UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Transmission Relay Loadability	**)**	**Docket Nos.**	**RM08-13-000**
Reliability Standard	**)**		**RM08-13-001**

COMPLIANCE FILING OF THE NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION IN RESPONSE TO ORDER NOS. 733 AND 759 – TRANSMISSION RELAY LOADABILITY RELIABILITY STANDARD

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February 19, 2013

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The North American Electric Reliability Corporation ("NERC")[1] hereby submits this filing in compliance with Federal Energy Regulatory Commission ("FERC" or the "Commission") Order Nos. 733[2] and 759[3] directing NERC to file with the Commission a test for Planning Coordinators to identify sub-200kV critical facilities, and the results of that test on a representative sample of utilities in three Interconnections (*i.e.*, Eastern, Western, and the Electric Reliability Council of Texas "ERCOT").[4]

I. BACKGROUND

In a July 30, 2008 filing, NERC submitted Reliability Standard PRC-023-1 to the Commission for approval.[5] On May 21, 2009, the Commission issued a Notice of Proposed Rulemaking ("NOPR") proposing to approve PRC-023-1 and directing modifications to the

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[1] The Federal Energy Regulatory Commission certified NERC as the electric reliability organization ("ERO") in its order issued on July 20, 2006, in Docket No. RR06-1-000. *North American Electric Reliability Corporation*, 116 FERC ¶ 61,062 (2006).
[2] *Transmission Relay Loadability Reliability Standard*, Order No. 733,130 FERC ¶ 61,221 (2010) ("Order No. 733); *order on reh'g and clarification*, Order No. 733-A, 134 FERC ¶ 61,127 (2011); *clarified*, Order No. 733-B, 136 FERC ¶ 61,185 (2011).
[3] *Transmission Relay Loadability Reliability Standard*, Order No. 759, 138 FERC ¶ 61,197 (2012) ("Order No. 759").
[4] Unless otherwise specified, capitalized terms used herein have the meanings specified in the *NERC Glossary of Terms*, available at: http://www.nerc.com/files/Glossary_of_Terms.pdf.
[5] *See Petition of the North American Electric Reliability Corporation for Approval of PRC-023-1 Reliability Standard,* Docket No. RM08-13-000 (July 30, 2008).

standard.[6] On August 17, 2009, NERC submitted comments in response to the NOPR supporting its original petition.[7]

On March 18, 2010, the Commission issued Order No. 733 in which it approved PRC-023-1 and directed further modifications to PRC-023-1. Specific to the instant compliance filing, the Commission directed that NERC modify PRC-023-1 to specify a test that Planning Coordinators must use to determine whether a sub-200 kV facility is critical to the reliability of the Bulk-Power System, and "file its test, and the results of applying the test to a representative sample of utilities from each of the three Interconnections, for Commission approval no later than one year from the date of this Final Rule."[8]

On April 19, 2010, NERC submitted a Request for Clarification or Rehearing of Order No. 733.[9] The Commission issued Order No. 733-A, on February 17, 2011, granting NERC's request "that the deadline for filing the test and the results from a representative sample of utilities in each of the three Interconnections be extended to twenty-four months from the date of this order."[10]

In a March 18, 2011 petition,[11] NERC submitted Reliability Standard PRC-023-2 (the successor standard to PRC-023-1) to the Commission for approval. In Attachment B to PRC-023-2, NERC specified the test that Planning Coordinators must use to determine whether a sub-200 kV facility is critical to the reliability of the Bulk-Power System. On September 15, 2011,

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[6] *Transmission Relay Loadability Standard*, 127 FERC ¶ 61,175 (May 21, 2009).
[7] *See Comments of the North American Electric Reliability Corporation in Response to Notice of Proposed Rulemaking* Docket No. RM08-13-000 (2009).
[8] Order No. 733 at P 69.
[9] *Request of the North American Electric Reliability Corporation for Clarification and, in the Alternative, Rehearing of Order No. 733*, Docket No. RM08-13-000 (2010).
[10] Order No. 733-A at P 78.
[11] *See Petition of the North American Electric Reliability Corporation for Approval of a Protection and Control (PRC) Reliability Standard*, Docket No. RM13-08-000 (2011).

the Commission issued a NOPR in which it proposed to approve PRC-023-2.[12] On November 21, 2011, NERC submitted comments in response to the NOPR supporting its original petition.[13] On March 15, 2012, the Commission issued Order No. 759 approving PRC-023-2 and directing NERC to include specific information in this compliance filing.[14]

By this filing, NERC submits the results of applying the test set forth in Attachment B of PRC-023-2 (criterion B1 to B6) to a representative sample of utilities from each of the three Interconnections, and also addresses three specific questions raised by the Commission.[15] This filing also evaluates relay loadability under criterion B4, consistent with the voltage and power factor specified in PRC-023-2, Requirement R1.[16]

II. NOTICES AND COMMUNICATIONS

Notices and communications with respect to this filing may be addressed to the following:[17]

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[12] *Transmission Relay Loadability Reliability Standard*, 136 FERC ¶ 61,187 (2011) ("September 15 NOPR").
[13] *See* NERC, *Comments of the North American Electric Reliability Corporation in Response to Notice of Proposed Rulemaking* Docket No. RM11-16-000 (2011).
[14] Order No. 759 at P 71.
[15] *Id*. at P 77.
[16] *Id*. at P 78.
[17] Persons to be included on the Commission's service list are indicated with an asterisk. NERC requests waiver of the Commission's rules and regulations to permit the inclusion of more than two people on the service list.

III. SUMMARY OF TEST AND TEST RESULTS

The investigation of the August 14, 2003 Northeast Blackout identified relay loadability as playing a pivotal role in accelerating and spreading the early part of the cascade in Ohio, Indiana, and Michigan. As a result, recommendations were made for the review and mitigation of relay settings in NERC Blackout Recommendation 8a[18] and U.S.-Canada Power System Outage Task Force Recommendation 21a.[19] While the electric utility industry undertook a significant reliability initiative to review and mitigate settings in response to these recommendations, Reliability Standard PRC-023 was developed to create mandatory and enforceable requirements to ensure that technical solutions to the problem of relay loadability are maintained and properly codified in the NERC Reliability Standards.

The work performed by industry to address NERC Blackout Recommendation 8a was focused on protection systems applied on circuits operated at 200 kV or higher, while the work to address U.S.-Canada Power System Outage Task Force Recommendation 21a was focused on protection systems applied to operationally significant circuits operated at 100 kV to 200 kV as identified by each NERC Region. In Recommendation 21a, the US – Canada Power System Outage Task Force identified circuits that are part of monitored Flowgates or interfaces as examples of operationally significant circuits.

