Facility Interconnection Requirements

MID-ATLANTIC OFFSHORE DEVELOPMENT
(MAOD)

Revision History

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1 Introduction

1.1 Purpose

Mid-Atlantic Offshore Development (MAOD) is a Designated Entity that has executed a Designated Entity Agreement with PJM Interconnection, LLC (PJM) to develop and construct certain transmission facilities. Prior to operation of the facilities, MAOD will become a NERC registered Transmission Owner (TO), within the *Reliability First* Corporation (RF) jurisdiction, and a member of the PJM Regional Transmission Organization (RTO).

Per the requirements stipulated in NERC Reliability Standard FAC-001-4, "*Facility Interconnection Requirements*", which are applicable to Transmission Owners (TOs), MAOD developed the Facility Interconnection Requirements ("FIR") provided herein. This document provides minimum technical requirements and other information to assist entities that are seeking interconnection with MAOD's Facilities.

The below requirements, cited from FAC-001-4, are applicable to TOs:

> *"**R1**. Each Transmission Owner shall document Facility interconnection requirements, update them as needed, and make them available upon request. Each Transmission Owner's Facility interconnection requirements shall address interconnection requirements for:*
>
> *1.1. generation Facilities;*
>
> *1.2. transmission Facilities; and*
>
> *1.3. end-user Facilities."*

> *"**R3**. Each Transmission Owner shall address the following items in its Facility interconnection requirements:*
>
> *3.1. Procedures for coordinated studies for new interconnections or existing interconnections seeking to make a qualified change as defined by the Planning Coordinator and their impacts on affected systems.*
>
> *3.2. Procedures for notifying those responsible for the reliability of affected system(s) of new interconnections or existing interconnections seeking to make a qualified change.*
>
> *3.3. Procedures for confirming with those responsible for the reliability of affected systems that new Facilities or existing Facilities seeking to make a qualified change are within a Balancing Authority Area."*

The first part of this document stipulates MAOD's FIR to address FAC-001-4 Requirement R1 with emphasis on sub-requirement R1.1 "Generation Facilities". At the initial release of this document, MAOD is in the process of designing and building its first transmission facility, the Larrabee Collector Station (LCS). The main purpose of this substation is to support the integration of offshore wind generation into PJM's AC grid. Refer to Section 1.2 for further details about the LCS facility.

Per FAC-001-4, Requirement R3, the second part of this document identifies the processes for notifying responsible entities regarding the interconnection of new generation, transmission, and end-user facilities, and qualified changes to existing end-user, generation, and transmission facilities. The document addresses MAOD's responsibility for cooperating on FAC-002-4 facility interconnection studies with PJM to assess the reliability impact of new interconnection requests and qualified changes to existing facilities, by providing modeling data, as necessary, evaluating study results, and coordinating with entities involved. Within the PJM RTO, PJM performs the Transmission Planner, Planning Coordinator, and Balancing Authority functions.

This document is intended to communicate MAOD's interconnection requirements and is not intended to fully replicate PJM's interconnection requirements or documentation. Interconnection Customers (ICs) should review PJM documentation for specific PJM requirements.

The information contained herein is subject to change. MAOD reserves its right to revise the contents of this document by adding, omitting, or modifying any requirements at any time without prior notice. Users of this document should review the latest version of the document, which will be posted on https://www.midatlantic-offshore.com and www.pjm.com.

1.2 About MAOD

MAOD is a 50/50 joint venture between EDF Renewables North America (EDF) and Shell New Energies US, LLC (Shell).

At the time of releasing the first edition of this FIR, MAOD is in the process of designing and constructing an onshore transmission facility in Howell Township, New Jersey, in response to the New Jersey Board of Public Utilities' (BPU) October 26, 2022, selection of MAOD's Larrabee Collector Station (LCS) as a component of the state's inaugural offshore wind coordinated transmission effort, utilizing PJM's State Agreement Approach (SAA).

The LCS is a planned electrical substation capable of collecting and integrating approximately 5000 MW of electricity onto the bulk electric grid. Once operational, the substation will function as an onshore point-of-interconnection for electricity generated from offshore wind energy areas off the coast of New Jersey. This project is part of PJM's Baseline Project b3737 (NJ SAA Project).

Prior to operation of the LCS, MAOD will become a NERC registered Transmission Owner (TO), within the *Reliability First* Corporation (RF) jurisdiction, and a member of the PJM Regional Transmission Organization (RTO).

For more information about MAOD and the LCS, visit https://www.midatlantic-offshore.com/.

1.3 Commonly Used Acronyms and Definitions

Table 1 Acronyms

Acronym	Stands For	Comments
AC	Alternating Current	
ADSS	All-Dielectric Self-Supporting	Fiber Optic Cable
BIL	Basic Impulse Levels	
BPU	Board of Public Utilities	For the State of New Jersey
CVT	Capacitor Voltage Transformer	Including but not limited to onshore HVDC converters that deliver the power of offshore wind generators.
CT	Current Transformer	Used for revenue metering, protection, or telemetry applications
CEII	Critical Energy Infrastructure Information	All modeling data and one-line diagrams are considered CEII
DC	Direct Current	
EMF	Electromagnetic Field	
FACTS	Flexible AC Transmission System	A group of power electronics and static controllers used to support the power grid (e.g. to provide reactive power support)
FE	FirstEnergy	Parent company for Jersey Central Power & Light Company (JCP&L)
FERC	Federal Energy Regulatory Commission	
FIR	Facility Interconnection Requirements	By default, FIR always refer to MAOD requirements unless explicitly mentioned otherwise.
GIA	Generation Interconnection Agreement	
HVDC	High Voltage Direct Current	
IBR	Inverter-Based Resource	Including but not limited to onshore wind, solar, and energy storage resources. Per IEEE 2800-2022 footnote 11, for offshore wind parks combination of isolated IBR wind park and Voltage Source Converter (VSC) High Voltage Direct Current (HVDC) transmission facility is regarded as the IBR to which IEEE 2800-2022 is applicable. These Requirements will apply the same IBR definition.
IC	Interconnection Customer	The developer or owner of the Interconnecting Facility (IF) requesting interconnection with a MAOD Facility
IF	Interconnecting Facility	The facility owned or to be owned by the IC requesting connection with MAOD's Facility

