors, with the authority residing with the personnel overseeing the contractor. One participant granted the same level of authority to contractors as granted to company personnel once the contractor demonstrated that it understood the company's processes and procedures.

Observed Best Practices for Consideration

One participant performed all commission testing with in-house company personnel. In-house personnel typically had more in-depth knowledge of the system and were more accessible than third-party contractors. In-house commissioning also allowed senior staff to pass knowledge on to junior staff within the company. Company personnel have a vested interest in ensuring that there are no latent errors in the installation. This vested interest is expected to result in more thorough commission testing.

One participant reported that when using a third-party contractor, it required a company subject matter expert to review the commission testing results before placing the project equipment into service. Such reviews of the test results were more likely to find installation errors and equipment deficiencies that the contractor may have missed.

Another participant reported that it did not allow third-party contractors to make changes to the design or installation of the equipment being commissioned, and it required company personnel to approve all changes. This ensured that the participant was aware of any changes and agreed with those changes.

One participant reported that during contractor selection, it used a multi-layer selection process. Initially, the participant vetted the contractors for required qualifications. Then the participant's protection and control personnel vetted the contractor employees who would perform the actual commission testing. This resulted in a thorough vetting process down to the individual who will be working in the participant's substations and better ensured qualified third-party contractors.

Some participants used oversight personnel to evaluate the contractor in the areas of project management, construction management, quality performance, and safety performance. Participants used these evaluation rankings to guide decisions to award future work.

Some participants reported that their oversight personnel have frequent meetings with the contractor to review work performance, as this allows for prompt resolution of issues. Discussion items during such meetings address such matters as: quality of the work; the overall project completeness; whether the contractor followed rules, processes, and procedures; possible instances of lessons learned; and whether the contractor properly documented the test results.

One participant reported that it tries to minimize the number of contractors working on a project to ensure consistency and prevent omission of steps.

When using contractors, another participant reported that it starts new contractors off with simpler projects and gradually increases project complexity as experience and confidence grow.

F. Feedback methods to improve the plan

One of the key elements of an effective PSC program is having a feedback loop for improvement. No matter how good the protection system design or commissioning phases are, there may be issues that arise, or shortcomings found in the process. Correcting these issues or shortcomings and communicating the remediation to the proper groups is paramount to provide continuous improvement to the PSC program.

Observations

All participants prepared lessons-learned documents that identify issues arising during the commissioning testing process. Some participants used a job journal or a field issues log to communicate issues. Several other participants used a shared database to store and disseminate the information. One participant had employees complete a standardized report form, including the lessons learned at the conclusion of each project, and then compiled the reports quarterly to share on its intranet site. In addition to the documentation, sharing and network accessible storage of lessons learned, this participant included the documented lessons learned from past, similar projects in its new project scope of work development process. Several participants also reported that they receive and share lessons learned information externally with industry organizations.

Opportunity for Improvement

Some participants did not have controls in place to educate future project teams of previous projects' experience with encountered issues.

Recommendations

All Entities should use internal controls to find, track, and correct issues in their PSC programs. Entities should implement controls to ensure that lessons learned are documented and available for future project design and commissioning processes (e.g., by using a new project checklist that includes a review of feedback from previous projects).

Observed Best Practices for Consideration

Some participants used a standardized form to document lessons learned; they made it accessible through a network application; and they required its review in a documented scope development process for new projects. Others also regularly shared lessons learned information with external industry groups.

V. Protection System Commissioning Procedures

The PSC procedure documents the required steps to accomplish the stated goals and objectives of the PSC program.[26] A PSC procedure includes the following eight core elements.

- Planning and sequencing
- Print and technical review
- Preparing installed equipment for modification
- Equipment and device acceptance testing
- Equipment isolation
- Functional testing
- Operational (or in-service load) checks
- Documentation

The joint staff review team relied on the IEEE WG I-25 guide as a primary source when evaluating commission procedures. The joint team found that all participants maintained commissioning procedures that aligned with at least *some* of the core elements of the IEEE WG I-25 Guide.

A. Planning and Sequencing (IEEE WG I-25 Guide section 2.3)

The joint staff review team used the guidance provided in section 2.3 (Planning and Sequencing) of the IEEE WG I-25 guide to evaluate the participants' responses. As set forth in Section 2.3, the first step before developing a PSC plan is to identify a qualified commissioning agent responsible for each element of the PSC program. The guide also includes an example list of responsibilities for the commissioning agent.[27] After identifying the responsible parties, the guide recommends identifying all necessary steps in the commissioning process. IEEE recommends incorporating these steps into a commissioning checklist or checkout guide that includes milestones and required tests. The commissioning agent can then use this checklist to track progress throughout the sequence of the PSC procedures; check the quality of tests and measurements; and confirm that the various groups involved in commissioning have performed each step.

