NERC
NORTH AMERICAN ELECTRIC
RELIABILITY CORPORATION

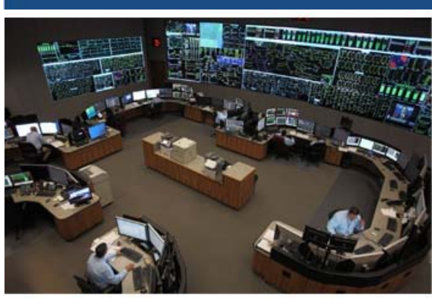
Order No. 754

Assessment of Protection System Single Points of Failure Based on the Section 1600 Data Request

System Protection and Control Subcommittee (SPCS) and
System Modeling and Analysis Subcommittee (SAMS)

September, 2015

RELIABILITY | ACCOUNTABILITY

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Preface

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to ensure the reliability of the bulk power system (BPS) in North America. NERC develops and enforces NERC Reliability Standards;[1] annually assesses seasonal and long-term reliability; monitors the BPS through system awareness; and educates, trains, and certifies industry personnel. NERC's area of responsibility spans the continental United States, Canada, and the northern portion of Baja California, Mexico. NERC is the electric reliability organization (ERO) for North America, subject to oversight by the Federal Energy Regulatory Commission ("FERC" or "Commission") and governmental authorities in Canada. NERC's jurisdiction includes users, owners, and operators of the BPS, which serves more than 334 million people.

The North American BPS is divided into several assessment areas within the eight Regional Entity (RE) boundaries, as shown in the map and corresponding table below.

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

[1] Capitalized terms include, but are not limited to the Glossary of Terms Used in NERC Reliability Standards. March 3, 2015. (http://www.nerc.com/pa/Stand/Glossary%20of%20Terms/Glossary_of_Terms.pdf) and Definitions Used in the NERC Rules of Procedure (ROP), Appendix 2. July 1, 2014. (http://www.nerc.com/FilingsOrders/us/RuleOfProcedureDL/Appendix_2_ROP_Definitions_20140701_updated_20140602.pdf).

Executive Summary

This report provides the results of an assessment of protection system single points of failure (SPF) in response to FERC Order No. 754,[2] including analysis of data from the NERC Section 1600 Request for Data or Information. Based on the analysis of data received, the report provides a discussion of alternatives to address this reliability concern and recommends a course of action to address the concern using a risk-based method.

Nearly 4,000 buses energized above 100kV were examined in detail. This is a comprehensive set of the key buses in the Bulk Electric System. This assessment confirms the existence of a reliability risk associated with single points of failure in protection systems that warrants further action.

Regarding single points of failure in protection systems, the System Protection and Control Subcommittee (SPCS) and the System Modeling and Analysis Subcommittee (SAMS) considered a variety of alternatives, and concluded that the most appropriate recommendation that aligns with O754 directives and maximizes reliability of protection system performance is to modify NERC Reliability Standard TPL-001-4 (*Transmission System Planning Performance Requirements*) through the NERC standards development process defined in the NERC Rules of Procedure. The recommended modifications address specifics of Protection System component failure, aspects of steady state and stability performance testing, and expansion of extreme event assessment requirements in order to minimize the potential risk of SPFs. Chapter 2 contains a discussion of alternatives considered. Specific guidance for modifying NERC Reliability Standard TPL-001-4 is provided in Chapter 3.

[2] *Interpretation of Transmission Planning Reliability Standard*, Order No. 754, 136 FERC ¶ 61,186 (2011) ("Order No. 754") (http://www.ferc.gov/whats-new/comm-meet/2011/091511/E-4.pdf).

Introduction

Objective

The objective of this assessment is to determine whether there is a reliability concern that NERC should address regarding the study of single points of failure on protection systems and, if so, what forum and process should be used to address the issue. This report provides the results of a comprehensive assessment of the study of data from the NERC Section 1600 Request for Data or Information collected in response to FERC Order No. 754. Based on the analysis of data, there is some degree of elevated reliability risk from SPF in certain key instances. The report provides discussion of alternatives to address this reliability concern and recommends a course of action to address the concern using a risk-based method.

Background

The issue of protection system failures brought to the forefront potential reliability concerns in Requirement R1.3.10 of the NERC transmission planning Reliability Standard TPL-002-0b (*System Performance Following Loss of a Single Bulk Electric System Element (Category B)*). The concern relevant to this assessment is whether Requirement R1.3.10 requires the study of protection system failures as part of Category B disturbances.