Acronym	Stands For	Comments
IEEE	Institute of Electrical and Electronics Engineers	
ISA	Interconnection Service Agreement	
ISO	Independent System Operator	
JCP&L	Jersey Central Power & Light Company	FE is JCP&L's parent company. Hence, both names can be used throughout this document interchangeably.
kV	kilo Volt	
LCC	Line Commutated Converter	
LOTO	Lockout Tagout	
MW	Mega Watt	
NDA	Non-Disclosure Agreement	
NERC	North America Electric Reliability Corporation	
OATT	Open Access Transmission Tariff	
OEM	Original Equipment Manufacturer	
OPGW	Optical Ground Wire	
PCC	Point of Common Coupling	
PLL	Phase-Locked Loop	
PJM	PJM Interconnection, LLC	aka PJM RTO
POC	Point of Change of Ownership	
POI	Point of Interconnection	
QOWP	Qualified Offshore Wind Projects	
RMS	Root Mean Square	
RTO	Regional Transmission Organization	
RVC	Rapid Voltage Changes	
SAA	State Agreement Approach	
SCADA	Supervisory Control and Data Acquisition	
SCR	Short-Circuit Ratio	
SIS	System Impact Study	
THD	Total Harmonic Distortion	
TO	Transmission Owner	
TVR	Transient Recovery Voltage	
VSC	Voltage Source Converter	

Table 2 Definitions

Term	Definition	Comments
Interconnection Customer (IC)	Any person or entity that requests to interconnect a new generating or load facility, or modify an existing interconnection, with the grid via a transmission facility owned by MAOD.	
Interconnecting Facility (IF)	A facility (e.g., a generator, a HVDC converter station, or a load) that is requested, by an IC, to be interconnected with a MAOD Facility.	
Facility	By default, it is the hosting transmission facility (e.g., substation) owned by MAOD that an IC requests to interconnect its own facility (IF) to.	
Full MW Output	The maximum real (active) power Generator is allowed to deliver at its respective POI measured in MW. This value must be explicitly included in the ISA.	
Generator	A synchronous generator or an IBR including but not limited to the onshore HVDC facility for an offshore wind facility.	For onshore HVDC converter stations that support offshore wind generators, “Generator”, “Generating facility”, and “Generator Substation” herein, refer to the onshore HVDC converter only with emphasis on the AC side of the HVDC that will interface / interconnect with a MAOD Facility.
PCO	Point of Change in Ownership is where the Project Developer’s Interconnection Facilities connect to the Transmission Owner’s Interconnection Facilities.	Refer to PJM Manual-14H, Section 4.9 for more details.
POI	Point of Interconnection is the point or points where the Interconnection Facilities connect with the Transmission System.	Refer to PJM Manual-14H, Section 4.9 for more details.
Requirements	MAOD’s Facility Interconnection Requirements per NERC FAC-001-4 or later versions	
Substation	A transmission facility that transforms voltage and switches in/out electrical equipment (e.g., transmission lines, transformers, busbars, capacitor, or reactor banks, etc.).	

1.4 Applicable Industry Standards and Requirements

IC shall design, install, operate, and maintain its Interconnecting Facilities in accordance with the latest revisions of the National Electric Code (NEC), National Electric Safety Code (NESC), American National Standards Institute (ANSI) standards, Institute for Electrical and Electronics Engineers (IEEE) standards, National Fire Protection Association Standards, and any applicable federal, state, and local codes along with any applicable NERC, ReliabilityFirst (RF) and PJM requirements.

The interconnection requirements stipulated herein are based on, but not limited to, the latest version of the following standards and manuals. In case of conflicts between any of these requirements, the most stringent requirement shall prevail.

1.4.1 Federal Energy Regulatory Commission (FERC)

- FERC Order 827 “Reactive Power Requirements for Non-Synchronous Generation”, 2016-06-16

1.4.2 North America Electric Reliability Corporation (NERC) Reliability Standards

- FAC-001-4 “Facility Interconnection Requirements”
- FAC-002-4 “Facility Interconnection Studies”
- PRC-024-3 “Frequency and Voltage Protection Settings for Generating Resources”
- PRC-023-6 “Transmission Relay Loadability”
- TPL-001-5.1 “Transmission System Planning Performance Requirements”

1.4.3 IEEE Standards

- IEEE Std 519-2022
- IEEE Std 2800-2022

1.4.4 PJM Requirements

- PJM Manual 01 “Control Center and Data Exchange Requirements”, Rev 47, 2023-05-09
- PJM Manual 03 “Transmission Operations”, Rev 65, 2023-11-15
- PJM Manual 07 “PJM Protection Standards”, Rev 04, 2019-05-30
- PJM Manual 14D “Generator Operational Requirements”, Rev 65, 2023-12-20
- PJM Manual 14E “Upgrade and Transmission Interconnection Requests”, Rev 09, 2023-07-26
- PJM Manual 14G “Generation Interconnection Requests”, Rev 08, 2023-07-26
- PJM Manual 14H “New Service Requests Cycle Process”, Rev 00, 2023-07-26
- All other PJM Manual 14 Series
- PJM Planning Modeling Data Requirements and Reporting Procedures
- PJM Dynamic Modeling Development Guidelines for Interconnection Analysis

1.4.5 PJM’s State Agreement Approach (SAA) requirements, as applicable

1.4.6 Other federal, state, and local technical and environmental regulations, as applicable

2 General Grid Characteristics

2.1 Nominal AC Voltage, Normal Operating Range, and Emergency Limits

PJM RTO is responsible for operating the grid, including MAOD's Facility(ies), within the normal operating range shown in Table 3. Under certain emergency conditions, PJM may determine the need to operate the grid, including MAOD's facilities, for pre-determined periods of time within the emergency operating range in Table 3. All voltages below are in RMS and line to line values.

For complete information, refer to PJM Manual 03, Section 3.3 Voltage Limits.

During normal operation, Generating and/or Transmission facilities requesting interconnection with MAOD's Facility must be capable of remaining connected and operational, without interruptions, within the Normal Operation Voltage Range. Similarly, during outage or contingency conditions, as outlined by NERC TPL-001-5.1, Table 1, Generating and/or Transmission facilities requesting interconnection must be capable of remaining connected and operational, without interruptions, within the Emergency Operation Voltage Range.

If the below voltage ranges are not acceptable for the safe operation of sensitive equipment at an End-User facility requesting interconnection, the Interconnection Customer (IC), at its own expense, shall install its own voltage regulating equipment that can stabilize the voltage seen by the equipment, within an acceptable range.

MAOD will not provide the Interconnecting Facility (IF) with voltage measurements or tripping signal if the voltage falls outside the acceptable operating limits required by the IC's equipment. The IC shall furnish its IF with the necessary voltage sensing relays to protect its own facility from abnormal voltage excursions.

