WECC

Installing and Maintaining Protective Relay Systems

Relay Work Group

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Introduction

Relay systems protect high-voltage equipment and transmission lines to ensure safe, stable systems. Although failure of a protective relay system may have severe local or regional impacts, most protective relay systems are not required to operate to prove they are in working order.

Ensuring that protection systems operate reliably is crucial, and a good preventive maintenance program ensures that protection and relay systems function properly without causing additional problems. Facilities need to perform installation tests, implement preventive maintenance programs, and perform comprehensive commissioning tests to verify the integrity of both existing protective relay systems and new protection systems.

This document makes minimum recommendations for installing, modifying, and maintaining protection systems and applies to the following:

- "Bulk Electric System" (BES), as defined by NERC
- Transmission Owners (TO), Generator Owners (GO) and Distribution Providers (DP)
- Underfrequency load shedding program (UFLS)
- Undervoltage load shedding program (UVLS)
- Remedial action schemes (RAS)

The recommendations and guidelines in this document are based on the experience and judgment of WECC members and include criteria for developing protection system best practices that, when implemented and used consistently, result in dependable, secure protection systems. This paper is an overview of recommended maintenance practices but does not include tests for specific types or brands of protection equipment. Refer to vendor instruction manuals for specific tests and test methods.

NERC has developed Standard PRC-005, to ensure that all transmission and generation protection systems affecting the reliability of the BES are maintained and tested.

In accordance with the NERC Standard, each TO, GO, and DP shall:

- Establish a Protection System Maintenance Program (PSMP) as identified in PRC-005.
  - Establish and maintain its performance-based maintenance (PBM) intervals, when used, in accordance with the Tables of PRC-005.
  - Implement and follow the PSMP for PBM as per PRC-005.
  - Establish and maintain its time-based maintenance (TBM) intervals, when used, in accordance with the Tables in PRC-005.
  - Implement and follow the PSMP for TBM as per PRC-005.
- Procedure to correct unresolved maintenance issues.
- Provide program implementation documentation that includes evidence to verify the following:
  - Components included in a TBM program were maintained in accordance with PRC-005.
  - Components included in a PBM program in accordance with PRC-005.

- Documented efforts to correct identified, unresolved maintenance issues in accordance with PRC-005.

Scope

For the purpose of this paper, the Protection System, as defined by the NERC Glossary of Terms Used in Reliability Standards, includes the following:

- Protective relays that respond to electrical quantities
- Communication systems necessary for correct operation of protective functions
- Voltage and current sensing devices that provide inputs to protective relays
- Station DC supply associated with protective functions (including station batteries, battery chargers, and non-battery-based dc supply)
- Control circuitry associated with protective functions through circuit breaker trip coils or other interrupting devices

PRC-005 has added several components to this list that are necessary to be covered by PSMP including reclosing and sudden pressure relays as described in the latest version of the standard.

Each facility owner or operator is responsible for ensuring the facility complies with NERC Standards. This paper describes prudent practices designed to ensure system integrity as established by NERC.

A utility may elect to implement several types of protection system tests. The system tests required for each protection system depend on the following:

- Type of relay or protection system in use
- The age of the equipment
- The application

Removing Protection Systems from Service on Energized Equipment

Before removing a protection system from service, carefully evaluate its impact on the reliability of the BES and notify any entities that may be affected. At a minimum, do the following before removing the protection system from service.

- Determine, in accordance with NERC Reliability Standards, whether notification with neighboring Transmission Operators and Balancing Authorities is required.
- Review protection system documentation to verify that removing the system from service will not adversely affect either local or remote operations. Review the following:
  - Protection System drawings
  - Installed settings for the protective relays
  - Existing operating procedures
  - Alarming to system operators or control centers

- Consider what impact removing the Protection System may have on the operation of any associated RAS or other Protection System.
- Verify that any affected power system element has adequate protection to remain in service.
- Determine whether backup protection systems need to be adjusted.
- Develop and follow a procedure for removing and restoring the protection system.
- Use training, tagging, or work procedures to reduce the possibility of leaving switches and isolating devices in incorrect positions.
- Isolate outputs from the impacted systems such as trips, breaker failure initiation, communication information, RAS triggering, etc.
- Consider the effect that disabling or modifying the communications systems may have.
- Consider the effects of inputs and isolate them, if necessary.
- Be careful when shorting current transformers (CT):
  - Know the impact on all devices in the CT string
  - Identify any parallel CT circuits
  - Understand the CT inputs to current differential protection at both local and remote terminals

WARNING: **Do not open-circuit CTs.** Hazardous voltages may occur and can injure personnel and/or damage equipment.