[26] IEEE WG I-25 guide at 7

[27] IEEE WG I-25 guide at 8-9.

Observations

All participants established a testing guideline for commissioning various equipment. Other participants developed specialized testing requirements for each project.

Most participants used different personnel to perform necessary steps and provide quality checking on the tests and measurements to the overlapping work scopes. For producing and using a PSC test checklist, all participants except one reported an established testing guideline for the commissioning of equipment for each project. The remaining participant reported that it plans to draft check lists for future projects. Of the six participants that used contractors for commissioning projects, several reported using processes and procedures to ensure that the contractor followed proper practices for protection system installations.

All participants reported a similar organization process for coordinating PSC testing when other facility owners are involved. Coordination started with a review between the design personnel at each company and continued with discussions between the testing personnel. Some participants required end-to-end testing to be performed with the remote terminals of the line. One participant also required a laboratory test on relays used for tie lines' protection prior to performing end-to-end testing.

All participants included human error prevention techniques throughout the PSC processes. Each participant designed a specific human performance improvement tool kit that contained various barrier mechanisms. The participants reported using the tool throughout the process to verify task completion and satisfactory test results before continuing with commissioning.

Opportunity for Improvement

One participant had an optional checklist to ensure that an installed design met the engineer's intent; however, personnel could use their discretion to determine which checklists were appropriate for any given job. This discretion could result in a failure to include all the tests necessary to ensure the design met the engineers' intent.

Recommendations

To ensure that the installed design meets the engineer's intent, all Entities' individual technicians should use a consistent PSC test checklist that includes, at least, all the tasks listed in the Commissioning Checklist of the IEEE WG-25 guide Annex A and the expected deliverables from the commissioning procedure.

Observed Best Practices for Consideration

Some participants described a defined process to qualify personnel to work on or lead commissioning projects. This process involved a combination of classroom learning and on-the-job training, and it could take years to qualify as a commissioning lead. The described qualification process included a proficiency test and interviews with supervisors before becoming a commissioning lead.

Some participants issued a checklist and expected deliverables for third-party contractors. The checklist required contractors to use computerized relay test-routines with entity-approved templates for the type of relay and scheme. The expected deliverables required the commissioning team to follow the PSC plan developed by the project design engineer. To ensure adherence to the PSC plan, in-house engineers reviewed and approved the completed test report data.

Some participants maintained a document outlining recommendations for when to employ human performance tools and techniques during commissioning activities. Field test crews used the guide and implemented recommendations. Participants implemented the following five tools to ensure that personnel clearly understood what to do and what to avoid.

1. Pre-Job Briefing: A human performance tool that allows workers to think through a job and use their knowledge to make the job as safe and efficient as possible.
2. Two-Minute Rule: This requires workers to take time before starting a job to assess risks and ensure proper defenses are in place for hazards that are present.
3. STOP When Unsure and Seek Help: A tool to be used when a worker is uncertain, confused, or in doubt about his/her aspect of job assignment. It allows the worker to obtain correct information about the issue and get other individuals involved with resolution of the issue before proceeding with the assignment.
4. Self-Checking: Focuses attention on the right component; think about the intended action; understand the expected outcome before acting; and verify the intended results after the action.
5. Adherence to Procedures: Adherence to procedural direction ensures that workers do not rely solely on their memory but know and follow procedures for the task to which they are assigned.

Some participants employed a peer review process to assess test results and avoid bias. The person tasked with performing a test was different from the person responsible for reviewing test results and determining whether they were acceptable to certify the equipment for service.

As part of the commissioning process on tie lines, some participants employed back-to-back relay testing (i.e., in a testing in a laboratory environment) and end-to-end testing onsite. Back-to-back testing was also performed when installing unfamiliar relay models, configurations, and or firmware editions. This practice increased confidence in relay settings and quality checking on the tests and measurements to the corresponding work scopes.

