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INSTALLATION AND MAINTENANCE GUIDELINE FOR PROTECTIVE RELAY SYSTEMS

Western Electricity Coordinating Council
Relay Work Group

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I. INTRODUCTION:

Relay systems protect high voltage equipment and transmission lines, providing safety and system stability. The failure of a protective relay system may have severe local or regional impacts. Many of the protective relay systems are seldom called upon to work and have little means of proving they are in working order. Thorough installation testing and a preventive maintenance program verify the integrity of these protective relay systems. Comprehensive commissioning tests of new protection systems is a crucial step to ensure the reliability of the protection system. A good preventive maintenance program ensures the protection system is in functioning order. A preventive maintenance program should ensure the functionality of the relay system without causing additional problems in the process.

This document establishes minimum guidelines for the installation, modification, and routine maintenance of protection systems. This guide is intended to bring the Western Electricity Coordinating Council (WECC) into compliance with the North American Electric Reliability Council (NERC) Planning Standards (Reference 3) regarding installation and maintenance of protection systems. This guide is applicable to all "main grid" transmission systems as defined by NERC and the WECC. It is also applicable to generator protection, frequency and voltage load shedding schemes, and special protection or remedial action schemes. It is based on the experience and judgment of WECC members, supplemented by survey information of other utility groups. This document suggests maintenance intervals and/or practices that should result in dependable and secure protection system operation. There are reasons peculiar to many individual situations that may justify more frequent maintenance. Each member must evaluate its own particular circumstances and determine if additional maintenance is required. This guideline is intended to be an overview. It does not include tests for specific types or brands of protection equipment. It is necessary to refer to individual vendors' instruction manuals for specific tests and test methods of their equipment.

Section 11.4 of the WECC Minimum Operating Reliability Criteria stipulates that "Each system shall provide for periodic testing of protective relay systems and remedial action schemes which impact the reliability and security of the interconnected system operation." The WECC Reliability Management System, Phase 3 requires that "Each Transmission Owner (TO) shall develop, document and implement a Transmission Maintenance and Inspection Plan (TMIP), perform maintenance in accordance with that Plan, and maintain maintenance records as required by this Transmission Maintenance Standard." The maintenance plan will include the schedule interval for time based activities and/or a description of conditions that trigger any performance based activity. (Reference 7) NERC has the following requirement: "Each system should implement protection system application, operation and protective maintenance procedures which will enhance their system reliability with the least adverse effect on the interconnection. These protection system procedures should be provided to all appropriate system

personnel and should provide for instruction and training where applicable. Each system should coordinate these procedures with any other systems that could be affected." The NERC Planning Standards on System Protection and Control states: "Protection and control system reliability is also dependent upon sound testing and maintenance practices. These practices include defining what, when, and how to test equipment calibration and operability, performing preventive maintenance, and expediting the repair of faulty equipment." The NERC criteria also has a standard requiring members to develop and implement a protection system maintenance and testing program. Members of the WECC that follow this WECC Installation and Maintenance Guideline will be in compliance with the WECC and NERC criteria.

II. SCOPE:

For the purpose of this guideline, we define the protection system to include the entire protective relay system including all relay inputs and their sources, the protective relay or relays themselves, and the relay outputs all the way to the circuit breaker trip and close coils. This includes the associated wiring, pilot channels, and pilot equipment when utilized. The IEEE Power System Relay Committee has made the following definitions: Relay system is defined as the protective relays, communication system, voltage and/or current sensing devices, and the dc system up to the terminals in the circuit breaker. Circuit breaker is a generic term for any fault interrupting device. Protective system includes both the relay system and the circuit breaker. (Reference 9)

This guideline applies to those protection systems used for the protection of bulk power system within the WECC. Other high voltage power systems, not normally considered to be part of the bulk power system, but which may have significant impact to the system should also be included. This guideline also applies to lower voltage electrical systems which may be included as part of special control schemes, such as load shedding, etc. This guideline is also applicable to generation that is connected to the WECC system. It is the responsibility of the owner that they, their operator or their agent complies with this guideline. The objective of this guideline is to prevent any individual utility, owner, or operating group from degrading the system integrity as established in the WECC Reliability Criteria. This guideline defines prudent utility practice within the WECC region.