- Be careful when removing AC voltages from relays.
  - Know what impacts directionality has on other protection systems
  - Identify any affected protection relay restraint elements
- Ensure that relays equipped with remote communication have the communication interfaces effectively disabled to prevent an accidental operation.

Performing Commissioning or Installation Tests

Performing thorough commissioning or installation tests on the protection system is an important step when installing a new terminal or when modifying a protection system. Although each utility may perform its own specific procedures and tests, the actual protection equipment also determines the type and extent of commissioning tests required. At a minimum, perform the following commissioning/installation tests.

- Verify all protection system inputs including:
  - Current transformers (CT).
    - Check CTs for proper ratio, polarity, connections, accuracy, and appropriate grounding for the circuit involved.
    - Verify that shorting of unused CT windings is done properly and that CT windings used for protection systems are not shorted.

        - For more information about current transformers see the following documents:
            - IEEE C57.13.1-2006: Guide for Field Testing of Relay Current Transformers (ANSI).
            - IEEE C57.13.3-2014: Guide for Grounding of Instrument Transformer Secondary Circuits and Cases (ANSI).
    - Voltage transformers
        - Check voltage transformers for proper ratio, polarity, connections, accuracy, and appropriate grounding.
        - Verify that shorting of voltage windings have been removed prior to energization.

      Note: For more information about voltage transformers see IEEE C57.13.3-2014: Guide for Grounding of Instrument Transformer Secondary Circuits and Cases (ANSI).
    - Other inputs to the protection system:
        - Check battery supplies, circuit breaker auxiliary switches, pilot channel inputs, etc., to verify they are at the proper levels and in the correct state.
- Verify protection system settings as follows:
    - Check protection system settings to ensure they match the issued settings of record.
    - Perform protection system acceptance tests, if not already done.
    - Verify that any changes to relay settings required for relay acceptance testing are returned to the desired issued settings of record.
    - Verify multiple setting groups, if used.
- Verify protection system drawings and wiring to ensure that:
    - Switchboard panel wiring is intact and matches drawings.
    - Interconnections between protection system and other devices are intact and match drawings.
    - Drawings are correct.
    - Panel signage is correct.
- Verify all protection system outputs as follows:
    - Trip outputs.
        - Trip intended trip coils.
        - Verify all trip paths to circuit breaker including functional test of all circuit breaker trip coils.
    - Close outputs.
        - Close the breakers.
    - Pilot channel keys.
    - Check other outputs such as breaker failure to initiate, RAS signals, reclose initiate and reclose block, relay alarms, event recorder points, and any other relay outputs to other equipment.
    - Perform tests for each unique setting group, as required.
- Verify that the relay system operates properly as follows:

  - Perform coordinated, end-to-end tests to assure the protective systems are operating correctly.
    - Use an electromagnetic transients program, fault study data, or fault recorder data to develop test quantities for the relay system under test. When creating the test quantities, consider internal and external faults with different load flows, different fault resistances, and state conditions.
    - Ensure that all relays and/or recording equipment are time synchronized.
    - Verify that test sets are locked on satellites and synchronized between line terminals.
    - Run the automated tests that apply the voltages, currents, and/or inputs to the relay at the local terminal. Use a breaker simulator in place of the power circuit breaker or, if available, use a test set that provides breaker simulation.
    - Review the local relay and the sequence of events recorder (SER) or digital fault recorder (DFR) event report to ensure that correct quantities were applied to the relay.
    - Verify that the relay elements operated properly, that appropriate communication transmit and receive signals were present, and that proper timing between relay elements, signals, and breaker operations was achieved.
    - Archive the collected relay events, SER, and DFR data.
  - Check automatic reclosing, synch check, or special conditions to assure the scheme operates properly.
  - Verify programmed logic functions.
  - Verify digital I/O.
  - Verify pilot scheme logic.
  - Perform tests for each unique setting group as required.
- Verify communication channel operation as follows:
  - Measure channel delays.
  - Check for noise immunity.
  - Check for proper settings, programming, etc.
  - Check transmit and receive levels.
  - If automatic channel switching or routing is used, check for proper relay operation for alternate routing.
- Perform in-service tests as follows:
  - Measure the AC current and/or voltage magnitudes applied to the relay system.
  - Measure the AC current and/or voltage phase angles applied to the relay system.
  - When applicable, test the relay system for proper directional operation.

Some guidance has been developed to help industry perform thorough commission testing. Note: For more information about commissioning protection systems, see IEEE PSRC, WG I-25 Commissioning Testing of Protection Systems and the Joint Review of Protection System Commissioning Programs published by FERC.

Modifying a Protection System

When modifying a protection system, NERC Standards require each facility to perform tests similar to the commissioning/installation tests outlined in Performing Commissioning or Installation Tests on page 12.