Table 3 PJM Voltage Normal and Emergency Operating Ranges

Nominal Voltage	Normal Operation Voltage Range		Emergency Operation Voltage Range	
	High	Low	Emergency Low	Load Dump*
230 kV	241.5 kV (105% of the nominal voltage)	218.5 kV (95% of nominal voltage)	211.6 kV (92% of nominal voltage)	207.0 kV (90% of nominal voltage)
500 kV	550 kV (110% of the nominal voltage)	500 kV (100% of nominal voltage)	485 kV (97% of nominal voltage)	475 kV (95% of nominal voltage)

* MAOD is not a Distribution Provider, and it does not serve any loads, hence, it does not participate in any Undervoltage Load Shedding (UVLS) schemes/programs to arrest the system voltage. It is possible that neighboring TOs participate in a UVLS program.

2.2 Nominal Frequency and Normal Operating Range

The nominal frequency is 60.0 Hz with a typical daily variation of ±0.05 Hz.

MAOD will not provide the IC with frequency measurements or tripping signal if the frequency falls outside the acceptable operating limits required by the IC's equipment. The IC shall furnish its IF with the necessary frequency sensing relays to protect the IC's facility from abnormal frequency excursions.

MAOD is not a Distribution Provider, hence it does not serve any loads, hence, it does not participate in any Underfrequency Load Shedding (UFLS) schemes/programs that arrest the system frequency. It is possible that neighboring TOs participate in a UFLS program.

2.3 Short-Circuit Strength

The short-circuit strength, at the Point of Interconnection (POI) or Point of Change in Ownership (PCO) may vary depending on the voltage level(s), proximity with large synchronous machines, generation dispatch, equipment impedances, station/substation configuration, system outages, etc.

Upon request, MAOD shall provide the necessary short-circuit models for its equipment within the Facility at which the IC is requesting connection. Since MAOD does not own the short-circuit modeling data of PJM's system outside of MAOD's Facility, the IC shall request the applicable short-circuit model(s) of the PJM system directly from PJM.

Prior to requesting any modeling data, the IC must execute a Critical Energy Infrastructure Information (CEII) Non-Disclosure Agreement (NDA) with PJM. Prior to sharing its Facility modeling data, MAOD will require the IC to provide a proof that the IC has executed the necessary CEII NDA with PJM.

The IC shall use the above two pieces of modeling data (i.e., MAOD's Facility and PJM's system), to update the necessary short-circuit models and calculate the estimated short-circuit strength at its POI or PCO.

The IC is responsible for designing its protection system and Inverter-Based Resource (IBR), if applicable, to function properly under the entire range of expected short-circuit strength levels.

MAOD recommends that, when applicable, the IC shall work closely with the Original Equipment Manufacturer (OEM) of the IBR to determine the lowest Short-Circuit Ratio (SCR) threshold below which detailed Electromagnetic Transient (EMT) studies shall be performed. Generally, many OEMs recommend performing EMT studies if the SCR is expected to drop below 3.0. MAOD may require that EMT study reports be submitted to MAOD for review.

3 General Interconnection Requirements

Unless specified otherwise, the following requirements shall be applicable to all types of Interconnection Facilities (i.e., Generation Facilities, Transmission Facilities, and End-User Facilities) requesting interconnection with a MAOD Facility ("Facility").

3.1 Power Factor Requirements

3.1.1 Generation Facilities

Per FERC Order 827 and PJM Manual 14H Section 9.2, new Generation Facilities requesting interconnection with a MAOD Facility, are required to maintain the applicable power factor range stipulated in Table 4, at its Full MW Output.

Table 4 Generator Power Factor Requirements (PJM Manual-14H, Section 9.2)

Generator Type	Size	Required Power Factor	Measure Point
Synchronous	≤ 20 MW	0.95 lead to 0.90 lag	Point of Interconnection (POI)
Synchronous	> 20 MW	0.95 lead to 0.90 lag	Generator terminals
Wind and non-synchronous (e.g., IBR)	Any	0.95 lead to 0.95 lag	High-side of generation facility sub transformer

During normal operation, the total apparent power measured in Mega Voltage Ampere (MVA), injected, or withdrawn by the Generator must never exceed 99% of the continuous (normal) summer rating of any Facility equipment that is radially connected with the Generator.

3.1.2 Transmission Facilities

A Transmission Facility directly connected to a MAOD Facility must provide flexibility at moving electric power under a wide range of expected system conditions (e.g., power flow directions and loading) without causing excessive high or low voltages.

3.1.3 End-User Facilities

An End-User Facility directly connected to a MAOD Facility shall operate as close as possible to a unity power factor under its entire loading range.

3.2 Power Quality Requirements

The following requirements are applicable to synchronous machine-based Generation Facilities, Transmission Facilities, and End-User Facilities. **For IBR Generation Facilities only**, refer to Section 5.7.

3.2.1 Harmonics Distortion Limitations

IF shall not inject harmonics into MAOD's Facility that exceed the harmonics distortion limits stipulated herein, at the respective POI. If the IF cannot meet these harmonics requirements, the IC must install the appropriate AC filter(s) at the IF's POI to mitigate any harmonic(s) above the limit(s). The IC must provide detailed AC harmonic models and AC harmonic analysis, based on actual IF design, to support the IF's compliance with these requirements.

3.2.1.1 Voltage Distortion Limits

Per Section 5.1 of IEEE 519-2022, the magnitude of any individual voltage waveform harmonic (up to and including the 50^{th} harmonic) must not exceed 1% of the magnitude of the fundamental (60 Hz) voltage waveform.

Also, the voltage total harmonic distortion (THD) must not exceed 1.5% of the magnitude of the fundamental voltage waveform. Table 5 summarizes the above requirements. Refer to IEEE 519-2022, Section 5.1, for the complete set of requirements and/or exceptions.

Table 5 Allowed Voltage Distortion Limits (IEEE 519-2022, Section 5.1)

Bus Voltage V at POI	Individual harmonic (%) h ≤ 50	Total Harmonic Distortion (THD)
V > 161 kV	1.0	1.5

3.2.1.2 Current Distortion Limits

Per Section 5.5 of IEEE 519-2022, the maximum current distortion limits in percentage of rated current are summarized in Table 6. Refer to IEEE 519-2022, Section 5.5, for the complete set of requirements and/or exceptions.

