PNNL-34345

Regulatory Protection and Control Standards Applicable to the Vietnam Grid with High Inverter-Based Resource (IBR) Penetration

A Review of Standards Applicable for Vietnam Grid

June 2023

Kiana Brown
Bhaskar Mitra
Marcello Elizondo
Scott Morris

PNNL-34345

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from
the Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062
www.osti.gov
ph: (865) 576-8401
fox: (865) 576-5728
email: reports@osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd.,
Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
or (703) 605-6000
ov
line ordering: http://www.ntis.gov

PNNL-34345

Regulatory Protection and Control Standards Applicable to The Vietnam Grid with High Inverter-Based Resource (IBR) Penetration

A Review of Standards Applicable for Vietnam Grid

June 2023

K. Brown
B. Mitra
M. Elizondo
S. Morris

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99354

Abstract

This report provides a review of the current standards and practices followed by regulatory authorities for interconnection of inverter-based resources (IBR). With the increased penetration of IBRs into the transmission and distribution networks, the legacy protection methodologies are getting challenged. Due to the lack of regulations on IBR operations under a fault, it is essential to have a thorough understanding of the present-day interconnection standards to ensure proper IBR operations. A focus is placed on the regulation and standards enforced by the North American Reliability Corporation (NERC), Federal Energy Regulatory Commission (FERC), Institute of Electrical and Electronics Engineer (IEEE), Underwriters Laboratories (UL) and other regulations proposed by the responsible commissions.

Executive Summary

Conventional power system protection practices in the United States (U.S.) date back over 100 years, when IBR penetration levels were negligible, and fault current contributions were dominated by the response of rotating machines (primarily synchronous generators). The response of a synchronous generator to a fault on the bulk power systems (BPS) is determined by the physics of the rotating machine. The fault response of an IBR, in contrast, is determined by a control system response to its terminal conditions. The way the fast-acting controls within the inverter respond to rapidly changing terminal conditions is an engineered feature, but not well understood by system protection engineers. Low fault current contribution from IBRs challenge present day protection settings. The fault detectors need to be set to very sensitive levels to detect faults, thus risking operating all the relays under no-fault scenarios. Traditional protection schemes (including directional, non-directional, and differential) schemes work well for traditional power systems but may experience reduced reliability (Chowdhury et al.) with high IBR-penetrated systems. IBRs have a different fault current signature as compared to the conventional synchronous generators (SGs). SG fault signatures are driven by laws of physics while IBRs depend on the converter control and current limiting scheme. Specifically:

Fault current magnitudes are typically lower for IBR-controlled generation.

The fault current has an initial transient response followed by the nominal transient response (this response varies for different types of installations). IBRs have negligible or fast decaying fault response lacking the magnetic characteristics of a traditional SG.

Fault current phase angle is dependent on the inverter operating mode (reactive power/voltage control).

In the cases where negative sequence currents are utilized for relay operations; IBR controlled sources have negative current partially or fully suppressed.

Presently in the US, there are no standardized responses for IBR fault currents connected to transmission systems (TS) (Behnke et al.). IBR are usually operated using: (i) Coupled sequence control and (ii) De-coupled sequence control. Coupled sequence control in IBRs does not allow injection of negative sequence currents and decoupled sequence control provides priority to positive sequence currents to manage the fault ride through (FRT) settings. Under such a scenario, fault current is limited by inverter controls and makes it challenging for different relays to distinguish between normal operation and fault scenarios.

The initial current magnitude could be as high as 2.5 p.u. for ¼ to 2 cycles and then reduces, which can make it difficult for protection schemes to pick up the fault current (Reno 2021 et. al.).

IBRs can be designed to be operated as both voltage and current source inverters whereas utility-scale inverters are seen as a voltage source; however, during a fault they switch to serving as a current source since the controls actively limit the current output under such conditions (NERC Report 2018).

Inverter control regulates the fault response of IBRs, and this varies between different manufacturers, IBRs can inject positive sequence current, negative sequence depending upon the switch control, and do not provide a path for zero sequence current.

Such challenges in detecting fault currents have created several catastrophic events. At BC Hydro in Canada, a 230 kV ground fault occurred on a transmission line leading from a large wind plant consisting of Type 3 doubly fed induction generators (DFIG). Ground fault protection at each line terminal consisted of negative sequence voltage-polarized ground overcurrent elements in multi-function microprocessor-

based relays. The terminal near the wind plant failed to trip due to the negative sequence forward directional element failing to assert, caused by an unforeseen angular difference between the negative sequence voltage and current phasors (Nagpal et al. 2018). In August 2016, an instantaneous phase-jump was misinterpreted, resulting in the loss of significant IBR generation resources amounting to nearly 1,200MW in the Western Interconnection (NERC 2017). Lack of negative current injection under an unbalanced fault results in temporary overvoltage conditions in the un-faulted phases Similar events were recorded with unbalanced faults in 2018 and 2019 (NERC 2018, NERC 2019). The 2022 Odessa Disturbance was categorized as a Category 3a event in the NERC Event Analysis Process due to the magnitude of generation loss. A B-phase-to-ground fault occurred on the 345 kV bus when a lightning arrestor failed at a synchronous generation plant near Odessa, Texas. This resulted in the loss of generation that nearly exceeded the Texas Interconnection Resource Loss Protection Criteria. The fault cleared in three cycles, disconnecting part of the plant that was carrying 333 MW. Other units in the plant unexpectedly tripped for an additional immediate loss of 202 MW (Odessa Disturbance 2022).

Acknowledgements

The authors thank the U.S. Department of State, Bureau of Energy Resources, Power Sector Program (PSP), which provides technical and regulatory support to the Asia Enhancing Development and Growth through Energy (EDGE) initiative and the Japan-United States Mekong Power Partnership (JUMPP). Under the PSP, Pacific Northwest National Laboratory delivers technical and analytic support to National Load Dispatch Center (NLDC) Vietnam Electricity (EVN) in modeling and simulation capabilities, analytic support, and training, including for increased penetration of variable renewable and distributed energy resources.