B. Print and Technical Review (IEEE WG I-25 Guide, Section 2.4)

The joint staff review team used the guidance provided in Section 2.4 (Print and Technical Review) of the IEEE WG I-25 guide to evaluate the participants' responses. Section 2.4 explains how a commissioning group should conduct an independent, comprehensive review of the entire construction print package (drawings and specifications) prior to the start of any construction activities involving relay protection systems (e.g., electromechanical relay replacement with digital relays). This review validates that the protection system design: (1) will protect the subject equipment as anticipated; (2) follows the appropriate design standards for the entity that owns the equipment; and (3) does not contain errors that could lead to its misoperation when the protection system is put into service.[28] This review also provides an in-depth understanding of the project for the commissioning group for the development of complete commissioning tests.

As stated in Section 2.4, if the commission group finds errors during the review, it should refer these possible errors to the engineering group for validation. While the commissioning group may make simple corrections, making sure to document any field changes for inclusion on the as-built drawings or setting

[28] IEEE WG I-25 guide at 11-12.

orders at the completion of the project, any serious errors in the construction package should be sent back to the engineering department for a redesign as the IEEE WG I-25 guide discourages attempts at a field redesign. As described in Section 2.4, if the commissioning group were to make the design changes, the review would no longer be independent (i.e., the commissioning agent would then be a designer of the scheme) and such design changes would remove the opportunity for a peer review by the engineering group. This separation of responsibility avoids the possibility of the commissioning group not fully understanding the intent of the design and introducing error.

Separate from the survey, the joint review notes that several NERC Lessons Learned documents address topics pertaining to Section 2.4 of the IEEE WG I-25 guide. For example, NERC Lessons Learned LL20200401 notes that the commissioning team at the entity did not conduct a complete review of the engineering package prior to the start of construction. As a result, the construction team failed to notice that a jumper in several CURRENT TRANSFORMER circuits was missing in the transformer neutral differential on three of the transformers. Since the commissioning team did not thoroughly review the engineering package, the commissioning team did not completely understand the job scope and missed an opportunity to rectify the issue beforehand by reviewing the engineering package. The subject entity subsequently revised its commissioning processes to ensure the completion of the review. Other Lessons Learned that are pertinent to this section are:[29]

- NERC Lessons Learned LL20100703 discusses the use of project controls such as design package review prior to the start of construction and use of checklists with verification of the completion of each step.
- NERC Lessons Learned LL20110707 discusses the importance of verifying field changes with the design group prior to implementation of field changes that arise from lack of understanding the scheme.
- NERC Lessons Learned LL20110801 discusses the importance of design package review prior to start of construction due to as-builts from a previous project not being incorporated into the current project.

Observations

While some participants maintained procedures consistent with the IEEE WG I-25 guide, the majority did not. Of those that fell short of the guide, one participant reported that it performed no added schematic validation on the schematic diagrams prior to construction activities. The third-party contractor participant reported that its commissioning group only performed a design review prior to beginning commissioning if required by the contract. Another participant reported that, ideally, the commissioning team reviewed the construction prints prior to the start of the job.

Only a few participants reported that the commissioning group performed a design review independent from the engineering group prior to the start of any construction activities. Some participants described validations that are performed during the commissioning process but did not mention whether the commissioning group performed an independent design review prior to the start of the commissioning activities. Several participants reported using highlighters to mark the schematics and their associated wiring

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[29] *See* NERC, *Lessons Learned Quick Reference Guide*, https://www.nerc.com/pa/rrm/Documents/Lessons_Learned_Quick_Reference_Guide.pdf.

diagrams in their validation process as visual feedback to ensure the entire design is reviewed and the schematic and wiring matched. Only one participant reported that it sent relay and logic settings from all construction packages to a team in their commissioning group to test relays prior to installation with the proposed settings and logic installed. This group used these results to develop appropriate commissioning tests.

Opportunity for Improvement

Most of the participants' procedures did not specify that the commissioning group must perform an independent design review prior to the start of any construction activity. This task is a necessary control so that the PSC program can attempt to uncover and correct design errors.[30]

One participant reported that it did not perform a design validation prior to construction activities because its design process included a quality control check.

In one instance, as described above, the third-party contractor participant only performed a design review if its contract required it.

Recommendations

Entities should ensure that a design review is performed prior to the start of construction activities. When using third-party contractors, all Entities should ensure that the contract requires this design review. This is even more important in instances where the project involves multiple owners and separate design groups. The independent design review allows the correction of any identified errors with the concurrence of the design group(s) while keeping the objectivity of the commissioning group. Making field changes without a design review could introduce more errors than it resolves, especially with complex systems.

