2023 TECHNICAL UPDATE

Development of NERC Reliability Standards for IBRs Covering Data Sharing, Model Validation, Planning and Operational Studies, and Performance Requirements

EPRI Comments on FERC's NOPR Issued on November 17, 2022, Docket No. RM22-12-000

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Technical Update, September 2023

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ABSTRACT

Disturbance events in California and Texas documented in North American Electric Reliability Corporation (NERC) disturbance reports in the last few years have highlighted performance issues with inverter-based resources (IBRs) ranging from ride-through to modeling concerns. This has led FERC to develop a Notice of Proposed Ruling (NOPR) RM22-12-00 to address those issues by directing NERC to develop Reliability Standards for IBRs that cover data sharing, model validation, planning and operational studies, and performance requirements. EPRI has provided comments to this FERC NOPR, which are published in this technical report.

Based on the past and ongoing ERPI research and industry findings, EPRI has reviewed the proposed language in the NOPR and provided comments related to the use of industry-defined terms, reliability impacts of IBR technologies and related industry efforts, ride-through requirements, modeling and model validation requirements, and gaps like sufficient plant capability and performance conformity assessment.

Several utilities and ISOs have started performing gap analysis against IEEE standards (such as IEEE 2800-2022) and proposed modifications in their interconnection requirements to address reliability issues associated with the increasing penetration of IBRs. EPRI's comments related to ride-through and modeling requirements for IBRs can serve as a reference as example language and considerations to draft such requirements to support bulk system reliability.

Keywords

Disturbance report
Inverter-based resources (IBRs)
North American Electric Reliability Corporation (NERC)
Notice of Proposed Ruling (NOPR)
Reliability standards

EXECUTIVE SUMMARY

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Primary Audience: FERC, transmission owners, transmission operators, distribution owners, distribution operators, project developers, generator owners, generator operators

Secondary Audience: NERC, original equipment manufacturers, third-party consultants

KEY RESEARCH QUESTION

Disturbance events in California and Texas documented in North American Electric Reliability Corporation (NERC) disturbance reports in the last few years have highlighted performance issues with inverter-based resources (IBRs) ranging from ride-through to modeling concerns. This has led FERC to develop a Notice of Proposed Ruling (NOPR) RM22-12-00 to address those issues by directing NERC to develop Reliability Standards for IBRs that cover data sharing, model validation, planning and operational studies, and performance requirements. EPRI has provided comments to this FERC NOPR, which are published in this technical report.

RESEARCH OVERVIEW

Based on the past and ongoing ERPI research and industry findings[1], EPRI has reviewed the proposed language in the NOPR and provided comments related to the use of industry-defined terms, reliability impacts of IBR technologies and related industry efforts, ride-through requirements, modeling and model validation requirements, and gaps like sufficient plant capability and performance conformity assessment.

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[1] a) Adaptive Protection and Validated Models to Enable Deployment of High Penetrations of Solar PV (PV-MOD): Project Website. EPRI. Palo Alto, CA: 2022. [Online] https://www.epri.com/pvmod

b) EPRI Informational Webinar on FERC NOPR on Generator Interconnection (Transmission). EPRI Member Webcast. September 22, 2022. [Online] https://www.epri.com/research/programs/067417/events/33867756-483F-47E9-9ABF-B6235342F9FE

c) J. Boemer: "Interconnection study process, reliability implications and improvements needed," Presentation at a Joint Generator Interconnection Workshop held August 9-11, 2022, by the Energy Systems Integration Group, North American Generator Forum, North American Electric Reliability Corporation, and Electric Power Research Institute. Reston, VA: 2022 [Online] https://www.esig.energy/event/joint-generator-interconnection-workshop/

KEY FINDINGS

- EPRI research supports that the latest suite of published consensus technical standards like IEEE 2800-2022 (for registered IBRs and potentially unregistered IBRs) and IEEE 1547-2018/1547a-2020 (for IBR-DERs) support specifications of improved technical minimum capability and performance requirements for IBRs and DERs.
- The benefits of referencing the relevant IEEE interconnection performance standards and their definitions of applicable terms should be considered by FERC and other regulatory agencies given that:
- IEEE standards have been developed through a rigorous, open, and collaborative process comprising hundreds of stakeholders
  - EPRI's research shows that the resulting performance requirements included in IEEE 2800 and 1547 supports system reliability while providing sufficient flexibility for regional adoption by RTOs/ISOs, and to interconnection customers inverter original equipment manufacturers (OEMs) have publicly stated that state-of-the-art equipment is compatible with the majority of the capabilities required by IEEE 2800 at the unit and plant level.
  - The proposed directives to NERC on ride-through requirements do not seem to sufficiently state all reasons for tripping and inadequate performance of IBRs during disturbances as identified by NERC and are not entirely aligned with, nor are they as intentional and clear as the applicable industry standards like the recently published IEEE 2800-2022.
- EPRI recommends FERC direct NERC to ensure that all IBR unit and IBR plant models are verified, validated, appropriately parametrized, and appropriately used to assess plant conformity. All models, including user-defined models, have their applications and benefits, and the submission of user-defined models should not be discouraged or prohibited.
- On reliability impacts of IBR-DERs as identified by the NOPR, EPRI's research has demonstrated that capability and performance requirements specified in IEEE 1547-2018 and 1547a-2020 could support bulk-power system reliability. Noting that the penetration levels of DERs are increasing in many jurisdictions, EPRI recommends that FERC consider requiring comparable technical minimum capability and performance requirements from all FERC-jurisdictional IBR-DERs.

WHY THIS MATTERS

FERC SGIP and LGIP and related updates affect interconnections into transmission, sub-transmission, and distribution systems via requirements and rules set by public utility commissions, transmission providers, and ISOs. As such, it is important to ensure that such modifications are aligned with other applicable standards—such as voluntary IEEE standards—and adequately address commonly observed issues in the industry.

HOW TO APPLY RESULTS

Several utilities and ISOs have started performing gap analysis against IEEE standards (such as IEEE 2800-2022) and proposed modifications in their interconnection requirements to address reliability issues associated with the increasing penetration of IBRs. EPRI's comments related to ride-through and modeling requirements for IBRs can serve as a reference as example language and considerations to draft such requirements to support bulk system reliability.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI's Supplemental Project Notice (SPN) for the new "Verifying Performance of Bulk Power-System-Connected Solar, Wind, and Storage Plants" project (3002025832). This project aims at supporting participants, including bulk system planners, operators, and interconnection engineers, in their efforts to improve technical interconnection requirements for large IBRs to at least the level of minimum capability requirements that are specified in IEEE 2800-2022.
- IEEE P2800.2 Working Group is drafting a "Recommended Practice for Test and Verification Procedures for Inverter-based Resources (IBRs) Interconnecting with Bulk Power Systems" (https://sagroups.ieee.org/2800-2/). This recommended practice complements the IEEE 2800 test and verification framework with specifications for the equipment, conditions, tests, modeling methods, and other verification procedures that should be used to demonstrate conformance with IEEE 2800 technical minimum requirements for the interconnection, capability, and performance of applicable IBRs.

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PROGRAMS: Transmission Planning, Program 40; Integration of Renewables and DERs, Program 173

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UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

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 (RM22-12)

Docket No. RM22-12-000

November 17, 2022

Comments on 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 (RM22-12). February 06, 2023

I. INTRODUCTION

1.The Electric Power Research Institute (EPRI)[2] respectfully submits these comments (This Response) in response to the Federal Energy Regulatory Commission's (FERC) Notice of Proposed Rulemaking (NOPR) to direct North American Electric Reliability Corporation (NERC) to develop Reliability Standards for inverter-based resources (IBRs) that cover data sharing, model validation, planning and operational studies, and performance requirements (RM22-12), issued on November 17, 2022. EPRI closely collaborates with its members, inclusive of electric power utilities, Independent System Operators (ISOs), and Regional Transmission Organizations (RTOs), as well as numerous other stakeholders, domestically and internationally. In its role, EPRI conducts independent research and development relating to the generation, delivery, and use of electricity for the public benefit by working to help make electricity more reliable,

[2] EPRI is a nonprofit corporation organized under the laws of the District of Columbia Nonprofit Corporation Act and recognized as a tax-exempt organization under Section 501(c)(3) of the U.S. Internal Revenue Code of 1996, as amended, and acts in furtherance of its public benefit mission. EPRI was established in 1972 and has principal offices and laboratories located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; and Lenox, Mass. EPRI conducts research and development relating to the generation, delivery, and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety, and the environment. EPRI also provides technology, policy and economic analyses to inform long-range research and development planning, as well as supports research in emerging technologies.

affordable and environmentally safe. EPRI's comments on this topic are technical in nature based upon EPRI's research, development, and demonstration experience over the last 50 years in planning, analyzing, and developing technologies for electric power.