Contents

Abstract i
Executive Summary ii
Acknowledgements iv
Contents v
Table of Figures vii
Table of Tables vii
Acronyms viii
1.0 Introduction 1
2.0 Standards Relevant to the Vietnam Grid 3
2.1 PRC-001-3 3
2.2 PRC-002-3 3
2.3 PRC-004-5 4
2.4 PRC-014-0 5
2.5 PRC-023-5 5
2.6 PRC-027-1 5
3.0 Standards That May be Applicable to Vietnam Grid Code 6
3.1 PRC-005-6 6
3.2 PRC-006-5 6
3.3 PRC-007-0/PRC-008-0/PRC-009-0 7
3.4 PRC-010-1 7
3.5 PRC-011-0 7
3.6 PRC-012-2 7
3.7 PRC-013-1 8
3.8 PRC-015-1/PRC-016-/PRC-017-1 8
3.9 PRC-024-3 9
3.10 3PRC-025-3 9
3.11 PRC-026-1 9
4.0 Standards Not Necessarily Relevant to Vietnam Grid Code 10
4.1 PRC-018-1 10
4.2 PRC-019-2 10
4.3 PRC-020-2 10
4.4 PRC-021-2 10
4.5 PRC-022-1 11
5.0 NERC Strategies and Guidelines 12
5.1 Inverter-Based Resource Strategy 12

5.2 Reliability Guideline – BPS-Connected Inverter-Based Resource Performance 12
5.3 Reliability Guideline – Recommended Approaches for UFLS Program Design with Increasing Penetrations of DERs 13
5.4 FAC-002-2: Facility Interconnection Study 13
5.5 MOD-033-1: Steady-State and Dynamic System Model Validation 13
6.0 FERC Orders 14
6.1 FERC RD22-4/RM22-12/RD22-5 14
7.0 IEEE Standards 15
7.1 IEEE Std 1547.9 – 2022 15
8.0 Miscellaneous Resources and Standards 16
8.1 Underwriters Laboratories: UL Std 1741 SA 16
8.2 California Public Utilities Commission (CPUC): California Rule 21 16
9.0 Major Findings 17
10.0 References 19

Table of Figures

Figure 1: PRC-002-3 frequency protection details. 3
Figure 2: PRC-004-5 compliance procedure. 4
Figure 3: UFLS design and modelling for most interconnection (PRC-006) [left]; UFLS design and modelling curves for Quebec interconnection (PRC-006) [right]. 6
Figure 4: Flow chart describing the process flow of PRC-012-2. 8
Figure 5: Procedure for identifying risk associated with inverter-based resources connected to the BPS. 12
Figure 6: Characteristic curve for negative-sequence current injection of IBRs (Technische Regeln). 17
Figure 7: Integration of VDE-AR-N 4120 with the Grid-side Converter (GSC) current control scheme. 18

Table of Tables

Table 1: Vietnam grid frequency protection details. 4

Acronyms

BES	Bulk Energy System
BPS	Bulk Power System
CAP	Corrective Action Plan
CPUC	California Public Utilities Commission
DDR	Dynamic Disturbance Recording
DER	Distributed Energy Resource
DFIG	Doubly-fed Induction Generators
DME	Disturbance Monitoring Equipment
DOE	Department of Energy
EDGE	Enhancing Development and Growth through Energy
EMT	Electromagnetic Transient
EPS	Electric Power Systems
EVN	Vietnam Electricity
FERC	Federal Energy Regulatory Commission
FR	Fault Recording
FRT	Fault Ride Through
GSC	Grid-side Converter
IBR	Inverter-based Resources
IEEE	Institute of Electrical and Electronics Engineer
ISE	interconnection System Equipment
kV	kilovolt
JUMPP	Japan-United States Mekong Power Partnership
MOITT	Ministry of Industry and Trade
MVA	Megavolt-amperes
MW	Megawatt
NERC	North American Reliability Corporation
NLDC	National Load Dispatch Center
PRC	Protection and Control
PSMP	Protection System Maintenance Program
PSP	Power Sector Program
RAS	Remedial Action Schemes
RRO	Regional Reliability Organizations
SER	Sequence of Event Recording
SGs	Synchronous Generators
SOL	System Operating Limit
SPS	Special Protection Systems
TS	Transmission Systems
UFLS	Underfrequency Load Shedding
UL	Underwriters Laboratories

USA	United States of America
UVLS	Undervoltage Load Shedding Programs

1.0 Introduction

The North American Reliability Corporation (NERC) standards define the reliability requirements for planning and operating the North American bulk power system and are developed using a results-based approach that focuses on performance, risk management, and entity capabilities. The protection and control (PRC) standards specifically focus on the protection and control of power systems to ensure that appropriate protective measures are in place to detect and mitigate abnormal operation or disturbances that could potentially jeopardize the performance of the bulk power systems and grid reliability. The reliability functional model defines the functions that need to be performed to ensure the bulk power system operates reliably and is the foundation upon which the reliability standards are based.

The NERC PRC standards were developed by engagement between industry stakeholders, regulatory authorities, and experts. The development process for the NERC standards requires a development process outlined as follows:

1. Requirement: In developing a new PRC standard a need is identified from current changes in technology, events occurred, or lessons learned from previous incidences. NERC through its various committee and subgroups assesses the need for development of a new standard with inputs from its different stakeholder participants.
2. Drafting Team: A drafting team comprising of subject matter experts from industry, academics and NERC members who review the proposed standards. The developed team drafts the proposed standard keep the technical aspects, industry best practices and consideration from different regulatory authorities are included in the draft and provide comments and feedback.
3. Review and Voting: The drafted standard is circulated among different members of NERC registered entities including transmission owners, generation owners and other members for inputs, feedback and vetting of the proposed standard. Comments from the members are considered and relevant changes are made. NERC organizes workshops and technical conferences to get additional feedback from the open platform. These help in refining the proposed standards.
4. Regulatory review and approval: The proposed standard once ready are submitted to appropriate government regulatory authorities such as Federal Energy Regulatory Commission (FERC) to make sure that it aligns with current regulation and operational framework.
5. Implementation and Enforcement: Once the regulatory committee has provided their approval the standard is published and ready to be enforced. NERC along with other organizations form compliance monitoring committees that ensure proper implementation is made by the concerned authorities.
6. Review and Updates: The published standards are subject to periodic review to ensure they are relevant and effective to current operational standards. As technology keeps on developing regular updates are provided to the already published standards. The revision of the standards follows same path as listed above.