There are several other types of protection system tests that a utility may elect to perform. Some of these tests are defined in the definition section but may not be performed during commissioning or routine tests. These tests do provide additional means to ensure the integrity of the protection system.

III. DEFINITIONS:

Utilities often refer to types of tests or test methods by different names. For this document, we have chosen this nomenclature and corresponding definitions. Tests are quite dependant upon the type of relay or relay system used, the generation of the equipment, and the application.

Acceptance Testing: This test may be done to verify each relay is in proper working order and calibration when it is received or installed.

Calibration Test: This is a test of the relay to verify that the relay functions according to its settings and specifications. Typical tests include characteristic tests, timing tests, pickup tests, etc. These tests may be done as part of an acceptance test or as part of the installation or routine maintenance. Some utilities perform an "as found" calibration test, or at least a subset of the entire calibration test to verify the characteristics of the relay. Following any corrective actions to the relay, an "as left" calibration test is then performed. It is becoming more common and acceptable to forgo the "as found" test unless the relay is undergoing a special test following some sort of problem.

Commissioning or Installation Tests: The testing of relay systems as they are installed or revised. This is a thorough test of all of the elements of the protection system. It includes special tests of the instrument transformers. It also includes overall operational or functional tests of the relay to verify the relay does provide all the necessary outputs required by the circuit. Circuit integrity is also checked. Section IV of this guide lists the typical tests required for commissioning or installation of a new or revised protective relay system.

Condition Based Maintenance: Relay alarms and/or operations are evaluated and the level and extent of additional maintenance is determined as needed.

Coordinated End-to-End Tests: This is the simultaneous testing of complete relay systems at all terminals. The communications channel(s) are also tested as part of this test. Time synchronized relay test sets are used to inject prefault, fault, and post fault values into the relays. Test sets use EMTP, fault study data, or fault recorder data to derive test quantities for the relays. End to end testing includes overall testing of relays and their associated pilot channel. This testing may be used as a part of the commissioning/installation testing or for diagnosis or trouble shooting of an inservice protection system problem. This type of test procedure is also an acceptable method for the functionality test. This test procedure may be used as a model line test in a laboratory. Tests include verifying protection system operation for both internal and external faults, with different load flows, and with different fault resistances.

Diagnostic or Corrective Tests: This is the testing of equipment to find and correct errors or problems. These tests are usually initiated after a relay problem is identified or suspected, such as a failure to trip or an overtrip.

Directional Test: This is a test of directional relays to verify that the relay will operate or block properly when the relay input quantities are in the appropriate direction. A directional test is done with the equipment carrying normal load quantities. This test most often involves special connections of the currents and/or voltages to the relay to get the directional elements to operate. It should be done as part of relay system commissioning and may be done as part of a routine test.

Evaluation or Type Testing: This is a test of a new product or device to verify its suitability, specification compliance, and evaluation of its performance. Type testing includes a variety of tests of the relay or relay system. It includes tests of relay accuracy. Does the relay meet the accuracy requirements specified by the vendor? Does the relay meet the accuracy needs of the user? Operating speed and performance is generally tested to verify the relay meets vendor's specifications and end user's needs. A wide range of environmental tests are done including SWC, fast transient, thermal tests, etc. Testing for specific or critical applications also generally includes model line testing of the relay or relay system. Type testing may also include the development and evaluation of microprocessor relay standard logic to meet the user's requirements. Type testing also includes a review and evaluation of firmware changes and revisions.

Functionality Test: This test is generally of an operational nature. The test includes an operational or trip test of the relay system. The test should include monitoring of relay outputs to other equipment such as a breaker failure relay, pilot scheme, etc. The functionality test also should test the operation of any automatic reclosing function. Coordinated end to end testing of both/all of the transmission line terminals is becoming a common and very acceptable method to perform the functionality test.

In Service Test: See Load Test.

Load Test: A load test generally involves the measurement of the AC currents and/or voltages applied to the relay. Generally the relative phase angles of the currents and/or voltages are also measured during the load test. The load test is done with the equipment carrying normal load quantities.

Model Line Testing: Laboratory testing of a specific relay or relay system on a model power system configured to match a specific application. Model line testing may be done at a factory to verify a relay package before purchase, or to evaluate the performance and features of a relay system. Model line testing may also be done on a relay system following a system problem to investigate and correct potential problems with the relay system. See Reference 1 for more details on model line testing.