In FERC Order No. 754, issued September 15, 2011, the Commission agreed with commenters that this issue does not have to be addressed in TPL-002-0b, Requirement R1.3.10. However, the Commission also stated their belief that there is "an issue concerning the study of the non-operation of non-redundant primary protection systems; e.g., the study of a single point of failure on protection systems."[3] To address this concern, the Commission directed FERC staff to meet with NERC and its appropriate subject matter experts to explore the reliability concern, including where it can best be addressed, and identify any additional actions necessary to address the matter.

To satisfy the directive, a FERC Technical Conference was held October 24–25, 2011, to facilitate an open exchange among FERC staff, NERC staff, and industry stakeholders. One outcome of the FERC Technical Conference was that NERC would conduct a data collection effort to provide a broad factual foundation that could aid in assessing whether single points of failure in protection systems pose a reliability concern. NERC staff worked with the SPCS and SAMS to develop a request for data or information under Section 1600 of the NERC Rules of Procedure[4] (the "Data Request" or "Order No. 754 Data Request"). The NERC Board of Trustees approved the Data Request on August 16, 2012.

The responsible Functional Entities ("entities") have submitted data to NERC for buses operated at 100 kV and above. Data is presented in Appendix A of this report according to voltage range (100–199 kV, 200–299 kV, 300–399 kV, 400–599 kV, and 600 kV or higher). The SPCS and SAMS have reviewed the submitted data, which provides statistical information on the number of buses at which a protection system single point of failure could result in an adverse impact to reliability of the bulk power system. The data also indicates the extent to which exposure to single points of failure exists at these buses, broken down by specific component categories of a protection system.

The assessment of this data set forms the basis for identifying the risk associated with protection system single points of failure, development of alternatives to address associated concerns, and subsequently a recommendation of the preferred alternatives to address the associated concerns.

[3] Id. at P.19.
[4] (http://www.nerc.com/FilingsOrders/us/RuleOfProcedureDL/NERC_ROP_Effective_20140701_updated_20140602%20(updated).pdf

Chapter 1 – Analysis of Data

Order No. 754 Data Request

Overview

The Order No. 754 Data Request[5] required that Transmission Planners, working with the Generator Owners, Transmission Owners, and Distribution Providers within their transmission planning areas, assess their portion of the Bulk Electric System (BES) for locations at which a three-phase fault accompanied by a protection system failure could result in a potential reliability risk. To accomplish this task in an effective and efficient manner, the SPCS and SAMS developed a method that entities could follow to create the statistics associated with this Data Request. Entities were permitted to use an alternate method, including combining steps, skipping steps, or reordering steps, to minimize burden based on their particular circumstances, and could use information from existing studies and existing assessments of protection systems in developing responses to the data request. For example, TPL-004-0a (*System Performance Following Extreme Events Resulting in the Loss of Two or More Bulk Electric System Elements (Category D)*) simulations from transmission planning assessments could be used in developing responses to the Data Request.

Entities that followed an alternate method or utilized existing studies and existing assessments of protection systems in developing responses were required to provide a complete subset of buses containing both of the following characteristics:

- The bus has at least one Element for which the protection system does not fully meet the redundancy attributes for all component categories of Table B (from the data request), "Protection System Attributes
- Planning studies simulating a three phase fault, show that clearing times resulting from a single point failure of at least one protection system on an Element connected to that bus will result in system performance exhibiting one of the adverse impacts identified in Table C (from the data request), "Performance Measures."

The process of using differing methodologies to obtain this list of buses results in inconsistencies in the specific numbers of Protection Systems and buses evaluated in the various tables of Protection System attributes.

The Data Request included criteria to limit the assessment to a sample of buses using qualitative criteria that identified and included the buses more likely to have a more significant stability impact on the bulk power system. See Table 1.1 below, which is Table A from the Data Request.

[5] Request for Data or Information: Order No. 754 Single Point of Failure on Protection Systems, August 16, 2012.

Table 1.1: Criteria for Buses to be Tested
Buses operated at 200 kV or higher with 4 or more circuits
Buses operated at 100 kV to 200 kV with 6 or more circuits
Buses operated at 100 kV or higher that directly supply off-site power to a nuclear generating station
Any additional buses operated at 100 kV or higher that the Transmission Planner believes are necessary for the reliable operation of the bulk power system

For the buses meeting the Table 1.1 criteria, the Transmission Planner assessed the system performance for a three-phase fault accompanied by a protection system failure. For the purposes of the Data Request, Transmission Planners were to simulate clearing, based on the remote protection that would operate for the bus fault. The Transmission Planners were not to simulate operation of any local protection with the exception of local breaker failure protection (where provided) in instances where a single trip coil was the only single point of failure for protection systems on all Elements connected to the bus. In these cases, operation of the breaker failure protection was allowed in the simulation.