Table 6 Allowed Current Distortion Limits (IEEE 519-2022, Section 5.5, systems rated > 161 kV)

Maximum harmonic current distortion in percent of I_L						
Individual harmonic order (h)						
I_{sc}/I_L	2≤ h < 11	11 ≤ h < 17	17 ≤ h < 23	23 ≤ h < 35	35≤ h ≤ 50	TDD
< 25	1.0	0.5	0.38	0.15	0.1	1.5
25 < 50	2.0	1.0	0.75	0.3	0.15	2.5
≥ 50	3.0	1.5	1.15	0.45	0.22	3.75

4 General Design Requirements

The following are general requirements for the IF's design, including design of any station that will be interconnected with a MAOD Facility. Unless agreed upon otherwise, the IC shall design, procure, install, test, and maintain all the following at its own expense. The IC shall use its engineering judgement to proactively coordinate designs with MAOD and/or PJM, as needed.

The following requirements shall be applicable to Generation Facilities, Transmission Facilities, and End-User Facilities. Sections 5 to 7 of this document are dedicated to any additional requirements that are applicable to each individual type of facility.

4.1 Protection System Requirements

The IC requesting an interconnection with a MAOD Facility must equip its IF with the following protection requirements.

All applicable requirements of the Protection System standards (e.g., IEEE C37 and C57), NERC Reliability Standards (e.g., PRC-023 and PRC-024), and PJM Manual 07 must be adhered to even if not explicitly mentioned herein.

MAOD reserves the right to review the designs of the IF's proposed protection system, and request modifications if needed.

4.1.1 Main Generator Circuit Breaker Current Carrying and Interrupting Capabilities

The IC must install, own, operate, test, and maintain a circuit breaker at the IF's PCO. The circuit breaker must meet the following requirements:

- It can carry the circuit's (tie-line) full current.
- It can simultaneously interrupt the largest possible three-phase, two-phase, two-phase to ground, or single-phase to ground fault currents that can be applied at either side of the breaker.
- The circuit breaker tripping control must be powered from an AC source that is independent from the AC transmission circuit that connects the IF with MAOD's Facility.[1]
- The breaker tripping and closing mechanisms shall be powered from a hydraulic, pneumatic, or spring-loaded energy storage mechanism.

4.1.2 Protection System Capabilities

The IC shall equip its IF with a protection system that is capable of providing protection under all possible operating conditions that include, but are not limited to, the following:

- Single phasing of supply system faults.
- Equipment failure.
- Abnormal voltage or frequency.
- Lightning and switching surges.

[1] This shall enable the operation of tripping the circuit breaker upon the loss of the AC transmission circuit intended to be protected by the circuit breaker.

- Excessive harmonic voltages and/or currents.
- Excessive negative sequence voltages.
- Separation from the grid
- Synchronization for generation to MAOD's Facility

4.1.3 Overlapping Protective Zones

The IC shall design and implement a protective system with overlapping protective zones that cover the entire energized equipment within the IF[2] station up to and including the tie-line between the IF station and the Facility.

The IF circuit breaker that interconnects the IF with MAOD's Facility, mentioned in 4.1.1, must be included in all applicable protective zones.

4.1.4 Redundant Fault Clearing Protective Schemes (Phase and Ground Protection)

The protective schemes must be able to detect all possible types of faults taking place within the protective zones of the IF. The faults must be isolated (i.e., cleared) by one or more of the IF's local circuit breakers.

All protective zones must be comprised of two independent protective schemes (i.e., main and backup protective schemes). To guarantee full redundancy and independence, the main protective scheme must not share any of the following equipment with the backup protective scheme, and vice versa:

- High speed protective relay schemes
- CTs and CCVTs (or VTs)
- DC control circuits, with no common wiring or cabling
- Isolating switches or auxiliary tripping relays
- Circuit breaker trip coils
- DC supply circuits with independent protection schemes
- Breaker failure relay scheme

4.1.5 Tie-Line Protection Coordination

The protection of the tie-line between the IF and MAOD's Facility must be coordinated with MAOD. IC must provide the necessary redundant protective relaying from its terminal. Refer to Section 4.1.4 for redundancy requirements.

MAOD prefers line current differential protection and step distance schemes, but other schemes can be considered with valid justification.

The tie-line protective relays at the IF's terminal must be able to detect and clear, if necessary, ground faults and/or phase faults taking place at the MAOD Facility.

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[2] For Generation Facilities that have an onshore HVDC converter station that supports offshore wind generation, the IF (Interconnecting Facility) herein, refers to the onshore HVDC converter only, with emphasis on the AC side of the converter station, which will interface/interconnect with the MAOD Facility.

4.1.6 Circuit Breaker Failure Protection (Back-Up Protection)

The IF is required to detect failure conditions (e.g., stuck breaker) of its own circuit breakers and send a tripping signal, when applicable, to the corresponding MAOD Facility circuit breaker at the remote end (i.e., the remote end of the protected zone) to isolate the fault. MAOD and the IC shall coordinate the necessary international time delays.

4.1.7 Direct Transfer Trip Equipment

At its own expense, IC is responsible for providing and installing at and along its IF and at the MAOD Facility, the equipment listed below to facilitate sending and receiving tripping signals between the two facilities:

- Transfer Trip Transmitter
- Transfer Trip Receiver
- Communication Channels between the two facilities. The expenses shall also cover monthly or annual leasing fees, if applicable. By default, fiber optic communication is MAOD's preferred telecommunications medium.

4.1.8 Utility-Grade Protective Relays

The IC is responsible for designing, installing, testing, operating, owning, and maintaining all the required protective relays. All relays, including but not limited to time delay and auxiliary relays, must be utility-grade. All protective relays interconnecting with MAOD will be reviewed and approved by MAOD to ensure all relay models, part numbers, firmware, etc. are identical.

4.1.9 Power Source for the Circuit Breaker(s) Tripping Control

The tripping control of the circuit breaker at the IC's terminal of the tie-line with MAOD's Facility (i.e., the main circuit breaker) must be powered from an AC source that is independent from the AC source delivered by the tie-line itself.

4.2 Equipment Ratings

The IC must provide all equipment ratings for switches, circuit breakers, bus, strain bus, etc. for MAOD to review. All current carrying equipment shall be in accordance with IEEE and PJM rating guidelines. If requested, the IC must provide MAOD all manufacturer test reports, documentation, rating sheets, etc. All equipment ratings shall be reviewed and verified during the planning or design phase. The minimum short circuit rating will be 63kA.

