NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

Considerations for Maintenance and Testing of Autoreclosing Schemes

System Analysis and Modeling Subcommittee
System Protection and Control Subcommittee

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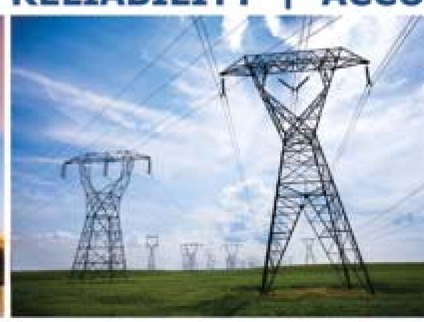
RELIABILITY | ACCOUNTABILITY



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NERC's Mission

The North American Electric Reliability Corporation (NERC) is an international regulatory authority established to enhance the reliability of the bulk power system in North America. NERC develops and enforces Reliability Standards; assesses adequacy annually via a ten-year forecast and winter and summer forecasts; monitors the bulk power system; and educates, trains, and certifies industry personnel. NERC is the electric reliability organization for North America, subject to oversight by the U.S. Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada.[1]

NERC assesses and reports on the reliability and adequacy of the North American bulk power system, which is divided into eight Regional areas, as shown on the map and table below. The users, owners, and operators of the bulk power system within these areas account for virtually all the electricity supplied in the U.S., Canada, and a portion of Baja California Norte, México.

Note: The highlighted area between SPP RE and SERC denotes overlapping Regional area boundaries. For example, some load serving entities participate in one Region and their associated transmission owner/operators in another.

NERC Regional Entities	
FRCC Florida Reliability Coordinating Council	**SERC** SERC Reliability Corporation
MRO Midwest Reliability Organization	**SPP RE** Southwest Power Pool Regional Entity
NPCC Northeast Power Coordinating Council	**TRE** Texas Reliability Entity
RFC ReliabilityFirst Corporation	**WECC** Western Electricity Coordinating Council

[1] As of June 18, 2007, the U.S. Federal Energy Regulatory Commission (FERC) granted NERC the legal authority to enforce Reliability Standards with all U.S. users, owners, and operators of the bulk power system, and made compliance with those standards mandatory and enforceable. In Canada, NERC presently has memorandums of understanding in place with provincial authorities in Ontario, New Brunswick, Nova Scotia, Québec, and Saskatchewan, and with the Canadian National Energy Board. NERC standards are mandatory and enforceable in Ontario and New Brunswick as a matter of provincial law. NERC has an agreement with Manitoba Hydro making reliability standards mandatory for that entity, and Manitoba has recently adopted legislation setting out a framework for standards to become mandatory for users, owners, and operators in the province. In addition, NERC has been designated as the "electric reliability organization" under Alberta's Transportation Regulation, and certain reliability standards have been approved in that jurisdiction; others are pending. NERC and NPCC have been recognized as standards-setting bodies by the Régie de l'énergie of Québec, and Québec has the framework in place for reliability standards to become mandatory. NERC's reliability standards are also mandatory in Nova Scotia and British Columbia. NERC is working with the other governmental authorities in Canada to achieve equivalent recognition.

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This technical document was approved by the NERC Planning Committee on November 14, 2012.

Introduction

On February 3, 2012, the Federal Energy Regulatory Commission (FERC) issued Order No. 758[2] approving an interpretation of NERC Reliability Standard PRC-005-1, Transmission and Generation Protection System Maintenance and Testing. In addition to approving the interpretation, the Commission directed that concerns identified in the preceding Notice of Proposed Rulemaking (NOPR) be addressed within the reinitiated PRC-005 revisions.

The concerns raised in the NOPR pertain to automatic reclosing (autoreclosing) relays that are either "used in coordination with a Protection System to achieve or meet system performance requirements established in other Commission-approved Reliability Standards, or can exacerbate fault conditions when not properly maintained and coordinated," in which case "excluding the maintenance and testing of these reclosing relays will result in a gap in the maintenance and testing of relays affecting the reliability of the Bulk-Power System."[3] To address these concerns, the Commission concludes that "specific requirements or selection criteria should be used to identify reclosing relays that affect the reliability of the Bulk-Power System."[4]

This report provides technical input from the NERC System Analysis and Modeling Subcommittee (SAMS) and the System Protection and Control Subcommittee (SPCS), both subcommittees of the NERC Planning Committee, to support the Project 2007-17 standard drafting team assigned to modify PRC-005. This report recommends technical bases to identify those autoreclosing applications that may affect reliability of the bulk power system. Such applications should be included in the Applicability section of PRC-005 to address the directives in Order No. 758.

