Commissioning Testing of Protection Systems

Assignment:

To create a report, at the request of the North American Electric Reliability Corporation (NERC) System Protection and Control Subcommittee (SPCS), to serve as an industry reference document on protection system testing practices. The SPCS believes that it would be beneficial for IEEE to produce a document on commissioning testing in an effort to help reduce the number of misoperations resulting from improper commissioning.

Working Group Members:

R. Garcia (Chair); K. Donahoe (Vice-Chair); R. Aguilar; A. Apostolov; H. Ashrafi; J. Barsch; N. Bilimoria; J. Brown; C. Bryant; D. Buchanan; E. Carvalheira; N. Casilla; G. Halt; W. Knapek; A. Lee; B. Mackie; H. Malson; B. Moores; G. Moskos; A. Newman; L. Polanco; S. Saminfni; E. Schock; T. Seegers; M. Siira; M. Stojak; A. Uribe; J. Verzose; D. Ware; M. Wright; V. Yedidi

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1. Introduction

There are many different types of protection system testing described and explained in IEEE C37.233, Guide for Power System Protection Testing [B1]. Although part of the guide covers the subject of commissioning testing of protection systems, this report is intended to strictly focus on providing recommendations on commissioning testing.

As discussed in IEEE C37.233 – 2009, the objective of commissioning tests are to evaluate 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. The focus of the tests is to confirm that the systems function as designed.

The guide identifies the following commissioning test objectives:

- Install and integrate the system components with the site current transformers (CTs), voltage transformer (VTs), sensors, communications systems, wiring and auxiliary power supplies.
- Verify that factory-supplied connections are correct and complete.
- Verify each component performs in accordance with vendor specifications and type testing for that component.
- Test interactions and overall system performance with samplings of test cases across the spectrum of possibilities, but not a comprehensive suite as used for factory type tests.
- Test the overall scheme by simulating power system events that cannot be generated on demand using techniques described in the guide. Examples include: transient simulation and tests for abnormal conditions.
- Operate other power apparatus or secondary control systems in the vicinity to show that the system is secure and/or dependable in the face of spurious environmental influences or communications traffic.
- Verify proper mapping and operation of the protective device with other data/control systems to which it is interconnected.

The objectives identified in the guide, are accomplished through testing protocols and other analysis techniques, as well as specific approaches to how equipment is added to the existing infrastructure.

The testing protocols and techniques are covered in the next section “Commissioning testing of protection systems.” The approaches for specific schemes are covered in the section titled “Commissioning testing of protection schemes.”

2. Commissioning testing of protection systems

2.1. Protection system commissioning program

In order to be efficient and accurate, protection systems commission testing or protection systems commissioning (PSC) requires a development and 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. An effective program consists of the following key elements:

- 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

The PSC program generally achieves the following goals:

- 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 that concisely displays 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.

2.2. Protection system commissioning process

The PSC process, often referred as the PSC procedure, is a sequence of required steps to accomplish the stated goals and objectives of the PSC program. A process should be designed using a practical performance methodology that is applicable to the items being commissioned. It must be broad enough to accommodate circuit breakers, CTs, VTs or CCVTs, relays, communication devices, batteries, and protection/control circuits. It must also be created with an appreciation for factors within the working environment such as management interaction, workforce training and experience, availability of test equipment, use of contractors and switching limitations. A successful commissioning testing process is generally supported by the following key attributes:

- A foundation in safety - There are many other important aspects of the process that must be considered, but none come before the safety of employees, contractors and the general public.
- A well-trained professional/technical staff -The professional staff, consisting mostly of engineers and technicians, must be properly trained and should have significant relevant work experience. There is no substitute for a well-trained staff and there is absolutely no equivalent substitute for experience. The process should be designed to allow those with greater experience to mentor others.
- A committed management team - The management team, a combination of local and corporate functions, must be committed to properly performing the process by balancing those competing priorities and accomplish the commissioning testing process as designed. There is often competition for time and resources that directly compete with the commissioning testing process.
- An engaged workforce - Everyone in the workforce should be fully engaged by familiarizing themselves with the goals and responsibilities of the process.
- A properly-equipped workforce – The workgroup should be equipped with the necessary tools to execute the requirements of the process as stated below.
- A focus on ensuring Bulk Electric System (BES) integrity - Maintaining the integrity of the BES is an important aspect of the commissioning process.

Although the details of the commissioning testing process can vary among utilities, there are eight core elements, listed below, that are common to most processes.

- 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

There are many integrated steps and activities that occur for the completion of these core process elements. Each one is covered separately in the following sections.

2.3. Planning and sequencing

Before the PSC plan can be developed, the responsible parties and commissioning team must be organized.

2.3.1. Organizing the commissioning team

For a PSC program to succeed, the responsible groups and individuals must be identified. 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. For smaller projects, the commissioning agent can be the same person that is not only directing the work but performing the work itself. On any given substation project there can be multiple entities (installation crews, test technicians, vendors, project managers, etc.) involved in the installation and testing of a substation addition or modification. The goal is to verify that these various groups have performed all necessary steps and have provided quality checking on the tests and measurements to the overlapping work scopes. In these instances, it is essential to have one point of coordination and oversight.

Responsibilities of a commissioning agent:

- Safety - A commissioning agent and their team members should perform duties and responsibilities in a safe manner. This includes actively participating in daily and spontaneous (work, crew or condition changes, etc.) job briefings and having a questioning attitude throughout the process.
- Equipment isolation support - The commissioning agent validates that adequate protection exists for in-service equipment and verifies that appropriate measures to prevent unintended tripping of transmission and distribution sources have been identified and mitigated.
- Communicating testing requirements - The commissioning agent is responsible for defining appropriate visual checks, measurements and tests required verifying the design and construction of a substation protection system modification is appropriate for the intended application. By defining the appropriate tests, a set commissioning plan is developed for individuals involved in the physical work (installation, testing, etc.). This plan is captured into a commissioning checklist, or similar tool, becoming a communication tool to individuals outside of or new to the process. It can also serve as a progress tracking method toward completion of the commissioning.
- Technical support during construction - The commissioning agent supports field installation and other test crews by resolving technical questions. They could spend a portion of their time in the field, prior to acceptance and functional testing, in order to provide timely answers to questions.
- Test leader - A commissioning agent can serve as the test leader. Although not always expected to directly perform tests themselves, all tests and measurements are performed under the test leader's direction or review whether or not they are present at the time of test.