Reliability Standard PRC-023-1 codified the ongoing analysis of transmission relay loadability, and, in doing so, assigned Planning Coordinators the responsibility to identify circuits operated at 100 kV to 200 kV to which the standard would be applicable. However, as the Commission noted in Order No. 733, "[n]either the Final Blackout Report nor the Reliability

[18] *August 14, 2003 Blackout: NERC Actions to Prevent and Mitigate the Impacts of Future Cascading Blackouts*, approved by the NERC Board of Trustees (February 10, 2004).
[19] *U.S.-Canada Power System Outage Task Force, Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations* (Apr. 2004) ("Blackout Report"), available at https://reports.energy.gov/BlackoutFinal-Web.pdf.

Standard establishes a mandatory test for planning coordinators to use to determine if a facility is 'operationally significant' or 'critical to the reliability of the bulk electric system' with respect to relay settings and the prevention of cascading outages."[20] As the Commission further noted, "…PRC-023-1 must apply to relay settings on all operationally significant sub-200 kV facilities that could trip on relay loadability and contribute to cascading outages and the loss of load, including those within a sub-region or a company."[21] The test in PRC-023-2, Attachment B, was developed to identify all such circuits.

Specifically, Attachment B to PRC-023-2 provides a six-criterion test that Planning Coordinators must apply to identify sub-200kV critical facilities that are subject to compliance with the Reliability Standard. In accordance with Order No. 733, Planning Coordinators must uniformly implement the PRC-023-2 test (across all Regions) to identify circuits for which protection systems are needed to meet the relay loadability requirements of PRC-023.[22]

A. Overview of the Test Defined in Attachment B of PRC-023-2

Requirement R6 of PRC-023-2 requires that Planning Coordinators apply the Attachment B test to (i) transmission lines operated at 100 kV to 200 kV and transformers with low voltage terminals connected at 100 kV to 200 kV, and (ii) transmission lines operated below 100 kV and transformers with low voltage terminals connected below 100 kV that are part of the Bulk Electric System ("BES"). Specifically, the Attachment B test is conducted to determine what circuits within the Planning Coordinator's area are subject to Requirements R1 through R5 for applicable entities (*i.e.*, Transmission Owners, Generator Owners, and Distribution Providers).

[20] Order No. 733 at P. 74**.**
[21] *Id*. at P 76.
[22] *Id*. at P 69.

A Facility is subject to PRC-023-2 if the Facility meets any one of the following six criteria, which are applied by Planning Coordinator:

B1. The circuit is a monitored Facility of a permanent flowgate in the Eastern Interconnection, a major transfer path within the Western Interconnection as defined by the Regional Entity, or a comparable monitored Facility in the Québec Interconnection, that has been included to address reliability concerns for loading of that circuit, as confirmed by the applicable Planning Coordinator.

B2. The circuit is a monitored Facility of an IROL,[23] where the IROL was determined in the planning horizon pursuant to FAC-010.

B3. The circuit forms a path (as agreed to by the Generator Operator and the transmission entity) to supply off-site power to a nuclear plant as established in the Nuclear Plant Interface Requirements (NPIRs) pursuant to NUC-001.

B4. The circuit is identified through the following sequence of power flow analyses[24] performed by the Planning Coordinator for the one-to-five-year planning horizon:

a. Simulate double contingency combinations selected by engineering judgment, without manual system adjustments in between the two contingencies (reflects a situation where a System Operator may not have time between the two contingencies to make appropriate system adjustments).

b. For circuits operated between 100 kV and 200 kV evaluate the post-contingency loading, in consultation with the Facility owner, against a threshold based on the Facility Rating assigned for that circuit and used in the power flow case by the Planning Coordinator.

c. When more than one Facility Rating for that circuit is available in the power flow case, the threshold for selection will be based on the Facility Rating for the loading duration nearest four hours.

d. The threshold for selection of the circuit will vary based on the loading duration assumed in the development of the Facility Rating.

i. If the Facility Rating is based on a loading duration of up to and including four hours, the circuit must comply with the standard if the loading exceeds 115% of the Facility Rating.

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[23] Interconnection Reliability Operating Limit ("IROL") is defined as the "value (such as MW, MVar, Amperes, Frequency or Volts) derived from, or a subset of the System Operating Limits, which if exceeded, could expose a widespread area of the Bulk Electric System to instability, uncontrolled separation(s) or cascading outages."

[24] Past analyses may be used to support the assessment if no material changes to the system have occurred since the last assessment.

ii. If the Facility Rating is based on a loading duration greater than four and up to and including eight hours, the circuit must comply with the standard if the loading exceeds 120% of the Facility Rating.

iii. If the Facility Rating is based on a loading duration of greater than eight hours, the circuit must comply with the standard if the loading exceeds 130% of the Facility Rating.

e. Radially operated circuits serving only load are excluded.

B5. The circuit is selected by the Planning Coordinator based on technical studies or assessments, other than those specified in criteria B1 through B4, in consultation with the Facility owner.

B6. The circuit is mutually agreed upon for inclusion by the Planning Coordinator and the Facility owner.

The Attachment B test was designed with the objective of minimizing any additional analytical burden on the Planning Coordinators by leveraging existing studies. As such, criteria B1, B2, and B3 of the test assess circuits based on previously identified criticality of the circuit consistent with identification as part of Flowgates, Interconnection Reliability Operating Limits ("IROLs"), Nuclear Plant Interface Requirements ("NPIRs"), or other similar criteria depending on the Interconnection in which the circuit is located. The studies conducted to determine the importance of such circuits are quite rigorous and are performed on a regular basis. Given that tripping these elements may lead to known thermal loading problems; instability, uncontrolled separation(s) or cascading outages; or tripping critical generating units, it is appropriate to have PRC-023-2 applicable to the protection systems on these circuits without requiring any additional analysis.

Criterion B4 assesses circuits based on evaluating N-2 contingencies[25] to determine the potential for cascading outages due to thermal overloads that are within the short-time capability of a circuit, but are high enough to challenge protection systems, resulting in circuit tripping before an operator has time to take action to remedy the situation. Such testing is often done in planning studies to determine the strengths and weakness of the system. Criterion B4 was designed to leverage that work. Criterion B4 is used to identify additional thermal loading conditions of concern in the context of transmission relay loadability that are not identified by applying criteria B1 through B3. Criterion B4 intentionally is more stringent than the testing required in TPL-003-0a.[26] Testing N-2 contingencies, without manual system adjustments in between the two contingencies, is in line with the reliability objective of PRC-023-2 by modeling a situation where a system operator may not have time between the two contingencies to make appropriate system adjustments. That situation reflects the events that led to the cascading outages due to transmission lines tripping on load encroachment on August 14, 2003.