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2 See FERC Order No. 758, *Interpretation of Protection System Reliability Standard*, 138 FERC ¶ 61,094.

3 *Id.* at P. 16.

4 *Id.* at P. 26.

Considerations for Applicability of PRC-005

Autoreclosing is utilized on transmission systems to restore transmission elements to service following automatic circuit breaker tripping. When an autoreclosing application may affect reliability of the bulk power system, the autoreclosing relay[5] should be included in the applicability of PRC-005.

The concerns identified by the Commission in Order No. 758 can be grouped into two categories:

- situations in which autoreclosing fails to operate when required to maintain bulk power system reliability; and
- situations in which autoreclosing operates in manner that is not consistent with its design, adversely affecting reliability of the bulk power system.

The following sections address these two categories of concern.

Applications to Improve Bulk Power System Performance

Consideration of Autoreclosing to Increase Operating Limits

Planning and operation of the bulk power system must consider autoreclosing applications.[6] Autoreclosing following automatic circuit breaker tripping may be successful if the condition that initiated the tripping (e.g., a fault) is no longer present, or it may be unsuccessful if the condition is still present in which case the circuit breaker will trip again. While successful autoreclosing enhances reliability of the bulk power system, autoreclosing into a permanent fault may adversely affect reliability. Since the potential for autoreclosing into a permanent fault exists for any application, it is not possible to depend on successful autoreclosing as a means to meet the system performance requirements in the NERC Reliability Standards or to increase the transfer limit associated with an Interconnection Reliability Operating Limit[7] (IROL).

Single-pole tripping and autoreclosing also may be used to minimize the impact to the system for a single-phase fault; however, the same issues exist for single-pole autoreclosing with regard to the potential for an autoreclose into a permanent fault after which all three poles are tripped. In the event an autoreclosing relay fails to initiate reclosing after a single-pole trip, protective functions will detect the condition and trip all three poles after a time delay.

SAMS and SPCS have not identified an application in which autoreclosing is used in coordination with a protection system to meet the system performance requirements in a NERC Reliability

[5] Autoreclosing relays in this context include dedicated autoreclosing relays and the autoreclosing function in multi-function relays.

[6] For example, TPL-001-2, adopted by the NERC Board of Trustees on August 4, 2011, requires that analyses include the impact of subsequent successful high-speed autoreclosing and unsuccessful high-speed autoreclosing into a fault where high-speed autoreclosing is utilized.

[7] Capitalized as referenced in the NERC Glossary of Terms.

Standard or in establishing an IROL. As discussed above, the need to consider autoreclosing into a permanent fault precludes dependency on autoreclosing for this purpose. SAMS and SPCS therefore recommend that no modification is necessary to the applicability of PRC-005 to address autoreclosing applications necessary for bulk power system performance.

Autoreclosing as Part of a Special Protection System

Special Protection Systems[8] (SPS) may be applied to meet system performance requirements in the NERC Reliability Standards or to increase the transfer limit associated with an IROL. When autoreclosing is included as an integral part of such a SPS, a failure of the reclosing function may adversely impact bulk power system reliability. NERC Reliability Standard PRC-005-2[9] includes minimum maintenance activities and maximum intervals for SPS. SAMS and SPCS recommend that PRC-005 be modified to explicitly address maintenance and testing of autoreclosing relays applied as an integral part of a SPS.

Applications to Aid Restoration

Autoreclosing typically is installed to alleviate the burden on operators of manually restoring transmission lines. Autoreclosing also provides improved availability of overhead transmission lines. The degree to which availability is improved depends on the nature of the fault (permanent or temporary) and on transmission operator practices for manually restoring lines. While faster restoration of transmission lines following temporary faults does provide an inherent reliability benefit, this section addresses applications that are not necessary to meet system performance requirements in NERC Reliability Standards. In these applications it is possible for undesired operation of the autoreclosing scheme, not consistent with its design, to adversely affect system reliability. The following sections discuss credible failure modes that may lead to undesired operation and the associated potential reliability impacts to the bulk power system, to identify applications that should be included in the Applicability section of PRC-005.

Credible Failure Modes of Autoreclosing Schemes

This section discusses credible failure modes of autoreclosing schemes. These failure modes are assessed in the next section to identify which may impact reliability of the bulk power system. Applications for which one or more of these failure modes could adversely affect reliability will be provided to the Project 2007-17 standard drafting team to support development of revisions to PRC-005 directed in Order No. 758.

