NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Technical Rationale for Reliability Standard PRC-023-6

October 2022

PRC-023-6 – Transmission Relay Loadability

Rationale for Applicability Section

No changes are proposed to the Applicability of Reliability Standard PRC-023-6 from the prior version.

Rationale for Deletion of Requirement R2

The standard drafting team (SDT) recommends the retirement of PRC-023-5, Requirement R2.

> R2. Each Transmission Owner, Generator Owner, and Distribution Provider shall set its out-of-step blocking elements to allow tripping of phase protective relays for faults that occur during the loading conditions used to verify transmission line relay loadability per Requirement R1.

The SDT also recommends the retirement of Attachment A, Item 2.3 exclusion:

> 2.3 Protection systems intended for protection during stable power swings [excluded].

Summary of Justification to Retire Requirement R2

- The fault condition regulated by Requirement R2 is also regulated by Requirement R1 and requires the same entity response.
- A significant error in the "Determination and Application of Practical Relaying Loadability Ratings," Appendix C, January 9, 2007 documentation of power swing blocking capabilities appears to have led to development of Requirement R2.
- The development history of Requirement R2 used an incomplete discussion of power swings that appears to have convinced FERC to direct a separate requirement on the subject, rather than accept alternate technical solutions that would assure detection and clearing of faults that may occur during power swings.
- The primary intent of this standard is to address a security aspect of the protection system. Adding a dependability focused requirement in this standard results in confusion in setting the protective relays.
- The roughly 10 years of experience under Requirement R2 has shown that neither compliance, system operations, nor system disturbances have had any significant impact on system reliability. In addition, whatever the original risk addressed by Requirement R2, that is now reduced due to subsequent Protection System upgrades.

Requirement R2 is Effectively Redundant to the Performance Required by R1PRC-023-5 R1 includes the phrase "… prevent its phase protective relay settings from limiting transmission system loadability *while maintaining reliable protection of the BES* ***for all fault conditions***." (emphasis added).

Requirement R2 singles out a specific fault condition when it specifies that the applicable entity "shall set its out-of-step blocking elements to allow tripping of phase protective relays for faults that occur during the loading conditions used to verify transmission line relay loadability per Requirement R1." This is not an expansion of the "… all fault conditions" identified in R1. So if an entity failed to comply with R2, they would also fail to comply with R1.

I. Power Swing Blocking, Appendix C Error

NERC System Protection and Control Task Force (SPCTF) wrote the initial version of PRC-023 Reference Determination and Application of Practical Relaying Loadability Ratings, 8/14/2006. This document was revised on January 9, 2007 and added Appendix C to discuss out of step blocking. This discussion only referenced the type of schemes that are typically implemented using electromechanical relays. The conclusion was that "if (and as long as) a system load condition operates the out-of-step blocking relay, the distance relay will be prevented from operating for a subsequent fault condition. A timer can be added such that the relay issues a trip if the out of step timer does not reset within a defined time." Subsequent versions of this document (2017 is the latest) have not changed this wording. These two sentences appear to be the origin of the item that addressed out of step blocking in PRC-023-1 Attachment A.

The above quoted "… subsequent fault condition!" statement remains true for traditional electromechanical relay schemes. The subsequent (and last) sentence indicates that the (optional?) timer would be used to trip the element. This is not appropriate because tripping should not occur during the identified heavy load conditions unless a fault actually occurs on the element. A timer is not capable of such fault detection.

Appendix C does not discuss why the "… subsequent fault condition!" that became Requirement R2 should be excluded from "… all fault conditions" that remains part of Requirement R1. Given the context of Appendix C, the appropriate conclusion would seem to be that unmodified traditional electromechanical PSB schemes, depending on their settings, may not be able to comply with the R1 or R2 requirements. Unfortunately, the lack of discussion of either "… all fault conditions" or more advanced PSB schemes leaves the impression that there is no acceptable technical solution to this issue.