Criteria B5 and B6 provide the opportunity for the Planning Coordinator to identify circuits based on other technical assessments or by mutual agreement between the Planning Coordinator and Facility owner. The last two criteria are intended to be used less frequently than the first four criteria, and would involve unique situations requiring detailed knowledge of the system. For this reason, NERC has focused its application of the test on the first four criteria. For the test to be robust enough to capture all circuits necessary to achieve the reliability objective of PRC-023-2, the four criteria that are used in the sample must be uniformly applied

[25] N-2 contingencies (sometimes referred to as “double contingencies”) remove two circuits from service without any system adjustment.

[26] NERC Reliability Standard TPL-003-0a — System Performance Following Loss of Two or More BES Elements, available at: http://www.nerc.com/files/TPL-003-0a.pdf.

by Planning Coordinators to identify most, if not all circuits. Criteria B5 and B6 are reserved for special cases that cannot be readily identified with a continent-wide test.

As noted, NERC has applied this test to a representative sample of utilities only for the purpose of verifying whether the test is robust enough to identify all circuits necessary to achieve the reliability objective of PRC-023-2. The results of this analysis will not be used to identify all circuits to which PRC-023-2 is applicable, and NERC's testing does not relieve the Planning Coordinators of their obligation to comply with Requirement R6 of PRC-023-2. While NERC expects that the results of its testing to be very similar to the results obtained by the Planning Coordinators, detailed knowledge applied by the Planning Coordinators in consultation with the Facility owners may result in identification of a different list of circuits. However, such variations in testing results are not expected to be significant enough to prevent assessing the validity of the test based on a representative sample.

It is also important to note that NERC has not included a list of the circuits identified in this report. By the nature of this testing, the list of circuits can provide information regarding where the power system is potentially vulnerable to cascading outages for N-2 contingencies. Therefore, NERC considers the lists of identified circuits to be privileged or Critical Energy Infrastructure Information ("CEII") as defined by the Commission Rules of Practice and Procedure (18 C.F.R. Part 388), Commission Orders and NERC Rules of Procedure. That is, the information would pertain to proprietary or business design information, including design information related to vulnerabilities of CEII that is not publicly available. Accordingly, NERC describes the results of its testing in qualitative terms, supported by statistical analysis, to demonstrate the validity of the test.

B. Summary of the Representative Sample of Utilities from each of the Three Interconnections to which NERC has Applied the Test

In accordance with Order No. 733, NERC applied the Attachment B test to a representative sample of utilities from each of the three Interconnections.[27] Additionally, as the Commission clarified, NERC's representative samples include large, small, rural, and metropolitan entities reflecting various topologies. Specifically, NERC applied the test to the following entity power systems:[28]

Eastern Interconnection

- American Electric Power ("AEP")
- Florida Power & Light Company ("FPL")
- Southern Company Services, Inc ("Southern Company")
- Western Farmers Electric Cooperative ("WFEC")

ERCOT Interconnection

- CenterPoint Energy ("CNP")

Western Interconnection

- Idaho Power Company ("IPCO")
- Public Service Company of New Mexico ("PNM")
- Tri-State Generation and Transmission Association Inc. ("TSGT")

The Tri-State and WFEC systems represent small entities, while the AEP and Southern Company systems represent large entities. Moreover, the Tri-State and WFEC systems include rural areas, while the remaining systems selected include both rural and metropolitan areas. This sampling of systems also includes various topologies, such as densely networked systems and systems characterized by long transmission lines separating load and generation centers.

[27] Order No. 733 at P 69.
[28] For the systems tested by NERC, the Transmission Owner is also registered as the Planning Coordinator, with the exception of AEP, CNP, TSGT, and WFEC.

C. Characteristics of Circuits to which PRC-023-2 Should be Applicable to Achieve the Desired Reliability Objective

To determine whether the Attachment B test is robust enough to consistently identify all applicable circuits, NERC considered the attributes of the 100 kV to 200 kV circuits that tripped on August 14, 2003, and the general characteristics of circuits that could be involved in a cascading outage if relay loadability requirements are not applicable. Circuits of interest in this context could include circuits between Regions or sub-regions, as well as circuits within sub-regions or a single entity's system. The characteristics of such circuits involve locations where a number of circuits are operated in parallel to transfer power between portions of the Bulk-Power System or between the Bulk-Power System and major load centers. When multiple circuit outages occur simultaneously or in rapid succession, the remaining parallel circuits experience increased loading. When the increased loading is within the short-time overload capability of the remaining circuits, it is vital that protective relay settings do not result in tripping the circuits before a system operator has an opportunity to intervene to mitigate the overloads.

Whether a circuit is susceptible to significant overloading (*i.e.*, above the long-time emergency capability, but within the short-time emergency capability) depends on the number of circuits in parallel, the loading on the circuits, and the characteristics of the circuits. For example, if four circuits with equal rating and impedance are operated in parallel and two circuits trip, the loading on the two remaining circuits will increase by 100 percent. Whereas, if six such circuits are operated in parallel and two circuits trip, the loading on the four remaining circuits will only increase by 50 percent.

The voltages of the lines are also important. For example, if two 345 kV lines and four 115 kV lines are operated in parallel, tripping the two 345 kV lines will result in a significantly greater loading on the remaining 115 kV lines than if two of the 115 kV lines trip.

Thus, for the test to be robust it should identify circuits operated below 200 kV, and circuits that are operated in parallel with other circuits, which transfer power between two portions of the Bulk-Power System or between the Bulk-Power System and major load centers, where the circuits will experience significant increase in loading following simultaneous loss of transmission circuits. Therefore, an N-2 contingency is prescribed where two transmission circuits are tripped and an operator does not have sufficient time to take action in the time between tripping the first and second circuit. That is most often the situation during major system disturbances.

D. Specific Questions the Commission Directed NERC to Address in this Filing

In the NOPR the Commission set forth four questions intended to assist the Commission's understanding of the test in Attachment B of Reliability Standard PRC-023-2:[29]

- Whether the power system assessment proposed in criterion B4 includes the critical system conditions utilized under Reliability Standard TPL-003-0 Requirement R1.3.2;

- Whether applicable entities evaluate relay loadability under the B4 criterion consistent with Requirement R1 which requires, in part, that they "evaluate relay loadability at 0.85 per unit voltage and a power factor angle of 30 degrees" in addition to applicable current data;

- What "technical studies or assessments" will be used by planning coordinators to identify critical facilities under criterion B5; and

- Whether Attachment B is sufficiently comprehensive to capture all circuits in a planning coordinator's area that could have an operational impact on the reliability of the bulk electric system.