The NERC PRC standards were developed keeping in mind the traditional generation and transmission assets. IBRs follow their set of technical requirements and standards that are essential to be interconnected with the grid. With more IBRs coming online it is essential that there are cross-references between the published NERC PRC standards and other IBR requirements for a utility’s awareness, and to help them comply with existing regulations. This would help to ensure safe and reliable integration and operation of IBRs to ensure grid reliability and system stability.

This document highlights the essential PRC standards. They have been categorized in terms of applicability and relevance with the Vietnam grid for National Load Dispatch Center (NLDC). **Section 2.0** discusses standards directly related to the Vietnam grid and the PNNL project scope involving IBRs. **Section 3.0** discusses standards that are tangentially related to the Vietnam grid that may not be directly related to IBRs but can be modified to be directly related or are relevant to the surrounding system where IBRs are involved. **Section 4.0** discusses standards that are important for overall system stability and reliability but are not directly related to IBRs; PNNL recommends that NLDC review these standards for applicability to their specific and unique systems. **Section 5.0** discusses the different NERC guidelines mentioned for IBR reliability and interoperability. **Sections 6.0 and 7.0** discuss the adaptation of FERC and IEEE orders with respect to IBR interconnections. **Section 8.0** discusses some practices and standards adapted by utilities, and **Section 9.0** concludes the report with major findings related to standards and implementations made in certain European countries.

2.0 Standards Relevant to the Vietnam Grid

2.1 PRC-001-3

Purpose: Ensure system protection is coordinated among operating entities.

Details: Transmission operators, balancing authorities, and generator operators must document protection schemes and notify other entities of failures.

Applicability: Communication between operators in the Vietnam power grid can mitigate misoperations or coordination issues, especially in cases that involve IBRs.

Note: Some of the details mentioned in Section 2.1 were later revised and moved to Section 2.6 and Section PER-006-1.

2.2 PRC-002-3

Purpose: Adequate data available to facilitate analysis of Bulk Energy System (BES) disturbances.

Details: Transmission Owners and Generator Owners must identify BES elements that require sequence of event recording (SER), fault recording (FR), and/or dynamic disturbance recording (DDR) and keep record of events recorded for a required period and of needed resolution. This applies to generating resources with a nameplate rating greater than or equal to 500MVA or generating resources with a nameplate rating greater than or equal to 300MVA that belong to an aggregate facility with a rating greater than or equal to 1000MVA. Events must be recorded continuously. If equipment is incapable of continuous recording due to age, event records must be at least three minutes long and be triggered by the following:

At least one of the following three triggers:

- Off nominal frequency trigger set at:

	Low	High
Eastern Interconnection	<59.75 Hz	>61.0 Hz
Western Interconnection	<59.55 Hz	>61.0 Hz
ERCOT Interconnection	<59.35 Hz	>61.0 Hz
Hydro-Quebec Interconnection	<58.55 Hz	>61.5 Hz

- Rate of change of frequency trigger set at:

Eastern Interconnection	< -0.03125 Hz/sec	> 0.125 Hz/sec
Western Interconnection	< -0.05625 Hz/sec	> 0.125 Hz/sec
ERCOT Interconnection	< -0.08125 Hz/sec	> 0.125 Hz/sec
Hydro-Quebec Interconnection	< -0.18125 Hz/sec	> 0.1875 Hz/sec

- Undervoltage trigger set no lower than 85 percent of normal operating voltage for a duration of 5 seconds.

Figure 1: PRC-002-3 frequency protection details.

Compared to Vietnam grid code requirements from Ministry of Industry and Trade (MOIT) document no. 30/2019/TT-BCT:

Table 1: Vietnam grid frequency protection details.

Contingency	Allowable fluctuation	Time to restore	
N-1	49 Hz - 51 Hz	2 minutes to bring frequency back to 49.5 Hz - 50.5 Hz	5 minutes to bring frequency back to 49.8 Hz - 50.2 Hz
N-k, k≥2,major disturbance, or emergency situation	47.5 Hz - 52 Hz	10 seconds to bring frequency back to 49 Hz - 51 Hz	
		5 minutes to bring frequency back to 49.5 Hz - 50.5 Hz	10 minutes to bring frequency back to 49.8 Hz - 50.2 Hz

Applicability: Monitoring of key elements (breakers, generators, buses) during events will aid in analyzing events to prevent misoperations. This can be especially helpful in IBR systems, where fewer events may be documented.

2.3 PRC-004-5

Purpose: Identify and correct the causes of misoperations of protection systems for BES elements.

Details: Transmission owners, generator owners, and distribution providers must report if their BES interrupting device caused misoperations, determine the cause, and develop a Corrective Action Plan (CAP) to prevent future misoperations.

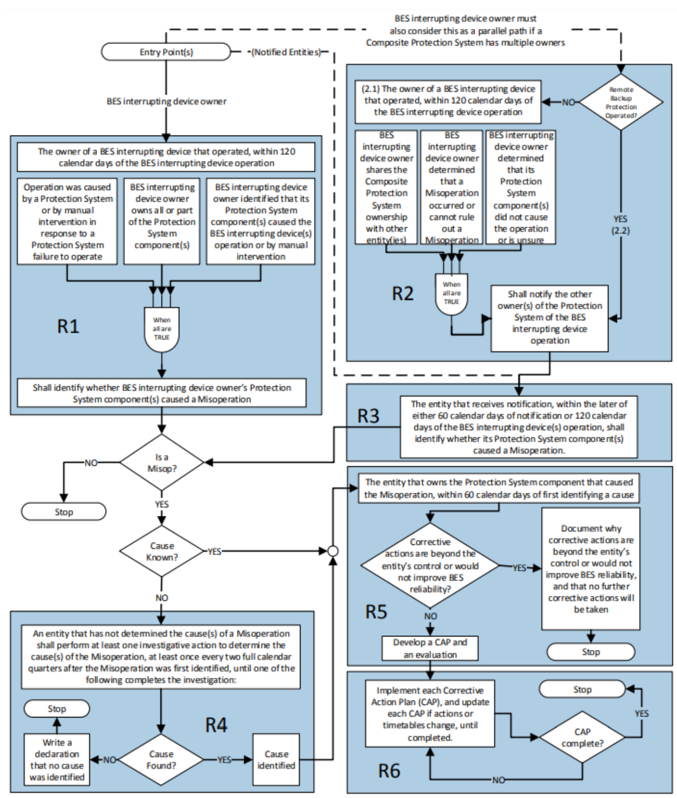

Figure 2: PRC-004-5 compliance procedure.