- Field modifications - As errors are discovered through the commissioning testing process and are confirmed by the design engineer, the commissioning agent makes appropriate corrections to the initial project design and verifies appropriate testing is done. These additional tests are performed to confirm that the initial errors have been resolved and no new errors have been introduced as a result of the changes made. This may require performing additional tests, such as functional testing on circuits that were successfully tested to validate that the corrections introduced did not create new errors.
- Work verification - The purpose of commissioning testing is to verify that protection systems are installed and perform as expected to identify errors of any type, whether installation, design or manufacturer introduced. When 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. Therefore, the commissioning agent is responsible in challenging all aspects of the substation's design modifications, construction and testing approach to discover and correct any mistakes before the new substation or modification to an existing substation goes into service. Formal tracking of individual steps, like checklists, are recommended for the commissioning testing plan.
- Commissioning plan or procedure - The plan provides a complete task list for testing every piece of equipment. The documentation defines the necessary scope for each organization involved in the project.
- Energization plan - A plan for the energization of new or modified substation equipment that minimizes risks to the transmission and distribution system includes determining, when appropriate, where protection schemes are temporarily modified or isolated. This involves coordinating the plan with prepared switching orders.
- Determining job completion - A commissioning agent is responsible for determining when a new substation or any new or modified substation equipment in an existing substation is ready for initial energization. They are also responsible for determining when the same equipment, after operational checks are performed, is fully functional and ready to be turned over to the appropriate dispatch organization for use.

2.3.2. Typical PSC process sequence

The following identifies a practical sequential approach that can be applied to every project. Reviewing the individual steps and applying all those which are applicable helps verify that the commissioning testing process is always performed in a consistent and methodical manner. The steps of the commissioning testing process are as follows:

- Verify all company safety rules are being followed.
- Obtain and review engineering print packages and verify enough sets are available for use during the commissioning testing process, including any field modifications captured during commissioning, to reflect final as-built.

- Obtain construction material list.
- Confirm one-lines, relay and Instrumentation functional diagrams, and ac & dc schematics.
- Confirm all demolition prints when used.
- Contact Telecommunication and SCADA Support groups to verify all required communication equipment and circuits are available for the project.
- Support isolation of existing protection schemes at existing substation sites.
- Identify all additions and removals.
- Develop a custom commissioning plan (procedure) to be used throughout the commissioning testing process.
- Confirm relay and associated CT settings.
- Perform new benchmark electrical equipment testing.
- Perform new CT testing.
- Perform CT current injection testing.
- Perform dc functional testing on all added or modified required control (trip and close) paths.
- Confirm test switch position as open or closed.
- Perform voltage confirmation testing.
- Re-confirm proper relay settings are in correct relays.
- Determine proper switching sequences and communicate with appropriate dispatching authorities.
- Review all test data, Commissioning plan steps and switching orders.
- Perform energization plan.
- Obtain in service load checks including angle measurements.
- Acknowledge acceptable measurements to dispatching authority and turn new or modified equipment over for their use.
- Gather, organize and file all test data and information of job (including marked up prints) in appropriate file and submit a copy of the as-built drawings to engineering to update the system of record drawings.

2.3.3. Project commissioning checklist

The creation of a commissioning checklist or checkout guide will greatly aid the commissioning agent(s) in tracking their progress throughout the sequence of the PSC plan.

The commissioning checklist can be an important tool used to determine a successful commissioning testing process. It provides information on the job milestones, required tests, specific procedures and tasks that must be verified, witnessed or documented by the commissioning agent. The commissioning checklist assures job continuity, especially when different groups, both internal and external, are involved in a single project. It also helps communicate what has been accomplished and what remains to be done if the job is handed off between individuals. Once created, this checklist may be discussed with all affected persons associated with the project to clearly identify and address specific items. To installers and test crews, the checklist defines whether a testing or installation task requires coordination with the commissioning agent. If a commissioning checklist is used on the project, revisions to the commissioning checklist should be made to keep the document current and accurate.

All successfully completed steps identified in the checklist should be 'signed off' by qualified field personnel from the owning company. The owning company shall determine the process of how the checklist is documented and controlled.

"See Annex A for an example of a commissioning checklist."

2.4. Print and technical review

Before the start of any construction activity, the commissioning agent and team should review the print package. No project should begin until all the entities participating in the project have received the necessary prints. At this point, the commissioning agent studies the prints for overall applicability and accuracy. The print package generally includes the following:

- One-lines and three lines
- Relay and instrumentation diagrams
- Dc schematics
- Ac schematics
- Panel arrangement and front views
- Wiring diagrams (installation and demolition, where applicable)
- SCADA diagrams

The commissioning agent, upon review of the design package against the existing as-built substation prints and their company's design standards, develops in-depth knowledge of the modification in order to effectively lead its installation efforts and define appropriate testing.

Through this review, specific attributes of the design should be identified and validated. Some typical validation steps are as follows:

- Validates that current transformers utilized for particular relay sensing are electrically in the proper place to provide overlapping zones of protection and that their polarity conforms to standard design conventions.
- Validates that all relays that would trip a particular breaker or other fault-interrupting device are represented on all of the drawings. For example, if a line impedance relay (21) is shown to trip a breaker as represented on the one-line or similar drawing, then the dc schematic for that breaker's trip circuit should have an appropriate contact from that relay identified.

If possible design errors or deficiencies are identified in the drawings, a request for validation back to the engineering department or engineering service vendor is made. Once validated, simple corrections may be made onsite and the prints marked up for future updating. More serious problems should be sent back to the engineering department for redesign, which may require a site visit by the designer and have updated drawings issued. This approach is preferred rather than a field redesign because it confirms the commissioning agent's responsibility as an independent reviewer of the final design or in some cases, the commissioning agent may not fully understand the design intent. However, the commissioning agent may reject any prints that are considered to be technically deficient.

During this phase it is imperative an adequate configuration and document control system is in place. As prints and drawings are marked-up, changes need to be documented and all downstream documents affected and changed to the latest configuration.

2.5. Preparing installed equipment for modification

A critical part of a protection system addition or modification involves the temporary modification, isolation and de-energization of existing in-service protection and control equipment at the start of the project so that installation and testing can take place. If this temporary modification of the existing substation infrastructure is overlooked because it involves existing equipment, the opportunity for error exists.

The risk of error exists primarily because of the overlapping nature of protection and control schemes. Seldom is an existing protection and control scheme not put into a temporary, abnormal state while the modification and subsequent testing is going on. Verifying that these temporarily modified protection and control schemes remain functional for their intended purpose is a critical requirement early in the commissioning testing process.

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.

2.6. Equipment and device acceptance testing

Every new or modified substation component requires some basic acceptance tests performed to validate that it is not materially deficient and that any settings or adjustments are appropriate for the application. This extends beyond discrete components such as relays, instrument transformers, batteries, communication transceivers, etc. and can include panel board wiring (e.g. insulation resistance checks), test switches (e.g. visual verification that shorting blades are made up correctly) and termination hardware (e.g. tug test on crimped connectors or sufficient stud length on terminal strips). The commissioning agent must identify exactly what tests are required to validate that the equipment added or modified is acceptable per company standards. They should be aware of the testing done offsite or at the factory.

The commissioning agent will take direct part in tasks that are critical (e.g. high degree of error possible) or are definitive to the overall success such as the dc functional testing. Other tasks or steps that are important, but have a limited chance of invalidating the design, such as CT saturation tests that only validate the performance of the CT, may simply require the commissioning agent's review of the test results performed by others.

2.6.1. Verification

The commissioning agent reviews the results of a work task and attests that the work was completed in a satisfactory manner.

2.6.2. Witnessing

The commissioning agent that is physically present for certain tasks verifies that the work was performed in a satisfactory manner.