In Order No. 759, the Commission accepted NERC's proposal to address three of the questions in this filing:[30]

[29] September 15 NOPR at PP 41-45.
[30] Order No. 759 at P 77.

- A summary of the base cases used in applying the Attachment B criteria and an assessment of how the base cases used for the analysis relate to TPL-003-0, Requirement R1.3.2;

- A discussion of the types of studies that planning coordinators may use to identify circuits under Attachment B; and

- An assessment that demonstrates whether Attachment B is comprehensive enough to capture all circuits that could have an operational impact on the reliability of the bulk electric system in the context of transmission relay loadabilty.

The Commission also noted that it was not persuaded "by NERC's statement that it is not necessary for NERC to include in the report a comparison of the results obtained using criterion B4 to the results that would be achieved based on assumptions consistent with Requirement R1." Therefore, the Commission directed NERC to, "evaluate, in the report, relay loadability under the B4 criterion consistent with Requirement R1, which requires, in part, that NERC 'evaluate relay loadability at 0.85 per unit voltage and a power factor angle of 30 degrees' in addition to applicable current data."[31]

Thus, NERC addresses each of the questions raised by the Commission in the following four sections.

i. Comparison of the Base Cases Used in this Assessment to the Critical System Conditions Utilized under Reliability Standard TPL-003-0 Requirement R1.3.2

NERC Reliability Standard TPL-003-0a requires the Planning Coordinator and Transmission Planner to demonstrate through a valid assessment that its portion of the interconnected transmission systems is planned to meet specific criteria following loss of two or more BES elements. Requirement R1.3 of TPL-003-0a requires that the assessment is supported by a current or past study and/or system simulation testing that includes certain "elements" selected from each of the categories in Requirements R1.3.1 through R1.3.12. Specifically,

[31] *Id*. at P 78.

Requirement R1.3.2 requires that the study and/or simulation testing, "[c]over critical system conditions and study years as deemed appropriate by the responsible entity."[32]

The simulation testing performed by NERC to apply the test specified in criterion B4 used "base cases" modeling summer peak load for the Near-Term Transmission Planning Horizon, which is defined as the "transmission planning period that covers Year One through five."[33] The "base cases" used for NERC's simulation testing model one to two years into the future, depending on the system tested. These "base cases" are within the time frame specified in Attachment B of PRC-023-2. Using cases one to two years into the future is appropriate for this analysis because such cases provide a system representation containing circuits that already are in-service or have a very high certainty of being placed in-service. Testing different or additional years is not necessary for the purpose of validating the test specified in Attachment B. However, testing different or additional years may yield a different, but similar list of circuits with the same characteristics identified in this testing.

NERC selected base cases that model the summer peak load condition because this is consistent with the critical system condition that Planning Coordinators use in transmission planning assessments to evaluate system performance following loss of two or more BES elements. Summer peak load represents a stressed system condition for which transmission relay loadability is a significant concern based on past system disturbances. Testing different or additional critical system conditions would yield a different, but similar list of circuits with the same characteristics identified in this testing. In actual implementation of PRC-023-2, Planning Coordinators may elect to model additional critical system conditions that they use in their annual transmission planning assessments based on knowledge of their system.

[32] TPL-003-0a, Requirement R1.3.2.
[33] *NERC Glossary of Terms* at p. 8.

ii. Effect of Voltage and Power Factor on Evaluation of Critical Facilities under Criterion B4

When a circuit is loaded above the applicable sub-criterion d(i), d(ii), or d(iii) in criteria B4, the circuit is at risk of the associated apparent impedance resulting in a trip of the circuit under conditions for which an operator could have time (*e.g.*, 15-20 minutes) to take action to address the overload. The philosophy used in developing criterion B4 considers that the criterion could be easily applied as an extension of planning studies routinely performed by the Planning Coordinator, keeping any additional burden of performing the test to a minimum. Therefore, criterion B4 is based on a conservative assumption that the simulated voltage is 0.85 per unit and the simulated power factor angle is 30 degrees. This assumption significantly reduces the burden on Planning Coordinators as powerflow software readily allows an evaluation of the thermal loading on a circuit, but may not readily provide the voltage and power factor angle in an automated output.

The test in criterion B4 requires that the protection system applied on a circuit be subject to PRC-023-2 unless a specified margin is observed between the thermal loading in the solved powerflow and the circuit rating. The margin required is based on the time period on which the emergency rating is based, to provide time for a system operator to take action prior to potential tripping by a protective relay responding to a heavy loading condition.

It is possible to translate the thermal loading from a solved powerflow to apparent impedance on an R-X plane.[34] When the circuit's load point is plotted on an R-X plane with the operating characteristic of the protective relay, it is possible to determine whether the relay will trip for that loading condition, and if not, how far the load point is from the relay operating characteristic. Figure 1 (below) shows a load point from a powerflow simulation plotted against

[34] Protection engineers typically plot the operating characteristic of a protection system on a rectangular coordinate system, using resistance (R) as the "x-axis" and reactance (X) as the "y-axis." See Figures 1 and 2.

a relay operating characteristic, based on an assumption that the voltage is 0.85 per unit and the power factor angle is 30 degrees. For the purpose of the discussion, a mho characteristic[35] is considered. The mho characteristic is the most commonly applied type of transmission line impedance relay, and the type that typically results in the least relay loadability. A mho characteristic with a maximum torque angle ("MTA")[36] of 85 degrees is shown in Figure 1. A MTA of 85 degrees was selected because the MTA is usually the same or very near to the line impedance angle; thus, 85 degrees is a common setting. In this example, the load point is outside the relay mho characteristic.