2. EPRI research and technology transfer deliverables are generally accessible on its website to the public, either for free or for purchase, and are occasionally subject to licensing, export control, and other requirements.[3] The publicly available and free-of-charge milestone reports from a U.S. Department of Energy (DOE)- and EPRI-member-funded research project, Adaptive Protection and Validated Models to Enable Deployment of High Penetrations of Solar PV ("PV-MOD"), substantiate many of the comments made in This Response.[4]

3. While not a standards development organization (SDO) itself, EPRI conducts research and demonstration projects in relevant areas as well as facilitates knowledge transfer and collaboration that SDOs may, at times, use to inform technical and regulatory standards development, such as for Institute of Electrical and Electronics Engineers (IEEE), International Electrotechnical Commission (IEC), International Council on Large Electric Systems (CIGRE), and NERC.[5]

4. EPRI's comments in This Response address reliability and FERC directives to NERC in this NOPR to develop Reliability Standards for IBRs that cover data sharing, model validation, planning and operational studies, and performance requirements (RM22-12). All comments are aimed at providing independent technical information to respond to the questions posed by FERC based on EPRI's research and development results and associated staff expertise and do not necessarily reflect the opinions of those supporting and working with EPRI to conduct collaborative research and development. Where appropriate, EPRI's comments do not only address the specific questions of the NOPR but also related scope that may help to inform a final order. Some of EPRI's comments presented in This Response have also been submitted in response to the previous FERC NOPR *Improvements to Large and Small Generator*

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[3] https://www.epri.com (last accessed, January 24, 2023)

[4] PV-MOD Project Website. EPRI. Palo Alto, CA: 2022. [Online] https://www.epri.com/pvmod (last accessed, January 24, 2023)

[5] For transparency, we would like to disclose that EPRI collaborates with other organizations such as IEEE, IEC, CIGRE, and NERC; however, EPRI is not a regulatory- or standard-setting organization. EPRI research is often considered in the development of recommendations, guidelines, and best practices that are not determinative.

Interconnection Procedures and Agreements (SGIP and SGIA) submitted under Docket No. RM22-14-000[6] that includes additional EPRI comments related to potential improvements in the SGIP and SGIA for IBR plants with a rating of less than 20MVA connecting to distribution or sub-transmission grids.

[6] *Improvements to Large and Small Generator Interconnection Procedures and Agreements: EPRI Comments on FERC's NOPR issued on June 16, 2022, Docket No. RM22-14-000*. EPRI, Palo Alto, CA: 2022. 3002025703. *[online]* https://www.epri.com/research/products/000000003002025703 and https://elibrary.ferc.gov/eLibrary/filedownload?fileid=ad71793a-769b-c856-91eb-83d327900000 (last accessed, January 24, 2023)

II. GENERAL COMMENTS IN RESPONSE TO NOPR

A. IBRs Modeling and Performance Requirements

5. FERC recognized recent efforts made by NERC in publishing disturbance reports and reliability guidelines for IBRs, as well as revisions to existing NERC Reliability Standards and the creation of, where appropriate, new NERC Reliability Standards in light of recent IBR plant performance issues. NERC documented those IBR plants' performance issues with support from EPRI and industry stakeholders for the Blue Cut Fire (2016)[7], Canyon Fire 2 (2017)[8], Angeles Forest and Palmdale Roost (2018)[9], San Fernando (2020)[10], Odessa (2021)[11], CAISO Solar PV (2021)[12], Panhandle Wind (2022)[13], and Odessa (2022)[14] disturbances. Based on the cited NERC reports and further analysis by EPRI in the context of its DOE-, NERC- and member-funded PV-MOD project[15], it was found that, (i) normally-cleared faults on the transmission system can cause a temporary wide area loss of power injection from IBR plants into the grid if the inverters and/or plant controller in those plants lack certain capabilities or are configured with non-conforming performance settings; (ii) the documented performance issues were likely due to misconfigurations of the plant's IBR units' (i.e., inverters') performance settings that lead to

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[7] *1,200 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report*, NERC. Atlanta, GA: June 2017. [Online] https://www.nerc.com/pa/rrm/ea/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_/1200_MW_Fault_Induced_Solar_Photovoltaic_Resource_Interruption_Final.pdf (last accessed, January 24, 2023)

[8] *900 MW Fault Induced Solar Photovoltaic Resource Interruption Disturbance Report*, NERC. Atlanta, GA: February 2018. [Online] https://www.nerc.com/pa/rrm/ea/October%209%202017%20Canyon%202%20Fire%20Disturbance%20Report/900%20MW%20Solar%20Photovoltaic%20Resource%20Interruption%20Disturbance%20Report.pdf (last accessed, January 24, 2023)

[9] *April and May 2018 Fault Induced Solar Photovoltaic Resource Interruption Disturbances Report*, NERC. Atlanta, GA: January 2019. [Online] https://www.nerc.com/pa/rrm/ea/April_May_2018_Fault_Induced_Solar_PV_Resource_Int/April_May_2018_Solar_PV_Disturbance_Report.pdf (last accessed, January 24, 2023)

[10] *San Fernando Disturbance*, NERC. Atlanta, GA: November 2020. [Online] https://www.nerc.com/pa/rrm/ea/Documents/San_Fernando_Disturbance_Report.pdf (last accessed, January 24, 2023)

[11] *Odessa Disturbance,* NERC. Atlanta, GA: September 2021. [Online] https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf (last accessed, January 24, 2023)

[12] *Multiple Solar PV Disturbances in CAISO*, NERC. Atlanta, GA: April 2022. [Online] https://www.nerc.com/pa/rrm/ea/Documents/NERC_2021_California_Solar_PV_Disturbances_Report.pdf (last accessed, January 24, 2023)

[13] *Panhandle Wind Disturbance*, NERC. Atlanta, GA: August 2022. [Online] https://www.nerc.com/pa/rrm/ea/Documents/Panhandle_Wind_Disturbance_Report.pdf (last accessed, January 24, 2023)

[14] *2022 Odessa Disturbance,* NERC. Atlanta, GA: December 2022. [Online] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/NERC_2022_Odessa_Disturbance_Report%20%281%29.pdf (last accessed, January 24, 2023)

[15] Refer to Footnote 4.

either overly sensitive inverter tripping, or to momentary cessation (i.e., current blocking), or both; (iii) inadequate restoration of the power injection from the IBR plants following the temporary reductions in power was caused either by a too slowly configured ramp rate setting (as observed for momentary cessation performance) or by a too long configured intentional delay (as observed for inverter tripping), or both; (iv) additional performance issues that were documented include a) inverter tripping due to AC under- or overvoltage, under- or overfrequency, AC overcurrent, abnormal DC voltage, feeder AC overvoltage, or feeder underfrequency, b) phase locked loop (PLL) loss of synchronism, and c) inverter uninterruptible power supply (UPS) failure.

6. EPRI research and collaboration with electric utilities and other stakeholders, as well as a recently updated report by the International Renewable Energy Agency (IRENA), show that uniform technical minimum capability and performance requirements, including ride-through requirements, can support system reliability in the longer term with increasing penetration of IBRs.[16,17,18] Failure of specification—and verification—of such requirements can increase the risk of regularly occurring IBR performance issues that adversely impact bulk power system reliability in the future, possibly creating barriers to the achievement of federal and state policy goals like the decarbonization of electricity supply.

7. EPRI research supports that the latest suite of published and publicly-available consensus technical standards like IEEE 2800-2022 (for registered and unregistered IBRs) and IEEE 1547-2018/1547a-2020 (for IBR-DER)—as a whole—sufficiently specify technical minimum capability and performance requirements for newly interconnecting generating and storage resources,

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[16] Impact of Variable Generation on Voltage and Frequency Performance of the Bulk System: Case Studies and Lessons Learned. EPRI. Palo Alto, CA: December 2014. 3002003685. [Online] https://www.epri.com/research/products/000000003002003685 (last accessed, January 24, 2023)

[17] Analyzing the Impact of Aggregated DER Behavior on Bulk Power System Performance: A Summary of Three Case Studies. EPRI. Palo Alto, CA: December 2021. [Online] https://www.epri.com/research/products/000000003002019445 (last accessed, January 24, 2023).

[18] "Grid Codes for Renewable Powered Systems", International Renewable Energy Agency (IRENA). ISBN 978-92-9260-427-1: March 2022. [Online] https://www.irena.org/publications/2022/Apr/Grid-codes-for-renewable-powered-systems (last accessed, January 24, 2023)

and those existing (legacy) resources that may be significantly upgraded.[19,20,21] That is, i) IEEE 2800-2022 harmonizes interconnection requirements for large solar, wind, and storage plants connected to transmission and sub-transmission grids, including those connected via VSC-HVDC like offshore wind; and ii) IEEE 1547-2018, amended by IEEE 1547a-2020 to provide more flexibility for adoption of abnormal performance category III, has become a common reference in State Public Utility Commissions and distribution utility's technical interconnection requirements (TIRs) for distribution connected synchronous and non-synchronous generators and energy storage resources. Consistent use of the definitions of applicable terms from these IEEE standards may also create more coherency among technical performance requirements.