Some key commissioning tasks that may require direct participation (witnessing) are:

- Dc functional tests
- Loading of CT circuits
- Initial energization
- Phasing
- Operational (or in-service) measurements of all relays

2.6.3. Equipment assembly, logic application & acceptance testing

The commissioning agent verifies that all testing is performed in accordance with the utility's standards. Additionally, all testing required by the manufacturer is performed to further confirm proper operation and satisfy any warranty requirements. The commissioning agent may also give additional direction or require additional testing as warranted. Proper documentation must be made if additional testing is determined necessary.

2.7. Equipment isolation

Sometimes switching orders that are prepared to establish clearance do not have enough detail. Switching orders will define elements, such as control switches (e.g. reclosing on/off switch, transmitter send control handle, etc.), that are specifically designed to put a protection and control scheme in an abnormal state. However, other necessary isolation and modification activities, such as the shorting of CTs or the addition of jumpers to maintain a closed control path when an interlock is removed, are covered generically and do not provide specific details as to what the technicians performed.

A proper commissioning program must include an isolation log of some type that allows the installers and the commissioning team to identify, analyze and track the repositioning of individual test switches. These are the application or removal of jumpers, and other temporary measures utilized, to put existing protection and control schemes into an acceptably functioning state while system modifications are occurring. It is good practice to visually flag these affected areas to easily identify during restoration.

2.8. Functional testing

Functional (protection system) testing is designed to test individual components and subsystems as one cohesive system for the purpose of validating overall performance.

2.8.1. Component testing

There is a hierarchical approach that is taken when performing functional testing of protection and control systems. First, major subsystems such as the dc control, ac sensing, software logic and communications are tested discretely to validate their functionality and to find any wiring, design or component errors prior to an overall system functional test. For example, a validation that a carrier blocking system is working between transceivers prior to performing an end-to-end test allows a commissioning team to focus on a smaller set of possible solutions if a block signal is not being transmitted to the remote end. A second benefit to this approach is that overall system tests take more resources to perform and can take considerable time. Reducing the number of subsystem errors decreases the probability of an error during an overall systems test.

2.8.2. Dc functional testing

The evaluation of each protection control scheme is performed through the functional testing of trip and close paths utilizing schematic diagrams that detail the logic.

This process involves manipulating contacts, installing and removing fuses, 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 component is manipulated, allowing dc current to either flow or not flow, the response of the system (e.g. illumination of a light, picking up or dropping out of a relay coil, etc.) is witnessed to validate whether the expected response is achieved. It is important to note that this testing does not only attempt to get the desired response (e.g. closing a contact results in a relay coil picking up), but also verifies that no undesired responses occur. For example, if opening a specific test switch isolates or disables a specific portion of the dc circuit under test, you must also verify that no other portions of the overall circuit are impacted in any way by the repositioning of that particular test switch. As a result of this need to verify that each component only impacts its intended part of the circuit, dc functional testing can become involved as every combination of contact and test switch combinations are checked. This type of exhaustive 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.

Methods to manipulate dc circuits:

- Actual operation of device contact is preferred
- Jumper across device contact - typical for lockout or auxiliary tripping relays that cannot be operated due to shared equipment in service
- Voltage check
- Verify existence or absence of voltage
- Use of auxiliary devices
- Use of breaker simulators

Document the methods used, in accordance with the owning company's standards, on the schematics if a method other than actual operation of the device is used. Before commissioning testing is completed, it will be necessary to verify each device contact to the breaker trip coil (or breaker simulator) and each input device (lockout coil, relay inputs, etc.)

2.8.3. Marking of prints

Marking up a copy of the schematics is a commonly used method of documenting the dc functional testing [B2]. The owning company shall determine how schematics are marked to show individual elements validated by testing. If properly marked, this may provide a visual indication of any circuit path that remains to be tested.

2.8.4. Functional testing limitations when working on in-service equipment

For new relay and control circuits, every portion of each circuit should be tested in accordance with the owning company's standards. When modifying existing relay and control schemes, all affected portions of the existing schemes require testing. Retesting all portions of the relay and control scheme, regardless of whether they were disturbed, may be preferred (depending on the owning company's standards) to verify no unintended consequences occur, this is not always possible. For example, fully testing a new trip initiate contact from a breaker failure relay into an in-service bus differential scheme (with plans to trip all breakers) may not be possible due to outage constraints. However, even if the full relay and control scheme cannot be tested, it is still recommended that all portions of the scheme that may have been impacted by the new wiring changes should be checked to verify that the full functionality of the existing scheme remains.

2.8.5. End-to-end testing (protection system 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 a good method of validating communication assisted transmission line protection schemes. End-to-end testing is the utilization of GPS time synchronized dynamic testing utilizing secondary current injection to test the protection system, including the communication path at both ends of a line, at the exact same time. 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 very critical to maintain 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 good 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 I/O times will not be as accurate as actually testing everything together as a unit.

Although there are techniques for performing end-to-end testing like having personnel at one terminal only, controlling the activities of the opposing terminal remotely, as presented by Schreiner and Hunter [B33], it is much more common to have personnel at both terminals.

- The following equipment is typically used to perform end-to-end testing on a typical two ended transmission line: A computer with specialized testing software that can communicate with the test equipment and relays being tested. There are several manufacturers that can provide this software. The software package is designed to allow the user to view and retrieve data, as well as adjust the settings and application logic as needed.

- The actual test sets to be used must be equipped with GPS time synchronization feature and provide the required currents and voltages. Note, it is important to verify that the test equipment used at each end is compatible or the testing may not work as expected. For example, if using test sets by unique vendors at opposite ends of the line, the differing time to respond to an input of the test sets must be determined and taken into account.
- Software to generate fault sequences and waveforms to be reproduced in the test equipment, thereby supplied to the relays to simulate expected system fault information.
- Although modern microprocessor relays can capture much, if not all, of the needed performance information, a fault recorder can also be used to monitor all the necessary test points.
- The use of the GPS clock accuracy of 10 µs or better, at both ends of the line, verifies that there is time coordination at both terminals of the transmission line for best simulation results. An accuracy of 10 µs is equivalent to an angle of 0.216° at 60 Hz.
- Before conducting any testing, prearrangements can be made to obtain the required data needed for the protection system event performance analysis phase.
- Develop and document end-to-end test plan

Complete end-to-end test plan includes the following:

- Relay setting orders – settings in relays at time of testing
- Personnel contact information
- Test Plan utilized during the testing
- Test Plan description and a means to track results
- Visual representation of test plan
- Relay event records captured during testing – optional

2.8.6. Operational (in-service) load checks

The method of introducing new or modified station equipment to the transmission system is a very important part of any commissioning testing process. Substation modifications typically involve new or modified protective relay schemes. Until those schemes can be validated under load, their performance cannot be relied on.

2.8.7. Energization plan

An energization plan is designed to minimize the impact of a misperforming relay scheme on the system. It should include whether a protective relay scheme should be enabled or disabled until operational measurements can be made.