Following simulation of the events described above, the Transmission Planner evaluated the system performance against criteria provided in the Data Request that the SPCS and SAMS believe are indicative of the potential for instability, uncontrolled separation, or cascading outages. The criteria are contained in Table 1.2 below, which is Table C from the Data Request.

Table 1.2: Performance Measures
1. Loss of synchronism of generating units totaling greater than 2,000 MW or more in the Eastern Interconnection or Western Interconnection, or 1,000 MW or more in the ERCOT or Québec Interconnections
2. Loss of synchronism between two portions of the system
3. Negatively damped oscillations

For buses where the simulated system performance exhibited one or more of the adverse system response characteristics in Table 1.2, the protection system owners (Generator Owners, Transmission Owners, and Distribution Providers owning the relevant protection systems) provided detailed information regarding the protection systems on all elements connected to the bus. The presence of single points of failure was then assessed at the component level of a protection system, which consists of protective relays, communication systems, AC current and voltage inputs, and DC control circuitry. It should be noted that in some instances stability simulations were conducted prior to any review of the actual applied Protection Systems, while in other instances, the protection system owners may have conducted a preliminary assessment of the initial list of buses prior to simulations being conducted. Protection system owners evaluated the components of a protection system against the attributes defined in Table 1.3 below, which is Table B from the Data Request.

Table 1.3: Protection System Attributes to be Evaluated
Protective Relays: The protection system includes two independent protective relays that are used to measure electrical quantities, sense an abnormal condition such as a fault, and respond to the abnormal condition.
Communication Systems: The protection system includes two independent communication channels and associated communication equipment when such communication between protective relays for communication-aided protection functions (i.e., pilot relaying systems) is needed to satisfy system performance required in NERC Reliability Standards TPL-002-0b and TPL-003-0a.
AC Current and Voltage Inputs: The protection system includes two independent AC current sources and related inputs, except that separate secondary windings of a free-standing current transformer (CT) or multiple CTs on a common bushing can be used to satisfy this requirement; and includes two independent AC voltage sources and related inputs, except that separate secondary windings of a common capacitance coupled voltage transformer (CCVT), voltage transformer (VT), or similar device can be used to satisfy this requirement.
DC Control Circuitry: The protection system includes two independent DC control circuits with no common DC control circuitry, auxiliary relays, or circuit breaker trip coils. For the purpose of this data request the DC control circuitry does not include the station DC supply or the main DC distribution panel(s), but does include all the DC circuits used by the protection system to trip a breaker, including any DC control circuit (branch) fuses or breakers at the main DC distribution panel(s).

Data was collected separately for the station DC supply. This data was collected on DC supplies to all of the 3,916 buses that meet the Table A criteria. Station DC supply data was collected to assess the incidence of two station DC supplies as well as the level of monitoring for buses with only one station DC supply. See the station DC supply attributes to be reported in Table 1.4 below, which is Table D from the Data Request.

Table 1.4: Station DC Supply Attributes to be Reported
The protection system includes two independent station DC supplies
The protection system includes one station DC supply that is centrally monitored; if the station DC supply is a battery the monitoring includes alarms for both low voltage and a battery open condition
The protection system includes one station DC supply that is centrally monitored; the station DC supply is a battery and the monitoring does not include alarms for both low voltage and a battery open condition
The protection system includes one station DC supply that is not centrally monitored

Entities submitted data in a tabular format as described in the Data Request. The output of the collected data is collated in the following eight tables (see Appendix A).

- Table A.1 – Buses Evaluated by the Transmission Planner
- Table A.2 – Attributes of Evaluated Transmission Line Protection Systems
- Table A.3 – Attributes of Evaluated Transmission Transformer Protection Systems
- Table A.4 – Attributes of Evaluated Generator Step-Up Transformer Protection Systems
- Table A.5 – Attributes of Evaluated Step-Down Transformer Protection Systems
- Table A.6 – Attributes of Evaluated Shunt device Protection Systems
- Table A.7 – Attributes of Evaluated Bus Protection Systems
- Table A.8 – Station DC Supply Attributes

The data for each table, aggregated for all responding entities across North America, is presented in Appendix A. Row 4 of Table A.1 contains the subset of buses that contain at least one Protection System where a failure to trip due to an existing single point of failure would result in one of the performance issues listed in Table 1.2. The data in Tables A.2 through A.7 are dependent on the methodology used by the reporting entity in identifying the buses in Row 4 of Table A.1. The assessment in this report is based on extensive discussion recognizing the variability of the data. The SPCS and SAMS have recognized this variability in the following discussion of the data. While in some cases this variability prevents definitive quantitative statements, the SPCS and SAMS consider the data to be sufficient to draw valid conclusions based on a qualitative but technical assessment.

