



Grid Research, Innovation, and Transformation

Implementation Considerations for Negative Sequence Current Injection Requirements for Inverter- Based Resources in ERCOT

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Executive Summary

ERCOT continues to experience rapid growth in Inverter-Based Resources (IBRs), fundamentally changing the dynamic and fault-response characteristics of the transmission system. To address these changes, Nodal Operating Guide Revision Request (NOGRR) 245 established new capability and performance requirements for IBRs by formally adopting the following sections of IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems (IEEE Std 2800-2022):

- Section 5: Reactive power-voltage control requirements within the continuous operating region,
- Section 7: Response to transmission system abnormal conditions, including fault ride-through and current injection behavior, and
- Section 9: Protection-related requirements and coordination considerations.

Among these requirements, negative sequence current injection (NSCI) during unbalanced faults, as specified in IEEE Std 2800-2022 Clause 7.2.2.3.4, represents a significant new expectation for IBR performance in ERCOT. While NSCI was previously recommended by industry working groups, it is now a mandatory requirement for applicable new and modified IBR projects under ERCOT Nodal Operating Guide Section 2.9.1(2).

Unlike synchronous generators, which inherently produce predictable negative sequence currents during unbalanced faults, IBR fault response is mainly governed by power electronic controls. IEEE Std 2800-2022 establishes the requirement for NSCI, but it does not prescribe detailed performance characteristics such as current magnitude, phase-angle relationship, response time, duration, or current-priority logic. These parameters must therefore be defined based on transmission system needs, including protection performance, fault ride-through requirements, and equipment capability.

As a result, inconsistent or uncoordinated implementation of NSCI by IBRs could adversely impact transmission protection systems that rely on negative sequence quantities for fault detection, directionality, phase selection, and selectivity. In addition, the interaction between NSCI and positive sequence current injection must be properly evaluated to ensure that protection-supporting current injection does not compromise required

ride-through performance, voltage support, or fault-current recovery. The implementation of NSCI also introduces additional needs for short-circuit modeling, data collection, validation, and coordination among ERCOT, Transmission Service Providers (TSPs), Generator Owners (GOs), IBR developers, and original equipment manufacturers (OEMs).

To better understand these impacts and inform a coordinated path forward, ERCOT conducted a survey of TSPs through the System Protection Working Group (SPWG). The survey gathered feedback on the following areas:

- Existing transmission protection practices in systems with high IBR penetration,
- Observed and anticipated impacts of NSCI on key protection functions,
- Expectations for acceptable NSCI performance characteristics needed to support reliable protection operation, while maintaining required ride-through performance associated with positive sequence current injection and voltage support requirements,
- Recommendations for new processes, models, and data requirements to support NSCI implementation and protection coordination.

Survey feedback consistently emphasized the need for clear, system-specific NSCI guidance, improved visibility of IBR fault behavior in short-circuit and protection studies, and stronger coordination among ERCOT, TSPs, GOs, IBR developers, and OEMs. TSPs highlighted concerns related to relay dependability and security, directional element performance, weak-infeed conditions, model adequacy, short-circuit data requirements, and the absence of standardized validation and monitoring practices for NSCI behavior.

Based on the survey feedback and related technical review, this white paper recommends the following action items and a collaborative implementation approach to support consistent and reliable NSCI implementation in ERCOT:

1. Develop SPWG-led, TSP-driven NSCI performance guidance that defines expected NSCI characteristics needed to support transmission protection performance. This guidance should provide a common framework while allowing TSPs to develop more detailed NSCI profiles where needed.
2. Update IBR short-circuit modeling methodologies and data collection processes to better represent IBR sequence-current behavior and NSCI capability in protection and short-circuit studies.

3. Establish NSCI-related event monitoring and reassessment practices to identify protection events or misoperations that may be associated with unexpected NSCI behavior, and further to determine whether NSCI performance guidance, relay settings, or modeling practices should be updated.
4. Apply a coordinated implementation approach through ERCOT working groups, particularly SPWG and the Inverter-Based Resources Working Group (IBRWG), to align transmission protection needs with achievable IBR capabilities and limitations, and close remaining implementation gaps through coordinated industry engagement.