The commissioning agent works with system protection and dispatching groups to consider the options for energizing any piece of equipment to ensure that misoperations are minimized. The extent of any outage from a misoperation is limited and that adequate clearing exists to promptly isolate any faults. Once approved, the plan can then be used to develop switching orders.

The purpose of the plan is to provide a basis and additional details on why a particular switching approach is employed rather than the norm. The plan provides these details and acts as a mechanism for proper review and signoff by technical groups such as the system protection group.

The plan may contain additional details on which operational tests and measurements will be performed. Since switching orders are typically generic on describing actions (e.g. "disable relaying" might be all that is stated on a step), the plan provides detailed steps for the energization and switching process in order to reduce human errors.

2.8.8. Switching order review

The commissioning agent, working with the dispatching organization, should review the switching orders as they develop steps to restore the system and first energize the new equipment. Once the orders are created, the commissioning agent reviews and compares them to the energization plan to see if any corrections are needed.

During this review, particular focus should be placed in the following areas:

- Validation of the overall T&D system configuration versus what was assumed when the energization plan was developed.
- The location of hold points for operational checks.
- Steps involved in either putting into service or temporarily bypassing protection and control schemes.

2.8.9. Final walk-down

Prior to the actual switching, the commissioning agent should complete a final walk down of the entire project to validate that all pre-energization testing and commissioning steps have been completed and that the new or modified substation equipment is ready for the application of voltage. A job briefing, which includes stepping through the entire switching order with the assigned crew, is performed. During this time, the labels on all devices identified in the switching order are confirmed and switches and breakers are placed in the appropriate starting open or close position.

2.8.10. Releasing equipment for initial energization

Switching orders used for the commissioning of new or modified equipment should include a step where the commissioning agent releases the equipment for operational tests. This would allow the equipment to be energized at system voltages and for testing or analysis to be performed. This formal acknowledgement indicates that all pre-energization testing is complete and the equipment is ready for the application of system nominal voltages and currents.

2.8.11. Operational (in-service) tests

This testing provides a final check and approval from the organizations involved. In-service testing demonstrates and documents the performance of protection, communication, HMI equipment (if applicable) 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 will provide 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.

For protection and control schemes, this includes measuring and confirming that the voltages and currents measured at various instrument transformers and transducers are being supplied to each and every protective relay, meter, recorder, etc. These tests should also verify that the measurements are correct in magnitude, phase angle and polarity with respect to the primary quantities. Additionally, the proper metering by the relays, meters, fault recorders and other devices that use those same signals should be confirmed. If the in-service testing is performed and the line current is predicted to be below the minimum equipment requirements for current transformers, temporary load banks may be used to increase the current flow. This confirms that protective relays and other devices can be properly checked out.

Operational tests and measurements must be captured for individual protective relays and all other devices such as meters and DFRs. Prior to performing tests or capturing measurements, the expected values should be calculated based on system load flow from existing measuring devices, if available. These expected values should then be compared with the results of the live tests and measurements taken from the installed relays and other devices, confirming the phasor relationships (magnitudes and angles) and validating that what was expected is what is being captured. If differences exist during the operational tests between what is measured and what was expected, then an analysis must be performed to determine whether the error is in the installed equipment (such as a rolled CT secondary cable), in the method applied for operational testing (such as the polarity of the meter being backward), an error in the analysis (an interpretation error) or whether there was a change in systems conditions resulting in a new baseline to compare against. Regardless of where the error(s) may lie, the commissioning agent must resolve the problem before the commissioning process can proceed to its conclusion. This may require for the deenergization or physical changes to the equipment, whether it is wiring changes, equipment replacement or setting changes. Depending on the extent of the change, additional acceptance and functional tests may be required.

It is also important, as part of the post commissioning testing process, to analyze whether the errors caught at this stage are human errors made by the commissioning agent in failing to accurately perform required tasks, or whether the testing process is incomplete and needs to be revised.

The following are prerequisites for performing an in-service test:

- Verify that the relay settings have not been changed.
- Have the approved switching orders available.
- For non-standard designs, station service instructions should be developed and submitted to related operation and maintenance groups.
- Complete testing forms and documentation for in-service testing.
- A walk down has been performed with all groups involved in the project.
- All labeling is complete in the switchyard and relay house.
- Verify that enough charging current will be available either through line loading or a load bank to operate the relays.
- Transformer tap settings have been provided, if required.
- Capacitor settings have been provided, if required.
- A one Line diagram for operation personnel has been issued.

2.8.12. Releasing equipment for service

The technical aspects of the commissioning testing process are essentially complete and the equipment is ready to be turned over to the appropriate dispatching group once the equipment is fully energized and carrying sufficient load to perform all necessary operational tests. At this point, the equipment will be formally released for full operational service. By this release, the commissioning agent is indicating that there are no outstanding issues impacting the performance on the new or modified equipment and that the system operator can operate the equipment fully within the extent of its operational design without any limitations.

It is important to note that if there are limitations that remain or operational checks that hadn't been accomplished due to system limitations (e.g. insufficient load to validate that a differential relay is correctly summing its current inputs, etc.), then this final release may not be given or be given provisionally and the equipment cannot be considered as fully commissioned at this time. Additionally, there should be a procedure to identify and resolve post-commissioning issues.

2.9. Documentation

Keeping clear, undisputable records that support the activities performed during the commissioning testing process is essential. These records are needed to properly validate the program and serves as initial reference documentation for the first maintenance interval and in case of a misoperation investigation. A methodology for capturing, reviewing and storing records needs to be built into any commissioning testing process.

The final and important attribute of the commissioning testing process is the preparation, review and accumulation of all pertinent documentation that indicates the commissioning testing process is complete. Therefore, the final activity of a commissioning agent involves assembling the commissioning checklist, test data sheets, marked prints and other pertinent data to verify that all is complete and ready for retention within the document management system employed. This documentation, which is completed at various stages of the commissioning testing process, needs to be assembled and retained allowing easy accessibility during subsequent maintenance activities. This documentation, when completed thoroughly, provides a clear roadmap of the testing processes utilized to validate the in-service equipment. The documented dates associated with commissioning tests may also be used as the start date for the first maintenance cycle.

At a minimum, the following documents should be retained:

- A fully completed and signed commissioning checklist
- Operational test results showing the in-service magnitudes and angles of all new or modified protective relays, meters, DFRs, etc. under test.
- 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 contain any changes).
- Protective relay calibration test files
- An as-built set of relay settings including the final, down loaded settings left on any microprocessor based relay.
- End-to-end satellite testing files, when applicable (including results, such as a spreadsheet that shows relay elements that actuated for various applied faults).
- Instrument transformer and transducer test results.
- Communication channel checks.

- Battery and battery charger tests, when applicable.

3. Commissioning testing of protection schemes

3.1. Common considerations

This section is not intended to cover all possible protection system features or schemes but presents some of the features that are common and specific schemes that generally present challenges.

3.1.1. Breaker interlocks

Breaker 52a and 52b contacts are often used in protection and control circuits for electrically adjacent major equipment. Removal of the substation breaker from service without accounting for these interlocks, through the temporary addition of jumpers, can impact the functionality of the trip and close circuits of in-service equipment.