Table A.1: Buses Evaluated by the Transmission Planner

The data in Table A.1 provides general insight regarding the buses evaluated by the Transmission Planners and includes the following information for each voltage range:

1. the total number of buses,
2. the number of buses that met the Table 1.1 criteria (Data Request, Table A) for further review,
3. the number of buses that were evaluated using actual clearing times
4. the number of buses for which a simulation based on actual clearing times exhibited at least one of the adverse impacts in Table 1.2 (Data Request, Table C).

Table A of the Data Request included the criteria shown in Table 1.1 to focus the analysis on those buses more likely to have a significant impact on the stability of the bulk power system. Limiting the number of buses significantly reduced the effort required of responding entities while still providing NERC a data population sufficient to draw valid conclusions. The criteria in Table 1.1 included the number of circuits connected to the bus, whether the bus directly supplies off-site power to a nuclear generating station, and whether the Transmission Planner believes for any other reason that the bus is necessary for the reliable operation of the bulk power system. For the purpose of applying the Table 1.1 criteria, the number of circuits connected includes any elements that represent a significant source of fault current (i.e., transmission lines, transmission transformers with the primary terminal and at least one secondary terminal operated at 100 kV or higher, and generator step-up transformers connecting generating resources with aggregate gross nameplate rating greater than 20 MVA). These criteria resulted in a large enough sample of data to draw valid conclusions. This conclusion is based on both the number and percentage of buses in each voltage range that met the criteria in Table 1.1. At the high-voltage (HV) levels (up to 230 kV), entities tested over 1,000 buses in each voltage range. At the extra high-voltage (EHV) levels (greater than 230 kV), entities tested over one-half of the total number of buses.

The reporting entities identified the following numbers of buses meeting the requirements of Table A in the data request:

- 1,522 buses (7 percent of all buses) operated at 100–199 kV,
- 1,310 buses (34 percent of all buses) operated at 200–299 kV,
- 768 buses (57 percent of all buses) operated at 300–399 kV,
- 262 buses (67 percent of all buses) operated at 400–599 kV, and
- 54 buses (81 percent of all buses) operated at 600 kV and above.

Table 1.5: Buses Evaluated by the Transmission Planner

Row	Description	100-199 kV	200-299 kV	300-399 kV	400-599 kV	≥600 kV
1	Total number of buses in the transmission planning area	21,817	3,848	1,350	392	67
2	Total number of buses in the transmission planning area that meet the criteria in Table A, “Initial Criteria for Buses to be Tested”	1,522	1,310	768	262	54
	Percentage of buses in the transmission planning area that meet the criteria in Table A, “Initial Criteria for Buses to be Tested”	7%	34%	57%	67%	81%

In general, the short-circuit strength at a bus is indicative of the potential risk that a prolonged fault will impact reliable operation of the bulk power system. Therefore, on a qualitative basis, the set of buses that met the criteria in Table A is more likely to include buses at which a protection system single point of failure may result in an adverse impact to reliability of the bulk power system than the buses with fewer connected circuits.

Rows 3 and 4 of Table A.1 provide information on the number of buses evaluated based on maximum expected clearing times and the number of buses at which simulation of a three-phase fault and a protection system single point of failure indicate system performance that exhibits at least one of the adverse impacts in Table 1.2 of the Data Request. The adverse impacts are indicative of a risk to reliable operation of the bulk power system and include the following:

- loss of synchronism of generating units totaling greater than 2,000 MW or more in the Eastern or Western Interconnections, or 1,000 MW or more in the ERCOT or Québec Interconnections,
- loss of synchronism between two portions of the system, and
- negatively damped oscillations.

Although various equivalent methodologies were allowed, the data in Row 4 is essentially the number of buses with both a Table C performance issue and the presence of a Protection System with a single point failure issue. This may overstate the problem somewhat, as not all SPF result in a failure to trip, and that many SPF will result in actual clearing times that are less than those resulting from a bus fault. Never the less, viewing the data in rows 3 and 4 of Table 1.6 in relation to each other demonstrates that, in general, the probability that a failure of a protection system to clear a fault will impact reliable operation exists and increases at higher voltages as shown in the table.