8. The benefits of referencing the relevant IEEE interconnection performance standards and their definitions of applicable terms should be considered given that (1) these IEEE interconnection performance standards have been developed through a rigorous, open, and collaborative process comprising hundreds of stakeholders with many perspectives and sets of expertise and the standards have gained approval rates above 90% of working group members and balloters; [22,23,24] (2) EPRI's research shows that the resulting performance requirements

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[19] IEEE 2800-2022, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems. [Online] https://standards.ieee.org/ieee/2800/10453/ (last accessed, January 24, 2023)

[20] IEEE 1547-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. [Online] https://standards.ieee.org/ieee/1547/5915/ (last accessed, January 24, 2023); as amended by IEEE 1547a-2020, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces--Amendment 1: To Provide More Flexibility for Adoption of Abnormal Operating Performance Category III. [Online] https://standards.ieee.org/ieee/1547a/7696/ (last accessed, January 24, 2023)

[21] Refer to Footnotes 3, 16, and 17 for a collection of EPRI technical updates that partially evaluate and support the technical minimum requirements set forth in IEEE 2800 and IEEE 1547.

[22] *"The IEEE standards development process is rooted in consensus, due process, openness, right to appeal and balance. It adheres to and supports the principles and requirements of the World Trade Organization's (WTO) Decision on Principles for the Development of International Standards, Guides and Recommendations. In particular, the IEEE operates in active agreement with the WTO principle that standards should not create unnecessary obstacles to trade, and whenever appropriate, should specify requirements in terms of performance rather than design or descriptive characteristics.",* Source: Website of the IEEE Standards Association (IEEE SA): Developing Standards. [Online] https://standards.ieee.org/develop/ (last accessed, January 24, 2023).

[23] Boemer, Jens; Cummings, Bob; Hoke, Andy; Morjaria, Mahesh; Patel, Manish (2022): Addressing Grid Reliability As Renewable Energy Integration Speeds up. IEEE 2800™ Standard Tells How to Connect Large Solar, Wind, and Other Inverter-Based Resources to the Grid While Maintaining Reliability. In *IEEE SA Beyond Standards Blog*. [Online] https://beyondstandards.ieee.org/addressing-grid-reliability-as-renewable-energy-integration-speeds-up/ (last accessed, January 24, 2023).

[24] *IEEE 2800-2022 Update: New IEEE Interconnection Standard for Large-Scale Solar, Wind, and Energy Storage.* On-demand webinar. Recorded on May 2, 2023 by IEEE Standards Association. [Online] https://engagestandards.ieee.org/IEEE-2800-Update-Registration-LP.html (last accessed, January 25, 2023)

included in IEEE 2800 and 1547 provide for IBR performance that supports system reliability while providing sufficient flexibility for regional adoption by RTOs/ISOs,[25] and to interconnection customers for innovations in plant design to achieve the specified capability and performance; and (3) inverter original equipment manufacturers (OEMs) have publicly stated that state-of-the-art equipment already has the majority of the capabilities required by IEEE 2800.[26]

9. FERC Orders or Directives to NERC to develop Reliability Standards for IBRs that would include specification of ride-through capability and performance requirements should consider i) a clarification that ride-through performance requirements in accordance with "Good Utility Practice" could explicitly refer to the cited IEEE standards as examples for technical minimum requirements while also being inclusive of additional technical requirements specified by RTOs/ISOs or another responsible entity where justified, ii) aligning all applicable definitions proposed in the NERC Reliability Standards with these standards, and iii) evaluating potential benefits and processes of aligning additional definitions or performance specifications with potential future revisions of the cited IEEE standards, as these may occur over time, to keep

[25] RTOs/ISOs may require additional capabilities and performance for all IBRs interconnecting in their region as determined in regional reliability studies, and/or for a specific IBR plant interconnecting at a specific point of interconnection as determined in an interconnection impact or cluster study.

[26] Energy Systems Integration Group (ESIG) (2022): Summary of the Joint Generator Interconnection Workshop August 9-11, 2022. Virtual workshop held by the Energy Systems Integration Group, North American Generator Forum, North American Electric Reliability Corporation, and Electric Power Research Institute, August 9-11, 2022. Reston, VA. [Online] https://www.esig.energy/event/joint-generator-interconnection-workshop/ (last accessed, January 24, 2023); page 27ff.

pace with advancements in technology and standardization.[27,28,29] Failing to consider the advancements in the standardization of interconnection and interoperability requirements reflected in the cited IEEE standards could create technical barriers to IBRs. Further, paraphrasing of IEEE standards rather than directly referencing the standards' requirements could lead to an inhomogeneous implementation in different regions across the U.S. and with insufficient reliability benefits. If a 'wholesale' adoption of all the requirements specified in a given IEEE standard is not desired by FERC or NERC, the combination of a 'general reference' to the pertinent IEEE standard with a list of excepted clause and sub-clause numbers could allow for successive striking of such exceptions over time, signaling and aiming at a 'wholesale' adoption of the standard in the longer term.[30]

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[27] There is a precedence of FERC Orders and NERC reliability standards that refer to IEEE standards, including:

1. FERC Order 828 (Requirements for Frequency and Voltage Ride Through Capability of Small Generating Facilities) states, "Once finalized, IEEE Standard 1547 may be used as a technical guide to meet the requirements adopted herein."
2. FAC-008-3 (Facility Ratings) refers to ANSI and IEEE industry standards in general, if they developed through an open process such as IEEE or CIGRE.
3. PRC-002-2 (Disturbance Monitoring and Reporting Requirements) explicitly refer to C37.111, IEEE Standard for Common Format for Transient Data Exchange (COMTRADE), revision C37.111-1999 or later and C37.232, IEEE Standard for Common Format for Naming Time Sequence Data Files (COMNAME), revision C37.232-2011 or later.
4. PRC-019-2 (Coordination of Generating Unit or Plant Capabilities, Voltage Regulating Controls, and Protection) list as associated documents IEEE C37.102-2006, IEEE Guide for AC Generator Protection and IEEE C50.13-2005, IEEE Standard for Cylindrical-Rotor 50 Hz and 60 Hz Synchronous Generators Rated 10 MVA and Above.
5. PRC-023-4 (Transmission Relay Loadability) refers by footnote to C57.109-1993, IEEE Guide for Liquid-Immersed Transformer Through-Fault-Current Duration, Clause 4.4, Figure 4, and to C57.91, Tables 7 and 8, and Annex A.
6. PRC-025-1 (Generator Relay Loadability) list as associated document IEEE C37.102-2006, Guide for AC Generator Protection.
7. PRC-27-1 (Coordination of Protection Systems for Performance During Faults) refers by footnote to ANSI/IEEE Standard C37.2, Standard for Electrical Power System Device Function Numbers, Acronyms, and Contact Designations.
8. NERC project 2007-07 (Transmission Vegetation Management) reviewed the suitability of IEEE 516-2003 standard for minimum vegetation clearance and has been approved by FERC. The project found that the use of IEEE 516-2003 in version 1 of FAC-003 was a misapplication and laid out a preferred technical method. Among other factors when looking at changes to some technical data in FAC-003-1 was the identified problem of associated with referring to tables in another standard (IEEE 516-2003).

[28] If there is an issue pertaining to a purchase fee for IEEE standards, one approach is to leverage the IEEE virtual "Standards Reading Room" where, [Quote from IEEE website] "*Standards in the Reading Room are available in "view only" format. Standards are available in recognition of their incorporation by reference in the U.S. Code of Federal Regulations (CFR) along with other initiatives.*", see https://ieeexplore.ieee.org/browse/standards/reading-room/page. Standards in that Reading Room are available to anyone who registers with a free-of-charge IEEE account. For a specific standard to be made available in the reading room, it must first be incorporated into the U.S. CFR, for example when FERC publishes an Order in the Federal Register that includes the above URL and the standard's number and title. Some example IEEE standards in the Standards Reading Room include IEEE C2-2012 - National Electric Safety Code(R) (NESC(R)); IEEE 803-1983 - IEEE Recommended Practice for Unique Identification in Power Plants and Related Facilities - Principles and Definitions; IEEE 802.3-2022 - IEEE Standard for Ethernet.

[29] One example for potential revisions to IEEE 1547 and 2800 could be the emerging need for so-called grid-forming (GFM) inverter-based resources. The *universal interoperability for grid-forming inverters (unifi) Consortium* is a U. S. Department of Energy funded effort to advance grid-forming (GFM) inverter technology. Among other activities, *unifi* conducts standards developing, including the identification of potential technical barriers in the IEEE standards to GFM technology and potential gaps in the IEEE standards with regard to capability and performance requirement for GFM technology. For more information, refer to https://sites.google.com/view/unifi-consortium/ (last accessed, January 25, 2023)

[30] One necessity for such approach could be the evolution of market rules as discussed in Footnote 47.

10.An alternative approach to the one recommended in paragraph 9 is proposed where NERC Reliability Standards could use the precise language and definitions as published in the industry standards. This approach may require appropriate copyright releases and a review and revision of applicable NERC Reliability Standards whenever an industry standard has been revised.