4.3 Disconnecting Equipment

Three phase gang operated disconnects shall be required on each transmission supplied entrance to an IC. MAOD will install, own, operate, and maintain its own three phase gang operated line disconnect switch at MAOD's Facility. Similarly, the IC shall be responsible to install, own, operate, and maintain its own three phase ganged operated line disconnect switch at the PCO.

These disconnects shall provide a visible break to confirm isolation during planned or emergency outages. The IC shall allow MAOD to apply locks on the disconnect switches for safety purposes during outages involving the IC's facility.

If applicable, all mechanical or keyed interlocks shall be used to interlock breakers or disconnects for worker or operational safety.

4.4 Basic Insulation Level (BIL) Rating

The minimum required Basic Insulation Level (BIL) is 900kV for 230kV and 1800kV for 500kV. The IC must provide all BIL ratings for MAOD to review.

4.5 Surge Protection

Surge arresters shall be installed before the line disconnect on the PCO side. All power transformers or other winding equipment shall have surge protection. Arrester protective margins shall not be less than 20% as determined by IEEE standards methods. All surge arresters shall be polymer housed, station class, and of metal oxide type. Minimum duty cycle for 230kV is 180kV and 500kV is 396kV. The IC must provide all surge arrester ratings for MAOD to review. When sizing the surge arrestors needed at the IF, the IC must exclude any nearby surge arresters owned/installed by MOAD at its Facility.

4.6 Station Insulators

Insulators shall have electrical characteristics, creepage and leakage distance values equal to or exceeding those listed in C29.8 or C29.9. Higher insulation levels of insulators must be considered in areas with high pollution or contamination. All insulators shall have sufficient mechanical strength to withstand applicable operating or short circuit forces. The IC must provide all insulator information for MAOD to review.

4.7 Station Outdoor Bus and Clearances

Electrical station design clearances are listed in C37.32. These clearances shall be used for any IC facility connecting directly to MAOD. MAOD reserves the right to review and approve the IC's station clearances at the PCO. All other clearances shall be in accordance with the NESC, ANSI, IEEE or applicable state and local codes, whichever provides greater clearances. MAOD shall provide demarcation location for IC's responsibility. Phasing will be mutually agreed upon or provided by MAOD.

4.8 System Grounding Requirements

Station ground grids shall be designed in accordance with IEEE 80 to establish safe step and touch potentials as well as safe Ground Potential Rise values and tested in accordance with IEEE 81. All ground connections shall be in accordance with IEEE 837. All ground grid conductors shall be minimum of 4/0 AWG and be installed at a minimum depth of 18 inches below grade. If required, all ICs should have provisions made to prevent copper theft. Where the IC's grid is connected to or in close proximity to MAOD's ground grid or structures, the IC must provide MAOD grounding designs, analysis, reports or other requested files or documents compatible with MAOD's standards such as CDEGS. Ground grid connections between MAOD's facilities or structures and the IC's facilities must be designed and installed in compliance with MAOD's standards or strict conservative design standards. Determinations regarding connecting the IC's ground grid with MAOD or neighboring ICs shall be made during design review.

All equipment, structures, metallic fences, platforms, railings, and structures shall be adequately grounded.

A ground mat shall be installed at the operating handle of all air disconnect switches. The mat shall be adequately grounded to the station ground grid. Further requirements shall be specified by MAOD during design or planning phase.

4.9 Station Fence Requirements

The IC's fence must comply with the NESC, grounding requirements in IEEE 80, and other applicable local municipal codes or standards. Fences shall be, at a minimum, height of 8 feet of tight mesh galvanized steel or aluminum chain link with an applicable 1-foot top structure equipped with both top and bottom rails to prevent or discourage entry. All gates shall utilize woven mesh straps to ensure continuity at all hinged joints. Access to the IC's facility shall be adequately designed for personnel entrance, vehicular or equipment entrance. The IC must submit all fence designs to MAOD for review and approval.

4.10 Metering and Telecommunications

The IC shall furnish its IF with metering and telecommunication. The equipment shall meet the following requirements.

4.10.1 Instrument Transformer Requirements

The metering equipment shall utilize Current Transformers (CTs) and Capacitive Voltage Transformers (CVTs), to measure the current and voltage magnitudes and angles. The instrument transformers must meet the following requirements:

- All CTs and CVTs must meet or exceed the specification and performance of the most recent applicable versions of IEEE C57.13-2016 and C57.13.5-2019.
- All CT and CVT burden ratings shall exceed the total VA load of all connected circuits.
- All CTs must withstand continuous operation and maintain rated accuracy at twice or more of rated current.

The continuous current rating on the CTs shall not exceed the primary nameplate rating with the thermal current rating factor applied. The system fault current shall not exceed the CT's short circuit rating.

Instrument transformer nameplate data must be provided to MAOD for review.

4.11 Revenue Metering Arrangements

By default, IC shall install the necessary instantaneous bi-directional revenue metering equipment at its IF, following PJM Manuals 01 and 14D.

4.11.1 Metering Polarity Requirements

All revenue instrument transformers shall be located in radial connections at the IC's facility close to the POI. When allowed otherwise, they shall be as close as possible to the PCO. The necessary losses adjustments shall be made to estimate the measurements at the POI. The revenue instrument transformer polarities will be determined and verified during design review. As an example, if the power flow is from the IC to MAOD, then the revenue meters will represent -MWh at the IC and +MWh at MAOD. If the power flow is from MAOD to IC, then the revenue meters will represent -MWh at MAOD and +MWh at the IC.

Under special circumstances and upon the IC's request, MAOD may consider installing the IF's revenue metering equipment at MAOD's Facility. Such consideration will be at MAOD's discretion. If the IF's metering equipment is located at MAOD's Facility, the IC must provide MAOD with sufficient notice if the IC needs to inspect the metering equipment.

4.11.2 Telecommunication Design Requirements

For all fiber optic cable, such as Optical Ground Wire (OPGW) or All-Dielectric Self-Supporting (ADSS) cable, sufficient footage will be provided or agreed upon for the IC at the transmission structure or at a dedicated handhole in the IC's facility. All required materials such as above and below grade conduits, splice enclosures, inner ducts, fiber terminations, fiber optic cable, etc. will be furnished by the IC from the demarcation point to the IC's control enclosure and approved by MAOD. All required fiber materials, panels, enclosures, terminations, etc. are the responsibility of the IC. All final testing of the fiber optic cable shall be performed by MAOD after all terminations are made by the IC. All fiber strands must be terminated and properly labelled.