Observed Best Practices for Consideration

One participant reported that, after the engineering group issued the construction print package, a commissioning technician reviewed the package and brought any discrepancies to the attention of supervision and the engineering group. The participant explained that the engineering group must approve any proposed design modifications. This process provides an independent review by the commissioning group as recommended by the IEEE WG I-25 guide.

One participant reported that it required the commissioning group to review the settings and logic issued by the design engineering group. Relay settings would be placed on relays of the same model and tested prior to installation against expected outcome. Logic is validated against DC schematics for accuracy. The participant explained that the commissioning group refers any issues discovered to the engineering group. The relays settings and logic are also used to develop the commissioning test procedure for the project.

[30] IEEE WG I-25 guide at 6.

C. Preparing installed equipment for modification (IEEE WG I-25 Guide, Section 2.5)

The joint staff review team used the guidance provided in Section 2.5 (Preparing Installed Equipment for Modification) of the IEEE WG I-25 guide to evaluate the participants' responses. Section 2.5 states that the "risk of error exists primarily because of the overlapping nature of protection and control schemes."[31] IEEE, therefore, recommends the proper isolation and de-energization of existing in-service protection and control equipment. Isolating existing equipment also allows for the installation and testing of new or modified equipment.[32]

While preparing for isolation, Section 2.5 advises that the commissioning team should identify the parts of the station that need to operate while the work is being performed and to ensure these modifications do not impact the necessary protection and control systems. The commissioning team then communicates the details of this evaluation to the department responsible for writing up the switching orders to allow for the modification.

Observations

Most participants stated that the lead protection and control technician worked with the commissioning lead to evaluate potential issues affecting protection of in-service elements during all stages of an upcoming project in a pre-construction setting. The system protection group then evaluated the in-service elements to determine whether to keep the elements in service (e.g., through temporary settings) or isolate the elements. If at any point adequate protection could not be maintained, then that piece of equipment was kept de-energized until the technicians restored protection or completed the work. Participants explained that if equipment isolation was needed, then the relay information was sent to the system planning group so that it could perform load flow and stability studies to identify concerns. If none, then the request to isolate the identified elements is submitted to grid operations to review and approve the request.

Best Practices

One participant reported that the engineering package identified all equipment that needed to be isolated or shorted to ensure adequate in-service protection throughout all stages of the project. The participant explained that it also required the commissioning group to perform a peer-check of the isolations and shorted equipment on drawings and review any discrepancies or questions prior to the outage.

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[31] IEEE WG I-25 guide at 12.

[32] Section 2.5 of the IEEE WG I-25 guide also recommends that "prior to switching orders being developed to isolate substation equipment in preparation for a modification, the commissioning team needs to evaluate the scope of the modification against what portions of the substation need to remain in operation, then work with the dispatch organization that prepares the switching to verify all requirements are taken into account with the prepared switching orders."

D. Equipment and Device Acceptance Testing (IEEE WG I-25 Guide, Section 2.6)

The joint staff review team relied on the guidance provided in Section 2.6 (Equipment and Device Acceptance Testing) of the IEEE WG I-25 guide to evaluate the participants' responses. Section 2.6 explains that entities should assign responsibility to the commissioning agent for performing acceptance testing on any new or modified equipment associated with a project. Acceptance testing requires the commissioning agent to: (1) verify that the work is completed adequately; (2) be physically present for certain tasks (i.e., critical tasks, those with a high degree of possible error, or those that are "definitive to the overall success"); and (3) to verify that all manufacturer-required or owner/operator-required testing is completed.[33] For tasks that have a limited chance of invalidating the design, the guide gives discretion as to whether the commissioning agent must be physically present or can review results later.[34] Section 2.6 recommends that the commissioning agent look for physical deficiencies and the functional application of the equipment. The owner/operator of the equipment documents the type of acceptance testing the commissioning agent should perform on each type of equipment or device and the expectations of the commissioning agent in these tests. Proper performance and documentation of acceptance testing helps ensure assure proper incorporation of equipment and can also satisfy vendor's warranty requirements.

<u>Observations</u>

Participants' responses pertaining to acceptance testing practices included clear details of the specific tests required for each type of equipment and the role of the commissioning agent in those tests (witness or verifier). Documenting these practices prevented confusion in how to perform acceptance testing on new or modified equipment and the role of the commissioning agent in those tests.