There are many different types of autoreclosing relays. Autoreclosing relays may be electromechanical (and comprised of discrete components), solid state, or microprocessor-based and may be applied in a variety of autoreclosing schemes. Regardless of the type of autoreclosing scheme or vintage of design of the autoreclosing relay, there are a few main characteristics shared by most autoreclosing relays. These include:

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8 Capitalized as referenced in the NERC Glossary of Terms.

9 PRC-005-2 achieved 81.08 percent quorum and 80.51 percent approval in a recirculation ballot that ended October 24, 2012.

- Supervision Functions: Supervising elements typically monitor one or more voltage phases to determine if a circuit is energized (live), de-energized (dead), or in synchronism with another circuit, etc. Other types of supervision may be used to perform selective autoreclosing; e.g., autoreclosing is blocked for the detection of a three-phase fault, or for the loss of a communication channel. In some applications, autoreclosing is unsupervised.
- Timing Functions: Timing elements perform various timing duties with the most important being the desired time delay to issue a circuit breaker close; the minimum time delay being dictated by de-ionization time. In some applications, autoreclosing is initiated by protective relaying and issues a close signal with little or no intentional time delay.
- Output Function: The output function is typically some type of relay with contacts that close and apply DC voltage to the close circuit to effect a circuit breaker close.

When analyzing autoreclosing relay failure modes, the functions described above are the ones most likely to lead to a failure. The failures can be analyzed without a detailed discussion of the many variations of autoreclosing logic that may be implemented throughout North America. The main failure modes of autoreclosing relays are:

- Supervision Function Failures: A failed voltage supervision function that requires a dead line to reclose may incorrectly interpret that the monitored circuit is live and consequently not issue a close signal to a circuit breaker as designed. Conversely, a failed voltage supervision function that requires a live line to reclose may incorrectly interpret that a dead circuit is live and, therefore, incorrectly issue a close signal to a circuit breaker. Further, failure of a synchronism check function may allow a close when static system angles are greater than designed, or inhibit a close when static system angles are less than designed.
- Timing Function Failures: Where intentional time delays are used, the time delay circuits may fail and issue a close with no time delay. Failure of the time delay circuits may also inhibit the autoreclosing relay from issuing a close signal.
- Output Function Failures: The output relay contacts may fail to close and thus no close signal will be issued to a circuit breaker. The output relay contacts may also fail in the closed position (“weld shut”) and send a constant close signal to a circuit breaker. Solid state outputs can exhibit both of these failure modes. This failure mode can result in one of two possible scenarios depending on the circuit breaker closing circuit design and whether the constant close signal occurs prior to tripping or during the act of reclosing the circuit breaker. One scenario is that no reclose will occur. The second scenario will result in only one reclose being attempted.

Thus, to assess the potential impact of an autoreclosing relay failure on the power system, the following types of failures should be considered:

- No close signal is issued under conditions that meet the intended design conditions. This is the most common failure mode and includes the vast majority of autoreclosing failures.
- A close signal is issued with no time delay or with less time delay than is intended.
- A constant or sustained close signal is issued. In this case, a multi-shot reclose scheme may attempt to reclose only once.
- A close signal is issued for conditions other than the intended supervisory conditions.

Potential Reliability Impacts

In this section each of the identified autoreclosing failure modes is analyzed to assess the potential for adverse impact to bulk power system reliability and the circumstances under which impacts may occur.

1. <u>No close signal is issued under conditions that meet the intended design conditions</u>: A failure to autoreclose would result in a failure to restore a single power system element. The system already must be planned and operated considering that autoreclosing will be unsuccessful. Thus, the impact to power system reliability for this failure mode results in a condition the system is designed to withstand, and therefore this failure mode does not create any additional considerations for inclusion of autoreclosing relays in PRC-005 beyond those related to SPS as discussed in the previous section.

2. <u>A close signal is issued with no time delay or with less time delay than is intended</u>: This failure mode can result in a minimum trip-close-trip sequence with the two faults cleared in primary protection operating time, and the open time between faults equal to the breaker closing cycle time. The sequence for this failure mode results in system impact equivalent to a high-speed autoreclosing sequence with no delay added in the autoreclosing logic.

   The potential reliability impacts of this failure mode are damage to generators and generator instability. Autoreclosing logic typically is selected to reenergize a dead circuit remote from generating units or strong sources to avoid adverse impacts associated with autoreclosing into a permanent fault. Typically when autoreclosing is applied at a generating station it is only for live-line conditions with synchronism check; however, applications do exist where autoreclosing from a generating station is used such as transmission lines between two generating plants, or radial lines that cannot be energized from another source. Where autoreclosing is applied at or in proximity to a generating station the potential for this failure mode exists.