4.12 SCADA Requirements

The IC is responsible for all data exchange and telecommunications requirements with PJM as required in PJM Manual 01. The IC must provide MAOD with the requested data via a direct communication link such as fiber from the IC's Remote Terminal Unit (RTU). Any media converters required will be at the IC's expense. At a minimum, the IC's RTU shall provide MAOD with the information and control capabilities (if applicable) listed below through standard communication protocols as determined by MAOD. The IC may be required to provide additional information and control capabilities beyond those listed below as determined by MAOD or during planning or design review.

- Control of interrupting devices in the IF.
- Provide status indication of all line disconnects and circuit breaker positions, and status of protective relay alarms that impact MAOD's Facilities. These might include breaker failure, line, bus, or other differential relaying schemes.
- If applicable, provide MAOD the status or tap positions of all load tap changers or voltage regulators.
- Provide MAOD instantaneous bi-directional real and reactive power (MW and MVAR), voltage and currents from metering device or protective relays.

4.13 Low Voltage Auxiliary Power (AC/DC) Power Requirements

All IC shall have two independent sources of AC auxiliary power and be capable of operating on station batteries for a minimum of 8 hours as defined by PJM without AC auxiliary power. All other AC and DC system design or application shall follow all required PJM, IEEE, NESC or other applicable standards. If applicable, all required generator permits and approvals are the responsibility of the IC.

4.14 Station Lighting

The IC shall have adequate yard lighting, as required by the National Electric Safety Code (NESC) and meet local municipal requirements to illuminate critical equipment such as disconnect switches, nametags, operators, control cabinets, circuit breakers, etc. for proper identification and visibility.

4.15 Naming and Designations

All equipment designations connected at the POI or up to an interrupting device will be mutually agreed upon or provided by MAOD. All outdoor nametags or phase tags must be clearly installed and visible at the equipment or structures.

4.16 Physical Access

Any personnel from the IC requiring access to MAOD's Facility shall be accompanied by MAOD's representative at all times. All visits must be properly communicated and notified. Likewise, the IC shall accompany a MAOD representative at the IC's facility for maintenance, inspections, outages, etc. MAOD shall also be provided access for any fiber maintenance or failures at the IC's facility. All facility access requirements shall be mutually agreed upon.

The IC shall be responsible for all snow removal and vegetation management within their fence to ensure the site is accessible at all times.

4.17 Lightning Protection Analysis

When MAOD's equipment is located in the IC's facility, the IC shall perform a lightning protection study and submit the study to MAOD for review with associated design drawings, program files, calculations, reports, etc. As mentioned in Section 4.20, MAOD must be notified of any connections from the IC's facility to MAOD's structures to ensure structural analysis is performed.

4.18 Circuit Breaker Transient Recovery Voltage Analysis

MAOD may request a circuit breaker transient recovery voltage (TRV) analysis report from IC for review.

4.19 Transformer Energization Analysis

The IC must perform a transformer energization study to confirm that the in-rush currents do not exceed the short-circuit ratings of all MAOD equipment that will deliver the power to the IC's transformer during energization. Also, during energization, the voltage at the POI must not drop below 0.7 pu of the POI's nominal voltage. At its own expense, the IC must mitigate any violation to these criteria. The IC must provide a supporting study report.

4.20 Transmission Line Design Requirements

MAOD will be responsible for installing shield wire or OPGW, transmission lines and dead-end assemblies up to MAOD's furnished transmission structures in the IC's facility. Grounding of the transmission structures, shield wire or OPGW to the IC's grounding grid will be the responsibility of the IC. All jumper terminals shall be compression type and furnished by the IC for the final connections to MAOD's dead end assemblies. Jumper terminals furnished by the IC shall be reviewed and approved by MAOD. At the IC's request, MAOD can provide information prior to the IC furnishing jumper terminals.

If any steel structures owned and installed by MAOD will support the IC's strain bus, conductors, surge arresters, insulators, rigid bus, shield wire, etc., the IC must coordinate with MAOD to ensure all structural analysis, such as tension, forces, loading, strength, foundations, anchor bolts etc., is conducted for a safe installation.

4.21 Testing, Commissioning, and Inspection Requirements

Before an IC facility can be energized, it must pass all of MAOD's inspections for station equipment, such as circuit breakers, disconnect switches, instrument transformers, surge arresters, relays, low voltage AC and DC systems, grounding systems, rigid or strain bus systems, etc. Inspections will include visual inspections of all equipment and review of IC's documentation and test results. Additional inspections or test results may be requested by MAOD based on the IC's design.

Frequency of in-person inspections or witnessing of testing and commissioning will be determined by MAOD after review of the IC's design. MAOD will assign a representative to coordinate and oversee all activities with the IC for testing, commissioning, and proper documentation. MAOD will provide a site-specific check list for the IC to conform to.

A Pre-Energization walkthrough or inspection shall be conducted well in advance at the IC's facility to ensure all necessary requirements have been fulfilled with no open items before energization. Proper notifications must be made to all interconnecting facilities, remote facilities, control centers, and PJM regarding outages, cut in requests, etc. to prevent energization delays.

All energization procedures shall be reviewed and approved by MAOD and other interconnecting facilities or groups to ensure proper coordination and switching procedures are followed. For example, bump procedures or other step by step procedures shall be submitted and reviewed by all groups.

4.22 Operations and Maintenance

The IC is responsible for developing and implementing a station maintenance program as defined by PJM following good utility practice. MAOD and the IC will efficiently coordinate all planned outages for maintenance or emergency outages with PJM and other groups.

All required maintenance shall be efficiently coordinated and mutually agreed upon to prevent multiple outage requests. Overlap of maintenance schedules is the preferred choice where possible.

MAOD and the IC shall provide all contact information for all critical operations personnel, remote facilities, or control centers. A list of all responsible operations and engineering personnel and their 24-hour access phone numbers shall also be provided and updated as soon as changes are made.

All communications and procedures during normal and emergency operating conditions shall follow all applicable requirements specified in PJM Manuals.

The IC must provide a simplified one-line diagram of the facility showing all major equipment, protection zones, ratings, etc., including any additional information requested by MAOD for reference. Any updates to the IC's one line diagram must be properly notified and submitted to MAOD.

In-service maintenance of relays interconnecting with MAOD will be mutually agreed upon.

4.23 Lockout Tagout Procedures

All Lockout Tagout (LOTO) procedures shall be discussed and mutually agreed upon to ensure the highest level of safety for MAOD and the IC's personnel. All portable protective grounds required during an outage shall be properly documented and communicated and removed before energization.