Applicability: Documentation and correction of misoperations can prevent future misoperations. In the case of IBR systems, a CAP may be applied to other similar system scenarios to prevent misoperations in other areas of the BES.

2.4 PRC-014-0

Purpose: Ensure that all Special Protection Systems (SPS) are properly designed, meet performance requirements, and are coordinated with other protection systems. To ensure that maintenance and testing programs are developed and misoperations are analyzed and corrected.

Details: Regional Reliability Organizations (RRO) shall assess the operation, coordination, and effectiveness of all SPSs in its region at least once every five years and document all findings for required elements.

Applicability: Reassessment of protection systems and schemes is crucial to ensuring setpoints are still appropriate, especially with increased use of renewable resources.

2.5 PRC-023-5

Purpose: Protective relay settings shall not limit transmission load ability, 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.

Details: Transmission owners, generator owners, and distribution providers shall set protection relays such that phase elements do not limit transmission system load ability while maintaining reliable protection for all BES fault conditions. This applies to transmission lines operated at 200kV and above.

Applicability: This standard is applicable to recent misoperations in which a phase element failed to trip during a fault scenario. This standard applies to transmission lines at 200kV or higher but can be adapted to suit the Vietnam power system.

2.6 PRC-027-1

Purpose: Maintain the coordination of protection systems installed to detect and isolate faults on BES elements, such that those protection systems operate in the intended sequence during faults.

Details: Transmission owners, generator owners, and distribution providers shall establish a process for developing new and revised protection system settings for BES elements such that the protection system operates as intended.

Applicability: Ensuring coordination and documenting coordination of protection elements aids in preventing misoperations and in troubleshooting misoperations if they do happen.

3.0 Standards That May be Applicable to Vietnam Grid Code

3.1 PRC-005-6

Purpose: Document and implement programs for the maintenance of all protection systems, automatic reclosing, and sudden pressure relaying affecting the reliability of the BES so that they are kept in working order.

Details: Transmission owners, generator owners, and distribution providers must establish a Protection System Maintenance Program (PSMP) for the purpose of maintaining protection systems, automatic reclosing, and sudden pressure relaying at a time-based or performance-based method. This standard is applicable for interconnection points that have an aggregate generation greater than 75MVA to a BES connection of 100kV or above.

Applicability: Ensuring equipment functions properly is crucial for mitigating misoperations. Regular maintenance and inspection of protection systems and protection schemes can reduce the risk of protection elements having inappropriate setpoints due to changes in system generation such as higher renewable penetration.

3.2 PRC-006-5

Purpose: Establish design and documentation requirements for automatic underfrequency load shedding (UFLS) programs to arrest declining frequency, assist recovery of frequency following underfrequency events and provide last resort system preservation measures.

Details: Planning coordinators should develop and document criteria to select portions of the BES that may form islands to use as a basis for designing UFLS programs.

Applicability: Rate of change of frequency increases with systems that have a higher percentage of IBR penetration. Because of this, UFLS setpoint response may vary based on the topology of the system. See NERC recommended approaches for UFLS Program design with increasing penetrations of DERs in Section 5.3. The UFLS standards are shown in Figure 3.

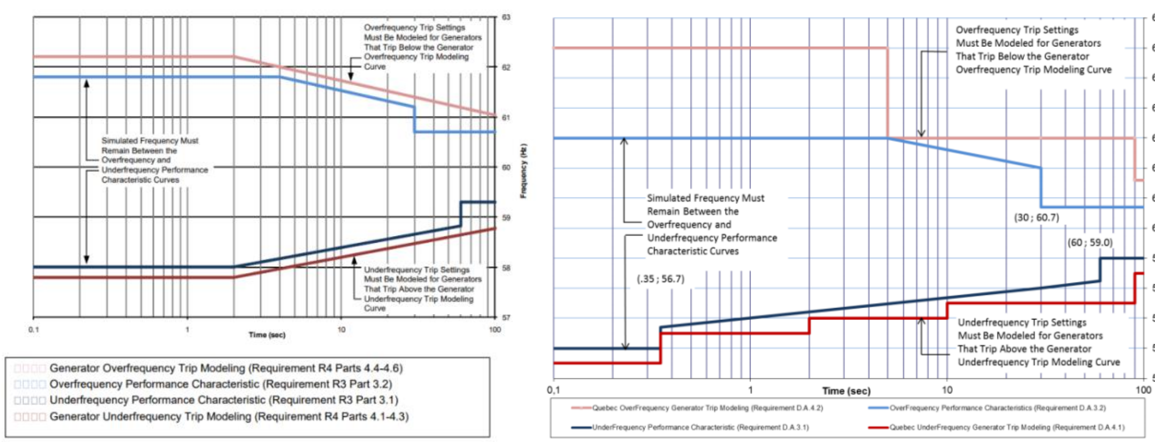

Figure 3: UFLS design and modelling for most interconnection (PRC-006) [left]; UFLS design and modelling curves for Quebec interconnection (PRC-006) [right].

3.3 PRC-007-0/PRC-008-0/PRC-009-0

Purpose: Provide last resort System preservation measures by implementing an UFLS program.

Details: Requires entities to have UFLS.

Applicability: Reference Section 3.2 applicability.

3.4 PRC-010-1

Purpose: Establish an integrated and coordinated approach to the design, evaluation, and reliable operation of Undervoltage Load Shedding (UVLS) programs.

Details: Planning coordinators or transmission planners that are developing UVLS programs must evaluate their effectiveness and document their specifications and implementation schedule. The UVLS Program shall be reevaluated at least every 5 years. If deficiencies are found, a CAP shall be developed and implemented.

