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NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Report to the Planning Committee

Reliability Fundamentals of System Protection

NERC System Protection and Control Subcommittee

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to ensure the reliability of the bulk power system

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This Report was approved by the NERC Planning Committee on December 8, 2010.

1. Background

The NERC Reliability Fundamentals Working Group (RFWG) was formed to further the work of the Operating Limit Definition Task Force (OLDTF) which defined the term "Adequate Level of Reliability" and developed the NERC Document, *Reliability Concepts*. The RFWG was charged with overseeing maintenance of the *Reliability Concepts* document and expending the document to add chapters incorporating subject matter expertise developed by standard drafting teams and NERC committees and subcommittees.

The SPCS was charged with developing a section for this document addressing reliability fundamentals associated with system protection. Although work on expanding the *Reliability Concepts* document has ceased, the SPCS believes there is value in publishing this work as a stand-alone report describing basic fundamental reliability concepts associated with system protection in basic terms. Should work resume on the NERC *Reliability Concepts* document in the future, this information could easily be reformatted and incorporated into the document.

2. Introduction to System Protection

Electrical "faults" occur within the electric network due to equipment failures or outside disturbances such as lightning. The electric network is protected for these types of events by relay "protection systems" that opens a circuit within the network to isolate the electrical fault. These protection systems sense the voltages and currents due to the electrical fault on electric network. It is important that any system faults are detected and cleared, and other mitigating actions are taken quickly. These faults can include electrical short circuits (shorts) between adjacent transmission lines or between a transmission lines and the ground. Very high currents associated with faults can be very destructive to network equipment.

2.1. Protection Versus Control

Reliable protection systems are necessary for the Bulk Electric System to meet system performance requirements in the NERC Reliability Standards. They are designed to automatically disconnect elements from the transmission system to isolate all electrical faults or protect equipment from damage due to other abnormal operating conditions, such as voltage, current, or frequency excursions outside of the design capability of the elements.

In contrast, control systems are those systems that are designed to automatically adjust or maintain system parameters (voltages, facility loadings, etc.) within pre-defined limits or

cause elements to be disconnected from or connected to the power system to maintain the integrity of the overall power system.

2.2. Protection System Components

Protection systems utilize components commonly referred to as protective relays. When a protective relay detects a fault, it sends a signal to a circuit interrupting device (e.g. a circuit breaker) that quickly disconnects the affected elements. Protection systems are generally comprised of protective relays, communication systems necessary for correct operation of protective functions, voltage and current sensing inputs to protective relays and associated circuitry from the voltage and current sensing devices, station dc supply, and control circuitry associated with protective functions from the station dc supply through the trip coil(s) of the circuit breakers or other interrupting devices.

3. Protection System Reliability

There are two aspects of reliable operation of protection systems: dependability and security.

3.1. Dependability

Dependability of protection systems is "The facet of reliability that relates to the degree of certainty that a relay or relay system will operate correctly.[1]" Dependability is a concern when a fault occurs within the protected zone. A dependability-related failure raises concerns with the consequence of a failure to operate when required or to operate at the designed speed.

3.2. Security

Security of protection systems is "That facet of reliability that relates to the degree of certainty that a relay or relay system will not operate incorrectly.[2]" Security is a concern for external faults and unfaulted operating conditions. A security related failure raises concerns with the consequence of undesired operation, including operating faster than designed.

[1] IEEE Standard C37.100-1992.
[2] Ibid.

4. Attributes that Support Protection System Reliability

4.1. Protection System Design

4.1.1. Redundancy[3]

Protection systems must be highly reliable to meet system performance requirements. To meet the desired level of protection system reliability, protection systems are designed with redundancy to account for at least a single component failure within the protection system. Redundancy is defined as "the existence of more than one means for performing a given function. " Redundancy may be achieved locally through duplication of protection systems or through remote backup protection. Determining the appropriate form of redundancy is a task requiring collaboration between protection and planning engineers. The proper solution for each element should be based on the relationship between performance of the protection system and the performance of the power system.

4.1.2. Performance Requirements

To provide proper performance protection systems must provide proper sensitivity and selectivity and clear faults within an appropriate time.