Participants reported performing acceptance testing on all five elements of a protection system:[35]

1. Current Transformers (CT): Participants tested CTs prior to and after installation. Tests performed included ratio, excitation, saturation, polarity, and insulation tests. The participants verified the selected CT tap against the relay settings and metering reads on the relay. Load checks complemented this process.
2. Voltage Transformers (VT): Participants commonly tested VTs before and after installation. The most reported acceptance testing for VT devices included insulation power factor, polarity and ratio, and secondary insulation resistance testing. Upon energization, these devices are commonly phased and in-service values are compared to a known reference point for accuracy.
3. Protective Relays: Common acceptance testing participants performed on protective relays included verification of part number, firmware version, current and voltage inputs, and testing of control inputs and outputs. Some participants included additional practices such as testing all enabled features in the relay including alarm logic and performing single-end and end-to-end testing with fault simulating inputs provided by system protection engineer.

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[33] IEEE WG I-25 guide at 13.

[34] *Id.*

[35] *See* NERC Glossary, *supra* n.1 (defining the elements of a protection system).

4. Communications Equipment: The participants stated that the acceptance tests they performed on communications equipment used for protection purposes varied based on the communication medium and protection application. In general, the participants responded that they set up and calibrated the communications systems using the manufacturer's recommendations. Then these systems were verified by checking for proper settings, transmit and receive levels, and the operation of inputs and outputs. Where applicable, wave traps were tuned and tested. Some participants stated that they would test the entirety of any communication-assisted relaying scheme by using a GPS-synchronized test set.
5. Station DC Supply Equipment: Participants performed acceptance testing for station DC supply equipment by visually inspecting both the batteries and charging equipment for any physical damage or imperfections. Once the system is installed, the participants connected a battery string to the charger and set it on "equalize" for an initial charge. Participants took internal resistance measurements after equalizing to look for any poor connections for cell issues. Participants also said that they performed voltage and current measurements to confirm that charger and DC connections were made correctly.

Recommendations

All Entities should compare their acceptance testing practices to those listed in Section 3 (Commissioning Testing of Protection Schemes) of the IEEE WG I-25 guide and incorporate practices that provide opportunities for process improvement. Thorough acceptance testing can help ensure that the correct equipment has been provided; that the equipment is in good working order; and that it is functioning as designed.

E. Equipment isolation (IEEE WG I-25 Guide, Section 2.7)

The joint staff review team referenced the guidance provided in Section 2.7 (Equipment Isolation) of the IEEE WG I-25 guide to evaluate the participants' responses. A detailed isolation procedure can mean the difference between a successful commissioning project and one with unintended operations or other consequences. Switching procedures establish clearances and identify control devices used for isolating affected protection and control schemes. Beyond switching orders, specific equipment isolation procedures are necessary to place protection system schemes in an abnormal but acceptably functioning state during system modifications.[36] As explained in Section 2.7, "proper commissioning program[s] must include an isolation log of some type."[37] Specific tools for identifying and tracking isolation activities such as isolation logs and visual flags are essential to a good PSC program as they help to mitigate the potential for unintended operations.

Observation

Only one participant did not require an isolation log as a normal practice in its commissioning and testing procedures. That participant only required an isolation log for "high risk facilities or tasks." Other participants did not require an isolation log for individual test switches; however, most of the participants

[36] IEEE WG I-25 guide at 14.

[37] *Id.*

logged temporary jumpers and wiring used to place existing protection schemes in acceptably functioning states during system modifications. Several participants used logging systems that included placing "Work-In-Progress" tags at the location of the isolation in conjunction with maintaining a log to identify, analyze and track the repositioning of individual test switches to ensure circuits have been returned to their correct state at the end of the job.

Opportunity for Improvement

As mentioned above, one participant did not require a documented isolation log in its commissioning procedures. Not using an isolation log creates the potential for leaving temporary system configuration changes in place, which can result in misoperations. The IEEE WG I-25 guide emphasizes the need for isolation logs to manage such errors.

Recommendations

All Entities should maintain a documented isolation log. The contents of the isolation log should be standardized and include, at a minimum, the repositioning of test switches, temporary jumpers, and shorting blocks; who made the changes; time and date of the change; and when the equipment was returned to normal. A template that details the performance of commissioning activities, including recommendations for human performance tools and techniques, can minimize unintended operations. Entities should also include details on equipment isolation in this document or as a stand-alone document.