Applicability: If NLDC has UVLS programs, it may be beneficial to implement a procedure for ensuring that such programs are still applicable based on changes in load and generation profiles.

3.5 PRC-011-0

Purpose: Provide system preservation measures to prevent system voltage collapse or voltage instability by implementing an UVLS program.

Details: Transmission owners and distribution providers that own a UVLS system shall provide documentation of maintenance and testing programs.

Applicability: Reference Section 3.4 for applicability.

3.6 PRC-012-2

Purpose: Ensure that Remedial Action Schemes (RAS) do not introduce unintentional or unacceptable reliability risks to the BES.

Details: New RAS must be submitted for review by reliability coordinators and existing RAS must be reviewed every five years to ensure they mitigate system conditions, avoid adverse interactions with other RAS and protection and control systems, and does not contribute to significant BES disturbances in the event of an inadvertent operation. Figure 4 shows the process flow involved in implementing PRC-012-2 standard.

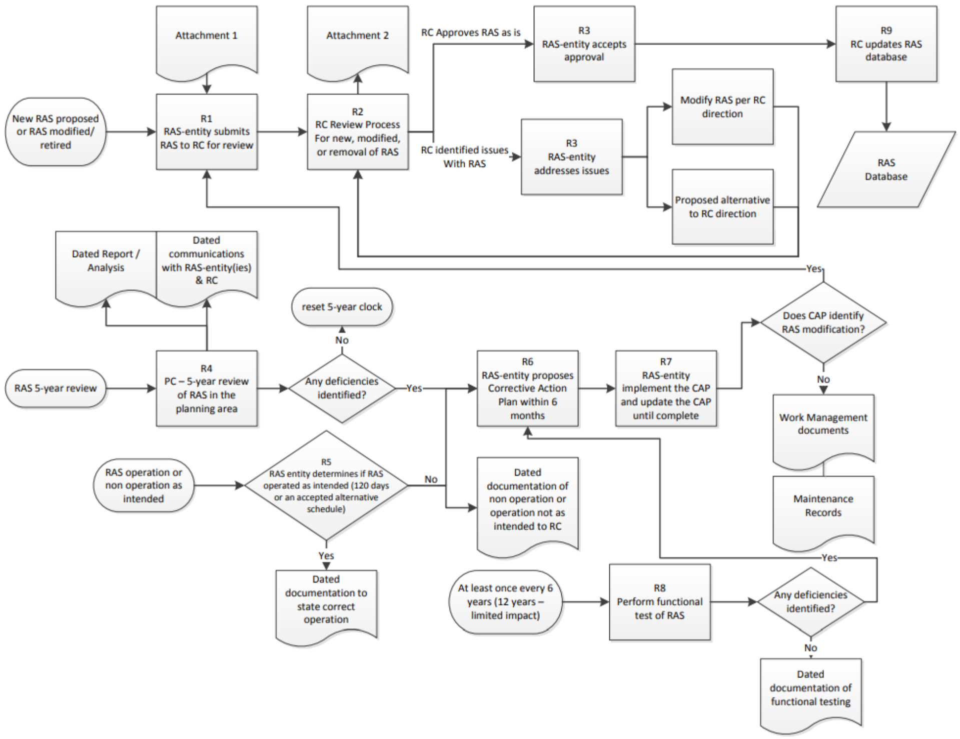

Figure 4: Flow chart describing the process flow of PRC-012-2.

Applicability: NERC defines a remedial action scheme as, "An automatic protection system designed to detect abnormal or predetermined system conditions and take corrective actions other than and/or in addition to the isolation of faulted components to maintain system reliability. Such action may include changes in demand, generation (MW and MVAR), or system configuration to maintain system stability, acceptable voltage, or power flows. An SPS does not include (a) underfrequency or undervoltage load shedding or (b) fault conditions that must be isolated or (c) out-of-step relaying (not designed as an integral part of an SPS). Also called RAS" (NERC 2014). This may be useful for NLDC to implement if they have not already to avoid large-scale blackouts.

3.7 PRC-013-1

Purpose: Ensure that all RAS are properly designed, meet performance requirements, and are coordinated with other protection systems.

Details: RROs must maintain a RAS database including design objectives, operation, and modeling.

Applicability: Kindly review Section 3.6 for applicability.

3.8 PRC-015-1/PRC-016-/PRC-017-1

Purpose: Ensure that maintenance and testing programs are developed and misoperations are analyzed and corrected.

Details: Transmission owners, generator owners, and distribution providers must maintain documentation of compliance to Section 3.7 and take corrective actions in the case of misoperations.

Applicability: Reference Section 3.6 for applicability.

3.9 PRC-024-3

Purpose: Set protection such that generating resource(s) remain connected during defined frequency and voltage excursions in support of the BES.

Details: Generator owners will set applicable frequency protection such that applicable protection does not cause generating resource to trip or cease injection current within the "no trip zone" during a frequency excursion.

Applicability: This standard is not specific to IBRs but can be modified to fit the Vietnam system to avoid tripping off renewable energy when it is required to support the bulk electric system.

3.10 3PRC-025-3

Purpose: Set load-responsive protective relays associated with generation Facilities at a level to prevent unnecessary tripping of generators during a system disturbance for conditions that do not pose a risk of damage to the associated equipment.

Details: Generator owners, transmission owners, and distribution providers shall apply settings such that unnecessary tripping of generators does not occur during disturbances that do not pose risk of damage.

Applicability: The standard is applicable generator owners, transmission owners, and distribution providers that have load-responsive relays connected to generating units, transformers, auxiliary transformer, and to all those elements that are identified as generating resources and generating units as the black start resources identified by the transmission provider. Similar to Section 3.9, this is not intended for IBRs but may be beneficial to adapt for the Vietnam system to aid in event ride through.

3.11 PRC-026-1

Purpose: Ensure that load-responsive protective relays are expected to not trip in response to stable power swings during non-fault conditions.

Details: Planning coordinators must notify transmission and generator owners if their BES Elements are affected by RAS, UFLS, or System Operating Limit (SOL) so that Owners can ensure proper action during power swings.