Table 1.6: Buses Evaluated by the Transmission Planner						
Row	**Description**	**100-199 kV**	**200-299 kV**	**300-399 kV**	**400-599 kV**	**≥600 kV**
3	Total number of buses evaluated by the Transmission Planner based on actual clearing times	716	813	356	164	44
4	Total number of buses evaluated by the Transmission Planner based on actual clearing times that resulted in system performance exhibiting any adverse impact defined in Table C, "Performance Measures"	160	316	212	101	43
	Percentage of buses evaluated by the Transmission Planner based on actual clearing times that resulted in system performance exhibiting any adverse impact defined in Table C, "Performance Measures"	22%	39%	60%	62%	98%

However, this information alone does not indicate a reliability concern. Assessment of this reliability concern is a function of both the potential consequence and the exposure to a single point of failure. Thus, it is necessary to analyze the Table A.1 data in conjunction with the protection system attributes data in Tables A.2–A.7.

Tables A.2–A.7 Data: Attributes of Evaluated Protection Systems

Data in Tables A.2–A.7 provides insight into the presence of single points of failure for various power system elements (transmission lines, transmission transformers, generator step-up transformers, step-down transformers, shunt devices, and buses). These tables provide information on the total number of protection systems evaluated, the number that contain a single point of failure, and the presence of single points of failure by components of a protection system: protective relays, communication systems, AC current and voltage inputs, and DC control circuitry (see Table 1.3). The data collected in Tables A.2-A.7 for DC control circuitry includes auxiliary relays and trip coils but excludes the station DC supply. Data for the station DC supply was collected separately in Table A.8.

The single points of failure reported in Tables A.2–A.7 are related to the buses at which the Transmission Planner identified a potential risk, based on simulation of a three-phase fault and protection system single point of failure using maximum expected clearing times. In developing the requested data, simulations performed by the Transmission Planners were based on the assumption that a component failure of a protection system associated with a single point of failure would, in all cases, result in a failure to trip. This assumption provided a conservative and uniform method for simulating faults. However, the impact of a single component failure will not always result in a protection system failure to trip, depending on the component that fails and the design of the overall protection system. This subject is discussed further for each component type in the following subsections of this report. The discussion of component types is arranged according to the perceived risk to reliability associated with a single point of failure, based on the experience of the SPCS and SAMS members. Technical analysis relative risk of various categories of failure is included in the next section of this chapter.

DC Control Circuitry

A single point of failure in DC control circuitry will result in the failure of a given protection system to trip and, depending on its design and the location of the failure, may also result in a failure to initiate breaker failure protection.

As discussed at the 2011 FERC Technical Conference on single points of failure, the single point of failure concern originated in a NERC Alert[6] based on the negative outcomes of three significant events. The root cause of these three events was the failure of a single relay (an auxiliary relay or lockout relay). Auxiliary relays and lockout relays are included in the DC control circuitry protection system attribute. These relays are generally unmonitored devices and, thus, may fail and remain undetected until they are periodically tested. Auxiliary relay failures in designs that include use of a single auxiliary relay for multiple functions will result in prolonged fault duration, particularly where a single auxiliary relay is used for both tripping and breaker failure initiation.

Protective Relays

A single point of failure of a protective relay poses a similar exposure to prolonged fault duration as that of failure of a DC control circuit; however, the risk depends on the relay type and protection system design. Many protection system designs using electromechanical relays are configured such that a failure of one relay will be backed up to some degree by other relays (i.e., an electromechanical protection system design is typically is made up of multiple relays and more than one may respond to a given fault). Similar to an auxiliary relay, an electromechanical relay may fail and the failure may remain undetected until the relay is tested. On the other hand, microprocessor relay may be monitored through an entity's supervisory control and data acquisition (SCADA) system; thus, most failure modes can be detected and addressed, in which cases the risk to the system is reduced to a relatively short period of time.

Communication Systems

A single point of failure in a communication system poses a lower level of risk. The Data Request only analyzed communication equipment in protection systems where communication-aided protection is needed to satisfy the system performance required in NERC Reliability Standards. The risk associated with a given protection system is dependent on the protection system design. Depending on the protection system design, a single point of failure may result in a failure of the communication-aided system to initiate a high-speed trip (e.g., a permissive overreaching transfer trip scheme), in which case delayed tripping will occur. In other designs, a communication system failure will not prevent high-speed tripping (e.g., a directional comparison blocking scheme).

Communication systems, regardless of vintage or design, are typically monitored and alarmed via SCADA or tested periodically.

AC Current and Voltage Inputs

A single point of failure in AC current and voltage inputs poses a lower level of risk of failure to trip. Instrument transformers are generally more robust than the other components of a protection system analyzed in the Data Request. However, cable runs, fuses, and terminations have a similar susceptibility to failure as DC control circuitry.