This document seeks to raise industry awareness of upcoming NSCI implementation considerations and promote effective coordination among ERCOT, TSPs, GOs, IBR developers, IBR OEMs, and relay manufacturers. The overarching objective is to ensure that NSCI requirements enhance transmission protection performance and system reliability, while supporting ERCOT's transition to a resilient grid with high levels of IBR penetration. By identifying key gaps and recommended actions, this white paper provides a basis for coordinated industry efforts to address protection coordination, ride-through performance impacts, short-circuit modeling, data collection, validation, and ongoing monitoring associated with NSCI implementation.



1. Introduction

As the penetration of inverter-based resources (IBRs) continues to increase across the ERCOT region, the dynamic and transient behavior of the power system is undergoing fundamental change. In particular, the distinct fault current signatures of IBRs, compared to those of conventional synchronous generators, have raised concerns regarding whether existing protection systems, originally designed for synchronous generator dominated networks, can continue to operate reliably under high levels of IBR integration.

Traditional power system protection practices were developed around the short-circuit current contributions of synchronous generators, which historically comprised the majority of ERCOT's generation fleet. The fault response of a synchronous generator is largely governed by the physical characteristics of its rotating machine and electromagnetic coupling, resulting in predictable, sustained, and relatively high magnitude fault currents. These characteristics have long supported dependable and selective operation of transmission protection schemes.

In contrast, the fault response of an IBR is determined primarily by its internal control systems and the electrical conditions at its point of interconnection. While ERCOT's current dynamic studies focus mainly on IBR behavior under balanced conditions such as positive sequence current injection during three-phase faults, the response of IBRs to unbalanced faults has received comparatively less attention. In particular, the ability of IBRs to contribute negative sequence current during unbalanced faults represents a potential gap when considering the continued effectiveness of protection systems that rely on negative sequence quantities for fault detection, directionality, and selectivity.

As ERCOT transitions toward a power system with a higher proportion of IBRs, addressing this gap is essential to ensure that protection systems can continue to detect and clear unbalanced faults reliably and maintain overall system security.

2. Fault Response of Generating Resources: Negative Sequence Current Injection (NSCI) and Protection Impact

In transmission grids dominated by synchronous generators, legacy protection schemes (distance, directional, differential, pilot) assume fault currents distinctively higher than load current, predictable fault currents, and stable sequence relationships. As IBR penetration rises, the effective short circuit strength generally declines and fault current signatures become increasingly dependent on inverter control behavior, including current magnitude, phase angle, response time and duration. These changes can challenge legacy transmission protection schemes that were designed around the predictable fault-current response of synchronous generators. Based on [\[1\]](#), this section summarizes the fundamental fault response characteristics of both synchronous generators and IBRs and discusses their implications for transmission protection performance and coordination.

2.1 Fault Response of Synchronous Generators

Under fault conditions, synchronous generators can supply very high levels of fault current, typically on the order of 5-7 per unit of rated current during the sub-transient period. This relatively large and predictable fault current contribution has been a fundamental assumption of conventional power system protection design, supporting dependable fault detection, selectivity, directional determination, and coordinated isolation of faulted equipment. While voltage at and near the fault remains depressed, the generator's electromagnetic fault current response and excitation support contribute to post fault voltage recovery and overall transient stability.