3.1.2. Testing of test switches

Test switches are typically used to isolate trip outputs, breaker failure initiates (BFI's) and other dc circuit related functionalities. During functional input and output checks of equipment with test switches, verify that each test switch works as intended with both open and closed confirmation. If there is space in the panel design, descriptive labels can be installed before the functional operation test and verified during the testing and commissioning process.

3.1.3. Isolation of line exits with multiple CTs

Many transmission terminals are configured in either a ring bus or breaker and a half lineup. As a result, the protective relaying employed to protect the line utilizes multiple CTs to account for all possible load sources. Depending on how the CTs are summed together and the type of test and shorting switches employed, caution must be taken to properly isolate CT contributions that are being changed and eliminated while allowing in-service current contributions not to be affected.

3.1.4. Linear couplers

Linear couplers are "air core" mutual reactors used in bus differential protection in places where CT saturation is a concern. Secondary voltages are generated based on primary current flow. When looped together in series, all voltages will sum to zero. When isolating an individual linear coupler, provisions to complete the loop of the secondary wiring loop must be employed.

3.1.5. Non-conventional instrument transformers (NCITs) and merging units (MUs)

The commissioning agent must engage with the test plan developers, the specific test guidance documentation of the NCIT or MU vendor, and with NCIT vendor technical support staff if required, to establish the chain of functionality from the power system signals being measured to the processing function of the protection system, and the means of commissioning testing. Properly calibrated performance of all the elements of this chain must be validated without gaps, with the results documented as specified elsewhere in this guide. The testing must include communications paths and fibers, auxiliary supplies for switchyard electronics or devices, system time synchronization means, and any binary input, low-level analog input, or control output functions of MU or switchyard-installed equipment.

3.2. Functional testing of control schemes

A control scheme is any scheme that operates a piece of primary equipment, such as a breaker or disconnect based on the status of other primary equipment or power system conditions. The difference from protective relaying schemes is that their primary function is not to clear faults, but rather to restore load and isolate equipment after a fault has been cleared. Examples of such schemes include, but are not limited to:

- Islanding control schemes
- Auto-transfer ('flop-over') schemes
- Sectionalizing schemes

These schemes can be implemented electromechanically using contacts and auxiliary relays. However, greater flexibility and functionality can be achieved when control schemes are implemented in microprocessor packages. These can either be stand-alone devices that are dedicated to performing the desired control function or part of a primary protective relaying scheme.

The operating principle for electromechanical control schemes is easily described with an elementary drawing. However, with a scheme implemented in a microprocessor relay the actual operating logic is encapsulated within the device, so the elementary drawing does not completely describe the scheme. As a result, another drawing or piece of documentation is required to describe the programmed logic inside the relay, such as settings file or a logic diagram.

Commissioning of control schemes is a relatively straightforward process that involves the following steps:

- Checking to make sure the scheme is wired correctly per the approved elementary and wiring schematics.
- Verifying all tripping contacts are completely isolated from operating any primary equipment.
- Checking to make sure any microprocessor relay setting files have been correctly loaded onto the relay.
- Checking to make sure all binary inputs and outputs on the microprocessor relay are operating correctly.
- Checking to make sure all auxiliary relays, contacts, timers, etc. in the scheme are operating correctly.
- Verifying the scheme functions as desired according to all applicable documentation and drawings.
- Typically, control logic that is integrated into a microprocessor package can be thoroughly tested (i.e. completely proving every logic element) in a lab environment prior to field installation. In a lab environment, it is easier to simulate test cases and make adjustments to logic as necessary verifying desired scheme operation.

3.3. Commissioning of batteries and chargers

Any battery bank installation should be performed under battery manufacturer's recommendations or use the company's standards. The installation test results should be retained for maintenance reference (refer to NERC Standard PRC-005-6 or the most recent version for maintenance testing requirements) which can also be used during commissioning. For the particular type of battery installed, the manufacturer recommends a proper battery cell voltage, per cell, at both float and equalized values. One recommendation for a substation 125 Vdc battery system is to set the float voltage per cell to be 2.25 Vdc for a battery bank that contains 60 cells, therefore the overall battery voltage would be 135 Vdc.

IEEE [B41] provides a helpful reference guide for the installation and maintenance of substation batteries to the manufacturers' recommendations. This installation task is typically performed by substation personnel. Battery charger alarms are expected to be properly set and verified to terminal points where the relay protection technician connects to. Examples of these alarm points are loss of battery charger A.C. voltage, and both high and low battery voltage alarm points.

It is the relay protection technician's responsibility during onset of a construction project to verify the installation of a substation battery ground detector circuit. As each new dc circuit, whether protection or control is introduced into the overall system, a battery ground detector check should be done.

A ground detector check should be performed on larger transmission substations, where there may be two independent battery systems, to make sure the systems are not wired together somewhere within the substation.

3.4. Commissioning of differential schemes

Differential schemes are utilized on generators, transformers and substation buses. The commissioning testing processes used in the validation of differential current circuit integrity are the same in other types of current circuits. The process includes checking for phasing, CT ratio, polarity, proper cable/wiring from CT termination block to relay terminals, and correct application and testing of relay settings.

Bus protection CT connections are usually wye connected with phase wire on the polarity terminal. Cables are terminated to the outermost CT's of the equipment, thereby overlapping the protection zones of other schemes. For high impedance bus differential schemes, the preferred solution is to have the same full CT ratio for all differential circuit sources. Be alert to cases where the full ratios do not match. For situations where CT ratios do not match, there are various solutions that can be used as referenced in B37 and B38.

Attention to phase sequence connections is needed when transformer differential protection using older conventional high impedance electromechanical relays to a wye-wye transformer have the CT's are connected delta, attention to phase sequence connections is needed.

For microprocessor-based current differential relays at initial load flow with current flowing through the relay, take an immediate reading of the phase current differential values and check the quantity of phase currents compared to another known current circuit. Immediately evaluate the accuracy of the phase angle readings. It is also possible to read the operate and restraint values in the relay directly. The operate quantity should be very low and a restraint quantity should be present.

For commission testing purposes of line current different relays, (87L) Satellite testing executed with all equipment installed can be performed to verify all required components are operating as expected before commissioning. If performed at one location, a second relay would be required. If there is a two terminal line with new 87L relays on each end, three phase test equipment with laptop, software program for testing and communication channel established would be required. With the actual relay settings, automated relay testing, with each relay communicating with each other, can be performed. The setting engineer can then provide fault simulation test data for go/no-go test evaluations. However, in some cases, pre-installation testing may be performed at one location with a second relay. For example, prior to installation on a two terminal line with new 87L relays on each end obtain both relays or acquire another identical relay where a bench test using fiber jumpers as the communication medium can be performed. The success of these tests would assure that the line could be energized with the newly set relays once communication channel has been validated.