   Premature autoreclosing has the potential to cause generating unit loss of life due to shaft fatigue. Accepted industry guidance is that planned switching operations, such as simple line restoration, should be conducted in a way that avoids significant contribution to cumulative shaft fatigue. Entities typically implement this guidance at generating stations by using time delayed autoreclosing to allow shaft oscillations to dampen, and/or live line autoreclosing or live bus-live line autoreclosing with synchronism check supervision to minimize shaft torque. By conducting planned switching in this manner, nearly all of the fatigue capability of the shaft is preserved to withstand the impact of unplanned and unavoidable disturbances such as faults, fault clearing, reclosing into system faults, and emergency line switching. Premature autoreclosing due to a supervision failure is a small subset of autoreclosing failures (the overwhelming majority of autoreclosing failures are failure to close) and is an infrequent unplanned disturbance. As a result, it is not necessary to consider the incremental loss of life that may occur for this infrequent event as the basis for whether to include maintenance and testing of autoreclosing relays in PRC-005.

Premature autoreclosing also has the potential to cause generating unit or plant instability. NERC Reliability Standards require consideration of loss of the largest generating unit within a Balancing Authority Area[10]; therefore, generation loss would not impact reliability of the bulk power system unless the combined capacity loss exceeds the largest unit within the Balancing Authority Area. Including maintenance and testing of autoreclosing relays in PRC-005 would therefore be appropriate for applications at or in proximity to generating plants with capacity exceeding the largest unit within the Balancing Authority Area. In this context proximity is defined as one bus away if the bus is within 10 miles of the generating plant. Transmission line impedance on the order of 1 mile away typically provides adequate impedance to prevent generating unit instability and a 10 mile threshold provides sufficient margin.

At these locations, maintenance and testing of autoreclosing relays should be subject to PRC-005, unless the equipment owner can demonstrate to the Transmission Planner that this failure mode would not result in tripping generating units with combined capacity greater than the largest unit within the Balancing Authority Area. This demonstration should be based on simulation of a close-in three-phase fault for twice the normal clearing time (capturing a minimum trip-close-trip time delay).

3. <u>A constant or sustained close signal is issued</u>: This failure mode can result in one of two possible scenarios depending on the circuit breaker closing circuit design and whether the constant close signal occurs prior to tripping or during the act of reclosing the circuit breaker. One scenario is that no reclose will occur. The second scenario will result in only one reclose being attempted. This scenario results in the worse impact; however this results in an outcome similar to failure mode No. 1 – less reclose attempts than planned. Neither of these failure modes creates any additional considerations for inclusion of autoreclosing relays in PRC-005.

4. <u>A close signal is issued for conditions other than the intended supervisory conditions</u>: This failure mode can result in two different scenarios.

   The first scenario is autoreclosing into a dead line with a fault when dead-line closing was not intended. Similar to failure mode No. 2 discussed above, the potential reliability

[10] Capitalized as referenced in the NERC Glossary of Terms.

impacts of this failure mode are instability and damage to generating units. The incidence of this failure mode is similar to failure mode No. 2 and therefore concern may be limited to the potential loss of generating units with combined capacity that exceeds the largest unit within the Balancing Authority Area. Including maintenance and testing of autoreclosing relays in PRC-005 would therefore be appropriate for applications at or in proximity to generating units as noted above. The primary difference between this scenario and failure mode No. 2 is this failure mode does not include a timing failure. As such both this scenario and failure mode No. 2 can lead to unintended autoreclosing into fault; however, the timing of the undesired autoreclosure in this scenario will occur after any intentional time delay included in the autoreclosing relay. For this reason a separate test is not necessary to exclude applications from maintenance and testing under PRC-005. Application of the test described for failure mode No. 2 adequately addresses this failure mode.

The second scenario is autoreclosing into a live line with an angle greater than the acceptance angle necessary to prevent potential equipment damage. The potential reliability impact of this failure mode is damage to generating units. As noted in the discussion of failure mode No. 2, accepted industry guidance is that planned switching operations, such as simple line restoration, should be conducted in a way that avoids significant contribution to cumulative shaft fatigue. By conducting planned switching in this manner, nearly all of the fatigue capability of the shaft is preserved to withstand the impact of unplanned and unavoidable disturbances such as faults, fault clearing, reclosing into system faults, and emergency line switching. Undesired autoreclosing at an angle greater than the sync-check acceptance angle due to a supervision failure is a small subset of autoreclosing failures and is an infrequent unplanned disturbance. As a result, it is not necessary to consider the incremental loss of life that may occur for this infrequent event as the basis for whether to include maintenance and testing of autoreclosing relays in PRC-005.