During unbalanced faults, the negative sequence voltage (V_2) is raised, and the negative sequence current (I_2) flows through the synchronous generator. The magnitude of this current is largely governed by the negative sequence impedance of the generator, which is commonly approximated as the average of the direct-axis and quadrature-axis sub-transient reactance, and

the surrounding power system. In symmetrical component fault analysis, synchronous generators are represented using the positive, negative and zero sequence networks, which are interconnected at the fault location according to the fault type. This representation results in predictable and well understood negative sequence current behavior during unbalanced fault conditions. As illustrated in Figure 1 [1], prior to the fault, V_2 and I_2 are zero under balanced operation. Once an unbalanced fault (e.g. a line-to-line fault) occurs, V_2 rises, and because a synchronous generator presents a low negative sequence impedance path, a substantial I_2 circulates through the machine. Using the common protection convention in which I_2 is defined as the negative sequence current contribution from the source toward the fault, the negative sequence voltage satisfies approximately $V_2 = -Z_2 I_2$. The negative sequence network seen from a synchronous generator is predominantly inductive, so for typical phase to phase faults the I_2 phasor leads V_2 by about 90° .

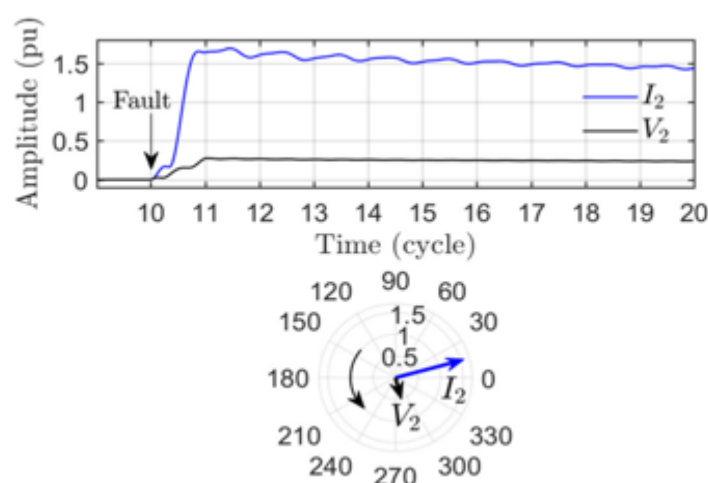


Figure 1: Negative sequence voltage and current - synchronous generators scenario

2.2 Fault Response from IBRs

Unlike conventional synchronous generators (with naturally occurring electromechanical response defined by physical machine characteristics), the fault current contribution from an IBR is based on programable controls. Their behavior depends on site specific conditions such as:

- Control philosophies of IBR (grid-following vs grid-forming)
- Current priority logic (power priority, voltage priority, real vs reactive priority etc.)
- OEM specific implementations
- Current limits in the hardware

These control differences can result in large differences in fault signatures. In addition, their magnitude is physically limited by semiconductor and thermal constraints (often $\sim 1.1 - 1.4$ per unit compared with $\sim 5-7$ per unit for synchronous generators).

Under unbalanced faults, the sequence coupling for IBRs occurs inside the controller. If the negative sequence current control is not specified, the voltage unbalance affects current injection in all sequences through the internal control logic. If the negative sequence current control is enabled, negative sequence fault current contribution from IBRs can be roughly divided into two categories:

1. Full Size Converter (FSC), like Type IV WTGs, PV plants and BESS: NSCI is a control output
2. Type III WTGs (DFIG): NSCI has a contribution from the induction machine, but controllers can reshape it