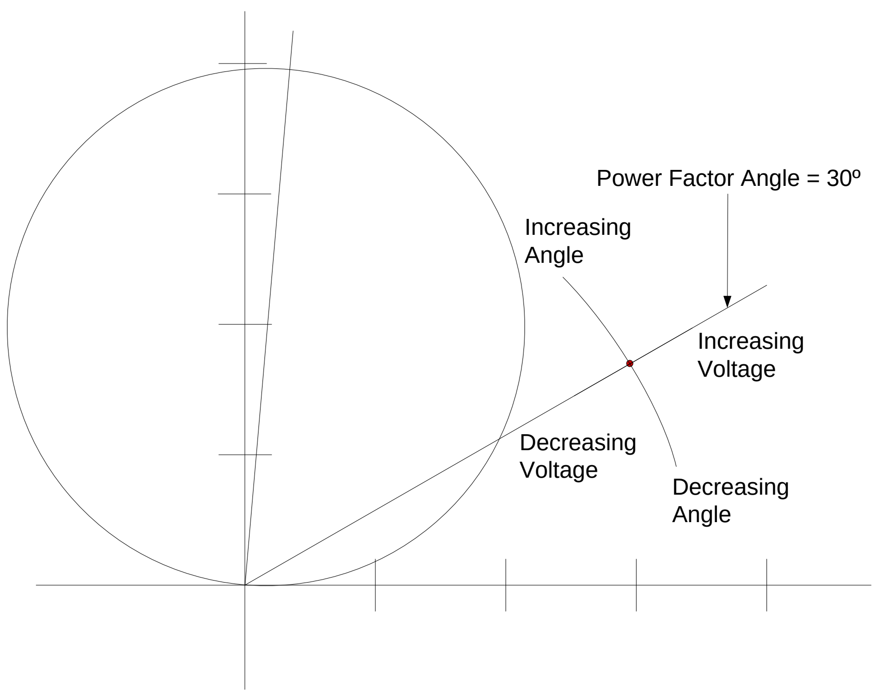

Figure 1 – Illustration of How Voltage and Power Factor Angle Affect Margin Against Tripping at a Given Value of Thermal Loading on a Circuit

[35] A mho characteristic is defined by a circular area for which a relay will trip if the apparent impedance enters inside the circle. It also is the most common characteristic shape for an impedance relay.
[36] The maximum torque angle is the angle at which an impedance relay has the maximum sensitivity and greatest ability to detect faults.

Figure 1 illustrates that if the voltage is different than the assumed value of 0.85 per unit, the load point will vary by moving closer to or farther away from the relay characteristic along a line that intersects the origin.[37] Thus, if voltage is greater than the assumed value the apparent impedance is farther from the relay characteristic, resulting in greater margin against tripping; if the voltage is less than the assumed value, the load point will be closer to the relay characteristic and the margin will be reduced. Similarly, Figure 1 illustrates that if the power factor angle is different than the assumed value of 30 degrees in criterion B4, the load point will vary by moving along an arc that is a constant distance from the origin. If the power factor angle is less than the assumed value, the apparent impedance is farther from the relay characteristic resulting in more margin against tripping; if the power factor angle is greater than the assumed value, the load point will be closer to the relay characteristic and the margin will be reduced.

NERC's experience applying the test confirms that when applying criterion B4, the solved voltage will be above 0.85 per unit and the solved power factor angle will be less than 30 degrees for most contingencies. As illustrated in Figure 1, when the voltage is above 0.85 per unit and power factor angle is less than 30 degrees, this indicates that there is a greater margin between the apparent impedance and the relay trip setting. NERC observed from running over two million contingency simulations that both of these conditions are met in over 99 percent of the simulations that resulted in thermal loading above the applicable emergency rating.

NERC has performed additional analysis to assess the impact on test results when the solved voltage in less than 0.85 per unit, or the power factor angle is greater than 30 degrees, or when both of these conditions occur. To understand the effect it is useful to examine the

[37] The origin is the point on the diagram at which the R-axis and X-axis intersect; also the point at which both R and X are equal to zero.

equation that defines the load point and how the load point varies with changes in voltage and angle.

The apparent impedance associated with the assumed voltage of 0.85 per unit and power factor angle of 30 degrees is:

$$\mathbf{Z = (0.85 \times V_{l\text{-}l})/(\sqrt{3} \times I)\ \text{at an angle of 30 degrees,} \qquad \text{(equation 1)}}$$

Where,

- 0.85 represents the assumed per unit voltage,
- $V_{l\text{-}l}$ is the rated line-to-line voltage on the circuit, and
- I is the current from the solved power flow.

As can be seen from this equation, if the assumed voltage is replaced by the solved voltage from the powerflow, the effect of a voltage lower than 0.85 per unit will be to move the apparent impedance closer to the origin (*i.e.*, the impedance will have a smaller magnitude). The new load point would be closer to the origin by a factor equal to the solved voltage divided by 0.85 per unit (*e.g.*, for a solved voltage of 0.80 per unit voltage the apparent impedance will be reduced by a factor of 0.80/0.85), or approximately a 6 percent reduction (*i.e.*, it would be necessary to reduce the thermal loading on the circuit by 6 percent to achieve the same level of margin). In an extreme case, if the solved voltage is low enough, it is possible for the load point to enter the trip region even when the thermal loading in the solved powerflow is below the threshold identified in criterion B4. However, it is important to note that 0.85 per unit voltage was selected as the basis for relay loadability in PRC-023 based on the lowest sustained voltage observed on August 14, 2013, and it is unlikely that system operation could be sustained at voltage much below 0.85 per unit.

Evaluating the effect of power factor angle is more complicated because the load limit of the relay characteristic varies with the angle. Thus, even though the magnitude of the impedance remains constant as power factor angle varies, the margin between the load point and the trip characteristic varies because of variation of the load limit of the relay. Figure 2 (below) illustrates the geometric relationship that defines how the load limit of the relay characteristic varies with power factor angle.

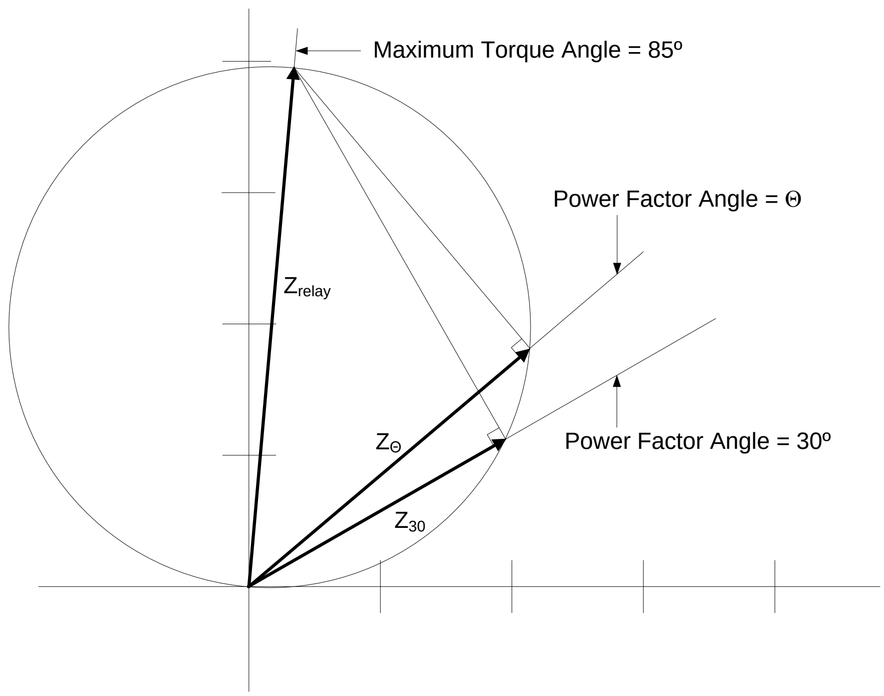

Figure 2 – Illustration of the Relationship Between Apparent Impedance Calculated at Different Power Factor Angles