4.1.2.1. Sensitivity

Sensitivity refers to assuring that the relays that are intended to operate for a given condition have a stronger propensity to operate for that condition than other (usually remote) relays. This assures that, no matter what the magnitude of the fault, or the location of the fault on the protected power system element, the intended relays will "see" the fault more strongly.

4.1.2.2. Selectivity

Selectivity, which also is sometimes referred to as timing coordination, refers to analysis to assure that the relays intended to operate for a given condition will operate faster than other relays that may provide backup protection for the condition.

[3] For more information on this subject please refer to the NERC SPCS technical paper, *Protection System Reliability: Redundancy of Protection System Elements*.

Selectivity is obtained when a minimum amount of equipment is removed from service for isolation of a fault or other abnormality.

4.1.2.3. Clearing Time

Faults must be cleared within a time that minimizes equipment damage and permits recovery of the power system to a stable operating state.

4.2. Maintenance

Protection systems continuously monitor the power system, but may be called upon to operate infrequently. Properly maintained protection systems help to assure both the dependability and security intended within the protection system design and application.

4.3. Availability

Maintaining a high degree of protection system availability supports system reliability. Thus, protection system failures should be addressed in a timely manner. If a protection system component will be out of service for an extended period of time (e.g. longer than typical maintenance outages), adjustments to operations may be appropriate considering other system conditions and the consequences of possible failure of additional protection system components.

4.4. Settings

To promote protection system reliability, settings should be developed considering a range of credible operating conditions.

4.4.1. Coordination

Protection systems must operate in a coordinated manner to ensure that only the protection system(s) applied to protect an element will operate for a fault on that element. Protection systems applied on other elements must be set and configured to prevent unnecessary tripping prior to operation of the protection system(s) applied on the faulted element.

4.4.2. Loadability[4]

Protection systems must be set and configured to ensure that protection systems do not operate unnecessarily for loading conditions at which the power system is expected to operate, including temporary extreme operating conditions from which the system is designed to recover. Loadability is a concern related to secure operation of a protection system.

4.4.3. Modeling

Development of coordinated protection settings that provide dependable and secure protection system operation is supported by modeling the settings in relay coordination programs and transient stability programs. Modeling in relay coordination programs can verify proper selectivity and modeling in transient stability programs can verify secure operation for stable swings, and where applied, proper operation of out-of-step tripping or out-of-step blocking functions for unstable power swings.

4.5. Performance Verification

Reliable operation is supported by protection system monitoring, analysis of misoperations, routine maintenance, and analysis of protection system failure rates.

4.5.1. Protection System Monitoring

Continuous monitoring of protection systems allows identification of failures and prompt corrective actions to prevent a latent failure from resulting in unreliable operation.

4.5.2. Analysis of Misoperations[5]

Analysis of all transmission and generation Protection System operations allows identification of misoperations. Analysis of misoperations supports reliable operation by identifying and correcting application, design, or setting errors, and by providing information to improve future protection system component selection, design, and application.

[4] For more information on this subject please refer to the NERC SPCS technical paper, *Determination and Application of Practical Relaying Loadability Ratings Version 1*.
[5] For more information on this subject please refer to the NERC SPCS report, *NERC SPCS Assessment of Standards PRC-003-1, PRC-004-1, and PRC-016-1*.

4.5.3. Routine Maintenance[6]

Protective relays do not generally demonstrate their performance until a fault or other power system problem requires that they operate to protect power system elements, or even the entire Bulk Electric System. Lacking faults or system problems, the protection systems may not operate for extended periods. A failure of the protection system to operate when needed, as described above, can result in degrading power system reliability. A maintenance or testing program is used to assure the performance, availability and protection reliability of protection systems. Where such performance verification identifies degrading or poor performance of protection systems, appropriate corrective action should be initiated to maintain adequate reliability.

4.5.4. Analysis of Protection System Failure Rates

Protection systems are designed, operated and maintained to a level of high reliability accounting for component failures within the protection system. However, over time, protection system components can degrade and/or fail based on some factors such as age, the installed environment (heat, dust), etc. Where the performance of such protection systems are substantially degraded (high failure rates, reach end-of-life, etc.), appropriate corrective action should be initiated to maintain adequate reliability.

[6] For more information on this subject please refer to the NERC SPCS technical paper, Protection System Maintenance: A Technical Reference.

APPENDIX A – System Protection and Control Subcommittee Roster

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