Maintenance Intervals and Activities

The SPCS reviewed the maximum maintenance intervals and minimum maintenance activities proposed in reliability standard PRC-005-2. Specifically, the SPCS reviewed Table 1-1 which is applicable to protective relays and Table 1-5 which is applicable to control circuitry associated with protective functions (excluding distributed UFLS and distributed UVLS). The SPCS review focused on whether any substantive differences exist between protective relays and autoreclosing relays, or between control circuitry associated with protective functions and circuitry associated with autoreclosing schemes, that would warrant different intervals or activities for maintenance of autoreclosing components.

Autoreclosing Relays

The SPCS concluded that electromechanical, solid-state, and microprocessor based autoreclosing relays are substantially the same with respect to design and manufacturing as their protective relay counterparts. As such, the SPCS recommends that the maximum intervals defined in Table 1-1 of PRC-005-2 should also be applicable to autoreclosing relays that may be subject to future versions of the standard.

The SPCS also assessed the maintenance activities included in Table 1-1 of PRC-005-2 and concluded that the activities are analogous to activities performed during maintenance and testing of autoreclosing relays and therefore Table 1-1 should be applied to autoreclosing relays that may be subject to future versions of the standard. For example, the activity to test and, if necessary calibrate, non-microprocessor relays would be applicable to testing and calibration of electromechanical and solid-state autoreclosing relays, and the activity to verify acceptable measurement of power system input values would be applicable to verification of permissive inputs used for voltage supervision and synchronism check.

Autoreclosing Control Circuitry

Similarly, the SPCS assessed the maintenance intervals and activities included in Table 1-5 of PRC-005-2 and concluded that the intervals and activities for maintaining control circuitry for autoreclosing schemes should be similar to those established for maintaining control circuitry associated with protective functions. The SPCS recommends that Table 1-5 should be applicable to control circuitry associated with autoreclosing relays that may be subject to future versions of the standard. The SPCS also recommends that the standard drafting team include minimum maintenance activities and maximum maintenance intervals for autoreclosing control circuitry that parallel the maintenance activities and intervals established for protective function control circuitry. It should be noted that, consistent with control circuitry defined for protective functions, the SPCS does not consider internal breaker control circuitry (e.g., anti-pump and coil interlock circuits) to be associated with autoreclosing component maintenance. Since the failure to close may represent a risk to reliability when breaker closing is integral to operation of an SPS, the closing coil should be considered in PRC-005. For use within a revision to PRC-005, control circuitry of autoreclosing schemes might be defined as:

"Control circuitry associated with autoreclosing schemes including the close coil, but excluding breaker internal controls such as anti-pump and various interlock circuits."

Recommendations

SAMS and SPCS recommend the following guidance for future development of NERC Reliability Standard PRC-005, *Transmission and Generation Protection System Maintenance and Testing*, to address the concerns stated in FERC Order No. 758.

1. Modify PRC-005 to explicitly address maintenance and testing of autoreclosing relays applied as an integral part of a SPS.

2. Modify PRC-005 to include maintenance and testing of autoreclosing relays at or in proximity to generating plants at which the total installed capacity is greater than the capacity of the largest generating unit within the Balancing Authority Area.
   - In this context, define proximity as substations one bus away if the substation is within 10 miles of the plant.
   - Include a provision to exclude autoreclosing relays if the equipment owner can demonstrate to the Transmission Planner that a close-in three-phase fault for twice the normal clearing time (capturing a minimum trip-close-trip time delay) does not result in a total loss of generation in the interconnection exceeding the largest unit within the Balancing Authority Area where the autoreclosing is applied.

3. Base minimum maintenance activities and maximum intervals on the activities and intervals in PRC-005-2.
   - Develop minimum maintenance activities and maximum intervals for autoreclosing relays similar to Table 1-1.
   - Develop minimum maintenance activities and maximum intervals for control circuitry of autoreclosing schemes similar to Table 1-5.
   - For the purpose of PRC-005, define control circuitry of autoreclosing schemes as: “Control circuitry associated with autoreclosing schemes including the close coil, but excluding breaker internal controls such as anti-pump and various interlock circuits.”

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