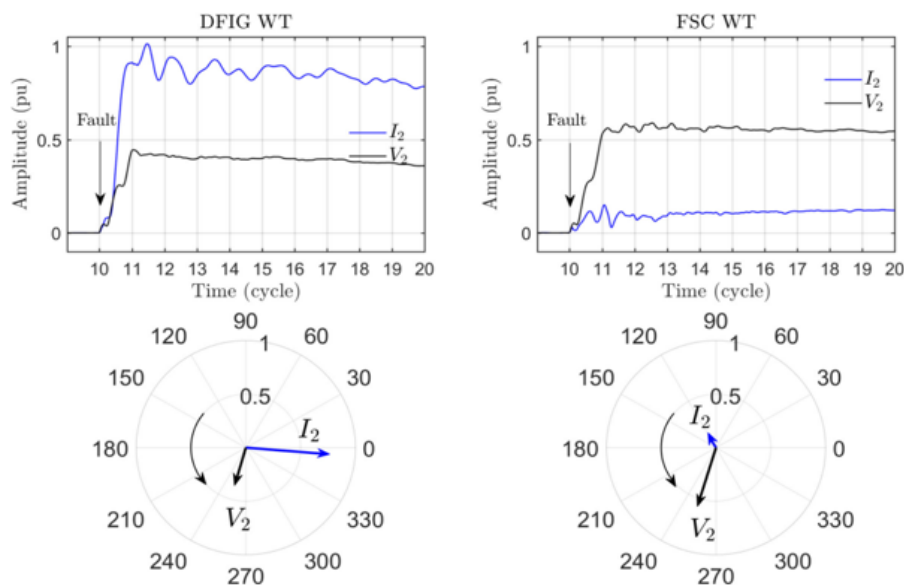


Figure 2: Negative sequence voltage and current - DFIG scenario (left) and FSC WTG scenario (right)

Figure 2 [\[1\]](#) compares the negative sequence voltage and current responses of two studied IBR technologies, a DFIG WTG (left) or an FSC WTG (right), under the same fault condition used for the synchronous generator response shown in Figure 1. Compared to the plots in Figure 1, Figure 2 illustrates two significant differences between the NSCI characteristics of IBRs and synchronous generators:

1. The amplitude of the negative sequence fault current is generally smaller for IBRs. This implies that IBRs generally do not provide a low, naturally occurring negative sequence impedance path, compared with synchronous generators, during unbalanced faults. The “equivalent impedance” is control dependent and should not be treated as a fixed physical impedance.
2. The phase angle relationship between V_2 and I_2 for IBRs is control dependent and may vary with OEM implementation. In contrast, for synchronous generators, this relationship is primarily governed by the machine negative-sequence impedance and is typically close to 90° , assuming the negative sequence reactance is dominant.

2.3 Protection Impacts with NSCI from IBRs

Traditional protection systems were designed based on the expected fault response of synchronous generators, which can provide relatively high and predictable short-circuit current during faults. IBR fault current characteristics are determined by power electronic controls, converter current limits, and the limited short duration overload capability of power electronic devices. As a result, IBRs typically provide lower and more control dependent fault current than synchronous generators. Thus, higher levels of IBR integration can challenge existing protection schemes that depend on high and predictable fault currents and stable phase relationships for fast and selective operation.

Similarly, the NSCI from IBR is control dependent and may vary in magnitude, phase, and duration. Without clear guidance, inconsistent NSCI behavior may adversely impact protection functions that rely on negative sequence signals. The smaller or variable I_2 magnitudes and inconsistent angle relationships under high IBR penetrations degrade element observability and directional security, increasing the risk of misoperations of the following relay elements and schemes across utilities [\[1\]](#):

- 50Q/51Q (negative sequence overcurrent)
Pickup settings assume substantial I_2 under unbalanced faults. IBRs may provide lower or control limited I_2 , reducing sensitivity and increasing the risk of delayed operation or no-trip conditions.
- 67Q (negative sequence directional overcurrent)
Two failure modes arise: (i) no assertion when I_2 is too small; (ii) direction misclassification when the $I_2 - V_2$ angle deviates from the expected $\sim -90^\circ$ forward signature. The EPRI report identifies cases where 67Q declared reverse on in line faults with FSC IBRs, and angle deviations under DFIGs triggered incorrect direction.
- Communication assisted pilot schemes (Permissive Overreaching Transfer Trip (POTT), Permissive Underreaching Transfer Trip (PUTT), Directional Comparison Blocking (DCB), and Directional Comparison Unblocking (DCUB))
These schemes rely on dependable directional supervision at each terminal. If local 67Q or another negative sequence based directional element misclassifies or fails to assert the fault direction due to insufficient or control dependent I_2 , the associated permissive, unblock/block signals may be incorrect or absent, leading to incorrect tripping at the remote end. The EPRI report shows misoperations across POTT/PUTT/DCB/DCUB under high IBR cases.
- Phase selection / Fault identification (FID)
FID sectors rely on stable sequence angle relationships (e.g., I_2 vs I_0). With FSC IBRs, the EPRI report demonstrates angles falling outside expected sectors, causing incorrect or failed phase identification, while DFIGs may remain correct depending on controls.