Applicability: NLDC witnessed an event in which power swing protection blocked distance elements. Implementing regulations around power swings can prevent such occurrences. More information is needed about this issue in the Vietnam system to provide applicability notes and recommendations.

4.0 Standards Not Necessarily Relevant to Vietnam Grid Code

4.1 PRC-018-1

Purpose: Ensure that Disturbance Monitoring Equipment (DME) is installed, and that disturbance data is reported in accordance with regional requirements to facilitate analyses of events.

Details: Transmission owners and generator owners must install DMEs that meet recording requirements in accordance with RRO and Section 2.2.

Applicability: This standard is similar to Section 2.2 but defines additional responsible parties.

4.2 PRC-019-2

Purpose: Verify coordination of generating unit facility or synchronous condenser voltage regulating controls, limit functions, equipment capabilities and protection system settings.

Details: Generator owners and transmission owners with applicable facilities shall coordinate the voltage regulating system controls with the applicable equipment capabilities and settings of the applicable protection system devices. This standard applies to individual generating units greater than 20MVA or generating plants/facilities that consist of units connected to a single bus with generation greater than 75MVA.

Applicability: Ensuring protection setpoints are appropriate for generation is crucial to ensuring system stability. This standard applies to generation over 20MVA and is likely not applicable to IBRs. However, this can be modified to better suit systems with IBRs.

4.3 PRC-020-2

Purpose: Ensure that a regional database is maintained for UVLS programs implemented by entities within the region to mitigate the risk of voltage collapse or voltage instability in the BES. Ensure the UVLS database is available for regional studies and for dynamic studies and simulations of the BES.

Details: RROs shall establish, maintain, and annually update a database for UVLS programs implemented by entities within the region to mitigate risk of voltage collapse or instability.

Applicability: This standard is similar to Section 3.4 for reliable operation under UVLS but defines additional responsible parties.

4.4 PRC-021-2

Purpose: Ensure data is provided to support the regional database maintained for UVLS programs that were implemented to mitigate the risk of voltage collapse or voltage instability in the BES.

Details: Transmission owners and distribution providers that own a UVLS program must annually update its UVLS data.

Applicability: This standard is similar to Section 3.4 but defines additional responsible parties.

4.5 PRC-022-1

Purpose: Ensure that UVLS programs perform as intended to mitigate the risk of voltage collapse or voltage instability in the BES.

Details: Transmission operators, load-serving entities, and distribution providers that operate a UVLS program must analyze and document all UVLS operations and misoperations.

Applicability: This standard is similar to Section 3.4 but defines additional responsible parties.

5.0 NERC Strategies and Guidelines

5.1 Inverter-Based Resource Strategy

Purpose: Provide framework for mitigating risks associated with inverter-based resources connected directly to the BPS.

Details: Identification of threats associated with IBR connection to the BPS is a complicated process. Several steps are associated with determining the appropriate measures to be taken. A flowchart determining the risks and proposed solutions are shown in Figure 5.

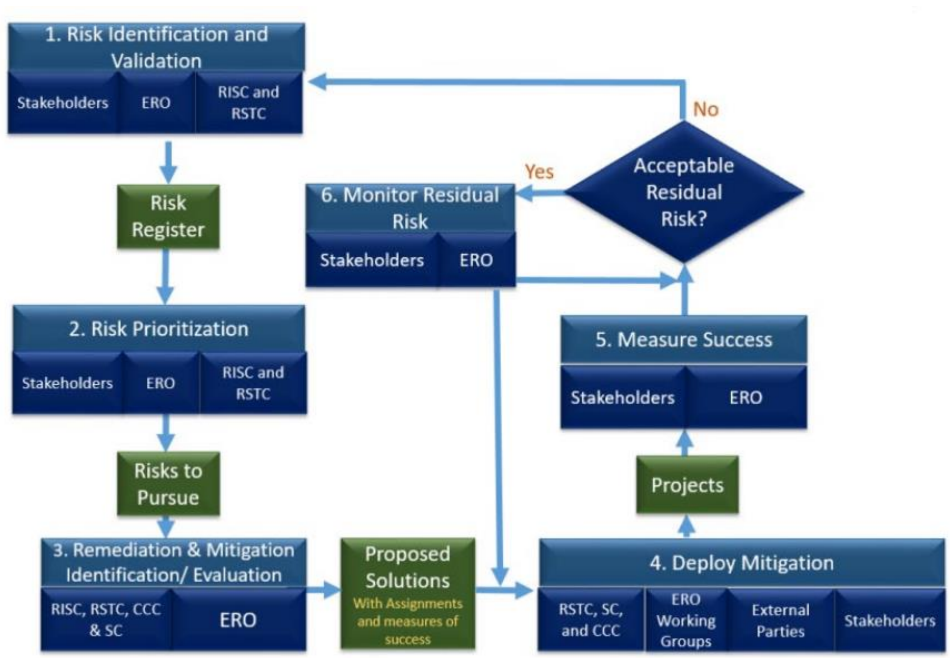

Figure 5: Procedure for identifying risk associated with inverter-based resources connected to the BPS.

Applicability: A framework for mitigating risks associated with IBRs is crucial to avoid misoperations.

5.2 Reliability Guideline – BPS-Connected Inverter-Based Resource Performance

Purpose: Develop reliability guidelines to distribute key practices and information on specific issues to support high levels of BES reliability.

Details: Ensure reliability of the BES by providing recommendations regarding performance of IBRs, including:

- Momentary cessation
- Active power-frequency control
- Reactive power-voltage control
- Inverter-based resource protection

- IEEE Std. 1547 and UL Std. 1741
- Measurement data and performance monitoring

Applicability: High applicability to all systems with IBR integration.

5.3 Reliability Guideline – Recommended Approaches for UFLS Program Design with Increasing Penetrations of DERs

Purpose: Mitigate risks that DERs may pose to underfrequency load shedding programs.

Details: Entities performing UFLS studies should do the following:

- Include dynamic models of both utility-scale and retail-scale DERs
- Ensure accurate modeling of BPS-connected generators including on-line operating reserves, governor response, voltage, and frequency trip protection settings, over excitation limitations and under excitation limitations, power system stabilizers
- Include additional cases reflecting other load conditions that peak load when developing the UFLS program

Applicability: Only applicable if Vietnam system implements UFLS programs.