Protection systems also require performing tests similar to commissioning/installation tests. The types of tests and the extent to which testing is required depends on the changes made to the protection system. Modifications may include, but are not limited to:

- Changing or making additions to protection circuits,
- Adding other equipment in current transformer (CT) or potential transformer (PT) circuits,
- Changing or upgrading protective relay firmware,
- Changing protective relay logic and/or settings, and
- Modifying communication circuits.

After modifying a protection system, each facility must perform applicable commissioning and installation tests. Such tests must be performed in accordance with specific system changes to ensure that systems operate correctly. When modifying a protection system, pay attention to any circuits that may be inadvertently affected by the changes. For example, replacing an auxiliary relay with multiple circuits connected to its outputs or modifications that may affect a RAS.

Performing Protection System Maintenance Tests

NERC Standards requires each facility to provide a summary of protection system maintenance and testing procedures. When performing protective relay system maintenance and testing, test the entire protective relay system including the following:

- Relay inputs,
- Relay sources,
- Protective relays,
- Relay outputs,
- Associated communication equipment,
- Voltage and current sensing devices providing inputs to protective relays,
- Station DC supply associated with protective functions, and
- Control circuitry associated with protective functions.

At a minimum, do the following when performing typical maintenance on a protective relay system:

- Verify all relay inputs including:
  - Voltages,
  - Currents, including CT ratios as compared to issued settings of record,
  - Pilot signals, and

  - Control signals.
- Verify individual relay performance including:
  - Timing,
  - Settings, and
  - Accuracy.
- Verify all relay outputs including:
  - Trips,
  - Close signal,
  - Transfer trip or pilot signals, and
  - Breaker failure initiate, alarms, etc., for all setting groups if applicable.
- Perform a functional trip test of the circuit breakers.
- Perform a functional test of all auxiliary relays, including lock-out relays.
- Perform load or in-service tests.
- Perform end-to-end testing when the relay scheme depends on quantities from the other end, such as line differential.

Test type, extent, and interval vary depending on the relay types used and how they are applied. Electromechanical and older electronic relays generally lack sufficient automatic monitoring to alarm or disable a relay should it fail and require more frequent maintenance.

Consider using other diagnostic tools such as:

- *Self-diagnostic firmware*, included with newer digital relays, to perform real-time tests on parts of the relay.
- *A sequential event recorder* to monitor various relay elements. Use it as a diagnostic tool to evaluate relay system performance following an operation.
- *A fault recorder* to analyze relay system performance.

Other Issues

This section provides guidelines for the following:

- Commissioning Other Equipment,
- Performing Evaluation or Type Tests,
- Performing Model Line Tests,
- Remedial Action Schemes (RAS),
- Maintaining Pilot/Transfer Trip Channels, and
- Designing Protection and Control Circuits.

Commissioning Other Equipment

Consider the following when commissioning new equipment.

- It may be necessary to place special settings on protection equipment before energizing new equipment.
- Some utilities routinely reset protection elements for increased sensitivity when energizing new equipment.
- A common practice is to make some directional elements non-directional for the initial energization.
- Many utilities prefer to energize new equipment from a weak source or from a remote terminal.
- Return any special settings made for an energization test to normal as soon as appropriate.

Performing Evaluation/Type Tests

An evaluation/type test verifies that a new product or device:

- Is suitable for the application.
- Complies with specifications.
- Meets performance requirements.

Type testing includes performing a variety of relay or relay-system tests and tasks including:

- Testing relay accuracy.
- Testing operation speed and performance.
- Performing environmental tests including surge withstand capability, fast transient, thermal tests, etc.
- Testing specific or critical applications, including model line testing of the relay or relay system.
- Developing and evaluating microprocessor relay standard logic.
- Reviewing and evaluating firmware changes and revisions.

Performing Model Line Tests

Use *model line* testing to perform laboratory tests of a specific relay or relay system on a model power system configured to match a specific application. Model line testing may be performed:

- At a factory to verify a relay package before purchase or to evaluate the performance and features of a relay system
- On a relay system, following a system problem, to investigate and correct potential problems with the relay system.

See *WECC White Paper on Model Power System Testing* for more details about model line testing.

Remedial Action Schemes

See *WECC Relay Work Group Remedial Action Scheme Design Guide* for more information about RAS.

Designing Protection and Control Circuits

Consider the following when designing protection and control circuits:

- Design protection and control circuits so they are easy to test.
- Provide enough test switches, isolation devices, etc., to permit work on relays with minimum risk of accidental trips.
- Design switches and isolation devices so that an open switch does not jeopardize the security of the overall protection system.
  - Avoid designs that make it necessary to:
  - Lift wires or modify circuits for the sole purpose of performing routine tests.
- Change relay taps or settings for test purposes.
- Provide proper alarming and indicators to monitor the position of these devices.