Observed Best Practices for Consideration

Some participants maintained an isolation log and tagged the circuits at the point of isolation for equipment isolation. Uniformity in documentation and procedures for equipment isolation provided consistency in the level of detail in isolation procedures. Participants performed isolation tasks in a deliberate manner and included a thorough peer check/walk-down of equipment isolation with standardized procedures and detailed documentation.

F. Functional Testing (IEEE WG I-25 Guide, Section 2.8)

- The joint staff review team used the guidance provided in Section 2.8 (Functional Testing) of the IEEE WG I-25 guide to evaluate the participants' responses. Functional testing of protection systems involves testing the individual components of the protection system and each subsystem as one cohesive unit to validate overall performance.

As discussed in Section 2.8, DC control systems, AC sensing devices, software logic, and communication are tested to validate functionality. Each protection and control scheme is evaluated through the functional testing of trip and close paths using schematic diagrams that detail the logic. This process involves manipulating contacts; installing and removing fuses; and changing the position of test switches and all other components represented on a DC schematic in a systematic fashion while energized from a DC source. As each part is manipulated, allowing DC current to either flow or not flow, how the system responds will confirm whether the expected response is achieved. It is important to note that the goal of this testing is not only try to obtain the desired response; but also to verify that no undesired responses occur. DC functional testing can become complex as every combination of contact and test switch is checked. This exhaustive testing is critical to verify that the circuit is wired correctly and that no unintended circuit paths exist that may affect the overall performance of the protection and control scheme. Using a highlighter to mark a copy of the schematic is a commonly used method of documenting the DC functional testing.

End-to-end testing simulates power system events to verify that the equipment meets the project's functional requirements, as implemented in the field. End-to-end testing is an effective method of validating communication-assisted transmission line protection schemes. End-to-end testing uses GPS time-synchronized dynamic testing and secondary current injection to simultaneously test both ends of a line protection system, including the communication path. This testing is typically applied during the commissioning of transmission line protection schemes to verify that the relay logic employed at each terminal and the communication scheme will properly operate as a system to detect and respond to faults within and external to the protected zone, as appropriate for the protection scheme being applied. The end-to-end testing may uncover a problem not found during individual component testing. Communications scheme timers are critical to support security while, at the same time, reducing the total clearing time. End-to-end testing can be used to try different channel settings until a compromise is reached rather than making educated guesses. Definitive testing of such systems requires the use of synchronized test sets. Testing the communications channel separately and estimating processing intervals and input/output times will not be as correct as actually testing everything together as a unit.

Observations

All participants provided defined processes and checklists for performing functional testing of DC schematics. In some cases, participants used the same processes and checklists for contractors that it used for their personnel. Several participants used highlighters to markup drawings as the DC circuitry was verified.

Some participants reported that functional tests are required and performed whenever a protection system is modified or a control system is disturbed, whether an auxiliary system or primary system. Other participants reported that they did not conduct functional test in all circumstances. For example, one participant reported that there was a limited scope of relay changes where it did not require functional testing, such as current pick-up or impedance reach changes. Another participant reported that it did not perform functional testing for minor changes, such as adding a monitoring point, in circumstances where the change is not providing a critical function. Another participant reported that it function-tested when a protective relay input or output performed tripping; when breaker failure initiated; or when adding or modifying a high-speed initiate and testing has not previously been performed to prove that the logic of the protective relay will operate the output as intended.

Opportunity for Improvement

One participant reported that it did not require functional testing for minor modifications to control circuits.

One participant noted that it performed testing only for A-phase to ground and 3-phase faults. An issue could remain undetected if the B-phase to ground, C-phase to ground, and phase-to-phase tests are not performed.

For traditional directional comparison blocking schemes, one participant noted that it did not perform end-to-end testing in cases where it owned both ends of the line. The IEEE WG I-25 guide recommends performing end-to-end communication tests for all lines where communication-based protection schemes are employed. NERC Lessons Learned document LL20101003 describes a misoperation that occurred on a 345 kV line for an external fault due to excessive or asymmetrical communications channel delays on a phase comparison protection system. In this event, the communication path between relay terminals was provided through three separate digital networks. Third-party providers owned and maintained two of the digital networks. This communication configuration contributed to inconsistent communication channel-time delays occurring in each direction. End-to-end testing during the commissioning phase may have detected this issue prior to the protection system misoperation.