4.24 Electromagnetic Interference (EMI) Withstanding

The IF shall be compliant with IEEE Std C37.90.2, IEC 61000-4-3, or other applicable industry standards with a minimum electric field strength of 30 V/m.

4.25 Allowable Electromagnetic Fields (EMF) Emissions Requirements

The IC shall meet all the applicable local, state, and national environmental EMF emissions requirements from either the HVAC or HVDC equipment to:

- not exceed the safe working limits for both MAOD and IC's personnel, and
- not interfere with any other electronic devices at nearby MAOD or other IC's sites

If the IF emits EMF beyond the permitted levels, the IC must implement all mitigation requirements at its own expense.

4.26 Allowable Acoustic Noise Requirements

The IC must provide all equipment noise levels (dB's) for MAOD to review. The IC must meet all local municipal noise level requirements. Noise assessments or studies must be performed by the IC and submitted to MAOD. The IC must implement all mitigation requirements to meet MAOD's or local municipal noise limits.

5 Additional Interconnection Requirements for Generation Facilities

In addition to the general interconnection requirements stipulated in Section 4, this section provides additional requirements that are applicable to Generation Facilities requesting interconnection with a MAOD Facility.

Under this section, any IC that intends to interconnect with a MAOD Facility to inject active power into the grid will be referred to as “Generator”. Generator can be a synchronous machine or an Inverter-Based Resource (IBR). Per IEEE 2800, the onshore High Voltage Direct Current (HVDC) converter substation that interconnects an offshore wind generating facility to the grid, shall be considered an IBR.

5.1 General Delivered Power Requirements

Generator must deliver balanced three-phase, 60 Hz voltages and currents. The nominal voltage of the injected power, at the Generator POI, must match the corresponding nominal voltage in Section 2.1. All voltage and current magnitudes, angles, and frequencies shall be measured at the IC’s respective POI. During normal operation, the measured values must be within the normal operating ranges specified in these Requirements.

5.2 Generator Real-Power Control

Generator-delivered real (active) power, measured at its respective POI, must not exceed the contracted Mega Watt (MW) value stipulated in the Generator Interconnection Agreement (GIA). This value will be referred to as “Full MW Output”.

Generator must deliver its power per the applicable requirements (e.g., deadband, droop, frequency response, etc.) stipulated under section 7.1.1 of PJM Manual 14D.

5.3 Generator Voltage Control and Voltage Schedules

Generator is required to regulate the voltage at its POI, following Generator Voltage Schedules stipulated under PJM Manual 3, Section 3.11.

IC must take into consideration the applicable requirements stipulated under section 7.1.2 of PJM Manual 14D.

5.4 Anti-Islanding Protection

At the IC’s expense, the IC must provide MAOD’s Facility with anti-islanding transfer trip and appropriate fault clearing telecommunication to prevent IC’s Generator from exclusively energizing transmission elements within the islanding boundary that may involve equipment located within MAOD’s Facility.

5.5 Fault Ride Through Capabilities

The Generator shall meet the applicable voltage and frequency fault ride-through requirements stipulated in the latest version of PRC-024 “*Frequency and Voltage Protection Settings for Generating Resources*” NERC Reliability Standard.

Refer to PJM Manual 36 “System Restoration” for potentially more stringent requirements.

5.6 Synchronization Requirements

Generator must follow all applicable PJM requirements and synchronization procedures.

Generator is responsible for designing, owning, testing, operating, and maintaining its own synchronization mechanism/relays with the Facility.

Generator is responsible for protecting its own equipment or facility from damage or loss of revenue caused by the incorrect design or the malfunctioning of the Generator’s synchronization mechanism.

Prior to closing the Generator circuit breakers located next to its POI, Generator’s synchronization mechanism must confirm that the voltage, phase-sequence, phase angle, and frequency at the Generator side of the circuit breaker match their corresponding values at the Facility’s side of the circuit breaker.

5.7 Power Quality for Inverter-Based Resources (IBRs) Only

5.7.1 Harmonics Distortion Limitations

Generator shall not exceed the harmonics distortion limits stipulated herein, at its respective POI. If Converter cannot meet these harmonics requirements, it shall install the appropriate AC filter(s) to mitigate any harmonic(s) above the limit(s). Generator must provide detailed AC harmonic analysis, based on actual Generator design, to support the Generator’s compliance with these requirements.

For IBRs, MAOD believes it is very unlikely that Line Commutated Converters (LCC) will be able to meet the allowed harmonic distortion level, set forth below. Therefore, MAOD strongly recommends the usage of IBRs with Voltage Source Converters (VSC).

5.7.1.1 Voltage Distortion Limits

Per Section 5.1 of IEEE 519-2022, the magnitude of any individual voltage waveform harmonic (up to and including the 50^{th} harmonic) must not exceed 1% of the magnitude of the fundamental (60 Hz) voltage waveform.

Also, the voltage total harmonic distortion (THD) must not exceed 1.5% of the magnitude of the fundamental voltage waveform. Table 7 Summarizes the above requirements.

Table 7 Voltage Distortion Limits (IEEE 519-2022, Section 5.1)

Bus Voltage V at POI	Individual harmonic (%) h ≤ 50	Total Harmonic Distortion (THD)
V > 161 kV	1.0	1.5

5.7.1.2 Current Distortion Limits

Per Section 8.2.1 of IEEE 2800-2022, the maximum current distortion limits in percentage of rated current are summarized in Table 8.

Table 8 Maximum current of rated current (IEEE 2800-2022, Section 8.2.1)

Bus Voltage (kV)	Individual Harmonic Order h (of the fundamental 60 Hz frequency)			Total rated current distortion (TRD) percent (%)
	h < 11 percent (%)	**5.7.2** 11 ≤ h < 17 percent (%)	**5.7.3** 17≤ h < 50 percent (%)	
V > 161 kV	1.5	1.0	1.0	2

Generator will be required to study, design, own, install, operate, tune, and maintain appropriate harmonic filters to keep its voltage and current harmonics distortion below the above limits.

MAOD and/or PJM may need to perform harmonics studies to evaluate the interactions of all harmonics/harmonic filters of all Generators requesting interconnection/interconnected at the same Facility. Responsible Generator(s) will be required to mitigate the identified harmonics and/or harmonic filter interactions.