The present SDT recommends that SPCWG review and update this document and has proposed several edits and additions, including several methods available to protection engineers to remediate the fault identification issues during PSB that were identified by the original drafting team. Some combination of these methods to PSB schemes answers the technical concern to allow tripping for any fault that occurs during a heavy loading condition that results in PSB operation. In combination with the existing wording in R1, this makes the existing R2 redundant and therefore unnecessary.

Therefore the present SDT asserts that no specific reference to power swing blocking is necessary as a PRC-023 requirement, but can be appropriately acknowledged in this Technical Rationale~~,~~ and in a revision to "Determination and Application of Practical Relaying Loadability Ratings," Appendix C.

II. Development History of Requirement R2

The original August 2006 version of PRC-023 Reference Determination and Application of Practical Relaying Loadability Ratings described the standard's objective with respect to faults:

> While protection systems are required to comply with the relay loadability requirements of Reliability Standard PRC-023; it is imperative that the protective relays be set to reliably detect all fault conditions and protect the electrical network from these faults.

The introduction also included item "1.3 Out-of-Step blocking," but with no further discussion.

The original wording in PRC-023-1, Attachment A regarding power swing blocking was:

> This standard includes out-of-step blocking schemes which shall be evaluated to ensure that they do not block trip for faults during the loading conditions defined within the requirements.

At least one commenter was concerned that this original wording from the PRC-023-1 SDT did not recognize that the PSB can be reset to allow detection of faults after the PSB function asserts. However, the SDT thought no change was necessary. This SDT response does not acknowledge that resetting of the PSB function is even possible.

- **Comment:** Attachment A 2. A word PERMANENTLY should be added before "block trip…"?[1]
  - **Response:** Attachment A 2- Most commenters seemed to understand the intent of this item without further clarification. If an out[-]of-step relay asserts on load and blocks the trip of fault protective relays, and a fault occurs during that loading condition, the out-of-step relay will prevent successful operation of the fault protective relay. (3/9/2007)

Another commenter expressed a related concern for remotely-connected systems. The SDT acknowledged that some scheme modification may be needed but did not describe what a "more complex" scheme would do.

- **Comment:** I am concerned that this standard as drafted would limit the application of out of step block trip functions for remotely-connected systems.[2]
  - **Response:** Attachment A, Item 2 is intended to ensure that facilities are adequately protected for faults. Out-of-step blocking elements may prevent tripping for true faults

[1] Microsoft Word - Consider_Comments_D2_Relay_Loadability_09Mar07.doc (nerc.com), DRAFT 2 comments, pp 41-43

[2] https://www.nerc.com/pa/Stand/Project%202010131%20Phase%201%20of%20Relay%20Loadability%20Trans/Consider_Comments_Initial_Ballot_PRC-023_Relay_Loadability_31Jan08.doc, DRAFT 4 Comments, p 16

> during extreme loading conditions. For conditions involving remotely-connected systems, more complex out-of-step blocking schemes may be needed. (1/31/2008)

When FERC reviewed (and eventually approved) the proposed PRC-023-1, an objection was that referencing out of step blocking in Appendix A as a "shall" item was important, but not enforceable because it was not a requirement and had no VSL or VRF. FERC observed the use of this "shall" language and directed that this item be rewritten as a requirement. FERC ordered: (Order 733, paragraph 244)

> We adopt the NOPR proposal and direct the ERO to include section 2 of Attachment A in the modified Reliability Standard as an additional Requirement with the appropriate violation risk factor and violation severity level.

The SDT for PRC-023-2 then proposed to add wording to Requirement R1:

> ". . . and to prevent its out-of-step blocking schemes from blocking tripping for fault conditions."

One commenter[3] addressed some technical aspects of this specific wording, in part:

> The specific wording proposed by the SDT may prevent using the out-of-step-block functions of many modern and widely used line protection relays (e.g. SEL-321 and later models and GE-UR). These relay's OSB function first blocks the protection elements from tripping, then uses a short delay and/or other information to determine whether the observed and perhaps evolving condition really represents a fault, in which case the blocking is reset to allow tripping. Such a block/reset operation is the most common technology available and would appear to lie within the intent of FERC in [Order 733] paragraph 244, but could be excluded by the presently proposed language.