As a result, coordinated specification of IBR fault response characteristics is necessary to ensure reliable protection performance and secure system operation.

2.4 Example of a Known Misoperation Due to a Lack of NSCI

In *Investigating a Transmission Line Misoperation Caused by IBR Penetration* [2], Nguyen et al. analyzed a misoperation that demonstrated how insufficient and unstable NSCI from an IBR can affect protection elements. On September 22, 2022, Dominion Energy experienced a misoperation after a single-line-to-ground (SLG) fault was not fully cleared

on a radial system with IBR facilities. To protect the weak source terminal (terminal with IBR facilities), Dominion Energy used the Directional Comparison Blocking (DCB) scheme with Transfer Trip (TT). Dominion Energy also used a negative sequence voltage polarized directional element (32QG) to provide directionality for ground fault protection.

During the fault, the strong source terminal correctly detected the fault, opened its local breakers, and sent the TT signal to the weak source terminal. However, there were fluctuations in the angle differences measured by the relays at the weak source terminal which caused the FIDS logic and directional elements to operate incorrectly. The FIDS logic uses the angle difference between zero sequence current (I_0) and I_2 to determine the type of fault. Because of the fluctuations, the fault type was misclassified. Additionally, the 32QG element uses the angle difference between V_2 and I_2 to determine whether the fault is in the forward or reverse direction. Given that there were fluctuations, the forward output relay word bit of the 32QG element, F32QG, asserted and de-asserted before the carrier coordination timer (21SD) timed out. The 21SD timer allows time for a block signal to arrive from the remote terminal before the local terminal trips. Consequently, the breakers at the weak source terminal did not trip. Also, the TT signal sent from the strong source terminal did not trip the weak source terminal breakers because the strong source terminal de-asserted the TT signal before the TT receive timer was satisfied at the weak source terminal.

Although the strong source terminal detected the fault and opened its breakers, the breakers at the weak source terminal remained closed, creating an island. The SLG fault then evolved into a line-to-line-ground (LLG) fault and was then cleared by phase distance protection. The event illustrates the impact of insufficient NSCI on fault identification logic and directional elements that rely on negative sequence quantities.

3. Industry Requirements and Practices

3.1 IEEE Requirements

IEEE Std 2800-2022 [3] establishes uniform technical minimum requirements for interconnection, capability, and lifetime performance of transmission connected IBRs. That includes how plants respond to abnormal transmission system conditions, addressed in Section 7 in the Standard, and protection related responses, addressed in Section 9 of the Standard.

Within Section 7, current injection during ride-through is required. The requirement of negative sequence current injection (NSCI) during unbalanced faults as required by IEEE Std 2800-2022 Clause 7.2.2.3.4 is listed below [3]:

For unbalanced faults, in addition to increased positive sequence reactive current, the IBR unit shall inject negative sequence current:

- *Dependent on IBR unit terminal (POC) negative sequence voltage and*
- *That leads the IBR unit terminal (POC) negative sequence voltage by an allowable range as specified below:*
 - *90 degrees to 100 degrees for full converter-based IBR units*
 - *90 degrees to 150 degrees for type III WTGs*

Assuming pre-fault negative sequence current output is zero or negligible, the negative sequence reactive current injection during a fault is an incremental negative sequence reactive current ($\Delta IR-2$). If the IBR unit's total current limit is reached, either $\Delta IR-1$, or $\Delta IR-2$, or both may be reduced with a preference of equal reduction in both currents. Additionally, the incremental positive sequence reactive current ($\Delta IR-1$) injection shall not be reduced below incremental negative sequence reactive current ($\Delta IR-2$). In case of type III WTGs, the $\Delta IR-1$ and $\Delta IR-2$ injection during a fault is driven by machine parameters and control dynamics and may not be controllable in a manner described above.