In most cases, a current circuit failure will result in an imbalance, which may result in a trip. In differential or ground overcurrent applications on transmission lines, buses, transformers, or shunt devices, AC current input

[6] Industry Advisory, Protection System Single Point of Failure, March 30, 2009. (http://www.nerc.com/fileUploads/File/Events%20Analysis/A-2009-03-30-01.pdf).

failure will typically cause a circuit to trip at a certain load or fault level. Additionally, where AC current input circuits are monitored via SCADA, loss of a current input may be identified by automated devices or dispatch personnel.

Most microprocessor relays alarm for a loss of potential via SCADA; thus, the time that failed equipment is connected to the system can be minimized. Most electromechanical relays that use voltage inputs are prone to tripping on loss of a single-phase voltage (the most common AC voltage input failure). Additionally, where AC voltage input circuits are monitored via SCADA, low voltage due to a circuit failure may be alarmed.

Overall Order 754 Data Interpretation

Below 600kV, simulated testing showed that the probability of a three-phase fault accompanied by a protection system failure could result in the adverse system impacts listed in Table 1.2. The probability of an adverse impact decreased as the voltage class was lowered. At these voltage levels, a significant percentage of protection systems included single points of failure. This data shows that the chance of an adverse system impact due to a single point of failure at buses as low as 100kV exists, and leads to the conclusion that some risk mitigating action must be taken.

Above 600kV, simulated testing showed that the probability of a three-phase fault accompanied by a protection system failure resulting in an adverse system impact was high. However, almost all protection system equipment was fully redundant at that voltage level. The data shows that the chance of an adverse system impact due to a single point of failure at 600 kV and above is low.

Chapter 2 – Alternatives

The SPCS and SAMS considered the following alternatives in order of preference for addressing reliability risks associated with single points of failure:

Standards Development Process

Modify Reliability Standard TPL-001-4 – Transmission System Planning Performance Requirements

- Modify footnote 13 to include, at a minimum, protective relays, DC control circuitry, and station DC supply
- Place additional emphasis on assessment of a three-phase fault and protection system failure
  - Keep as an extreme event, but require studies of instances of single points of failure
    - Provides assurance that areas where a three-phase fault accompanied by a single point of failure that will cause an adverse impact are identified and evaluated
  - Elevate to a planning event with its own system performance criteria
    - Probability of three-phase fault with a protection system failure is low enough that it does not warrant a planning event
  - Keep as an extreme event with no change (other than footnote 13)
    - Does not provide assurance a three-phase fault with protection system failure is studied in planning assessments
- Include a Guidelines and Technical Basis section related to the revisions pertaining to the study of protection system failures

Create a New Standard Addressing the Study of Protection System Single Points of Failure

- Remove relay failure from TPL-001-4 and create a separate TPL (transmission planning) or PRC (protection and control) standard on the study of protection system single points of failure (including the same options as the previous alternative)
  - Accomplishes same objective as modifying TPL-001-4
  - Retaining in TPL-001 is more efficient and keeps all planning tests in one standard (i.e., reason for combining TPL-001 through TPL-004)

Create a New Standard Requiring Redundant Protection Systems on BES Elements

- Create protection system redundancy PRC standard requiring redundant protection systems for all BES Elements
  - Not an efficient way to address the problem (precludes other solutions)
  - Promotes a zero-defect approach rather than a risk-based approach

Reliability Guideline

- Provides insight into modeling protection system failures in planning assessments
- Provides insight into evaluation of risk of a single point of failure

- Does not provide assurance a three-phase fault with protection system failure is studied in all planning assessments

NERC Alert

- Raises awareness based on findings from the Data Request
- Does not provide assurance a three-phase fault with protection system failure is studied in all planning assessments

Chapter 3 – Conclusion

Analysis of the data demonstrates the existence of a reliability risk associated with single points of failure in protection systems that warrants further action. The analysis shows that the risk from single point of failure is not an endemic problem and instances of single point of failure exposure are lower on higher voltage systems. However, the risk is sufficient to warrant further action. Risk-based assessment should be used to identify protection systems of concern (i.e., locations on the BES where there is a susceptibility to cascading if a protection system single point of failure exists). Not all failures adversely affect reliable operation of the bulk power system. The reliability risk varies based on which component of a protection system fails.