Several participants noted that they may not perform DC functional testing in some circumstances, notably for setting reach changes or for minor changes that affect only non-critical functions and alarms. NERC Lessons Learned document LL20110801 describes a misoperation that occurred at a generation facility due to an improperly wired relay, which caused a false breaker failure relay action. The generator owner used outdated prints that included actual cabling that should have been removed and excluded in the re-wiring process. Personnel followed the incorrect prints and connected the new replacement relay to the wrong cable. Proper DC functional testing of the revisions may have detected this incorrect wiring prior to the misoperation.

Recommendations

All Entities should perform effective commissioning tests, both functional and in-service tests, for robust wiring/setting/logic error prevention. In-service tests provide an overall check of current and potential circuits to verify that these circuits are properly connected and that measured levels of voltage and current are as expected. Entities should perform thorough DC function testing. Thorough DC function testing is critical to verify that the circuit is wired correctly and that no unintended circuit paths exist that may impact the overall performance of the protection and control scheme.

All Entities should implement end-to-end testing for all bulk electric system communication-based protection schemes as recommended by the IEEE WG I-25 guide. Communication failures are one of the top three causes for misoperations.

All Entities should perform current testing on all phases to ground, phase-to-phase, and 3-phase faults. This will ensure that CT ratios, CT and polarity, and polarization of ground elements is correct for all fault scenarios.

Observed Best Practices for Consideration

One participant reported that it verifies the correct phasing, ratios, and polarity by performing 3-phase primary injection testing on all CT circuits. This practice verifies the entire circuit from the CT primary, through the secondary conversion, and to the relay.

Some participants used performance testing of settings and logic in a laboratory environment prior to implementation in the field, with relays directly connected to each other, or "back-to-back." This provided additional confidence in the relay settings and logic performance, particularly on tie lines where multiple entities may be involved.

G. Operational (in-service) Tests (IEEE WG I-25 Guide, Section 2.8.11)

The joint staff review team relied on the guidance provided in Section 2.8.11(Operational (in-service) Tests) of the IEEE WG I-25 guide to evaluate the participants' responses. As the guide explains, operational testing requires a final check and approval from the entities involved.[38] The IEEE WG 1-25 guide warns that commissioning is not complete until the new or modified equipment is checked and tested. Section 2.8.11 also outlines the requirements of in-service tests for protection and control schemes and individual protective relays and other devices such as meters and digital fault recorders. Section 2.8.11 notes that errors should be assessed and ascribed to either human error on the part of the commissioning agent or to an incomplete testing process. The section concludes with the prerequisites (e.g. verify relay settings have not change) for performing in-service tests.[39] Of the twelve functional testing sections in the IEEE report, the team chose to emphasize section 2.8.11 (In-service Testing), specifically since in-service testing is likely to identify many issues that can result in misoperations.

In-service testing demonstrates the performance of protection, communication, and major electrical components. Although the intent of the commissioning testing process is to discover and correct any errors or inherent shortcomings, the testing methods leave opportunities for deficiencies to remain within the new or modified substation equipment. Accordingly, until system nominal voltages and currents are applied to the new or modified substation equipment and operational checks are performed, the new or modified equipment cannot be considered fully commissioned.

Observations

All participants reported performing in-service load checks, including verification of current and voltage magnitude, phase angle, phase rotation, and differential currents. Methods and measurement tolerances while performing these checks varied.

All participants reported that they perform final walkdowns. Some participants provided the checklist that must be completed during the walkdown while other participants responded that they performed a visual inspection.

All but one participant did not short or lift one phase to force current flow through the neutral or the differential circuit of in-service, energized equipment.

One participant reported that it took a snapshot of the relay currents and voltages and read the Common format for Transient Data Exchange for power systems (COMTRADE)[40] file to compare the readings against measurements taken with analog meters.

Recommendations

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[38] IEEE WG I-25 guide at 19.

[39] *Id.* at 20.

[40] *See* IEEE, *COMTRADE: a new standard for common format for transient data exchange*, (1992), https://ieeexplore.ieee.org/document/156995/citations#citations.

All Entities should perform a final walk-down and use a checklist to document the visual inspection after completing in-service testing. Adding a final walk-down in the commissioning process provides an extra layer of controls that can potentially prevent misoperations. The process should include:

- confirming the completion of all pre-energization tasks;
- verifying that all debris and packaging is removed from the equipment;
- verifying that test switches and controls are in the correct state to begin switching;
- verifying that all coupling capacitor voltage transformer units are un-grounded and carrier unit grounds are in the correct position;
- verifying that CT circuits have the correct ratio and are un-shorted;
- verifying that all necessary alarms are restored to service,
- and verifying that the supervisory control and data acquisition (SCADA) system/remote terminal units are operational for the equipment being energized.