Another commenter added[4]:

> "We suggest that the added phrase be removed from R1 and a new requirement created. Suggested wording is "Protection Systems that block for stable swings or out-of-step conditions shall be evaluated to ensure that appropriate tripping will occur for in-section faults that occur during the condition. Some additional delay may be required and is acceptable to ensure that the appropriate tripping occurs."

The SDT's conclusion was:

> The SDT agrees and removed out-of-step blocking from Requirement R1. The requirement pertaining to evaluation of out-of-step blocking protection has been moved to a separate

[3] https://elibrary.ferc.gov/eLibrary/filedownload?fileid=018154B3-66E2-5005-8110-C31FAFC91712 pp 169-170
[4] https://elibrary.ferc.gov/eLibrary/filedownload?fileid=018154B3-66E2-5005-8110-C31FAFC91712 p 189

> requirement (now Requirement R2) to more clearly delineate this requirement from assessment of relay loadability of phase protective relays.

Both of these commenters suggested what became R2 but did not question whether "… all fault conditions" in R1 already included the faults intended to be detected by R2. It appears that, although NERC is permitted to propose an equally efficient and effective alternative to address a FERC directive, the SDT did not consider any alternate solution to FERC's Order 733 directive to include a separate requirement to detect PSB-related faults.

The SDT's proposed (and eventually approved) Violation Severity Level (VSL) and Violation Risk Factor (VRF) for both PRC-023-2 Requirements R1 and R2 were the same.

The SDT realizes that the meaning of original language in the Attachment A was inverted as it was converted to Requirement R2. The wording was changed from "…shall be evaluated to ensure that they do not block trip …" to "… shall set its out-of-step blocking elements to allow tripping …". This resulted in a significant change in how the Requirement R2 is interpreted by protection engineers. The revised emphasis is on relay settings, rather than evaluation of the PSB scheme itself. The focus shifted from evaluating the PSB scheme to the PSB elements, primarily blinders, which are directly controlled by the settings. In cases of conflict, the remedy was to either not use the PSB scheme or significantly increase the scheme complexity.

At least one entity disabled at least two power swing blocking schemes

- Due to concern whether use of a reset timer would achieve the spirit of Requirement R2 to clear faults within appropriate time.
- The outer PSB characteristic could not be set within the loadability characteristics.

III. Security versus Dependability[5]

The purpose of PRC-023 is:

> Protective relay settings shall not limit transmission loadability; not interfere with system operators' ability to take remedial action to protect system reliability and; be set to reliably detect all fault conditions and protect the electrical network from these faults.

The emphasis of PRC-023 is on the security of the transmission system to avoid unnecessary trips during heavy load conditions when no fault occurs. The Purpose and Requirement R1 does include

[5] For the purpose of this discussion the IEEE Standard Dictionary of Electrical and Electronics Terms defines dependability (relay or relay systems) as the facet of reliability that relates to the degree of certainty that a relay or relay system will operate correctly. Similarly, security (relay or relay systems) is the facet of reliability that relates to the degree of certainty that a relay or relay system will not operate incorrectly. Finally, reliability (relay or relay systems) is a measure of the degree of certainty that a relay or relay system will perform correctly. NOTE: Reliability denotes certainty of correct operation together with assurance against incorrect operation from all extraneous causes.

language that "… all fault conditions" (dependability) must be recognized. Requirement R2 carves out a separate dependability item "… to allow tripping of phase protective relays for faults that occur during the loading conditions" as in R1.

The dependability language in R1 is an appropriate balancing of the intent of R1 (security), so mentioning dependability in R1 does not cause confusion. Retiring R2 will make the standard more focused and clear.

IV. Experience with Requirement R2 functionality

Experience is not a perfect guide to judging the necessity of Requirement R2. Absence of evidence is not evidence of absence of failure to clear faults during PSB operations. The approximately 10 years of available history since R2 has been enforceable does provide useful background to judge the scale of potential risk to the bulk power system following R2 retirement. No statistical analysis or antidotal examples can prove that faults will never occur while a relay has asserted its PSB function. However, the extremely small historical occurrence of events that may qualify as faults during a power swing, perhaps as low as zero in this summary, does significantly limit the risk to the bulk power system.