Additional emphasis in planning studies should be placed on assessment of three-phase faults involving protection system single points of failure. This concern (the study of protection system single points of failure) is appropriately addressed as an extreme event in TPL-001-4 Part 4.5. From TPL-001-4, Part 4.5: If the analysis concludes there is cascading caused by the occurrence of extreme events, an evaluation of possible actions designed to reduce the likelihood or mitigate the consequences and adverse impacts of the event(s) shall be conducted.

Any modifications to a NERC standard must be made through the NERC Standards Process under the NERC rules of Procedure. Regarding single points of failure in protection systems, the SPCS and SAMS make the following recommendations to a Standards Drafting Team that may be formed for modifying TPL-001-4.:

- For Table 1 – Steady State & Stability Performance Planning Events, Category P5:
  - Replace “relay” with “component of a Protection System,” and
  - Add superscript “13” to reference footnote 13 for the replaced term under the “Category” column.
- For Table 1 – Steady State & Stability Performance Extreme Events, under the Stability column, No. 2:
  - Remove the phrase “or a relay failure[13]” from items a, b, c, and d to create distinct events only for stuck breakers.
  - Append four new events for the same items a, b, c, and d in the above bulleted item to create distinct events replacing “a relay failure[13]” with “a component failure of a Protection System[13].”
- Replace footnote 13 in TPL-001-4 with, “The components from the definition of “Protection System” for the purposes of this standard include (1) protective relays that respond to electrical quantities, (2) single-station DC supply that is not monitored for both low voltage and open circuit, with alarms centrally monitored (i.e., reported within 24 hours of detecting an abnormal condition to a location where corrective action can be initiated), and (3) DC control circuitry associated with protective functions through the trip coil(s) of the circuit breakers or other interrupting devices.”[7]
- Modify TPL-001-4 (Part 4.5) so that extreme event assessments must include evaluation of the three-phase faults the described component failures of a Protection System[13] that produce the more severe system impacts. For example, add a new second sentence that reads “[t]he list shall consider each of the extreme events in Table 1 – Steady State & Stability Performance Extreme Events; Stability column item number 2.”

[7] See Order 754 (NERC website) Requests for Clarifications and Responses (http://www.nerc.com/pa/Stand/Order%20754%20DL/Order_754-Requests_for_Clarification_and_Responses_July2013.pdf).

Appendix A – Order No. 754 Data

Table A.1: Buses Evaluated by the Transmission Planner						
Row	**Description**	**100-199 kV**	**200-299 kV**	**300-399 kV**	**400-599 kV**	**≥600 kV**
1	Total number of buses in the transmission planning area	21,817	3,848	1,350	392	67
2	Total number of buses in the transmission planning area that meet the criteria in Table A, "Initial Criteria for Buses to be Tested"	1,522	1,310	768	262	54
3	Total number of buses evaluated by the Transmission Planner based on actual clearing times	716	813	356	164	44
4	Total number of buses evaluated by the Transmission Planner based on actual clearing times that resulted in system performance exhibiting any adverse impact defined in Table C, "Performance Measures"	160	316	212	101	43

Table A.2: Attributes of Evaluated Transmission Line Protection Systems						
Row	Description	100-199 kV	200-299 kV	300-399 kV	400-599 kV	≥600 kV
1	Total number of transmission line terminals at which protection system attributes were evaluated by the Generator Owners, Transmission Owners, and Distribution Providers	2,227	1,799	1,625	402	182
2	Number of transmission line terminals at which the protection system does not meet all of the specified protection system attributes for redundancy in Table B	1,190	996	227	270	12
3	Number of transmission line terminals at which the protection systems does not meet the specified protection system attributes for the protective relays	229	25	4	0	0
4	Number of transmission line terminals at which the protection systems does not meet the specified protection system attributes for the communication systems	364	301	42	7	0
5	Number of transmission line terminals at which the protection systems does not meet the specified protection system attributes for the AC current and voltage inputs	960	581	182	99	12
6	Number of transmission line terminals at which the protection system does not meet the specified protection system attributes for the DC control circuitry	785	642	42	205	0

Table A.3: Attributes of Evaluated Transmission Transformer Protection Systems						
Row	**Description**	**100-199 kV**	**200-299 kV**	**300-399 kV**	**400-599 kV**	**≥600 kV**
1	Total number of Transmission Transformers for which protection system attributes were evaluated by the Generator Owners, Transmission Owners, and Distribution Providers	382	519	559	129	87
2	Number of transmission transformers for which the protection system does not meet all of the specified protection system attributes for redundancy in Table B	186	297	188	63	3
3	Number of transmission transformers for which the protection system does not meet the specified protection system attributes for the protective relays	66	92	121	12	3
4	Number of transmission transformers for which the protection system does not meet the specified protection system attributes for the AC current and voltage inputs	81	135	33	3	3
5	Number of transmission transformers for which the protection system does not meet the specified protection system attributes for the DC control circuitry	143	260	131	51	0