3.5. Commissioning of line protection schemes

The commissioning of line protection schemes is considered the most complex of all relay testing. The complexity of the relays employed, the complexity of settings necessary to verify optimum performance, the use of various communication media and their impact on operations, and the distributed nature of the installations involving multiple pieces of equipment at remote locations. As a result, a detailed and methodical approach must be applied when testing a line protection scheme to verify that it will operate as intended.

3.5.1. Typical schemes

- Non-communication based schemes (step distance)
- Pilot Protection
  - Direction comparison blocking (DCB)
  - Directional comparison unblocking (DCUB)
  - Permissive overreach transfer trip (POTT)
  - Permissive underreach transfer trip (PUTT)
- Direct transfer trip (DTT)
- Line differential
- Phase comparison

3.5.2. Commissioning testing – recommended approach

The commissioning of line relay schemes should start from simple, discrete checks validating the functionality and completeness of each component that makes up a line relay scheme at each terminal, to then progress to complicated and encompassing tests that validate the overall scheme.

The following is a recommended sequential approach of commissioning a line protection scheme.

First, performing discrete tests, such as input/output verification checks and secondary loading of the instrument transformer circuits, are recommended. These basic tests help validate the interconnection wiring between the relays, instrument transformers and auxiliaries. Another basic test for communication schemes, is manual operation of the transmitter/receiver to verify the communication path is intact and performing as expected. Next comes functional tests of reclosing and logic settings to assure the system will operate as intended. Afterwards, element testing, whether manually or through the use of computer aided testing software and automated macros is conducted for commissioning a line relay scheme. Even if automated test macros are utilized, a few manual tests are recommended first to provide assurance that relay elements are performing as set before progressing to automated testing where it can be difficult to know immediately whether there is a settings or element problem versus a problem with the test. Once assured that the relay elements are picking up as expected, dynamic tests are recommended. Finally, for communication assisted protection schemes time synchronized end-to-end tests are conducted. These time-intensive tests provide greater assurance that the entire line-protective system works properly as one complete unit.

A further complex sequential description of the recommended tests is as follows:

3.5.3. Input and output contact testing

Relay - This test regime involves cycling the inputs and outputs to validate that they are both functional and that all inputs and outputs (I/O) points are assigned correctly to the overall control scheme. Microprocessor-based relays have commands available to easily exercise the outputs. Inputs can be verified by connecting station battery voltage or dc from a test set to the proper terminals. The relay will provide target information to indicate the input is active. Extreme care must be taken to fully isolate (I/O) before testing begins to avoid inadvertent tripping or activation of control schemes.

Communication devices - such as power line carrier receiver/transmitter units, fiber optic connections, multiplexers, or other devices should all be tested at the component and component system level to confirm correct operation.

3.5.4. Secondary loading of instrument transformers

The purpose of secondary loading of CTs and other instrument transformers is to validate that the secondary wiring of the ac quantities is correct as designed. This includes identifying unintentional grounds or missing return paths for current circuits.

3.5.5. Setting verification

Relays - The method of entering settings varies according to the relay technology used. For electromechanical and static relays, manual entry of the settings for each relay element is required. This method can also be used for microprocessor based relays. Typically, the amount of data to be entered for microprocessor relays is much greater making it normal to use the appropriate software supplied by the manufacturer instead of manual data entry. The software also allows for easy recording of the data.

Once the settings are entered, it is recommended they be verified to be as issued. When appropriate software is used for data entry, checks can be considered complete if the data is checked prior to download of the relay settings once the download is confirmed as complete. Otherwise, a check may require subsequent data entry, following all testing, by inspecting a downloaded record of the relay settings. This setting record is an essential part of the commissioning documentation.

Radios (such as transceivers) –There are settings (such as scheme timers) located in radios that work simultaneously with the settings in relays. As a pilot scheme uses information from the terminal at the remote end of the line, the settings at the remote terminal should match settings in the local radio.

Older radios – Settings will be accomplished via dip switches and jumpers located on the cards and chassis back plane. A setting standard should be compiled and based on the scheme.

3.5.6. Secondary current injection testing

Although primary current injection is preferred for testing the entire path, it is not always practical with large CT ratios used making secondary current injection more common. The purpose of secondary injection testing is to check that the protection scheme from the relay input terminals onwards is functioning correctly with the settings specified. This is achieved by applying suitable inputs from a test set to the inputs of the relays, and checking if the appropriate alarm/trip signals occur.

3.5.7. Element testing

- Overcurrent elements

It is recommended to check the relay characteristics over a range of input currents to confirm parameters for an overcurrent relay such as:

- The minimum current that gives operation at each current setting.
- The maximum current at which resetting takes place.
- The operating times at suitable value of current.

3.5.8. Impedance characteristic testing

With the advent of computer-based control of test sets, a comprehensive check of the entire shape of a mho circle or similar is possible. This method of testing allows a tester to verify that the relay responds correctly to every test point. This complete plotting is not required, but rather necessary where the relay is expected to operate for a given fault.
For modern microprocessor relays based on sampling of voltage and current inputs, the shape of the operating characteristic is fixed by logic and cannot drift. For these relays, it is adequate

to validate at a single point that the specified setting has been properly configured. Where logic or element settings determine which zones and functions are engaged, tests of a point for each element or functional behavior may be required. Beyond this, further testing of complete characteristic shapes at multiple points will not improve the quality of a commissioning test.

3.5.9. Directional tests

It is very important that element testing includes careful consideration of the directional setting values because settable impedance directional elements can affect the results of impedance plots and reach tests. Settable directional elements have impedance thresholds that can be tested. If a setting is positive, the impedance threshold, whether forward or reverse, will be tested as a reverse fault. If a setting is negative, the impedance threshold, whether forward or reverse, will be tested as a forward fault. Results are normally expressed in negative or zero sequence ohms depending on the element type.

3.5.10. Distance element checks

Multiple characteristic- Relays that contain a mho and quad characteristic for the same fault type should be tested together.

Line and resistive reach - Relay operation for zone boundaries should be tested. This should include phase to phase and phase to ground faults at the line angle. If the relay has a quadrilateral setting, then the resistive and reactive reach should be tested. Also test reverse elements if set and tripping times at a standard percentage of reach, such as 50%, for each zone.

Example:

50% of Z1 reach for Z1 (50% simply confirms that there is no doubt the timer will measure Z1 pickup only, realizing the timing may be slightly different along the boundary)
Z1 plus 50% of the difference (Z2-Z1) or equivalently, 50% of (Z1+Z2) reach for Z2 (50% confirms the timer is picking up well within Z2 but beyond Z1)
50% of (Z2+Z3) for Z3 (50% confirms the timer is picking up well within Z3 but beyond Z2)

Note: There will be cases with long lines followed by a very short line and the timing coordination of associated zones will have to be reviewed by the relay setting engineer. From a commissioning perspective, this exercise is simply for the purpose of testing the timing that has been provided in the settings.

Voltage supervision – Recommended for testing to include simulating a single and three phase loss of voltage supply and confirm voltage supervision operation. Also, test the relay distance elements that are blocked for Voltage supervision operation in accordance with relays designed operation.

Switch on to fault (SOTF) - It is recommended to test zone phase, zone ground and any specific overcurrent element timing for a switch on to fault condition. Also test “switch on to fault” drop off times.