Compliance Violations

A review of compliance violations of the existing Requirement R2 showed only two violations, both discovered about one year after the requirement became enforceable. Both were discovered through review of documentation of relay settings, not from system operations. In both cases the associated Risk Description indicated that the issues posed minimal risk to the reliability of the bulk power system.

An audit finding was due to a 12% deviation from the required loadability and only affected one of the two redundant protection systems. The entity re-calculated their relay settings and found no other related issues on their system.

A self-report identified that one of three redundant protection schemes on each of three transmission lines was impacted by an OSB calculation error. Relay settings on the other two protection schemes for each transmission line were not impacted and acceptable fault clearing would have occurred even if the loading conditions specified in PRC-023-2 R1 were to occur simultaneously with a three-phase fault on the line.

It does not appear that any risk was imposed to the Bulk Power System from these violations, or even whether failure of one of two or three redundant relays to trip for a fault would have constituted a Misoperation since the Composite Protection System would have operated correctly.

Outage and Misoperation Experience

The SDT reviewed TADS and MIDAS data for misoperations involving three phase faults which are more likely to result in power swings and are the events regulated by Requirement R2. For the approximately 5 years of reliable MIDAS data covering about 40,000 total operations, only 11 possible events were discovered, and only a single event involved relays. From the available event descriptions it is not clear that Requirement R2 prevented any of these events.

Major System Disturbances

The NERC Event Analysis web site includes reports for 18 major events. The SDT was also able to review the FRCC disturbance of February 26, 2008 (not listed on the NERC site). These reports were reviewed to discover whether any system impacts were identified from faults during relay power swing block operations. The time range of these events starts before R2 was enforceable until summer 2021. The short summary is that Requirement R2 does not seem to have improved or detracted from system performance during any of these major system disturbances.

Several event reports describe the issues that have been noted regarding PV (lack of) ride through capability during voltage sags associated with fault clearing. There are significant overlapping causes associated with these events. However, these reports describe nothing related to power swings or PSB.

- **June-August 2021 CAISO Solar PV Disturbance Report**
- **May/June 2021 Odessa Disturbance Report**
- **July 2020 San Fernando Solar PV Reduction Disturbance Report**
- **April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbances Report**
- **October 2017 Canyon 2 Fire Disturbance Report**
- **August 2016 1200 MW Fault Induced Solar Photovoltaic Resources Interruption Disturbance Report**

Several event reports cover system performance during cold weather events, hurricanes, and other major weather conditions. Most system impacts resulted from physical damage. None of these reports identified any system impacts due to faults during power swings or power swing blocking. Protection System impacts from all of these events ranged from very minor to none.

- **Cold Weather Training Materials**
  - This is guidance material for preparation and response rather than an event description.
- **January 2014 Polar Vortex Review**
- **October 2012 Hurricane Sandy Event Analysis Report**
- **October 2011 Northeast Snowstorm Event**
  - One relay misoperation was identified, though the specific cause was not described. However, many transmission outages did not destabilize the BPS or regional systems.
- **January 2018 South Central Cold Weather Event Report**
  - Large scale impacts to generation capability, but no specific faults involved, no PSB involved, no recommendation regarding protection against transmission power swings
- **September 2017 Hurricane Irma Event Analysis Report**

  - More than 100 storm forced transmission outages and 3300 MW forced plant outages. There were no identified misoperations that contributed to BPS facilities being out of service during the storm.

- **August 2017 Hurricane Harvey Event Analysis Report**
  - About 225 transmission assets impacted, maximum 21+ GW generation unavailable (ERCOT + MISO). No noted protection system misoperations, power swings, or PSB.

Several events had more traditional and direct electrical causes, but none indicated any power system impact due to faults during power swing blocking conditions.