Operational Performance Based Maintenance: This maintenance method looks at individual relay system operational performance for each fault operation and determines appropriate maintenance requirements based upon actual relay performance. Recent successful operations may eliminate or reduce the need to test some or all of the relay system elements.

Overall Test: This is a more complete test of the protection system. It includes the functionality test and load test but also includes a calibration of the relay. Some utilities may alternately schedule the functionality test and the overall test to meet their periodic test requirements.

Periodic Testing: Routine maintenance testing and calibration of the protection system performed on a time or calendar basis or scheduled basis. Also referred to as **Routine**, **Scheduled,** or **Time Based Maintenance.**

Reliability Centered Maintenance (RCM): Interpretations of RCM principles can vary considerably from utility to utility. Evaluations should produce a "Best Practice." However, the process may include an economic evaluation that may be inappropriate in terms of the WECC Reliability Criteria. RCM relies heavily upon operating history, equipment experience, and risk assessment with the protection system. Even though RCM principles may not be time based, RCM generally has a "drop dead" date which, when reached, requires some sort of inspection of equipment.

IV. PROTECTION SYSTEM COMMISSIONING/INSTALLATION TESTS:

Thorough commissioning or installation testing of the protection system is an important step for the installation of a new terminal or when changes to the protection system are made. Individual utilities may have their own specific procedures and tests they perform. The actual protection equipment used also will determine the type and extent of commissioning tests required. The following tests are the minimum tests that must be performed.

1. Verifying all inputs to the protection system.
    a. Current transformers--check for proper ratio, polarity, connections, accuracy, and appropriate grounding for the circuit involved. (References 1 and 2)
    b. Current transformers--verify that shorting of unused CT windings is proper and that CT windings used for protection systems are not shorted.
    c. Voltage transformers--check for proper ratio, polarity, connections, accuracy, and appropriate grounding. (Reference 2)
    d. Verify all other inputs to the protection system including battery supplies, circuit breaker auxiliary switches, pilot channel inputs, etc.
2. Verify protection system settings
    a. Check protection system settings, programming
    b. Acceptance testing of protection system if not performed previously.
    c. Verify that any changes in relay settings required for relay acceptance testing are returned to the desired, "as left" settings.
3. Protection system drawings and wiring
    a. Verify switchboard panel wiring is intact and matches drawings.
    b. Verify interconnections between protection system and other devices are intact and match drawings.
    c. Verify drawings are correct.
4. Verify proper relay system operation.
5. Verify all outputs of the protection system.

a. Trip outputs--trip intended trip coil(s)
b. Close outputs--close the breaker(s)
c. Pilot channel keying
d. Other outputs such as breaker failure initiate, special protection scheme signals, reclose initiate and reclose block, relay alarms, event recorder points, and any other relay outputs to other equipment.

6. Perform trip or other operational or functional tests to assure correct operation of the protective systems. Automatic reclosing should also be tested.
7. Pilot schemes
   a. Measure channel delays
   b. Check for noise immunity
   c. Check for proper settings, programming, etc.
   d. Check transmit and receive levels
   e. If automatic channel switching or routing is utilized, check for proper relay operation for alternate routing.
8. In Service, Load and Directional Tests
   a. Measure AC current and/or voltage magnitudes applied to the relay system.
   b. Measure AC current and/or voltage phase angles applied to the relay system.
   c. Test the relay system for proper directional operation when applicable.

Many utilities now use coordinated end to end tests to verify the overall operation of the protection system and the pilot channel as part of their commissioning tests. This is an acceptable method of operational testing.

Modifications to a protection system also require testing similar to that listed above. The extent of testing and types of tests required depend upon the modifications made. Modifications include changes or additions to protection circuits. Modifications also include changes or upgrades of protective relay firmware and changes in protective relay logic and/or programming. Many members also consider it good practice to perform various levels of tests and calibrations following changes in protective relay settings. Proper testing after modifications is required to ensure correct system operation and must be performed to the extent required by the specific system changes. When making protection system modifications, attention must be paid to any circuits that may be inadvertently affected by the modification; for example, replacement of an auxiliary relay having multiple circuits tied to its outputs.