Definitions

Some of the tests identified in this section may not be performed during commissioning or routine testing. However, such tests provide additional methods to ensure the integrity of the Protection System.

Testing is a specific act that exercises a function of the protection system to observe the performance.

Utilities often refer to types of tests or test methods by different names. This document uses following terms and their associated definitions.

Term	Definition
Acceptance Test	A test used to verify that each relay is: • In proper working order • Properly calibrated when it is received or installed Acceptance testing may also include use of the following: • Procedures recommended by the manufacturer • Calibration using specified settings • Other tests the user deems appropriate
Calibration Test	A test to verify that each relay functions accordingto its operating values and specifications. Typical calibration test procedures include characteristics, timing, pickup, etc.

Term	Definition
Commissioning/Installation Test	A test to verify that an installed or modified Protection System operates correctly when using specific relay settings.
Condition-Based Maintenance	A set of maintenance tests or inspections to be performed based on evidence-of-need. The need for testing is determined by: • Real-time monitoring of the condition of the protection system based on alarming and/or evaluated operations. • Continuously or frequently reported results from non-disruptive, self-monitoring of components that demonstrate operational status as those components remain in service. **NOTE:** Although the term "Condition-Based Maintenance" (CBM) is no longer used within the standard itself, it is important to note the CBM concepts are a part of the standard (in the form of extended time intervals through status-monitoring). These extended time intervals are only allowed in the absence of Performance-Based Maintenance (PBM) if the condition of the device is monitored (CBM).
Coordinated End-to-End Test	Simultaneous testing of the entire Protection System at all terminals to verify that it operates asexpected. • The communications channels are part of this test. • Time-synchronized relay test sets are used to inject pre-fault, fault, and post-fault values into the relays at each terminal.
Diagnostic/Corrective Test	A test used to find and correct equipment errorsor problems. Diagnostic tests are usually initiated after a relay problem, such as a failure to trip or an over trip, isidentified or suspected.

Term	Definition
Directional Test	A test to verify that a directional relay: • Is correctly connected to polarizing and operating sources. • Operates or blocks properly when the primarysystem quantities are in the appropriate direction.
Distance Reach Test	*See Impedance Test.*
Functionality Test	An operational test in which the tester does thefollowing: • Performs an operational or trip test of the relay system. • Monitors relay outputs to other equipment such as a breaker-failure relay, pilot scheme,or digital I/O. • Tests the operation of any automatic reclosingfunction. Coordinated end-to-end testing of both/all transmission line terminals is a common, acceptable method of performing a functionalitytest.
Impedance Test	A test to verify that the impedance/distance relayis: • Correctly connected to polarizing and operating sources. • Operates properly for the intended reach settings when the primary system quantitiesare applied.
In-Service/Load Test	A test that usually involves measuring AC currentsand/or voltages applied to the relay while it is in service carrying load quantities. Generally, the relative phase angles of the currents and/or voltages are also measuredduring the load test.

Term	Definition
Performance-Based Maintenance (PBM)	A method used to establish maintenance intervalsbased on analytical or historical results of Time- Based Maintenance (TBM) failure rates on a statistically significant population of similar components. • Some level of TBM is generally followed. • Statistical analyses accompanied by adjustments to maintenance intervals are used to justify continued use of PBM-developed extended intervals when test failures or in-service failures occur infrequently.
Time-Based Maintenance (TBM)	Testing and calibrating a protection system on ascheduled basis. It is also referred to as Routine, Scheduled, or Periodic Testing.

References

1. IEEE C37.13.1-2006: Guide for Field Testing of Relay Current Transformers (ANSI)
2. IEEE C37.13.3-2014: Guide for Grounding of Instrument Transformer Secondary Circuits and Cases (ANSI)
3. IEEE PSRC, WG I-25 Commissioning Testing of Protection Systems
4. Joint Review of Protection System Commissioning Programs published by FERC, NERC, and Regional Entities
3. IEEE Power System Relay Committee Transmission Protective Relay System Performance Measuring Methodology
4. NERC Reliability Standards, PRC-005-3: Protection System and Automatic Reclosing Maintenance
5. NERC Glossary of Terms Used in Reliability Standards, April 20, 2009
6. WECC Relay Work Group Model Power System Testing Guide
7. WECC Relay Work Group Remedial Action Scheme Guide
8. WECC Telecommunications Work Group Guide on Telecommunications Circuit Maintenance
9. IEEE C37.233-2009: IEEE Guide for Power System Protection Testing
10. WECC White Paper on Model Power System Testing

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