- **January 2019 Eastern Interconnection Forced Oscillation Event Report**
  - PT failure at a Florida plant induced oscillations throughout the Eastern Interconnection: 200 MW swings at the plant, 50 MW in New England. No faults involved, no PSB involved, no recommendation regarding protection against transmission power swings.
- **April 2015 Washington D.C. Area Low-Voltage Disturbance Event**
  - 58 second fault clearing resulting from equipment failure and protection system misoperations of two auxiliary tripping systems. Recommendations relate to trip auxiliary design and breaker failure initiate. No noted impacts from power swings or PSB.
- **September 2011 Southwest Blackout Event**
  - FERC/NERC Staff Report on the September 8, 2011 Blackout affecting Arizona and Southern California identified that large open circuit angles were not monitored for particular facilities in Arizona to determine whether closing could be safely accomplished. However, this result affected restoration rather than resulting from any power swing on the system, so did not involve PSB. The San Onofre nuclear plant also tripped on turbine control logic as local frequency spiked above 61 Hz. No fault or tripping was associated with a power swing or PSB.
- **FRCC System Disturbance**
  - The FRCC disturbance of February 26, 2008 included a zone 1 trip during a power swing (PSB was not applied) but was roughly the 15th event in the disturbance sequence. The report did not recommend any related protection system changes.
- **August 2003 Northeast Blackout Event**
  - The Northeast blackout of August 14, 2003 did involve a few out of step line trips on distance relay elements late in the event sequence that may have been prevented by application of PSB. However, the entire event did not include any case of failure to clear a fault due to PSB relay elements failing to reset under relay loadability conditions described in PRC-023.

Protection System Improvements

Most entities have continued to replace electromechanical, solid state, and early generations of microprocessor relays with newer microprocessor relays since Requirement R2 became effective. The effect of these upgrades is that these newer relays can more easily comply with the intent of the original

wording in Appendix A of PRC-023-1. This upgrade process further reduces any risk that is intended to be addressed by Requirement R2. For example, one entity that extensively applies PSB and out of step tripping on its transmission system began 2011 with 161 of 471 (34%) of affected line terminals protected by these lower capability (electromechanical) relays. By 2022 only 19 of 699 (2.7%) of the affected line terminals were still protected by these less capable relays. A second entity has upgraded all of their out of step applications to modern microprocessor-based schemes. A third entity has upgraded all of its out of step applications above 200 kV to modern microprocessor relays and has only a single electromechanical application still in service at 115 kV.

Justification to Retire Attachment A, Item 2.3 Exclusion

Attachment A item 2.3 excludes "Protection systems intended for protection during stable power swings". This exclusion is referencing "Protection systems installed specifically to separate portions of the system that are experiencing stable power swings relative to each other in order to maintain desirable performance relative to voltage, frequency, and power oscillations"[6]. Florida was cited in the record of development as an example of where these schemes were employed. Research has indicated that these schemes no longer exist and there is no need for a power swing tripping exclusion. PRC-026 covers stable power swings adequately. Since Item 2.3 is an exclusion, there is no overlap with PRC-026.

The original PRC-023-1 SDT response to comments included the following statements:

- (12) In some parts of North America (for example Florida), there are relay systems installed specifically to separate portions of the system that are experiencing stable power swings relative to each other to maintain desirable performance …. [footnote 6, p 48]
- Where out of step tripping or blocking relays are applied independently within the system they must comply with the standard. [footnote 6, p 55]

The normal practice for power systems generally should not be to intentionally separate during stable power swings. It is the understanding of the present SDT that the example scheme from Florida is no longer used. The second bullet response seems to say that exclusion 2.3 should never have been included.

The present SDT asserts that Attachment A, Item 2.3 can be safely retired without creating a reliability gap.

[6] See Project 2010-13.1 Phase 1 of Relay Loadability: Transmission Draft 1 Relay Loadability Standard Consideration of Comments https://www.nerc.com/pa/Stand/Project%202010131%20Phase%201%20of%20Relay%20Loadability%20Trans/Consider_Comments_1st_Draft_Relay_Loadability_Std_09Jan07.pdf