Table A.4: Attributes of Evaluated Generator Step-Up Transformer Protection Systems						
Row	**Description**	**100-199 kV**	**200-299 kV**	**300-399 kV**	**400-599 kV**	**≥600 kV**
1	Total number of generator step-up transformers for which protection system attributes were evaluated by the Generator Owners, Transmission Owners, and Distribution Providers	251	315	167	52	29
2	Number of generator step-up transformers for which the protection system does not meet all of the specified protection system attributes for redundancy in Table B	127	151	27	16	0
3	Number of generator step-up transformers for which the protection system does not meet the specified protection system attributes for the protective relays	68	66	12	4	0
4	Number of generator step-up transformers for which the protection system does not meet the specified protection system attributes for the AC current and voltage inputs	79	60	15	1	0
5	Number of generator step-up transformers for which the protection system does not meet the specified protection system attributes for the DC control circuitry	107	118	13	13	0

Table A.5: Attributes of Evaluated Step-Down Transformer Protection Systems						
Row	**Description**	**100-199 kV**	**200-299 kV**	**300-399 kV**	**400-599 kV**	**≥600 kV**
1	Total number of step-down transformers for which protection system attributes were evaluated by the Generator Owners, Transmission Owners, and Distribution Providers	345	182	32	11	0
2	Number of step-down transformers for which the protection system does not meet all of the specified protection system attributed s for redundancy in Table B	211	101	16	5	0
3	Number of step-down transformers for which the protection system does not meet the specified protection system attributes for the protective relays	62	25	6	4	0
4	Number of step-down transformers for which the protection system does not meet the specified protection system attributes for the AC current and voltage inputs	134	53	2	0	0
5	Number of step-down transformers for which the protection system does not meet the specified protection system attributes for the DC control circuitry	165	88	14	1	0

Table A.6: Attributes of Evaluated Shunt Device Protection Systems						
Row	**Description**	**100-199 kV**	**200-299 kV**	**300-399 kV**	**400-599 kV**	**≥600 kV**
1	Total number of shunt devices for which protection system attributes were evaluated by the Generator Owners, Transmission Owners, and Distribution Providers	205	151	142	66	114
2	Number of shunt devices for which the protection system does not meet all of the specified protection system attributes for redundancy in Table B	90	83	38	48	0
3	Number of shunt devices for which the protection system does not meet the specified protection system attributes for the protective relays	65	19	5	8	0
4	Number of shunt devices for which the protection system does not meet the specified protection system attributes for the AC current and voltage inputs	71	44	12	3	0
5	Number of shunt devices for which the protection system does not meet the specified protection system attributes for the DC control circuitry	86	64	29	43	0

Table A.7: Attributes of Evaluated Bus Protection Systems						
Row	**Description**	**100-199 kV**	**200-299 kV**	**300-399 kV**	**400-599 kV**	**≥600 kV**
1	Total number of buses for which protection system attributes were evaluated by the Generator Owners, Transmission Owners, and Distribution Providers	642	565	516	126	45
2	Number of buses for which the protection system does not meet all of the specified protection system attributes for redundancy in Table B	403	370	220	36	3
3	Number of buses for which the protection system does not meet the specified protection system attributes for the protective relays	342	268	188	8	2
4	Number of buses for which the protection system does not meet the specified protection system attributes for the AC current and voltage inputs	276	246	47	13	1
5	Number of buses for which the protection system does not meet the specified protection system attributes for the DC control circuitry	340	263	54	35	0

Table A.8: Station DC Supply Attributes						
Row	**Description**	**100-199 kV**	**200-299 kV**	**300-399 kV**	**400-599 kV**	**≥600 kV**
1	Number of buses for which the station DC supply includes two independent DC supplies	548	528	590	154	54
2	Number of buses for which the station DC supply includes one DC supply that is centrally monitored, and if the station DC supply is a battery, includes alarms for both low voltage and a battery open condition	234	179	37	13	0
3	Number of buses for which the station DC supply includes one DC supply that is centrally monitored, the station DC supply is a battery, and the monitoring does not include alarms for both low voltage and a battery open condition	657	489	95	35	0
4	Number of buses for which the station DC supply includes one DC supply that is not centrally monitored	51	33	3	2	0

Note: The data in Table A.8 was collected on DC supplies for all of the 3,916 busses meeting the requirements of Table A in the data request. These are the buses in Row 2 of Table A.1.