11.Another consideration is to align requirements with leading international practices and "grid codes" for generators.[31,32,33] The future bulk power system could potentially operate, at times, at or near 100% inverter-based generation and storage. By adopting the "capability before utilization concept" laid out in the IEEE 2800 and IEEE 1547 standards, along with all the requirements specified in those IEEE standards ('wholesale adoption' of the IEEE standards), the bulk power system could be made ready for this future. According to IEEE 2800-2022,

> *A "capability requirement" in this standard specifies that the IBR plant (and where applicable, IBR unit[s]) shall be able to provide a function, configuration, or performance as determined by design, installation, and operational status of equipment and control systems. A "performance requirement" in this standard specifies the IBR plant's (and where applicable, the IBR unit's) behavior when executing a specified function or mode, or when responding to a change in conditions.*
>
> *NOTE 1—A "capability requirement" is, in colloquial terms, a requirement that ensures the IBR plant (or IBR unit) is "ready to go at the flip of a switch." This is more stringent than a "readiness requirement" that is in colloquial terms a requirement that ensures the IBR plant (or IBR unit) is "almost ready to go," for example, by having at least all interfaces that are needed to (easily) retrofit the IBR with certain equipment and controls that can provide a specified capability. The concept of readiness is not used in this standard.*[…]
>
> *NOTE 2—A "performance requirement" is not an "utilization requirement." An "utilization requirement" is, in colloquial terms, a requirement that ensures the IBR plant (or IBR unit) is "actually providing" a specified performance, for example, by enabling a specified capability that makes the IBR continuously deliver a performance consistent with the specified default values for functional settings. As clarified in the list of what remains outside the scope of this standard below, requirements for utilization of any of the capabilities specified in this standard are outside the scope of this standard.*

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[31] European Commission (4/14/2016): Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators. In *Official Journal of the European Union* L112/1 (27.4.2016). [Online] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0631&from=EN (last accessed, January 24, 2023)

[32] Grid Code: Connection Conditions & European Connection Conditions. nationalgridESO: March 2022. [Online] https://www.nationalgrideso.com/electricity-transmission/industry-information/codes/grid-code/code-documents (last accessed, January 24, 2023)

[33] National Electricity Rules: Chapter 5—Network Connection Access, Planning and Expansion, Schedule 5.2—Conditions for Connection of Generators; Clause S5.2.5—Technical requirements. Australian Energy Market Commission (AEMC): September 2022. [Online] https://energy-rules.aemc.gov.au/ner/416/163468#S5.2.5 (last accessed, January 24, 2023)

Source: IEEE 2800-2022, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems. https://standards.ieee.org/ieee/2800/10453/ (last accessed, January 24, 2023)

Adopting all of the consensus technical minimum capability and performance requirements of IEEE 2800 (for registered and unregistered IBRs) and IEEE 1547 (for IBR-DER)—even if the capabilities specified in those IEEE standards are not immediately utilized when the plants enter commercial operation—could be a cost-effective[34] approach to mitigate the risk of future retrofit programs. Retrofits have become necessary in other countries around the world.[35,36] Examples from EPRI research show utilization of capabilities (such as fast dynamic voltage support in distribution-connected inverters) helps improve the stability of the network with a high percentage of distributed resources.[37] A similar concept can also be applied to transmission-network connected IBRs wherein stability can be improved by shifting voltage control from the plant controller (which is traditionally a slower form of control) to the inverter controller (whose control system is an order of magnitude faster). EPRI research[38,39,40] has observed that utilization of fast voltage control at the inverter level for transmission-connected inverters can greatly improve the stability of low short circuit networks with a high percentage of inverters. Similar findings have also been obtained in studies carried out in Australia.[41]

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[34] Refer to Footnote 19.

[35] *Grid Codes for Interconnection of Inverter-Based Distributed Energy Resources by Country: Recent Trends and Developments*. EPRI. Palo Alto, CA: November 2014. 3002003283. [Online] https://www.epri.com/research/products/000000003002003283 (last accessed, January 24, 2023)

[36] Dispersed Generation Impact on CE Region Security: Dynamic Study. 2014 Report Update. European Network of Transmission System Operators for Electricity (ENTSO-E), ENTSO-E SPD Report, Brussels, Belgium: December 2014. [Online] https://eepublicdownloads.entsoe.eu/clean-documents/Publications/SOC/Continental_Europe/141113_Dispersed_Generation_Impact_on_Continental_Europe_Region_Security.pdf (last accessed, January 24, 2023)

[37] *Program on Technology Innovation: Benefit of Fast Reactive Power Response from Inverters in Supporting Stability of Weak Distribution Systems: A Use Case of Grid Forming Inverters and their Performance Requirements*. EPRI, Palo Alto, CA: 2020. 3002020197. [Online] https://www.epri.com/research/products/000000003002020197 (last accessed, January 24, 2023)

[38] *IBR Modeling Guidelines for Weak Grid Studies and Case Studies*. EPRI, Palo Alto, CA: 2020, 3002018719. [Online] https://www.epri.com/research/products/000000003002018719 (last accessed, January 24, 2023)

[39] D. Ramasubramanian, "Differentiating between plant level and inverter level voltage control to bring about operation of 100% inverter based resource grids," *Electric Power Systems Research*, vol. 205, no. 107739, Apr 2022.

[40] Deepak Ramasubramanian, Wes Baker, Julia Matevosyan, Siddharth Pant, and Sebastian Achilles, "Asking for Fast Terminal Voltage Control in Grid Following Plants Could Provide Benefits of Grid Forming Behavior," *IET Generation, Transmission & Distribution*, 00, 1 – 16 (2022)

[41] Hardt C., Premm D., Mayer P., Mosallat F., Goyal S., "Practical experience with mitigation of sub-synchronous control interaction in power systems with low system strength," *(2021) CIGRE Science and Engineering*, 21 (June), pp. 5 – 13

III. COMMENTS IN RESPONSE TO REGISTERED AND UNREGISTERED IBRS

B. Section I. Introduction

12.This section of NOPR provides a comparison of the behavior and response of synchronous resources against IBRs and associated reliability concerns with IBRs. The technical context and language in this section could be modified and improved to provide a more complete technical background and justifications.

13.Footnote 6 in paragraph 2 states:

> "*A converter is a power electronic device that converts AC sinusoidal power to DC power through solid state switches.*"

EPRI would like to comment that the provided definition refers to a rectifier. "Converter" is a more general term *that covers both inverter and rectifier.*

14.Paragraph 3 includes the following statement:

> *"For example, synchronous resources that are not connected to a fault will automatically ride through a disturbance because they are synchronized (i.e., connected at identical speeds) to the electric power system and physically linked to support the system voltage or frequency during voltage or frequency fluctuations by continuing to produce real and reactive power. In contrast, IBRs are not directly synchronized to the electric power system and must be programmed to support the electric power system and to ride through a disturbance. The operational characteristics of IBRs coupled with their equipment settings may cause them to reduce power output, whether by tripping offline or ceasing operation without tripping offline (known as momentary cessation), individually or in the aggregate in response to response to a single fault on a transmission or sub-transmission system. Such occurrences may exacerbate system disturbances and have a material impact on the reliable operation of the Bulk-Power System."*

From a technical perspective, we have the following comments:

a. It is not clear what is meant by "*synchronous resources that are not connected to a fault.*" Presumably, it means synchronous resources which are not directly exposed to a fault (e.g., a fault within the plant) which requires the plant to trip to protect equipment and personal safety. It is recommended to modify this statement accordingly to add clarity.

b. Synchronous resources will not always automatically ride through a disturbance, as stated in this paragraph. Synchronous resources use electromechanical torque to synchronize to the grid frequency; however, depending on the type of fault, its location, and duration, synchronous resources could lose synchronism to the grid due to rotor angle stability or—in a general term—transient stability issues. EPRI would also like to note that existing Reliability Standards like PRC-024-3 do not prohibit synchronous generators on the loss of synchronism; rather, planning coordinators (PCs), transmission planners (TPs), reliability coordinators (RCs) need to understand such limitations through transient stability studies and establish appropriate measures such as system operating limits (SOLs).

c. While synchronous resources are synchronized to the grid by their electromechanical torque, IBRs also need to synchronize to the grid. However, IBRs use a control strategy such as PLL in order to maintain their synchronism with the grid. Therefore, the statement which says "*IBRs are not directly synchronized to the electric power system"* may need to be revised to add clarity.

d. There is repeated wording *"response to"* in the second last sentence of this paragraph.

15.*Paragraph 5 uses the term "IBR-DER,*" while this term is not introduced in the NOPR yet. This term is defined next page in footnote 15.