In Figure 2, the impedance for the load point at the assumed power factor angle of 30 degrees is represented by the vector, or arrow, labeled Z_{30}, the length of which is equal to the magnitude of the apparent impedance. Similarly, the impedance at the solved power factor angle from the powerflow (Θ) is represented by the vector labeled Z_{Θ}. A third vector, Z_{relay}, represents the relay reach at its maximum torque angle, which in this example is 85 degrees. This value,

Z_{relay}, is used to establish the relationship between Z_{30} and Z_{Θ}. The vector Z_{relay} is equal to the diameter of the circle; thus, geometric principles dictate that any triangle formed by the vector Z_{relay} and a point on the circle will form a right triangle. Two triangles are drawn in Figure 2. The first triangle has the vector Z_{30} as one side and the vector Z_{relay} as its hypotenuse (the side opposite the 90 degree angle in a right triangle). The angle between Z_{30} and Z_{relay} is the difference between the maximum torque angle of 85 degrees and the load angle of 30 degrees. Applying the principle that the cosine of that angle is the ratio of the adjacent side of the triangle, Z_{30}, and the hypotenuse, Z_{relay}, yields the relationship:

$\cos(85 - 30) = Z_{30} / Z_{relay}$, which can be rewritten as,

$$\mathbf{Z_{30} = Z_{relay} \times \cos(85 - 30).} \qquad \textbf{(equation 2)}$$

Applying the same principle to the second triangle yields the relationship,

$$\mathbf{Z_{\Theta} = Z_{relay} \times \cos(85 - \Theta).} \qquad \textbf{(equation 3)}$$

Thus, the relationship between Z_{Θ} and Z_{30} can be derived by dividing equation 3 by equation 2 to yield the relationship:

$$\mathbf{Z_{\Theta}/Z_{30} = \cos(85 - \Theta)/ \cos(85 - 30).} \qquad \textbf{(equation 4)}$$

Applying this relationship to an example in which the solved power factor angle is 35 degrees, the ratio Z_{Θ}/Z_{30} is 1.12, meaning the impedance at which the relay will trip at 35 degrees is 12 percent greater than the impedance at 30 degrees. The inverse of this relationship, Z_{30}/ Z_{Θ}, indicates that the margin is decreased by 11 percent, *i.e.*, it would be necessary to reduce the thermal loading on the circuit by 11 percent to achieve the same level of margin. Similar to the voltage relationship, it is possible in an extreme case for the solved power factor angle to be high enough for the load point to enter the trip region even when the thermal loading in the solved powerflow is below the threshold identified in criterion B4.

In applying the test, the concern is not simply whether the relay could trip. Rather the concern is whether, by basing the test on an assumed voltage and power factor angle, there could be some power flow solutions that have less margin than the minimum desired, even when the thermal loading of the circuit is below the threshold specific in criterion B4. There are four potential cases to evaluate:

(i) voltage is above 0.85 per unit and power factor angle is less than 30 degrees;

(ii) voltage is below 0.85 per unit and power factor angle is less than 30 degrees;

(iii) voltage is above 0.85 per unit and power factor angle is greater than 30 degrees; and

(iv) voltage is below 0.85 per unit and power factor angle is greater than 30 degrees.

As explained above, the first case results in more margin than with the assumed voltage and power factor angle. Conversely, the fourth case always will result in less margin than with the assumed voltage and power factor angle. The second and third cases are of particular interest because in these cases one factor, either voltage or power factor, has a negative impact on margin, while the other factor has a positive effect. The combined effect of these two factors can be evaluated by combining the two factors derived above. The effect of reduced voltage is to reduce the load point apparent impedance which decreases the margin by the factor, $V_{solved}/0.85$. Similarly, the effect of increasing power factor angle is to decrease the margin by the factor $Z30/Z\Theta = \cos(85 - 30)/\cos(85 - \Theta)$.[38] A margin adjustment factor ("MAF") can be defined by multiplying these factors such that:

$$\mathbf{MAF = (V_{solved}/0.85)(\cos(85 - 30)/\cos(85 - \Theta)).}$$

[38] Note that equation (4) assesses the impact on trip impedance, while the inverse of equation (4) assess the impact on trip margin; i.e., increasing the trip impedance results in reduced margin between the trip impedance and the load point.

When this factor is greater than 1.0 the solved voltage and power factor result in greater margin than the assumed voltage and power factor (*i.e.*, the assumption is conservative), and when this factor is less than 1.0 the margin is less than assumed. For example, a powerflow with solved voltage of 0.80 per unit voltage and 22 degree power factor results in an apparent impedance with 19 percent more margin than the assumed voltage and power factor angle – in this case the positive effect of a power factor angle less than 30 degrees outweighs the negative effect of the reduced voltage.

To assess the potential impact of basing criterion B4 on assumed values of voltage and power factor angle, NERC evaluated every occurrence of a circuit loaded between 100 percent of the applicable rating in sub-criterion d and the defined threshold (*e.g.*, when a circuit rating is based on a 4-hour duration) every occurrence of a circuit loaded between 100 and 115 percent was evaluated to determine whether the actual margin was more or less than assumed. Statistics for this analysis are presented in Table 1. Results are presented separately for circuits between 100 kV and 200 kV and circuits below 100 kV.[39]

Table 1

	100-200 kV	Below 100 kV	Total
Total number of contingencies evaluated with loading greater than the applicable emergency rating	152,153	265,494	417,647
Number of contingencies for which the margin based on the solved voltage and power factor angle is less than using assumed voltage and power factor	44	61	105
Number of contingencies with less margin, for which the thermal loading exceeds the threshold in criterion B4, sub-criterion d	20	43	63

[39] For the purposes of the this testing, NERC only considered circuits operated at or above 69 kV and below 100 kV since it is unlikely that circuits operated below 69 kV will be part of the BES.