Load encroachment blinders - It is recommended to test that the relay is blocked for load encroachment in accordance with relays designed operation.

3.5.11. Reclosing tests

Reclosing can be complex and difficult to test. Relays are now so sophisticated that the precise sequence of events should be simulated to assure a correct test. One challenge is to correctly simulate the breaker status input on the relay. In many cases, when the status does not change at the precise time the relay expects, the relay will consider it an improper operation of the breaker and proceed to lockout. For this reason, the easiest and best practice is to do a full-functional reclosing test allowing the breaker to cycle.

3.5.12. Logic tests

It is critical that any user-developed logic applied to relays used is tested during commissioning to verify correct operation. An exception to this may be if a relevant ‘default’ scheme is used. This would be a logic scheme built into the relay. Such logic schemes will have been proven by the manufacturer or programmer during relay type testing eliminating the need for proving tests during commissioning. However, where a user generates the scheme logic, it is necessary to confirm that the commissioning tests conducted are adequate to prove the functionality of the scheme, in all respects, if the logic has not already been proved out by the type testing. A specific test procedure, including the following, should be prepared:

- Checking of the scheme logic specification and diagrams to verify that the objectives of the logic are achieved.
- Testing of the logic to verify that the functionality of the scheme is proven, that correct outputs occur when expected, and confirm that no output occurs when they should not for the relevant input signal combinations.

3.5.13. Dynamic tests

Dynamic testing, as opposed to element testing, involves the application of fault simulations to the relay to test its response. This approach, utilizing automated test sets, validates complex relay element algorithms that cannot be easily or completely tested in a piecemeal function during element testing. The simplest test plans have three timed snapshots of voltage and current applied to the relay in succession. The first state is a “pre-fault” condition with normal voltage and load current applied to the relay long enough to satisfy memory polarization and let the relay stabilize. The second state applies the fault simulation of voltage and current, and the third state simulates the conditions following the opening of the breaker. Dynamic testing can closely approximate actual fault conditions that the relay will experience in service. Fault values can be calculated based on the reach of the relay in secondary ohms using simple hand calculations.

3.5.14. End-to-end tests

End-to-end testing provides dynamic testing of a line relay scheme and is recommended to be utilized whenever communication-based protection schemes are employed.

3.5.15. Special consideration-current differential and phase comparison relay schemes

It is recommended to use end-to-end testing whenever current differential or phase comparison relay schemes are employed to protect transmission circuits. End-to-end testing is the most effective way to validate that the remote quantities are summing properly with the measured quantities at each terminal.

In a standard communications-assisted scheme, the protection functions of the local relay are not dependent on any AC quantities from the remote relay(s), but only on a simple on/off trip permission or block. Therefore, the received signals in the scheme do not need to be aligned with any local signals, meaning that as soon as remote data arrives at the local relay, the signal can be directly consumed. In a current differential scheme (or similar), for the 87L element to be tested on the power system, it has to use signals that are measured at the same instant in time from all terminals involving the protected zone. Because data transmission does not occur instantaneously and data from different terminals arrive at different times, both the local and remote data must be stored within the 87L relays. Once all the data from the same instant in time are available in the relay, it aligns all data from the same instant in time and passes the data to the 87L function for processing.

3.5.16. Errors to avoid

The following are common errors made during commissioning testing of line relay schemes that can result in 1) failure to catch an error in either the design or application of a relay scheme, 2) the introduction of errors into the relay scheme by the commissioning test or 3) an inadvertent and unintentional relay operation of an in-service portion of the substation.

3.5.17. Failure to remove temporary mapping of I/O

The increasingly complex nature of line relay schemes, utilizing multiple elements of with complex logical combinations, makes the testing difficult. Often, to validate if a certain element is operational, the settings are modified temporarily to map the element under test to a specific output. This is either done manually by the technician or automatically by the testing software macros. The risk, however, is that following testing all temporary mapping may not be properly removed. Care must be taken to return the as-left mapping of I/O to the intended design. Although testing software utilized is supposed to accomplish this, a final validation that the software performed correctly is recommended. For these reasons either avoid temporary mapping if possible and conduct a full system performance test once the individual pieces have been tested. After testing is complete, the final step is to verify that the original settings are in the relay. It is recommended that prior to energization, all relay settings are confirmed to be applied properly.

3.5.18. Multiple setting groups

Microprocessor based relays typically provide the ability to employ multiple sets of settings (setting groups) to provide flexibility for changing conditions on the transmission system. From this feature, a risk can arise if an unused and improperly configured setting group is left enabled on an in-service relay scheme. Therefore, when multiple setting groups are not being utilized, it is recommended that all available setting groups are supplied with the same settings. This decreases the risk that if a relay is left in a wrong setting group the correct settings are still active rather than restoring to the default settings from the manufacturer or test settings. It is recommended that prior to energization, all relay settings are confirmed to be applied properly.

3.5.19. Validation of polarizing quantities

The incorrect wiring of zero sequence polarizing sources into protective relay schemes can be overlooked easily during commissioning testing because:

- Primary injection testing is not readily feasible. Most commissioning tests inject ac currents into instrument transformer secondary windings masking equipment and wiring installation errors.
- During normal system conditions, zero sequence voltage and current are not present in quantities that allow validation through meter checks, whether the installed relays are connected correctly.

3.5.20. Inadvertent trips on communication assisted relay schemes using direct tripping logic

Because line relaying is naturally distributed (multiple substation terminals) there is an increased risk of human error. Just the need for proper isolation of all the relays in a given scheme, regardless of the testing method and having to deal with multiple relays at multiple sites using larger test crews, can increase the number of errors. A common error to watch for and avoid include failing to isolate or restore critical outputs (trip or breaker failure initiate), cross-connecting wrong 87L relays, forgetting to isolate the remote relays when injecting currents into the local relay or isolating communication without consideration for the impact to the trip logic at the remote terminal.

Annex A (informative) – Relay commissioning common practices and checklist

In a typical substation construction project there are relay focused tasks that are common to all projects.

NOTE: Other qualified personnel are responsible for the substation yard, ground grid installation, installation of all substation equipment and devices including breakers, switches, power transformers, and bus. These other qualified personnel may be expected to perform the integrity tests on substation yard equipment. Check that the other responsibilities have been done and documented.

Commissioning agent or qualified relay person in charge is responsible for the following:

- Primary phase identification needs to be known with respect to corresponding phase connections of protection system inputs. During construction, verify proper phase connectivity. Walk the yard checking all bus sections with prints.
- Construction drawings (prints) should have at least four sets: one for relay construction, one for substation electrician and two other sets for after the project including a station copy and engineering set. These prints document changes are turned in for revision and have lessons learned.
- Analyze prints to see protection zone diagram has no “holes of protection” and understand how the substation is protected and controlled.
- Develop a work plan, with associated work crews and client representatives, to schedule the phases of construction work with dates, duration of work and clearance boundaries established.