16.Paragraph 5 has the following sentence:

> "*To achieve this, the Reliability Standards should ensure that generator owners, transmission owners, and distribution providers are required to share validated modeling, planning, operations, and disturbance monitoring data for IBRs with planning coordinators, transmission planners, reliability coordinators, transmission operators, and balancing authorities.*"

EPRI research[42] and industry findings support that all models should be validated and appropriately parameterized to reflect the actual behavior and response of a generation resource in applicable studies and deliver meaningful results. Therefore, we propose to modify

[42] *Differentiating between Applicability of Simulation Domains and Inverter Mathematical Models in these Domains*. 3002025063. Electric Power Research Institute (EPRI). Palo Alto, CA. [Online] https://www.epri.com/research/products/000000003002025063 (last accessed, January 24, 2023).

this sentence and other instances where "validated models" is used to state (additions highlighted in red font):

> *"To achieve this, the Reliability Standards should ensure that generator owners, transmission owners, and distribution providers are required to share validated and appropriately parametrized modeling, planning, operations, and disturbance monitoring data for IBRs with planning coordinators, transmission planners, reliability coordinators, transmission operators, and balancing authorities."*

C. Section II. B. Reliability Impacts of IBR Technologies

17. Paragraph 16 has the following statement:

> "*When appropriately programmed, IBRs can operate during greater frequency deviations (i.e., a wider frequency range) than synchronous generation resources.*[34]"

While EPRI, in general, agrees with the potential capabilities of IBRs listed in this NOPR, we note that reference [34] in the NOPR illustrates the capability of IBRs to provide frequency response during under-frequency events. The language used in the above statement in the NOPR suggests IBRs have the capability to operate in wider frequency deviations, which may be true compared to the capability of synchronous resources, but this is not what is shown in the reference document.

D. Section II. C. Actions to Address the Reliability Impact of IBR Technologies

18. We suggest fixing the hyperlink error message in footnote 48 in paragraph 20.

19. Paragraph 20 and footnote 51 refer to several Reliability Standard development projects that NERC IRPS and SPIDERWG have initiated to address IBR impacts on the reliable operation of the Bulk-Power System. The NERC Inverter-Based Resource Performance Subcommittee (IRPS), formerly known as NERC IRPTF and IRPWG, has also been working on submitting

Standard Authorization Requests (SARs) to modify existing or develop new Reliability Standards to address reliability issues associated with IBRs. This list of submitted or in-progress SARs is as follows:[43, 44]

- Revisions to FAC-001 and FAC-002
- Revision to TPL-001-5
- Model Quality Checks in FAC-002 and MOD-032 Standards
- Project 2021-04 Modifications to PRC-002-2
- Project 2020-02 Modifications to PRC-024 (Generator Ride Through)[45]
- Project 2020-06 Verification of Models and Data for Generators
- Project 2021-01 Modifications to MOD-025 and PRC-019
- Project 2022-04 EMT Modeling - Inclusion of EMT Models into MOD, TPL, and FAC Standards
- Project 2021-02 Modification to VAR-002
- (Future Project) Updates to EOP-004 - Gen Loss Criteria for IBRs
- (Future Project) IBR Performance Issues - Revisions to PRC-004 (or Complementary Standard)

20.In Paragraph 23 and footnote 58, please correct the naming of IEEE standard to 2800-2022, which is currently mentioned as IEEE 2800-2020.

21.Paragraph 23 of the NOPR refers to industry standards and manufacturer certification efforts related to IBRs that are published or underway, such as IEEE 1547-2018, IEEE 2800-2022, and UL 1741 standards, and makes the following statement:

> "*These efforts may enhance the operating performance and control capabilities of IBRs; however, these efforts remain at relatively early stages, do not apply to all relevant IBRs, and require adoption by state or other regulatory authorities*."

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[43] Inverter-Based Resource Performance Subcommittee (IRPS) Work Plan, NERC. Atlanta, GA: August 2022. [Online] https://www.nerc.com/comm/RSTC/IRPS/IRPS%20Work%20Plan.pdf (last accessed, January 24, 2023)

[44] Reliability Standards Under Development, [online] https://www.nerc.com/pa/Stand/Pages/Standards-Under-Development.aspx (last accessed, January 24, 2023)

[45] The ongoing revision of NERC PRC-024 may revise the "no-trip zone" to align with IEEE 2800-2022 that allows for "permissive operation" (including momentary cessation) during voltage ride-through performance when the voltage at the plant's reference point of applicability is below 0.1 pu, a condition for which injection of active current by an IBR plant could lead to local plant voltage angle instability. Refer to EPRI's comments submitted in response to the FERC NOPR *Improvements to Large and Small Generator Interconnection Procedures and Agreements* (SGIP and SGIA) submitted under Docket No. RM22-14-000 as referenced in Footnote 6 for further details.

As indicated in Paragraphs 7-11 in This Response, referring to IEEE standards could bring several advantages, which should be considered in modifying or developing Reliability Standards. Further, several ISOs and utilities have already started adopting IEEE 2800-2022 requirements.[46] However, EPRI has observed that requiring certain capabilities may conflict with current market rules in certain jurisdictions.[47] One approach to address such implementation issues is to adopt IEEE requirements through FERC and/or NERC. This could reduce barriers to harmonizing IBR plant technical minimum capability and performance requirements. Further, this would align with international practices (such as in Europe) of regulatory orders referencing consensus technical standards that are developed in an open process with relevant stakeholders [48,49,50]. Therefore, EPRI recommends that FERC considers the cited IEEE standard requirements as an alternative for, or in support of, NERC Reliability

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[46] Below are a few examples of ongoing efforts of which EPRI is aware:

- ERCOT: IEEE 2800 vs Existing ERCOT Interconnection Requirements, Gap Analysis Learnings, Stephen Solis, ERCOT, August 2022. [online] https://www.esig.energy/download/ieee-2800-vs-existing-ercot-interconnection-requirements-gap-analysis-learnings-stephen-solis/?wpdmdl=9265&refresh=62f587eaba49e1660258282 (last accessed, January 24, 2023)
- ISO NE: ISO-NE IEEE 2800 Adoption Update, Bradly Marszalkowski, September 2022. [online] https://www.nysrc.org/PDF/MeetingMaterial/5.%20Marszalkowski%20-%20%20ISO-NE_IEEE2800AdoptionUpdate_NYSRC.pdf (last accessed, January 24, 2023)
- Florida Power and Light: FPL Adoption of IEEE P2800, August 2022. [online] https://www.nerc.com/comm/RSTC/IRPS/IRPS_August_2022_Meeting_Presentations.pdf (last accessed, January 24, 2023)
- Southern Company: Transmission Interconnection Technical Requirements for Inverter-Based Resources, September 2022. [online] https://www.oasis.oati.com/woa/docs/SOCO/SOCOdocs/SOCO_IBR_Interconnection-Technical-Requirements_Effective_2022-09-15.pdf (last accessed, January 24, 2023)
- New York ISO: NYISO Implementation of IEEE 2800-2022, September 2022. [online] https://www.nysrc.org/PDF/MeetingMaterial/Nguyen%20-%20NYISO_NYSRC%20IEEE%202800-2022%20Workshop_091322_clean.pdf (last accessed, January 24, 2023)
- MISO: MISO's Review of Interconnection Requirements, October 2022. [online] https://www.esig.energy/download/session-2-misos-review-of-interconnection-requirements-patrick-dalton/?wpdmdl=9567&refresh=63602720b033e1667245856 (last accessed, January 24, 2023)

[47] Gap Analysis Between IEEE 2800 and Existing Interconnection Requirements, Jens Boemer, October 2022. [online] https://www.esig.energy/download/session-2-gap-analysis-between-ieee-2800-and-existing-interconnection-requirements-jens-boemer/?wpdmdl=9563&refresh=63602720a4ae91667245856 (last accessed, January 24, 2023)

[48] European Commission (4/14/2016): Commission Regulation (EU) 2016/631 of 14 April 2016 establishing a network code on requirements for grid connection of generators. In *Official Journal of the European Union* L112/1 (27.4.2016). [Online] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R0631&from=EN (last accessed, January 24, 2023)

[49] Grid Code: Connection Conditions & European Connection Conditions. nationalgridESO: March 2022. [Online] https://www.nationalgrideso.com/electricity-transmission/industry-information/codes/grid-code/code-documents (last accessed, January 24, 2023)

[50] National Electricity Rules: Chapter 5—Network Connection Access, Planning and Expansion, Schedule 5.2—Conditions for Connection of Generators; Clause S5.2.5—Technical requirements. Australian Energy Market Commission (AEMC): September 2022. [Online] https://energy-rules.aemc.gov.au/ner/416/163468#S5.2.5 (last accessed, January 24, 2023)

Standards development. Adoption of IEEE standards by reference in a FERC Order would, as stated on IEEE's website, lead IEEE to make the cited standards publicly available free-of-charge and read-only in the IEEE Standards Reading Room.[51]

22.IEEE 2800-2022 was approved and published in February and April 2022, respectively[52]. Please update footnote 58 with the correct month for approval and add the publication date as required.

E. Section III. A. Recent Events Show IBR-Related Adverse Reliability Impacts on the Bulk-Power System

23.Footnote 61 in paragraph 25 states that:

> *"NERC reported that the Blue Cut fire IBR erroneous frequency calculation issue was successfully mitigated."*

The above erroneous frequency measurement mentioned in the Blue Cut disturbance report was applicable to one OEM, which was subsequently fixed. However, the NERC disturbance report on California disturbances between June and August 2021 has the following statement, indicating the issue still exists for other OEMs.