5.4 FAC-002-2: Facility Interconnection Study

Purpose: Study the impact of interconnecting new or materially modified facilities on the BES.

Details: Transmission planners and planning coordinators shall study the reliability impact of interconnecting and materially modifying new generation, transmission, or electricity end-user facilities. Studies include reliability impact, adherence to NERC Standards, steady-state studies, short-circuit studies, dynamic-studies, and study assumptions. Evidence of such studies shall be documented.

Applicability: Requiring studies of newly installed generation, transmission, and facilities can help ensure that new generation does not cause negative system responses.

5.5 MOD-033-1: Steady-State and Dynamic System Model Validation

Purpose: Establish consistent validation requirements to facilitate the collection of accurate data and building of planning models to analyze the reliability of the interconnected transmission system.

Details: Planning coordinators must have a documented data validation process that includes comparison of the performance between actual system performance and planning models and guidelines to determine whether actual system performance is acceptable compared to planning models.

Applicability: Ensuring that actual system performance matches planning models ensures that appropriate protection setpoints and coordination settings are used. It also prevents future misoperations by verifying system models, especially in the case of high-IBR penetration.

6.0 FERC Orders

Note These orders, established November 17, 2022, are for NERC to further develop PRC guidelines to include IBRs. Such PRC requirements are in process but not yet approved.

6.1 FERC RD22-4/RM22-12/RD22-5

Purpose:

– **E-1-RD22-4-000:** Order directing NERC to develop a plan to register the entities that own and operate IBRs.

– **E-2-RM22-12-000:** A notice of proposed rulemaking to direct NERC to develop reliability standards for IBRs that cover data sharing, model validation, planning and operational studies, and performance requirements.

– **RD22-5-000:** An order approving reliability standard that are related to IBRs, which NERC proposed in early 2022.

Details: Unregistered IBRs connected to the BES are not required to comply with existing PRC standards.

Applicability: Incorporates IBRs into existing PRC standards.

7.0 IEEE Standards

7.1 IEEE Std 1547.9 – 2022

Purpose: Establishes criteria and requirements for interconnection of distributed energy resources with electric power systems (EPS) and associated interfaces.

Details: Defines and quantifies a set of technical requirements for interconnection of DERs with the local EPS, including ride through, active power-frequency control, reactive power-voltage control, and more.

Applicability: High applicability to all systems that include distributed energy resource (DER) interconnection.

8.0 Miscellaneous Resources and Standards

8.1 Underwriters Laboratories: UL Std 1741 SA

Purpose: Sets requirements that cover inverters, converters, charge controllers, and interconnection system equipment (ISE) intended for use in stand-alone (not grid-connected) or utility-interactive (grid-connected) power systems.

Details: Supplements IEEE 1547 by providing details and testing requirements regarding grid support functions for inverters, especially inverters with highly complex features, and tests other grid-interactive functions of such inverters. This includes:

- Anti-islanding
- Low/high voltage ride through
- Low/high frequency ride through
- Must trip test
- Ramp rate
- Specified power factor
- Volt/Var mode
- Frequency watt
- Volt watt

Applicability: High applicability to systems that involve inverters, either islanded or grid-connected.

8.2 California Public Utilities Commission (CPUC): California Rule 21

Purpose: Situations in which UL Std 1741 is applicable and lays out specific parameters that must be used for testing methods.

Details: Electric Rule 21 is a tariff that describes the interconnection, operating, and metering requirements for generation facilities to be connected to a utility's distribution system, over which the CPUC has jurisdiction.

Applicability: Can be useful for systems that involve inverters to know what sort of tests may be applicable to ensure maintained system performance.

9.0 Major Findings

When it comes to protection for IBR interconnections some specific requirements are necessary to ensure proper operation under fault. Some general requirements for connecting IBRs to the grid include:

Anti-Islanding Protection: Under events of grid disturbance, it is essential for IBRs to be disconnected from the grid to prevent inadvertently energizing/de-energizing different sections of the grid.

Voltage-Frequency Ride Through: Under abnormal grid conditions such as voltage sags, IBRs are required to continually operate without tripping under recommended guidelines. This help to ensure grid stability and reliability.

Grid Interconnection Standards: Along with the recommended NERC PRC standards, IBRs are required to comply with specific requirements and standards developed by ISOs or RTOs.

Currently no specific standards have been set for IBR controls during their operation under a fault in the US, however in Germany technical requirements for IBR operation under a fault has been suggested by the German Grid Code (Netzanschlussregeln) (Technische Regeln). To minimize the possibility of misoperation, the VDE-AR-N 4120 Technical Connection Rule suggests IBRs inject a negative sequence during unbalanced faults. Under this regulation the IBR control injects a negative sequence reactive current in order of magnitude "k", defined as the characteristic proportional gain ranging between 2 and 6. This provides the response of the IBR similar to that of a SG with $1/k^{th}$ p.u. negative-sequence reactance with operational limitations. The characteristic curve representing IBR operation is shown in Figure 6.

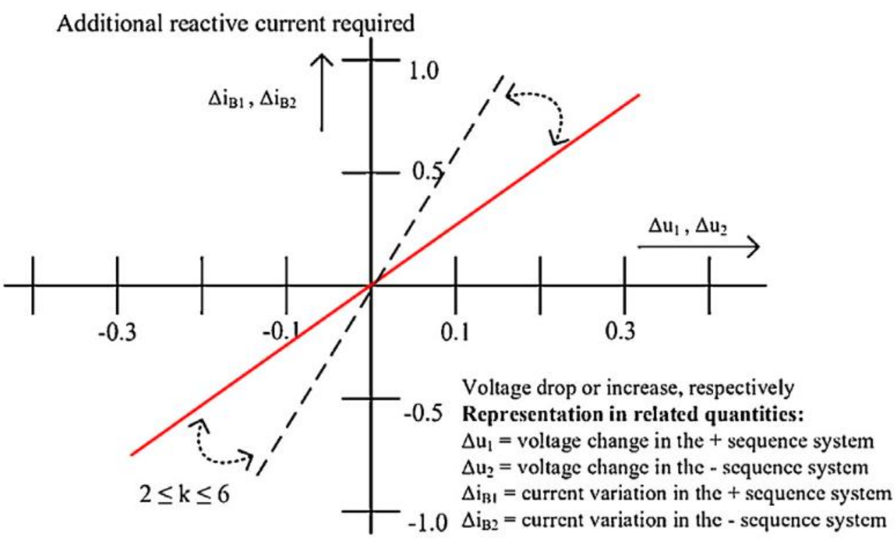

Figure 6: Characteristic curve for negative-sequence current injection of IBRs (Technische Regeln).