Commissioning checklist

What is included in a protection system commissioning checklist varies with the scope of the project. However, below are some items to be considered for applicability in any project:

- Verify CT integrity by performing normal CT testing check
- Class
- Polarity
- Ratio
- Excitation test
- Insulation checks
- Verify unused CTs are shorted and grounded
- Verify cable pulling circuit schedule is complete and accurate.
- Verify that someone has performed control cabinet wiring tightness checks.
- Verify cable wiring completed and checked to control equipment enclosure (CEE).
- Verify cable insulation checks per expected minimum ohm value.

- Verify all alarms used for local annunciation or SCADA from points in equipment to CEE and that SCADA alarms are received at the transmission control center.
- Verify CT cables are wired properly as designed, as in
  - Polarity
  - Phase
  - Wye versus delta connections and
  - Ratio

These methods can vary in performing task.

NOTE: CT ratio must match relay setting information/sheet provided by relay setting engineer.

Transformers:

- Verify transformer nameplate has correct information per design.
- Prior to energization verify transformer de-energized (No-Load) tap position is on desired tap position (A-E).
- Verify that transformer specific alarms have been checked to terminal points in control cabinet where control cables terminate. Checking that task has been done.
- Verify fans (proper direction) and pumps run when called upon both manually/automatically.
- Verify fans and pumps blocked from working during relay lock out; internal jumper removed.
- Verify tap changer controls work in transformer, remotely in CEE and via SCADA.
- Verify accuracy of remote position indicator in CEE and indication to SCADA.
- Test and operate all the sudden pressure (SP) relays on transformer per manufacturer's instructions, if not done by others.
  - NOTE: Newer, large transformers are being designed with multiple SP relays in a voting scheme that needs to be verified.
- Verify that transformer does or does not trip on low oil or high winding temperatures. Transformer may have "ON/OFF" switches to select to for above. Label normal position of switch.

Breakers (fault interrupting devices):

- Verify breaker bushing #1 position agrees with prints and manufacture drawings.
- Verify current transformer (CT) physical position in breaker,
- Example: #1 bushing at northeast corner of 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.

Note: Dc systems, batteries and chargers are generally handled by others, commissioning personnel need to know associated commissioning work has been performed and completed

Relays:

- Verify that wiring on all relay panels is checked for correctness and that all terminations are properly tightened.
- Verify current relay setting sheets are available.
- Install "as-issued" relay settings.
- Make adjustments to relay settings if issued settings do not agree with SCADA addresses provided by another group, (i.e., communication parameters/addressing.)
- Perform the relay test function. It may be automated which may only address the enabled elements. Save the relay test results in file folder, if in electronic format, be sure to download files to backed up permanent storage to minimize the possibility of losing the data due to equipment failures.
- Once circuits have been wired and checked, turn the circuits on to perform functional testing where the logic is proved in the relays. One method of tracking which circuits have been checked is to highlight and mark the schematic wiring diagrams identifying what functions or circuits are checked. Once complete, every circuit in the schematics must be highlighted.
- If not already done, label all relays and relay panels, including test switches, with their unique identifiers to clearly identify trips, breaker failure initiates, and other test switches.
- All inputs and outputs on relays are verified and proved for sign off.
- Prove that lock out relays do what they are intended and expected to do in the project design.
- If line relay end-to-end relay checks are needed, schedule that function within the work plan.
- Relay file management is an utmost priority. Save and compare the As-Left relay settings with the As-Issued relay settings to prove accuracy prior to primary energization.

The final set of station prints should capture all changes within the project and transferred to the permanent system of record set of prints.

Relay and control schemes

- o Tightness check of all wiring not only terminals and lugged connections

Test insulation (Megger or equivalent test) of control wiring. Use appropriate test voltage for insulation class of wires and connected equipment to be tested. Insulation integrity test is performed cable wire to ground and each wire within cable to each other.

- Primary relay
    - Perform acceptance test
    - Ring out current circuits
    - Verify correct CT ratio applied
    - Verify correct settings applied
    - Test relay with applied setting
    - Trip check
    - Test relay with applied settings
    - Verify inputs
    - Trip checks (outputs)
    - Verify remote relay communications

- Redundant or Backup relay
    - Perform acceptance test
    - Ring out current circuits
    - Verify correct CT ratio applied
    - Verify correct settings applied
    - Test relay with applied setting
    - Trip check
    - Test relay with applied settings
    - Verify inputs
    - Trip checks (outputs)
    - Verify remote relay communications

- Control power transformer (CPT)
    - Visual inspection for damage, key interlock, draw-out, etc.
    - Ratio check
    - Set at in- service tap
    - Doble/Megger test

- Voltage transformer (VT or CCVT)
    - Visual inspection for damage or draw-out
    - Ratio check
    - Doble/Megger test

- Communications processor
    - Verify correct settings applied
    - Verify communication with each connected relay
    - Check dial-in capability from remote location

- SCADA control & indication

- Verify correct settings applied
- Verify communication with each connected relay
- Verify all relay alarms
- Check dial-in capability from remote location

- Line Tuner
  - Megger coaxial cable with 500Vdc or 1000Vdc insulation test set (>10MΩ acceptable)
  - Verify lead in wire correct cable and supported on insulator
  - Verify tuner cabinet is grounded
  - Verify Coax shield only grounded in the control house
  - Verify high voltage cable terminations
  - Tune to correct frequencies

- Line Trap
  - Tune to correct frequencies
  - Verify trap is located on the bus side, not the line side

- Power line carrier
  - Transmitter
    - Verify frequency
    - Check transmit power level meets expectations
  - Check reflected power level for optimal level receiver
    - Verify frequency
    - Set and verify margins
    - Verify local receivers correctly recognize remote transmitters

- Power line carrier
  - Transfer trip transmitters
    - Verify frequency
    - Check transmit power level meet expectations
    - Check reflected power level for optimal levels

- Direct Transfer Trip
  - Transmitters
    - Verify frequency
    - Calibrate into a 50 ohm non inductive load
    - Check reflected power level for optimal levels
  - Receivers
    - Verify frequency
    - Set and verify Margins
    - Verify local receivers correctly recognize remote transmitters
    - Verify Single Channel Conditions, if applicable

- Metering
    - Program digital meters
        - Ring out current circuits
        - Ring out potential circuits
    - Correct CT ratio applied

- Dc batteries
    - Check batteries for proper voltage
    - Check battery charger for proper float and equalize volts
    - Check battery alarms locally and into SCADA
    - Check for any dc battery ground to dc system as each new dc circuit is introduced

- Miscellaneous
        - Check all heaters for proper operation
        - Check all air-conditioning for proper operation
        - Check for proper function of lights (fluorescent and incandescent)
        - Proper labeling of all equipment

- Phase low voltage cables to existing circuits

- In-service tests
        - Verify station service
        - Verify relay potential
        - CCVT PGS Operation test
        - Verify LTC operation
        - Phase (see detailed phasing procedure)
        - Load equipment
        - Relay load checks/phase angles

- Release for service
        - Miscellaneous: follow-up with field staff
        - Mark all field revisions on a clean set of prints or return to Engineering
        - Update maintenance management database

Annex B (informative)

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