> *"The sole inverter manufacturer involved in the Blue Cut Fire frequency-related tripping quickly and proactively responded by ensuring that all BPS-connected solar PV facilities changed their frequency protection settings to avoid future issues. However, these disturbances in 2021 involve different inverter manufacturers, illustrating that the issue is still not widely understood or addressed across all manufacturers and plant owner/operators."*

F. Section III. 2. a. Approved Component Models

24.Paragraph 36 includes the following statement:

> *"…NERC has worked with its stakeholders to develop, validate, and maintain a library of standardized approved component models (e.g., generator elements) and parameters for powerflow and dynamic cases. NERC's approved component model list is a collection of generic industry steady-state and dynamic models (e.g., excitor, governor, load, etc.) that*

[51] Refer to Footnote 28 for more information.

[52] IEEE 2800-2022, IEEE Standard for Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems. [Online] https://standards.ieee.org/ieee/2800/10453/ (last accessed, January 24, 2023)

when combined accurately reflect the steady-state and dynamic performance of a resource. Despite these efforts, some resource owners still provide modeling data that is based on a proprietary model rather than an approved industry-vetted model. The use of proprietary models in interconnection-wide models can be problematic because their internal model components cannot be viewed or modified, and thus produce outputs that cannot be explained or verified."

This paragraph focuses on the importance of industry-approved models available in commercial software platforms, also known as generic models. EPRI agrees on the importance and use of generic models in system-side planning or operations studies provided that such models are appropriately parametrized and validated, and continuously improved to stay current with emerging technology.[53] However, EPRI notes the importance of using proprietary or user-defined models (UDMs). Such models (provided that they are also appropriately parameterized and validated) may be needed for special interconnection or operational studies as they include unique controls and protection strategies implemented by OEMs which may not be captured sufficiently or at all by generic models. Hence, user-defined models may provide a more accurate response compared to generic models depending on the type of studies. Further, while the NERC-approved model list contains a collection of generic models, there are no requirements in NERC Reliability Standards, guides, etc., that prohibit the submission or use of UDMs[54]. The above language in the NOPR could indicate the submission and use of UDMs should be discouraged or prohibited; however, all types of models have their application purpose, and FERC should consider requiring the submission of validated UDMs in addition to the submission of validated generic models[55].

G. Section III. 4. a. Frequency Ride Through

25. Paragraph 56 includes the following statement:

> *"Synchronous resources will automatically ride through a disturbance because they are synchronized (i.e., connected at identical speeds) to the electric power system and physically linked to support the system frequency during frequency fluctuations by continuing to produce real and reactive power."*

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[53] Refer to Footnote 4 for EPRI research aiming at the continuous improvement of generic solar PV models across various time scales and voltage levels.

[54] *IBR Modeling Update Review of Findings and Recommendations from NERC Disturbance Reports and Guidelines,* Ryan Quint, December 2022, *[online]* https://www.esig.energy/download/ibr-modeling-update-ryan-quint/?wpdmdl=9704&refresh=6399d0cac30461671024842 (last accessed, January 24, 2023)

[55] Refer to Footnote 6.

As mentioned in EPRI's comment 14.b in This Response, the above statement may not always be accurate. It is recommended to be revised accordingly.

H. Section IV. B. IBR and IBR-DER Data and Model Validation

26.This NOPR does not include the need for electromagnetic transient (EMT) models. Recent NERC disturbance reports, including Odessa (2021)[56], CAISO Solar PV (2021)[57], Panhandle Wind (2022)[58], and Odessa (2022)[59] events, identified that some causes of IBR tripping could only be identified through EMT modeling and simulations. Further, multiple other factors—such as the size and location of interconnecting generation facility and also type of nearby plants and transmission equipment—may drive the need for performing EMT studies.[60,61] EPRI recommends collecting validated and appropriately parametrized EMT models during the interconnection process, irrespective of the need to perform an EMT study for the interconnecting generation facility. An EMT study may become necessary as the grid evolves, which could result in changes in system strength, addition of nearby IBRs, etc. Collecting an accurate and validated EMT model after the interconnection stage could be extremely challenging. The best time to obtain such models is during the interconnection stage, as there would be close coordination among project developers, consultants, OEMs, and plant designers to deliver a validated and appropriately parametrized model.[62]

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[56] *Odessa Disturbance,* NERC. Atlanta, GA: September 2021. [Online] https://www.nerc.com/pa/rrm/ea/Documents/Odessa_Disturbance_Report.pdf (last accessed, January 24, 2023)

[57] *Multiple Solar PV Disturbances in CAISO*, NERC. Atlanta, GA: April 2022. [Online] https://www.nerc.com/pa/rrm/ea/Documents/NERC_2021_California_Solar_PV_Disturbances_Report.pdf (last accessed, January 24, 2023)

[58] *Panhandle Wind Disturbance*, NERC. Atlanta, GA: August 2022. [Online] https://www.nerc.com/pa/rrm/ea/Documents/Panhandle_Wind_Disturbance_Report.pdf (last accessed, January 24, 2023)

[59] *2022 Odessa Disturbance,* NERC. Atlanta, GA: December 2022. [Online] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/NERC_2022_Odessa_Disturbance_Report%20%281%29.pdf (last accessed, January 24, 2023)

[60] [60] D. Ramasubramanian, "Differentiating between plant level and inverter level voltage control to bring about operation of 100% inverter based resource grids," *Electric Power Systems Research*, vol. 205, no. 107739, Apr 2022

[61] *Modeling and Study Guides for Integration of Inverter Based Resources in Low Short Circuit Grids*. EPRI, Palo Alto, CA: 2019. 3002016199. [online] https://www.epri.com/research/products/000000003002016199 (last accessed, January 24, 2023)

[62] *Reliability Guideline: Improvements to Interconnection Requirements for BPS-Connected Inverter-Based Resources*, NERC, Atlanta, December 2022. [online] https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Reliability_Guideline_-_Interconnection_Requirements-redline_June_16_2022.pdf (last accessed, January 24, 2023)

27.Paragraph 83 proposes to direct NERC to submit to FERC for approval one or more new or modified Reliability Standards to ensure that all necessary models – including registered IBRs, unregistered IBRs and IBR-DR – are validated. The NOPR comes short of providing the timing for which such models need to be provided for new resources. Multiple activities may be required during various stages of the interconnection process, including:[63]

a. Pre-commissioning stage to perform plant model design evaluation to ensure conformity with interconnection requirements. This activity would occur in the early stages of the interconnection process and is similar to a screening process.
b. Post-construction as-built evaluation and comparison against pre-commissioning design.
c. Continuous monitoring post-construction and model validation to ensure conformity with interconnection requirements during the operation stage considering ride-through and recovery assessment transmission system faults, switching events, etc.

In addition, the NOPR is not specific with respect to the model details and what should be included in the model (e.g., an IBR unit model, an IBR plant model, or both; are "supplemental IBR devices" included or not, etc.). From the language, it can be inferred that the intent is to provide a "plant-level" model, including all equipment in the IBR plant, such as IBR units, a plant controller, the plant's collector system, and any *supplemental* devices (both IBR and non-IBR, e.g., synchronous condensers). However, a "validated" plant model would not be available during the interconnection stage because validation of the plant model is not possible—within reasonable efforts—until after the commissioning and commercial operation of the plant have started. The IEEE P2800.2 working group, with its more than one hundred subject matter experts from a diverse group of stakeholders, is developing an IEEE Recommended Practice for Test and Verification Procedures for Inverter-based Resources Interconnecting with Bulk Power Systems that is expected to include detailed technical procedures, criteria, and consensus definitions, including the use of "verified plant models" that are based on validated and appropriately parameterized unit and supplemental equipment models with a frozen IBR plant

[63] Boemer, Shattuck, Matevosyan: "Need for North American Interconnection Process Review" ESIG Blog Article: December 2022 [Online] https://www.esig.energy/need-for-north-american-interconnection-process-review/ (last accessed, January 24, 2023)

design. These verified plant models could be used to assess the conformity of the IBR plant design with IEEE 2800-2022 requirements prior to commissioning. In the early stages of the interconnection process, "best available models," including an industry-accepted generic EMT model, could be allowed with appropriate parameters in lieu of a verified EMT model at the time of interconnection studies. EPRI has recently published proposed specifications for such a generic EMT model as one of the PV-MOD deliverables and can assist EMT software developers to incorporate that model into their standard libraries for ready application by transmission planning or interconnection engineers.[64,65,66]

28.EPRI, its staff, and its contractors have published a large body of research related to generic model development, validation, and improvement[67], with the DOE-, NERC-, and EPRI member-

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[64] Website of the IEEE P2800.2 Working Group: https://sagroups.ieee.org/2800-2/

[65] Generic Photovoltaic Inverter Model in an Electromagnetic Transients Simulator for Transmission Connected Plants: PV-MOD Milestone 2.7.3. EPRI, Palo Alto, CA: 2022. [Online] https://www.epri.com/pvmod (last accessed, (last accessed, January 24, 2023)