V. MAINTENANCE/ROUTINE TESTING:

Protective relay system maintenance includes the entire protective relay system consisting of relay inputs, the protective relays themselves, and the relay outputs. A typical maintenance of a protective relay circuit should include the following:

1. Verify all relay inputs--voltages, currents, pilot signals, control signals.
2. Verify individual relay performance, timing, settings, and accuracy.
3. Verify all relay outputs--trips, close signal, transfer trip or pilot signals, breaker failure initiate, alarms, etc.
4. A functional trip test to the circuit breaker or at least the lock out relay (86) is recommended.
5. Perform load or in service tests.

The extent of the tests, the types of tests, and the frequency may vary corresponding to the types of relays used and their application. Electromechanical and older electronic relays generally lack sufficient automatic monitoring to alarm or disable the relay should it fail. These devices may require more frequent maintenance. Newer digital relays may include self diagnostics that can perform real time tests of portions of the relay. Monitoring of the various relay elements on a sequential event recorder may also be used as a diagnostic tool to evaluate relay system performance following an operation. Fault recorder information is also an important tool in the analysis of relay system performance.

The type of preventive or routine maintenance program a member uses should comply with one or a combination of the following acceptable practices:

Routine Time Based Testing: This is the maintenance procedure most often used. Maintenance is determined strictly upon a calendar basis. It is very easy for a utility to implement. There is a risk that intervals are extended based not upon the performance of the protection system but on economic considerations.

Operational Performance Based Testing: This method may be used to extend the intervals between routine testing. It is based upon a determination that the relay system performed satisfactorily for a recent event. There is a risk that not all components of the relay system are called upon to operate during any one operation and therefore do not demonstrate their integrity. Performance based testing is most appropriate for transmission or distribution lines which experience periodic fault operations. This test is less appropriate for power transformer or bus protection which generally have a lower fault incident rate.

Reliability Centered Maintenance: This method utilizes a variable interval based upon such things as previous performance history, criticality of the equipment being protected, and projected failure modes. RCM does require extensive record keeping to develop historical performance levels. A broader historical data base will better define RCM needs. There is a risk that RCM will be used as an economic tool to reduce maintenance without sufficient regard to system integrity. RCM maintenance methods generally include a "not to exceed" or "drop dead" date. If this date is reached, the equipment should be inspected or maintained regardless of any other RCM indicators.

Many utilities utilize two or more different levels of relay maintenance. The simplest or minimum level involves a functional test and load test to verify the integrity of the scheme. This test is done most often or has the shortest drop dead date. Maintenance performed less often includes the above tests but also includes a calibration test.

Each WECC member shall annually report to the WECC staff the type of maintenance program they are using and the status of their maintenance program. The maintenance program should comply with WECC and NERC requirements.

VI. MAINTENANCE/TEST INTERVALS:

Several factors can be considered when determining the test intervals of protection systems.

Voltage Level: Some members choose test intervals based upon the voltage level. Generally, higher transmission voltages are tested more frequently. Higher voltage protection systems are typically more complex than for lower voltages. Increased complexity often leads to increased problems. Relay system problems at higher voltage levels most often have a larger impact upon the power system.

Relay Type: Some members elect to test relays of a similar type at the same interval. This is justified because like relays will experience similar problems and need a similar level of maintenance. It is a general consensus that newer microprocessor relays require less frequent and less extensive testing than electromechanical or older electronic relays. Many of these relays have some level of built in self testing and failure alarming capability. Successful completion of a self test may be a substitute for the individual relay performance test. It is important for the utility to understand the extent and limitations of relay self testing features. Self testing may not discover all of the failure modes a relay system may experience. Relay output alarms should be monitored via SCADA or annunciators to take advantage of the relay's monitoring capabilities. Other relay features such as the ability to display potential and current input magnitudes and angles and trip coil monitoring may fulfill the requirement for checking of voltage and current input circuits and trip circuit integrity. The overall relay system performance still needs to be verified, regardless of the type of relay used.

Manufacturer Recommendations: Relay equipment manufacturers often provide suggested maintenance practices and intervals. Individual manufacturer's recommendations tend to vary considerably. Within most substation facilities, equipment from many different manufacturers is found. This can make it difficult to determine a uniform practice for the entire facility. Unless the utility has different experience with a specific relay product, the manufacturer's recommendation is a good guide to determine test intervals.