In summary, IEEE Std 2800-2022 requires IBRs to provide NSCI as a minimum performance capability during ride-through for unbalanced faults. The standard uses mandatory 'shall' language for current injection but intentionally does not prescribe detailed numerical targets, such as exact per unit magnitude, duration, or V_2 - I_2 phase angle. These parameters are left to the TSP / Transmission Operator (TO) to define based on local system needs.

3.2 NSCI Requirement in ERCOT

The ERCOT Nodal Operating Guides, as revised by NOGRR 245, adopts IEEE Std 2800-2022 Sections 5 (reactive power/voltage control), 7 (response to abnormal transmission-system conditions), and 9 (protection) within Section 2.9.1 and related subsections [\[4\]](#).

Transmission connected IBR projects with

1. a Standard Generator Interconnection Agreement (SGIA) executed on or after August 1, 2024; or
2. a Generator Interconnection Modification (GIM) initiated on or after August 1, 2024,

must be both capable of and configured to perform NSCI during applicable unbalanced faults, in compliance with IEEE Std 2800-2022 performance obligations.

ERCOT does not prescribe detailed numerical targets for NSCI (e.g., per unit magnitude, injection duration, or the V_2 - I_2 phase relationship). Those quantitative characteristics are left to the TSPs to specify to suit local system needs and protection coordination.

3.3 Short-Circuit Modeling

Every year ERCOT produces short-circuit models using ASPEN Oneliner in coordination with TSPs. In these models, IBRs are modeled as current limited synchronous machines. These models have limitations for fully representing the fault current response of IBRs. However, newer models are available that more accurately simulate the fault contributions from IBRs.

These newer models within ASPEN Oneliner include voltage-controlled current sources (VCCS), Type-III wind plants, and converter-interfaced resources (CIRs). ASPEN and other software vendors are collaborating on black-box IBR models for short-circuit simulations that will allow for manufacturers to embed proprietary control details into the model. The VCCS model is an earlier design that allows for customized options about current magnitude and angle at various terminal voltages, but it only accounts for the positive sequence current injection, not negative sequence current injection. The Type-III plant, CIR and black-box models are required to model the IBRs positive and negative sequence current injection.

ERCOT is evaluating adopting the Type-III wind plant and CIR models but may need additional data to model these resources. ERCOT is also monitoring the development of black-box models and will consider their adoption as they are ready for use. Compounding the challenges of adopting a new modeling methodology is that data collection for generators is a multi-year effort as generation owners must coordinate with the equipment manufacturers to obtain the proper modeling parameters.

4. Survey on NSCI with TSPs in ERCOT

4.1 Purpose of the Survey

To facilitate the implementation of NOGRR 245 on NSCI from IBRs, in early December 2025, ERCOT collaborated with the SPWG to issue a voluntary survey on Protection System Practices for IBR Negative Sequence Current Injection Implementation to its members. The purpose of the survey was to gather information on TSP protection and modeling practices to support a coordinated approach to improving system protection coordination, ensuring consistency of IBR NSCI performance, and maintaining a reliable and resilient grid. The survey requested input on the following topics:

- Current protection practices for transmission systems with IBR integration,
- Expected impacts and necessary adjustments to major protection functions resulting from the enablement of NSCI,
- Associated acceptable levels and response characteristics of NSCI required for mandatory IBR control performance during fault conditions to satisfy system protection requirements, and
- Recommendations on new processes, models, and data submission requirements with respect to NSCI from IBRs.

The full set of survey questions is provided in Appendix A.

4.2 Key Findings from Survey Feedback

A total of 14 responses were received from TSPs in ERCOT. Collectively, their responses highlight converging practices and common gaps for integrating NSCI into transmission protection.