[66] *Generic Photovoltaic Inverter Model in an Electromagnetic Transients Simulator for Transmission Connected Plants: User Manual for PSCAD^{TM} Model Prototype.* EPRI, Palo Alto, CA: 2022. 3002025889. *[online]* https://www.epri.com/research/products/000000003002025889 (last accessed, January 27, 2023)

[67] Example publications related to generic model development, validation, and improvement include (all public and at no cost except where indicated with an asterisk *):

1) EPRI Report: Generic Models and Model Validation for Wind and Solar PV Generation: Technical Update, Product ID: 1021763, Technical Update, December 2011 (free to the public at: https://www.epri.com/research/products/000000000001021763) (last accessed, January 24, 2023)

- This is one of the original R&D reports on the development of the 2nd generation generic models, and shows verification of the proposed model structures against numerous field data for WTGs (including many vendor's cases)

2) Proposed Changes to the WECC WT3 Generic Model for Type 3 Wind Turbine Generators: Prepared by EPRI (Under Subcontract No. NFT-1-11342-01 with NREL), Issued 3/26/12 (revised 9/27/13) *https://www.wecc.org/Reliability/WECC-Type-3-Wind-Turbine-Generator-Model-Phase-II-012314.pdf* (last accessed, January 24, 2023)

- This is one of the original R&D reports on the development of the 2nd generation generic models. It clearly shows the efficacy of the models through multiple validation cases of individual WTGs (type 3 from various vendors) against actual measured data. ***Note:*** countless other runs were performed, but not shown.

3) Proposed Changes to the WECC WT4 Generic Model for Type 4 Wind Turbine Generators: Prepared by EPRI (Under Subcontract No. NFT-1-11342-01 with NREL), Issued 12/16/11 (revised 1/23/13) *https://www.wecc.org/Reliability/WECC-Type-4-Wind-Turbine-Generator-Model-Phase-II-012313.pdf* (last accessed, January 24, 2023)

- This is one of the original R&D reports on the development of the 2nd generation generic models. It clearly shows the efficacy of the models through multiple validation cases of individual WTGs (type 4 from various vendors) against actual measured data. ***Note:*** countless other runs were performed, but not shown.

4) Asmine, M.; Brochu, J.; Fortmann, J.; Gagnon, R.; Kazachkov, Y.; Langlois, C. E.; Larose, C.; Muljadi, E.; MacDowell, J.; Pourbeik, P.; Seman, S. A.; and Wiens, K., "Model Validation for Wind Turbine Generator Models" IEEE Transactions on PWRS, August 2011, pages 1769 - 1782. *https://ieeexplore.ieee.org/document/5671567* (last accessed, January 24, 2023)*

- This paper was an AdHoc IEEE TF effort between WECC, IEEE and IEC group members to illustrate the efficacy of generic models as they were be developed.

5) P. Pourbeik, J. Sanchez-Gasca, J. Senthil, J. Weber, P. Zadehkhost, Y. Kazachkov, S. Tacke and J. Wen, *"Generic Dynamic Models for Modeling Wind Power Plants and other Renewable Technologies in Large Scale Power System Studies", IEEE Trans. on Energy Conversion, September 2017.* https://ieeexplore.ieee.org/document/7782402 (last accessed, January 24, 2023)*

- This is a WECC TF paper that reports on the 2nd generic models.
- The paper shows clear evidence of the generic models validated against:
    i. Individual type 3, type 4 WTGs and PV inverters
    ii. Large wind plants validated for both volt/Var and frequency response based on field measurements and disturbance monitoring
    iii. The models having been benchmarked across the four major software tools
- On page 3 of this paper the "limitations" of the generic models are explained. Some of these limitations have been since addressed (by *REGC_B* and *REGC_C* – see below).

6) P. Pourbeik, S. Soni, A. Gaikwad and V. Chadliev, *"Providing Primary Frequency Response from Photovoltaic Power Plants", CIGRE Symposium 2017, Dublin, Ireland, May 2017.* (Published in the October 2018 issue of CIGRE Science and Engineering) https://e-cigre.org/publication/CSE012-cse-012 (last accessed, January 25, 2023)

- This paper shows clear evidence of the efficacy of the 2nd generation generic models in representing overall PV plant performance for both volt/Var and frequency response simulations, based on actual field tests by the vendor.

7) P. Pourbeik and J. K. Petter, *"Modeling and validation of battery energy storage systems using simple generic models for power system stability studies", CIGRE Science and Engineering, October 2017, pp. 63-72. https://e-cigre.org/publication/CSE009-cse-009 (last accessed, January 25, 2023)*

- This paper illustrates the efficacy of the 2nd generation generic models in representing the volt/Var and frequency response characteristics of a battery energy storage system, by comparing the 2nd generation generic models against highly-details and proprietary 3-phase equipment design models. Moreover, it does show the limitations of the models for trying to emulate the response to an unbalanced fault.

8) P. Pourbeik, N. Etzel and S. Wang, *"Model Validation of Large Wind Power Plants Through Field Testing", IEEE Transactions on Sustainable Energy, July 2018* (http://ieeexplore.ieee.org/document/8118170/ [ieeexplore.ieee.org]) (last accessed, January 24, 2023)*

- Validation of large wind power plants using the generic models; validation shown both at individual turbine level and plant level.

9) *Reliability Guideline Power Plant Model Verification for Inverter-Based Resources*, September 2018 https://www.nerc.com/comm/RSTC_Reliability_Guidelines/PPMV_for_Inverter-Based_Resources.pdf (last accessed, January 24, 2023)

- NERC's own document with contributions from numerous folks and vendors showing in various examples throughout the document the efficacy of the generic models.

10) Example for Verification of the proposed IBFFR model, Memo Issued to WECC REMTF, DATE: 7/1/19 (REVISED 7/11/19; 7/16/19; 7/17/19) *https://www.wecc.org/Administrative/Memo_RES_Modeling_Updates_010523_Rev25_Clean.pdf* (EPRI Funded R&D) (last accessed, February 6, 2023)

- This memo illustrates, using actual field measured data, the efficacy of the newly proposed IBFFR model for emulating inertial-based fast-frequency response for WTGs, using the generic models.

11) *Verification of the Generic Model for Inertial-Based Fast Frequency Response of Wind Turbine Generators.* Technical Update. EPRI. Palo Alto, CA: 2019. 3002016200. https://www.epri.com/research/products/000000003002016200 (last accessed, February 6, 2023)

- This public EPRI report also illustrates, using actual field measured data, the efficacy of the newly proposed IBFFR model for emulating inertial-based fast-frequency response for WTGs, using the generic models.

*1*2) D. Ramasubramanian, W. Wang, P. Pourbeik, E. Farantatos, A. Gaikwad, S. Soni and V. Chadliev, *"A Positive Sequence Voltage Source Converter Mathematical Model for Use in Low Short Circuit Systems", IET Generation, Transmission & Distribution, January 2020. https://ietresearch.onlinelibrary.wiley.com/doi/epdf/10.1049/iet-gtd.2019.0346 (last accessed, January 25, 2023)*

- This paper clearly shows, through simulations compared with field measurements from a PV plant, the efficacy of the newly proposed REGC_C model to address some of the limitations with the current-source mathematical models that were hitherto used for modeling the generator/converter interface.

funded "PV-MOD" project milestone reports[68] being the dissemination of research results. Clause 12 (Test and verification requirements) of IEEE 2800-2022 specifies the test and verification requirements and methods applicable to each IBR interconnection and interoperability requirement specified in the standard. The ongoing IEEE P2800.2 Working Group is working on establishing processes and criteria on how to perform model validation and IBR plant conformity assessment prior to and after IBR plant commissioning. Since IEEE P2800.2 may not be completed and published by the time FERC rules on a final order, the example publications related to generic model development, validation, and improvement listed in Footnote 67 could be referenced in lieu of the standard. The public could benefit from these publications, which include potential solutions to address the gaps identified by FERC in the interim.

29.Because a site-specific verified plant model may not be available at the time of interconnection studies, there might be a need for transmission providers to evaluate "material modification" and/or restudy the cluster once that model is available. This is likely to occur just prior to or during plant construction (or after commissioning), creating a potential risk where the verified IBR plant model may show reliability issues not previously observed by use of the

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13) D. Ramasubramanian, P. Pourbeik, E. Farantatos and A. Gaikwad, *"Simulation of 100% Inverter-Based Resource Grids With Positive Sequence Modeling", IEEE Electrification Magazine, June, 2021.* https://ieeexplore.ieee.org/document/9447546 (last accessed, January 25, 2023)*

- Granted that this paper is simulations only, but it is starting to show the potential efficacy of the generic models and positive sequence modeling even for 100% IBR systems.