In simulating over two million N-2 contingencies, NERC observed 417, 647 circuit overloads above the Facility Rating for the available defined loading duration nearest 4 hours. This analysis demonstrates that in more than 99 percent of the 417, 647 circuit overloads, the assumed voltage and power factor are conservative. In the 105 cases where the assumed voltage and power factor are not conservative, the test already identified 63 (60 percent) of these circuits as necessary to comply with PRC-023-2. This confirms that the decision to base the evaluation criterion on a conservative assumption using 0.85 per unit voltage and 30 degree power factor angle is justified.

Therefore, NERC concludes that a more elaborate criterion would add precision to the evaluation without adding accuracy, and would provide no measurable improvement in reliability of the Bulk-Power System criterion in Attachment B of PRC-023-2. Also, the significant additional analytical burden on the Planning Coordinator of a more elaborate criterion is unjustified, and leveraging observations prescribed in criterion B4 during the existing studies provides both an appropriate and robust applicability test.

iii. Technical Studies or Assessments Used by Planning Coordinators to Identify Critical Facilities under Criterion B5

Criterion B5 provides Planning Coordinators the ability to identify critical facilities subject to PRC-023-2 through studies other than those specified in criteria B1 through B4. Criterion B5 assigns sole responsibility for identifying circuits to the Planning Coordinator, but establishes parameters that (i) the studies and assessments must have a technical basis, and (ii) identification must be made in consultation with the Facility owner. The types of technical studies or assessments may include, but are not limited to:

- Assessments used to demonstrate compliance with TPL standard requirements;

- Seasonal reliability assessments;
- Operational planning studies;
- Studies performed to assess interconnection requirements for generation facilities, transmission facilities, and end-user facilities;
- Under voltage load shedding studies; and
- Analyses of actual system events.

The Planning Coordinator will identify that the protection on a circuit is subject to compliance with PRC-023-2 when the Planning Coordinator has technical studies or assessments, including those identified in this list, that demonstrate the potential for, or actual occurrence of, circuits tripping due to insufficient relay loadability or being loaded above their emergency rating under contingency conditions. As NERC stated in its comments on the NOPR, "Attachment B does not specify a finite list to avoid unnecessarily limiting the technical studies or assessments the Planning Coordinators may use to identify circuits."[40]

iv. Whether Attachment B is Comprehensive Enough to Capture All Circuits that could have an Operational Impact on the Reliability of the BES in the Context of Transmission Relay Loadability.

Based on applying the test specified in Attachment B to a representative sample of utilities from each Interconnection, NERC concludes that the test is comprehensive enough to indentify all circuits that may adversely affect reliability of the Bulk-Power System due to relay loadability constraints. The test is designed to be comprehensive by including six different criteria by which a circuit may be included in the applicability of PRC-023-2. This approach assures that the test is not dependent on any one criterion to identify circuits. The test also is designed to utilize information and existing analyses performed by Planning Coordinators and

[40] NERC Comments in Response to September 15 NOPR, at pp. 4-5 (November 21, 2011).

other entities responsible for planning and operating the Bulk-Power System to assure that existing knowledge of the system is applied in manner that is both effective and efficient.

NERC applied the Attachment B test to evaluate circuits operated between 100 kV and 200 kV as discussed below. The test is also applicable to sub-100 kV circuits that are part of the BES; however, the representative systems to which NERC applied the test do not contain sub-100 kV BES elements.

Criterion B1

Applying criterion B1 identifies 100 kV to 200 kV circuits for which the Planning Coordinator already has identified thermal loading concerns following loss of another circuit. During development of Attachment B, the standard drafting team received several comments that it is inappropriate to include circuits that are monitored facilities of Flowgates in the Eastern Interconnection, and similar circuits in the other Interconnections, because Flowgates are used to manage congestion. However, managing congestion and system reliability are not mutually exclusive concerns. Markets are constrained to ensure that the transmission system is operated within physical system constraints that if violated, could lead to instability, uncontrolled separation, or cascading. Thus, including monitored Facilities of Flowgates as applicable circuits under PRC-023-2 is an appropriate first criterion. The circuits identified by criterion B1 are by definition subject to loading up to the circuit rating following loss of another circuit; therefore, it is reasonable and appropriate to conclude these circuits may be loaded above their emergency rating following loss of additional circuits. For this reason, it is important that the protection systems applied on these circuits provide sufficient relay loadability to allow the operator time to reduce loading when the loading is within the circuit's short-time capability to prevent the circuit from tripping.

Criterion B2

Applying criterion B2 identifies 100 kV to 200 kV circuits that are monitored facilities of an IROL. By definition, exceeding the rating on such circuits "could expose a widespread area of the bulk electric system to instability, uncontrolled separation(s) or cascading outages."[41] Thus, it is imperative that protection systems applied on these circuits provide sufficient relay loadability to allow the operator time to reduce loading when the loading is within the circuit's short-time capability to prevent the circuit from tripping.

Criterion B3

Applying criterion B3 identifies 100 kV to 200 kV circuits that supply off-sire power to a nuclear plant. PRC-023-2 is applicable to the protection systems applied on these circuits due to the criticality of these circuits.

Criterion B4

Applying criterion B4 provides defense in depth by requiring additional analyses by the Planning Coordinator to confirm whether other 100 kV to 200 kV circuits exist that are that are important to reliability in the context of transmission relay loadability that have not been previously identified through other studies. This test is based on the conditions that have been observed in several significant events in which multiple transmission circuits trip and operators do not have time to secure the system between tripping of each circuit.

While the system is planned and operated to be secure when the operator has time to take action between contingencies, it is possible for the system to enter an unsecure state when contingencies occur that exceed planning and operating criteria. For this reason, criterion B4 is applied to identify whether loss of two circuits without system adjustments, will result in loading above the emergency rating of a circuit. In these cases, the circuit may be important to reliability

[41] IROL, *NERC Glossary of Terms* at p. 34.

in the context of transmission relay loadability and it is important that the protection systems applied on these circuits provide sufficient relay loadability to allow the operator time to reduce loading when the loading is within the circuit's short-time capability to prevent the circuit from tripping.