1. Protection practices are moving toward weak source tolerant schemes on transmission lines connecting IBR facilities and in areas with high IBR penetration. Respondents use or plan to use line current differential (LCD) and permissive overreaching transfer trip (POTT) on corridors hosting IBRs. Distance/directional elements remain in

service, but their polarization (sequence choice) and pickup thresholds are reviewed more critically in weak grid areas (e.g., dual differential, backup distance, and delayed backup configurations).

2. Legacy directional elements may need retuning. Several entries reference “directional element operation concern” and NO TRIP/misdirection risks in high IBR pockets, driving preference for zero sequence polarization, stronger weak infeed logic, and pilot assists to restore dependability/security.
3. NSCI behavior specification must be explicit to avoid misoperations. Respondents ask for clear NSCI requirements at the Resource Point of Accountability (RPA), including minimum negative sequence current magnitude, the expected phase angle relationship between I_2 and V_2 , and response time requirement. A well-defined NSCI profile is needed to support negative sequence directional security and phase selection validity.
4. Documented utility guidance is limited. Several respondents note “no documented requirements” and reliance on other utility or relay manufacturer application guidance, highlighting the need for a practice guidance to standardize expectations on NSCI profile.
5. Model/data gaps persist and slow implementation of consistent settings across ERCOT. Respondents seek vendor qualified models (with controller limiters, sequence domain behaviors) and uniform ASPEN libraries for NSCI, and generator data detailing $I_2(V_2)$ characteristics. As IBR controls dominate the behavior of an IBR in the first three cycles after a fault, relays must be validated against the IBR controls. A model that reproduces IBR controller behavior in the first few cycles is critical as that is when relays decide how to respond.

4.3 Recommended Actions and Implementation Approach

The following recommended actions are proposed to address the concerns and gaps, which were identified through the ERCOT TSP survey and highlighted in the previous section. The first three items are recommended action items. The fourth item describes the recommended collaborative implementation approach for moving these actions forward through ERCOT working groups and industry engagement.

1. Develop NSCI Performance Guidance

Building on IEEE 2800-2022 as adopted by ERCOT, SPWG should lead the development of TSP-driven NSCI performance guidance for IBRs. The guidance should establish a common framework for defining NSCI expectations needed to support transmission protection performance, while allowing individual TSPs to define a more detailed system-specific NSCI profile based on the local relay applications and system conditions. The guidance should specify:

- Negative sequence current response as a function of negative sequence voltage, $I_2(V_2)$, including expected magnitudes range and applicable converter current limits;
- Expected I_2 and V_2 phase angle relationship, including the applicable angle window;
- Response time expectations, including rise time, settling time, and response during the first few cycles of the fault;
- Response duration and behavior through fault clearing and post fault recovery;
- Current priority logic when positive sequence reactive current for ride through competes with NSCI under IBR converter limits;
- Applicability considerations for different IBR technologies, including Type-III wind, Type-IV wind, solar PV, battery energy storage, grid following controls, and grid forming controls, which is equivalent to ERCOT Advanced Grid Support Inverter based Energy Storage Resource (AGS ESR).

2. Update IBR Short Circuit Modeling Methodologies and Data Collection

ERCOT should implement the following recommendations to improve data collection and modeling practices to adopt newer IBR modeling methods for short-circuit programs that represent NSCI from IBRs:

- Provide a roadmap for adopting Type-III Wind Turbine, CIR, and eventually black-box models. The roadmap should include the parameters needed for modeling.
- Update RIOO to include the roadmap parameters required to collect the information needed to model Type-III Wind plant, CIR, and black-box models for ASPEN Oneliner.
- Develop processes for benchmarking short-circuit model responses against EMT models, and real-time events.

3. Establish NSCI Related Misoperation Monitoring

SPWG, in coordination with TSPs, should establish a process to monitor protection misoperations that may be related to insufficient or inconsistent NSCI behavior. When events indicate NSCI related issues (e.g., directional misclassification, phase selection failures), the event should trigger a reassessment of the applicable NSCI performance assumptions. Where appropriate, modeled IBR fault response behavior should be compared against field measurements to identify potential model gaps or needed improvements. Findings, lessons learned, and recommended updates to NSCI performance guidance or modeling practices should be shared with the industry through SPWG or other appropriate ERCOT working groups. This process should be coordinated with existing protection misoperation review and reporting practices and should not create duplicative reporting requirements unless additional process changes are determined to be necessary.