CT circuit errors represent a significant portion of misoperations from the commissioning process primarily due to incorrect CT ratios, incorrect CT polarity, and CT's left in the shorted position. Entities should perform:

- *A final walk-down process* to ensure that CT and VT circuits are correct prior to being placed in service.
- *In-service loading* is above the minimum equipment requirements so that sufficient current magnitude is available for accurate measurement.
- *Operational tests and measurements* include current and voltage magnitude, phase angle and polarity with respect to the primary quantities.
- *Operational measurements* from different relays, meters, fault recorders, SCADA transducers, and other devices that use the same voltage and current signals should be compared with each other to ensure similar measured quantities at each device.

Observed Best Practices for Consideration

The majority of participants advised to not short or lift one phase to force current flow through the neutral of a differential circuit, as this practice introduced unnecessary risk and safety hazards. According to participants, the practice of shorting or lifting one phase to force current flow through the neutral or differential is best performed with equipment de-energized, using test equipment to inject current.

H. Documentation (IEEE WG I-25 Guide, Section 2.9)

The joint staff review team referenced the guidance provided in Section 2.9 (Documentation) of the IEEE WG I-25 guide to evaluate the participants' responses. As recommended by the guide, "[k]eeping clear, undisputable records that support the activities performed during the commissioning testing process is essential."[41] The goal of a PSC program is to prepare and retain sufficient documentation that succinctly displays all acceptances. According to the IEEE WG I-25 guide, an important element of the commissioning testing process is the preparation, review, and archiving of all the documentation that shows

[41] IEEE WG I-25 guide at 21.

that the commissioning testing process is complete.[42] The last activity of the commissioning process requires the assembly of commissioning checklists, data sheets, and marked prints to verify that all documents are complete and ready for retention within the document management system.

The IEEE WG I-25 guide also highlights that an essential part of the process is to keep clear and indisputable records that support the activities performed during commissioning testing. The records must validate the PSC program and serve as the initial documentation for the first maintenance cycle. It can also serve as reference for any misoperations analysis. The IEEE WG I-25 guide recommends that Entities retain at a minimum the following documents:

1. A fully completed and signed commissioning checklist;
2. Operational test results showing the in-service magnitudes and angles of all new or modified protective relays, meters, and DFRs under test;
3. Final marked up sets of DC and AC schematics that will be used to update system prints (including all associated panel wiring prints that may have changes);
4. Protective relay calibration test files;
5. An as-built set of relay settings including the final, down loaded settings left on any microprocessor-based relay;
6. End-to-end satellite testing files, when applicable (including results, such as a spreadsheet that shows relay elements that actuated for various applied faults);
7. Instrument transformer and transducer test results;
8. Communication channel checks; and
9. Battery and battery charger tests, when applicable.

<u>Observations</u>

Several participants reported having documentation stored in a system for tracking records essential for process and quality control. Some participants also had an information management program to educate and support employees in the implementation of information policies and procedures, which provided a method to identify the information for efficient access and retrieval.

As discussed in section E, Equipment isolation (IEEE WG I-25 Guide, Section 2.7) of this report, one participant's PSC process did not require any official documentation of an isolation log. The use of an isolation log, in the commissioning process, allowed the installation and commissioning teams to identify, analyze, and track the repositioning of individual test switches. Using isolation logs helped to avoid leaving temporary test items in place that could result in misoperations.

As discussed in section A, Planning and Sequencing (IEEE WG I-25 Guide, Section 2.3) of this report, one participant made the documentation of a checklist optional rather than follow the guidance of the IEEE WG I-25 guide, which states that a checklist can be an important tool in aiding the tracking of the commissioning process.

<u>Opportunity for Improvement</u>

[42] *Id.*

One participant's documented protection system processes did not reflect the procedures actually followed by the commissioning team. In fact, if the participant's documented commissioning process were applied, it could have allowed unapproved design changes to be implemented—leading to errors and omissions. The participant explained that the procedure error was accidentally transposed from a general procedure used in other divisions of the participant's organization.

Recommendations

All Entities should update their PSC procedure documentation as necessary to accurately reflect what is being done in the field. Entities should pay particular attention when copying documentation from other procedures.

Appendix 1 – Joint Staff Review Team

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