In applying criterion B4, NERC found that the test is effective for identifying circuits operated below 200 kV that are subject to increased loading following the loss of two system elements. NERC notes that this is the mechanism by which cascading outages occurred in previous system events such as August 14, 2003. While NERC focused its application of the test on circuits operated at 100 kV to 200 kV, the test is also applicable and would be effective when applied to circuits operated below 100 kV. For example, NERC has confirmed that applying criterion B4 would identify sub-100 kV circuits that were contributory or causal in a recent system disturbance. NERC notes that in some cases the Planning Coordinator may identify significant overloads on sub-100 kV circuits that are not part of the BES. In these cases the Planning Coordinator may use this information as one factor in deciding whether a circuit is necessary for reliable operation of the interconnected power system, in which case they may file an exception request in accordance with the BES exception process defined in the NERC Rules of Procedure.

In NERC's evaluation of criterion B4, the number of circuits identified by applying criterion B4 to each system was dependent on the size, topology and operating characteristics of the system to which the test was applied. Results of the testing are presented in Table 2. Results are presented separately for circuits between 100 kV and 200 kV and circuits below 100 kV. This is because the test is applicable to all circuits between 100 kV and 200 kV, but only to circuits below 100 kV that are part of the BES. NERC has not differentiated between circuits below 100 kV that are or are not part of the BES in this analysis, and such determinations will be subject to the BES exception process.

Table 2					
System	B4(d) Rating Threshold (%)[42]	Circuits 100 kV to 200 kV		Circuits Below 100 kV	
		Evaluated[43]	Identified[44]	Evaluated	Identified
AEP	115	2128	2	1646	281
FPL	130	1175	33	63	0
Southern	130	4124	73	0	0
WFEC	115	126	0	162	15
CNP	115	596	17	86	7
IPCO	130	273	16	16	0
PNM	130	364	2	43	0
TSGT	115	194	18	61	0

The following observations are presented based on NERC's experience in applying the test. These observations account for the variations among the results for the systems to which NERC applied the test. It is important to note that when Planning Coordinators uniformly apply the test in Attachment B, the number of circuits identified by each Planning Coordinator will depend on the size, topology, and operating characteristics of their system. As such, some systems will have more circuits operated below 200 kV than others that are important in the context of transmission relay loadability.

- The test identified 100 kV to 200 kV circuits that are operated in parallel with EHV transmission lines when the 100 kV to 200 kV circuits account for a significant portion of the transfer capability, or are the limiting elements in defining transfer capability. For example, 100 kV to 200 kV lines operated in parallel with 345 kV transmission lines are likely to pick up a significant amount of power flow following tripping of multiple 345 kV circuits, and thus it is important that these 100 kV to 200 kV circuits do not trip due to insufficient relay loadability.

42 The B4(d) "Threshold" column lists the threshold for selection of the circuit specified in criterion B4, which varies based on the loading duration assumed in the development of the entities Facility Ratings.
43 The circuits "Evaluated" columns include all circuits in the power flow case in the relevant voltage range
44 The circuits "Identified" columns include all circuits loaded above the B4(d) Threshold in the relevant voltage range, which identifies the circuits that are important in the context of transmission relay loadability.

- The test did not identify 100 kV to 200 kV circuits that are operated in parallel with multiple levels of EHV transmission. For example, when 100 kV to 200 kV circuits are operated in parallel with both 765 kV and 345 kV transmission lines, or with both 500 kV and 230 kV transmission, the 100 kV to 200 kV circuits do not pick up a significant amount of power flow because the parallel higher voltage circuits have significantly lower impedance and therefore pick up most of the power flow. In these cases it is appropriate that the test does not identify circuits operated at 100 kV to 200 kV as they are not at risk of tripping due to increased loading and therefore are not important to reliability in the context of transmission relay loadability.

- The test is less likely to identify circuits when 100 kV to 200 kV circuits are not operated in parallel with EHV transmission system, with the exception of locations with several 100 kV to 200 kV circuits operated in parallel with each other to supply a major load center. This is consistent with the intent of the test in that loss of a small number of isolated circuits that are not operated in parallel with the EHV system will not result in cascading outages, since tripping radial transmission lines will not result in increased loading of other transmission circuits. However, when several 100 kV to 200 kV circuits supply a major load center, it is important to reliability that cascading outages do not result in an outage of the major load center and the subsequent effect on system stability and frequency associated with dropping a large amount of load. Planning Coordinators of such systems are normally very aware of the limitations of their system and could include circuits in the applicability 0f PRC-023-2 through criterion B5.

NERC also noted that for some N-2 contingencies the power flow solution did not solve or solved with an unrealistic voltage (*e.g.,* below 0.80 per unit). This reflects the severity of the test specified in criterion B4 and supports the robustness of the test when applied to the critical system condition of summer peak load. For the purposes of NERC’s evaluation of criterion B4, a number of solution techniques were applied to minimize the number of cases that did not solve or solved with unrealistically low local voltage. Although NERC did not pursue these remaining cases further, in application of the test by the Planning Coordinator, it will be necessary for the Planning Coordinator to consider options such as alternate power flow solution algorithms and techniques, modifying the load model in the power flow, or using alternate programs or study tools to determine the post contingency power flow.

Criteria B5 and B6

Although NERC did not apply these criteria, as noted in the description of the application of the test for this report, these criteria provide an additional level in the defense-in-depth strategy incorporated in Attachment B. These criteria allow inclusion of additional circuits based on the results of other technical analyses or by mutual agreement of the Planning Coordinator and the facility owner. As stated above, criterion B5 permits inclusion of circuits based on other technical analyses if for any reason they are not identified by any of the preceding criteria. In particular, this allows inclusion of a circuit based on operating experience or concerns identified during event analyses.

NERC's experience in applying the test in Attachment B to a representative sample of utilities in the Eastern, Western, and ERCOT Interconnections confirms that the test is robust enough to capture all circuits important to reliability in the context of transmission relay loadability. The Attachment B test for identifying sub-200 kV circuits is especially effective when viewed in concert with standard development and initiatives to provide defense-in-depth against future outages by addressing other factors that have played a role in past events, including vegetation management, implementing transmission relay loadability on all circuits operated at 200 kV and above, and revising the BES definition to include all circuits necessary for reliable operation of the interconnected transmission system.

IV. CONCLUSION

For the reasons stated above, NERC respectfully requests that the Commission accept this filing as compliant with Order Nos. 733 and 759.

Respectfully submitted,

/s/ Willie L. Phillips

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Dated: February 19, 2013

CERTIFICATE OF SERVICE

I hereby certify that I have served a copy of the foregoing document upon all parties listed on the official service list compiled by the Secretary in this proceeding.

Dated at Washington, D.C. this 19th day of February, 2013.

/s/ Willie L. Phillips

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