4. Recommended Collaborative Implementation Approach

ERCOT should facilitate a coordinated implementation approach through SPWG, Inverter-Based Resource Working Group (IBRWG), and other appropriate ERCOT working groups. This approach should bring together ERCOT, TSPs, Interconnecting Entities, Resource Entities, IBR developers, OEMs, and other technical stakeholders to address NSCI implementation gaps in a coordinated manner. This coordinated engagement should be used to:

- Align transmission protection needs with achievable IBR NSCI capability and limitations;
- Develop SPWG-led NSCI performance guidance that supports protection coordination while considering IBR control capability, converter current limits, ride-through requirements, and stability impacts;
- Support TSP development of more detailed NSCI profiles where needed for local protection applications;
- Define a path for Interconnecting Entities and Resource Entities to submit updated modeling packages and supporting data for IBR short circuit models and to develop validation methodologies; and
- Coordinate event monitoring, data review, and post-event analysis, and periodic reassessment of NSCI guidance, modeling practices, and protection performance as IBR penetration continues to increase

This collaborative approach will help ensure NSCI implementation is consistent across ERCOT, technically achievable for IBRs, supportive of reliable protection coordination, compatible with ride-through requirements, and properly represented in short circuit model. As IBR penetration continues to increase, addressing these remaining implementation gaps will be critical to maintaining reliable protection system performance and supporting overall grid reliability

5. References

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APPENDIX A Survey on Protection System Practices for IBR Negative Sequence Current Injection Implementation

1. Please describe and provide document references or links for system protection requirements or guidelines in your area that are specific to IBR integration (e.g., protection coordination, relay settings, fault performance criteria).
2. (a) What types of protection elements, such as overcurrent, directional, distance protection, or others, are most commonly used today for transmission lines or equipment connected to IBRs? (b) How do you approach protection element selection and settings for transmission lines with different levels of IBR penetration (both high and low), assuming no NSCI from IBRs?
3. (a) Have you observed misoperations of protection devices associated with IBR integration?
(b) If yes, please describe the events and identify the typical causes (e.g., under/over-reach due to incorrect impedance calculation, wrong phase selection, incorrect fault directionality, tripping delays, etc.).
(c) Do you anticipate an increase in such misoperations as IBR penetration continues to grow?
4. In your area of operation, are there any IBRs currently implementing NSCI during faults as required by IEEE Std. 2800? If so, please specify the unit(s) or project(s) involved.
5. What concerns, if any, do you have regarding existing relay elements and their settings if future IBR projects are required to provide NSCI?
6. What relay elements, settings, or protection schemes would you recommend for transmission assets in future IBR projects with NSCI enabled?
7. (a) From a system protection perspective, do you recommend specific characteristics for IBR NSCI when configuring transmission protection?
(b) If so, please provide recommendations regarding acceptable levels and response characteristics during unbalanced faults (e.g., response speed, injection duration, magnitude in p.u. of incremental or absolute NSCI, and the phase angle relationship between negative sequence voltage (V_2) and current (I_2)).
8. Do you expect any changes to fault clearing times with the implementation of NSCI in IBRs?
9. From a system protection perspective, what new procedures, data, or models from IBRs should be incorporated into the interconnection

process for future projects with NSCI enabled?

10. Do you recommend verifying IBR compliance with the NSCI requirements specified in NOGRR 245 to ensure correct operation of protection systems? If yes, please describe the methods or procedures you would suggest.
11. What additional modelling data and information would you need to incorporate NSCI into short-circuit models in order to accurately replicate IBR behavior observed in the field?
12. Do you have any additional concerns regarding transmission protection systems in relation to IBR integration that may not be adequately addressed today or in the future? For example, are there specific substation configurations that could further complicate relay settings or coordination?



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