14) Proposal for New Plant Controller and Electrical Controller, Memo Issued to WECC MVS on REECE and REPCD, Date: 5/13/22. *https://publicdownload.epri.com/PublicAttachmentDownload.svc/AttachmentId=82137* (last accessed, January 25, 2023)

- This memo presents enhancements in the electrical controls model and plant controller model (specifically for hybrid-plants or plants with multiple aggregated inverter-based generation models) as PV-MOD Milestones 2.7.5 and 2.7.6.

15) Proposal for New Features for the Renewable Energy System Generic Models, Memo Issued to WECC MVS, Date: 07/23/18 (REVISED 8/3/18; 11/14/18; 11/18/18; 12/13/18; 1/20/19; 2/7/19; 3/5/19; 6/24/19; 6/28/19; 7/3/19; 7/17/19; 8/19/19; 12/17/19; 8/14/20; 8/24/20;8/31/20; 11/12/20; 4/6/21; 4/15/21; 9/22/21; 11/11/21;9/19/22;12/12/22; 1/5/23). https://www.wecc.org/Administrative/Memo_RES_Modeling_Updates_010523_Rev25_Clean.pdf (EPRI Funded R&D) (last accessed, February 6, 2023)

- This memo summarizes enhancements of the following models: REGC_B, REEC_D, REPC_C & WTGWGO_A, WTGP_B, WTGT_B and WTGIBFFR_A. All of these models have been approved by WECC and benchmarked and tested in the major software tools used in WECC and should be available in the respective tools in the latest versions of the tools. Although already implemented by all the major software platforms, as of September 2022, and benchmark tested, the only model not yet formally approved and pending approval is the REGC_C model.

[68] Refer to Footnote 4.

best available model. In addition, redoing interconnection studies under tight timelines may create challenges for transmission providers. Both bulk power system reliability and speed of IBR plant interconnection to the grid should be adequately considered. To this end, IEEE 2800-2022 establishes consensus-based technical minimum requirements, which may help simplify and expedite the process.

a. One approach to help meet performance requirements and system reliability in an efficient and effective way would be to require models which generally conform to the applicable capability and performance standards (e.g., IEEE 2800-2022 and IEEE 1547-2018) during the interconnection process and studies subject to further assessment once a site-specific verified plant model is available. This concept is similar to provisional interconnection service, which was introduced in FERC Order 845. Interconnection customers with provisional agreements may proceed through the interconnection process based on an initial interconnection study with the best available models at the time compliant with performance requirements and then continue to proceed with additional studies as necessary, as wll as regularly updated studies. The provisional agreement may be in effect until the final results of the interconnection studies are available.
b. EPRI notes there are risks and liabilities associated with any change to the plant design and models, which results in a change to the plant capability and performance from the initial study per the transmission provider assessment. However, this may encourage the interconnection customers to conform the plant design (and continues to conform throughout the design, commissioning, and operation) to the specified performance requirements set in the IEEE standards.
c. EPRI also notes that IEEE 2800-2022 conformity does not ensure reliability as this standard specifies minimum capability and performance requirements, and a system impact study may result in additional performance requirements set forth by the interconnecting RTO/ISO or another responsible entity.

30.Paragraph 86 includes the following statement:

> *"We therefore propose to require that the new or modified Reliability Standards require the use of approved industry IBR models that accurately reflect the behavior of IBRs during both steady state and dynamic conditions. One way to do this would be to reference NERC's approved model list in the Reliability Standards and require that only those models be used when developing planning, operational, and interconnection-wide models. The proposed directives are consistent with the recommendations in NERC reports.[163]"*

As mentioned in comment #26 above, various models have their own applications and benefits depending on the type of study and objectives. Requiring only one type of model (i.e., generic model and not user-defined model) could limit TPs, PCs, RCs, and other entities from effectively and efficiently conducting planning and operational studies and lead to adverse impacts on bulk power system reliability. The use of approved generic models is important and valuable; however, model provision for IBRs should not be limited to generic models. Further, recommendation D1 from the reference cited in footnote 163 of the NOPR mentions that verified, validated, and accurately parameterized models need to be used. However, that reference does not include any statement recommending the use of only approved generic industry models in studies.

31.Section IV.B does not cover the need for developing new or modified Reliability Standards that address changes to registered IBRs, including settings, configurations, and ratings, as indicated in one of the gaps in paragraph 41. EPRI recommends that such changes be communicated between generator owners, transmission owners, planners, and operators as and when they occur, and that IBR plant conformity is re-assessed with updated verified plant models.

I. Section IV. D. IBR Performance Requirements

32.The NOPR proposes to direct NERC to develop new or modified Reliability Standards that would require generator owners and generator operators to ensure that their registered IBR facilities ride through system frequency and voltage disturbances. Further, the NOPR suggests that new or modified Reliability Standards need to address other registered IBR performance and operational characteristics that can affect the reliable operation of the Bulk-Power System, namely, ramp rate interactions and phase-locked loop synchronization.

EPRI notes that in addition to the loss of PLL synchronization, NERC has identified a number of other reasons for tripping and inadequate performance of IBRs during disturbance events, including:

- Transient AC overvoltage
- AC overcurrent
- DC overvoltage
- DC overcurrent
- Unknown/unanalyzed due to the lack of data

Further, inadequate restoration of the power injection from the IBR plants following the temporary reductions in power was caused either by a too-slowly configured ramp rate setting (as observed for momentary cessation performance) or by a too-long configured intentional delay (as observed for inverter tripping), or both.

The last sentence in paragraph 97 states:

> *"…require registered IBRs to continue to inject current into the Bulk-Power System at pre-disturbance levels during a disturbance."*

EPRI notes that maintaining current at the pre-disturbance level during a disturbance (i) may not be a practical requirement for ride-through; (ii) may not be needed to sufficiently support bulk power system reliability, given that voltage disturbances tend to be limited to a region relatively close to the fault location; and (iii) is not aligned with IEEE 2800-2022 or other international requirements such as the corresponding German technical requirements specified in the VDE Application Guides VDE-AR-N 4120 and 4130, because:

i. IEEE 2800-2022 and VDE-AR-N 4120/4130 allow for 10% power reduction in the post-fault period if the voltage at the Point of Measurement (POM) falls below 50% during the fault.

ii. IEEE 2800-2022 requires positive and/or negative sequence reactive current injection (for balanced and/or unbalanced faults) in the fault period, which could—depending on IBR plant configuration with active or reactive current priority mode—result in the intentional reduction of active current output during the ride-through period.

33.EPRI suggests using a language in the NOPR to direct NERC to develop new or modified Reliability Standards using comprehensive and holistic ride-through capability and performance requirements instead of explicitly mentioning causes of the trip (i.e., loss of PLL synchronism in this case) or causes of slow recovery (i.e., slow ramp rate), which may leave out other causes. For example, IEEE 2800-2022 specifies the following requirements on IBRs' response to transmission system abnormal conditions:

- Voltage disturbance ride-through requirements, including the capability and performance requirements during mandatory and permissive operations region and Current injection during ride-through mode
- Consecutive voltage deviations ride-through capability
- Transient overvoltage ride-through requirements
- Restore output after voltage ride-through
- Frequency disturbance ride-through requirements
- Rate of change of frequency (ROCOF) ride-through
- Voltage phase angle changes ride-through
- Return to service after IBR plant trip

34.Footnote 172 in paragraph 90 states:

> *"There are similar reliability impacts posed by tripping or momentary cessation of unregistered IBRs and IBR-DERs during Bulk-Power System disturbances; however, we are not proposing to direct NERC to develop new or modified Reliability Standards that would address unregistered IBR or IBR-DER performance requirements. We expect that any currently unregistered IBRs that become registered IBRs in the future following an approved NERC workplan in Docket No. RD22-4-000 would be required to comply with any applicable new or modified IBR performance Reliability Standards proposed in this NOPR once those Reliability Standards become enforceable."*

The NOPR recognizes the reliability impacts of IBR-DERs. EPRI's research has demonstrated that capability and performance requirements specified in IEEE 1547-2018 and 1547a-2020 could support bulk-power system reliability.[69] Noting that the penetration levels of DERs are increasing in many jurisdictions, we recommend that FERC consider requiring comparable technical minimum capability and performance requirements from all FERC-jurisdictional IBR-

[69] Analyzing the Impact of Aggregated DER Behavior on Bulk Power System Performance. A Summary of Three Case Studies. EPRI, Palo Alto, CA: 2021. 3002019445. [*online]* https://www.epri.com/research/products/000000003002019445 (last accessed, January 24, 2023)

DERs. This could be achieved by potential improvements in the SGIP and SGIA for IBR plants with a rating of less than 20MVA that participate in the wholesale market and connect to distribution or sub-transmission grids. For more information, refer to EPRI's comments in response to the FERC NOPR *Improvements to Large and Small Generator Interconnection Procedures and Agreements* submitted under Docket No. RM22-14-000[70].

[70] Refer to Footnote 6.

IV. CONCLUSION

35.EPRI appreciates the opportunity to provide FERC with its technical recommendations and comments on these crucial topics related to Reliability Standards for IBRs. EPRI looks forward to working with its members, FERC, and other stakeholders to provide further independent technical information on these important questions.

V. CONTACT INFORMATION

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