Historical Experience: Test intervals and the types of tests a utility uses can be based upon operational history and experience with a specific protection system or type of system. For instance, experience by WECC members with the Westinghouse SPCU

phase comparison relay system indicates this system should be tested at least annually. (Reference 6) Similar experience with Westinghouse KD relays shows a need for a calibration test about every three to four years because of capacitor problems which affect the relay's operating characteristics.

Criticality: Test intervals and types of tests are based upon the criticality of a particular circuit or piece of equipment. For instance, protection systems on major WECC path lines may need to be tested more often than other lines operating at similar voltages or with similar equipment.

WECC Recommendations:
Due to the following considerations, explicit maintenance time intervals are not set forth in this document:

1. A viable maintenance program, or particular elements of that program, need not be time based. Reliability Centered Maintenance (RCM), for example, is such a case.
2. Appropriate maintenance intervals can legitimately vary considerably based on the type of relay system. For example, self-monitoring relays tend to provide information that can allow maintenance to be deferred longer than for other types of relays.
3. Maintenance intervals may vary based on historical performance. For example, an internal relay component such as a capacitor, may exhibit a predictable time to drift out of tolerance, thereby necessitating a particular maintenance interval unique to that device.
4. Maintenance intervals may vary based on criticality of the circuits on which they are applied, which is essentially a consideration of system consequences due to misoperations.

It is recognized that members can legitimately defer maintenance on a specific terminal for a reasonable period of time if the member has definite plans to replace or upgrade that equipment. Also, members need to have some leeway in meeting their established intervals. It is suggested that a six to twelve month delay will generally not seriously impact the reliability of the protection system.

VII. OPERATIONAL ANALYSIS:

The NERC Planning Standards for System Protection and Control also require the review of relay performance. Specifically, all protection system trip misoperations shall be analyzed for cause and corrective action.

The current WECC Reliability Management System requires members to analyze the correctness of all protection system operations and take appropriate followup actions. This review can be included as a part of the member's maintenance program. Depending upon the member's selection of a maintenance technique, the determination of a successful operation may be substituted for a routine maintenance.

The WECC also recommends that relay settings being reviewed at least every five years or as required by changes in system conditions.

VIII. OTHER ISSUES:

Commissioning of Other Equipment: It is very important that protection engineers review the protection requirements necessary when new equipment or transmission lines are being energized. New equipment or lines must not be energized without sufficient or proper protective relays. There may be a need for special settings of protection equipment for the equipment energization. Some utilities routinely reset protection elements for increased sensitivity when energizing new equipment. It is also common 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. Any special settings made for an energization test should be returned to normal as soon as appropriate.

Special Protection and Remedial Action Systems: Refer to the Relay Work Group guide on Remedial Action Systems. (Reference 5) Note that this guide requires an annual functional test of these schemes.

Pilot / Transfer Trip Channels: Tone equipment and communications circuits--refer to WECC Telecommunications Work Group recommended maintenance guidelines. (Reference 8)

Design: Design protection and control circuits to allow ease of testing. Protection circuits need to have sufficient test switches, isolation devices, etc. to allow work on relays with minimum risk of accidental trips. At the same time, switches and isolation devices need to be applied so that an open switch does not jeopardize the security of the overall protection system. It should not be necessary to lift wires or modify circuits for the sole purpose of performing routine tests. It should not be necessary to change relay taps or settings for test purposes. Careful, well thought out training, tagging procedures, and work procedures can be used to reduce the chance of leaving switches and isolating devices in the incorrect position. Proper alarming and indication can also be used to monitor the position of these devices.

IX. REFERENCES:

1. IEEE C57.13.1-1981 Guide for Field Testing of Relaying Current Transformers (ANSI)
2. IEEE C57.13.3-1983 Guide for Grounding of Instrument Transformer Secondary Circuits and Cases (ANSI)
3. NERC Planning Standards, September 1997
4. WECC Relay Work Group Model Line Testing Guide
5. WECC Relay Work Group Remedial Action Scheme Guide
6. WECC Relay Work Group Report, Westinghouse SPCU Relay Discussion, September 10, 1997
7. WECC Reliability Management System Phase 3, Transmission Maintenance Standards
8. WECC Telecommunications Work Group Guide on Telecommunications Circuit Maintenance
9. IEEE Power System Relay Committee "Transmission Protective Relay System Performance Measuring Methodology"

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