The objective of this approach is to produce a negative sequence current under fault whose amplitude is proportional to the negative sequence voltage. A detailed integration of VDE-AR-N 4120 is shown in Figure 7 (U. Karaagac et al. 2019).

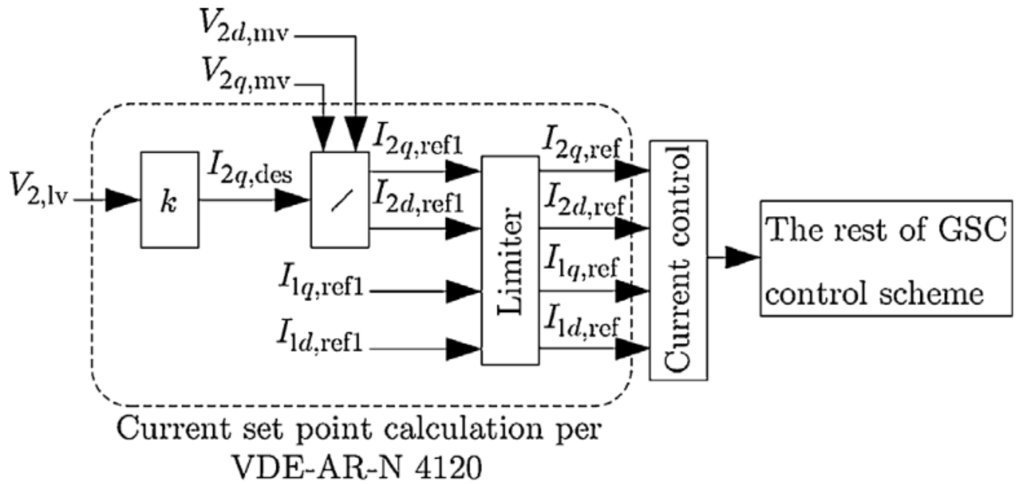

Figure 7: Integration of VDE-AR-N 4120 with the Grid-side Converter (GSC) current control scheme.

This control scheme provides priority to the negative sequence and positive sequence currents $I_{2q,ref}$ and $I_{1q,ref}$ respectively. The negative sequence current injection helps to comply with VDE-AR-N 4120 and the positive sequence complies with FRT settings. Detailed electromagnetic transient (EMT) studies related to the operation of IBR under such control sequence can be found in Karaagac et al. 2019.

Some other key NERC PRC standards like sections 3.9, 3.10, and 3.11 have been described for SG operators but could be utilized for IBRs as well under certain conditions. The PRC standards discussed in this document provide guidance and recommendation that helps to improve the protection and reliability of the system and helps to foster addition of IBRs to the grid. Incorporating appropriate PRC standards will help protect Vietnam's system from the vulnerabilities introduced by higher levels of IBRs relative to the historical/traditional electricity generation/transmission/distribution mix.

10.0 References

Behnke, Michael Robert, Custer, Gary, Farantatos, Evangelos, Fischer, Normann, Guttromson, Ross, Isaacs, Andrew, Majumder, Rajat, Pant, Siddhart, Patel, Manish, Reddy-Konala, Venkat, & Voloh, Ilia. Impact of Inverter Based Resource Negative Sequence Current Injection on Transmission System Protection. United States. https://doi.org/10.2172/1595917.

Chowdhury, Ritwik and McDaniel, Ryan and Fischer, Normann, Applying Line Current Differential Protection in Systems with Inverter-Based Resources. Available at http://dx.doi.org/10.2139/ssrn.4058823.

Karaagac, Ulas & Mahseredjian, Jean & Gagnon, Richard & Gras, Henry & Saad, Hani & Cai, Lijun & Kocar, Ilhan & Haddadi, Aboutaleb & Farantatos, Evangelos & Chan, K. & Wang, Liwei & Bu, Siqi. (2019). A Generic EMT-type Model for Wind Parks with Permanent Magnet Synchronous Generator Full Size Converter Wind Turbines. IEEE Power and Energy Technology Systems Journal. PP. https://doi.org/10.1109/JPETS.2019.2928013.

Nagpal, Mukesh & Henville, Charles. Impact of Power Electronic Sources on Transmission Line Ground Fault Protection. IEEE Transactions on Power Delivery. PP. 1-1. https://doi.org/10.1109/TPWRD.2017.2709279.

NERC, PER-006-1, https://www.nerc.com/pa/Stand/Reliability%20Standards/PER-006-1.pdf.

NERC, Blue Cut Fire Disturbance Report, June 2017.

NERC, Canyon 2 Fire Disturbance Report, February 2018.

NERC, Angeles Forest and Palmdale Roost Disturbance Report, January 2019.

NERC, Reliability Guideline, BPS-Connected Inverter-Based Resource Performance, September 2018.

NERC, Joint NERC, and Texas RE Staff Report 2022 Odessa Disturbance, December 2022.

NERC, Proposed Definition of "Remedial Action Scheme", October 2014, https://www.nerc.com/pa/Stand/Prjct201005_2SpclPrtctnSstmPhs2/Proposed%20RAS%20Definition_10262014_clean.pdf.

Reno, Matthew J., Brahma, Sukumar, Bidram, Ali, & Ropp, Michael E. Influence of Inverter-Based Resources on Microgrid Protection: Part 1: Microgrids in Radial Distribution Systems. United States. https://doi.org/10.1109/mpe.2021.3057951.

Technische Regeln für den Anschluss von Kundenanlagen an das Hochspannungsnetz und deren Betrieb (TAR Hochspannung), VDE-ARN 4120 Anwendungsregel: 2018-11.