5.7.4 Rapid Voltage Changes or Flicker Limitations

Each Converter shall not create unacceptable Rapid Voltage Changes (RVC) or flicker at its respective POI. For detailed requirements, refer to IEEE 2800-2022 Section 8.1.

5.7.5 Frequent RVC

For frequent events, such as frequent energization of transformers, frequent switching of capacitors, or from abrupt output variations due to mis-operation, each Converter shall not cause RVC at its respective POI to exceed 2.5% of nominal voltage. For detailed requirements, refer to IEEE 2800-2022 Section 8.1.2.1.

5.7.6 Infrequent RVC

For infrequent events, each Converter shall not cause the voltage to drop less than 0.88 x the initial voltage. And after 4 cycles, the minimum voltage shall be no less than 0.9 x the initial voltage. The voltage is measured at the POI. For detailed requirements, refer to IEEE 2800-2022 Section 8.1.2.2.

5.7.7 Voltage Flicker

The contribution of each Converter to the flicker, applied at the POI, shall not exceed the greater of the limits listed in Table 9 and the immediate individual contribution limits as per the procedure described in IEC TR 61000-3-7 Section 9. EPst and EPlt are the short-term and long-term planning levels.

Table 9 Converter Flicker Contribution Limits (at the POI)

EPst	EPlt
0.35	0.25

For detailed requirements, refer to IEEE 2800-2022 Section 8.1.3.

5.7.8 Electrical Interactions

If adverse electrical interaction (e.g., resonance) between any two or more Generators is observed via field measurements, studies, or complaints made by other Generator Owners, Generator Owner(s) shall cooperate with PJM and MAOD to investigate the root cause of the identified electrical interaction and implement the necessary corrective action plan. Cooperation may require providing more detailed EMT models and performing EMT studies.

5.8 Additional Requirements for Inverter-Based Resources

In accordance with the FERC Order No. 901, IBRs shall provide frequency and voltage support during frequency and voltage excursions in a manner necessary to contribute toward the overall system needs for essential reliability services. The frequency and voltage response requirements stipulated herein are based on the applicable IEEE 2800-2022.

5.8.1 Active Power – Frequency Response Requirements

The response provided by the generating facility shall be a timely and sustained response to any frequency excursions greater than ± 0.036 Hz deadband and follow a maximum 5% droop.

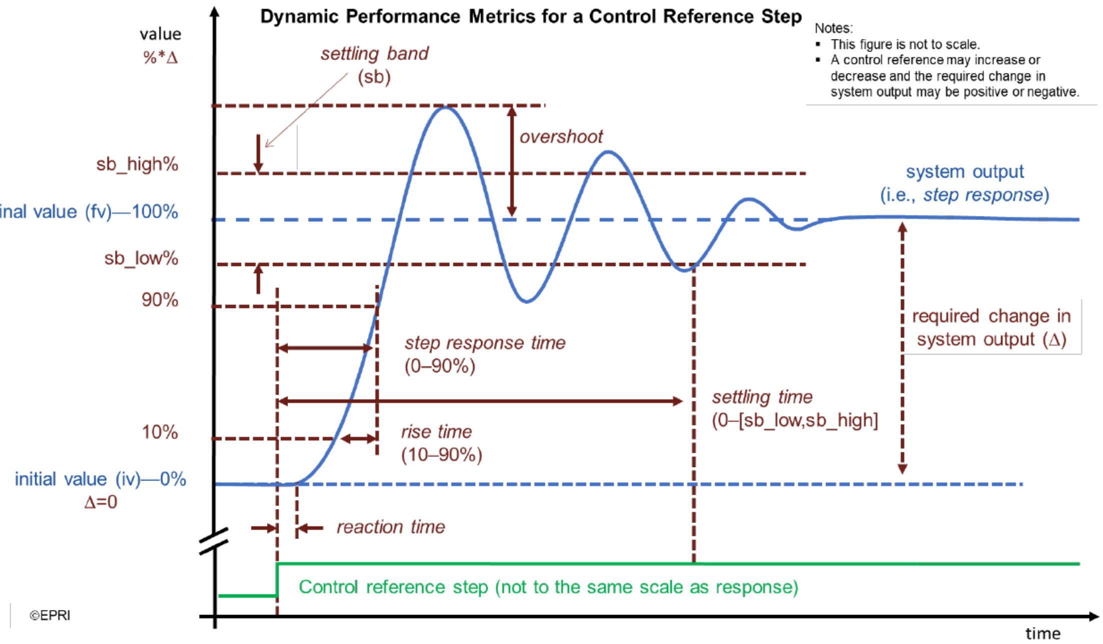
The overall dynamic response capability of the IBR plant for a step change, at the POI, in applicable frequency shall be within the ranges specified in Table 10.

For complete list of requirements and additional details, refer to IEEE 2800-2022 Section 6.0 and Annex L.

Table 10 Parameters of Active Power-Frequency Response Dynamic Performance for IBR Plant (IEEE 2800-2022)

Parameter	Description (Refer to **Error! Reference source not found.** for illustration)	Performance Target	Units
Reaction Time	Time between the step change in frequency and the time when the resource active power output begins responding to the change	<0.50	Seconds
Rise Time	Time in which the resource has reached 90% of the new steady-state (target) active output command	<4.0	Seconds
Settling Time	Time in which the resource has entered into, and remains within, the settling band of the new steady-state active power output command	<10.0	Seconds
Overshoot	Percentage of rated active power output that the resource can exceed while reaching the settling band	< 5%	% of Change
Damping Ratio	The measure of how the oscillations in the response of a system decay over time after a disturbance.	>0.3	N/A
Settling Band	Percentage of rated active power output that the resource should settle to within the settling time	<2.5%	% of Change

Figure 1 Dynamic Performance Metrics for a Control Reference Step (Frequency Response)



5.8.2 Reactive Power – Voltage Control Requirements

An IBR interconnecting to a MAOD Facility is required to be able to control voltage at its POI with a closed-loop, automatic voltage control mode to maintain the scheduled voltage specified by PJM within ±2% deviation. The selection of the reactive droop and voltage should be coordinated with PJM.

Small disturbance behavior is typically dominated by the plant-level controls while large disturbance behavior is typically dominated by the individual inverter controls. Generally, small disturbance behavior is where voltage stays within the continuous operating range and large disturbance behavior is where voltage falls outside this range (i.e., “low or high voltage ride-through mode”).

For small disturbance, the IBR shall have the capability to meet or exceed the performance characteristics shown in Table 11.

Table 11 Small Disturbance Reactive Power-Voltage Performance.

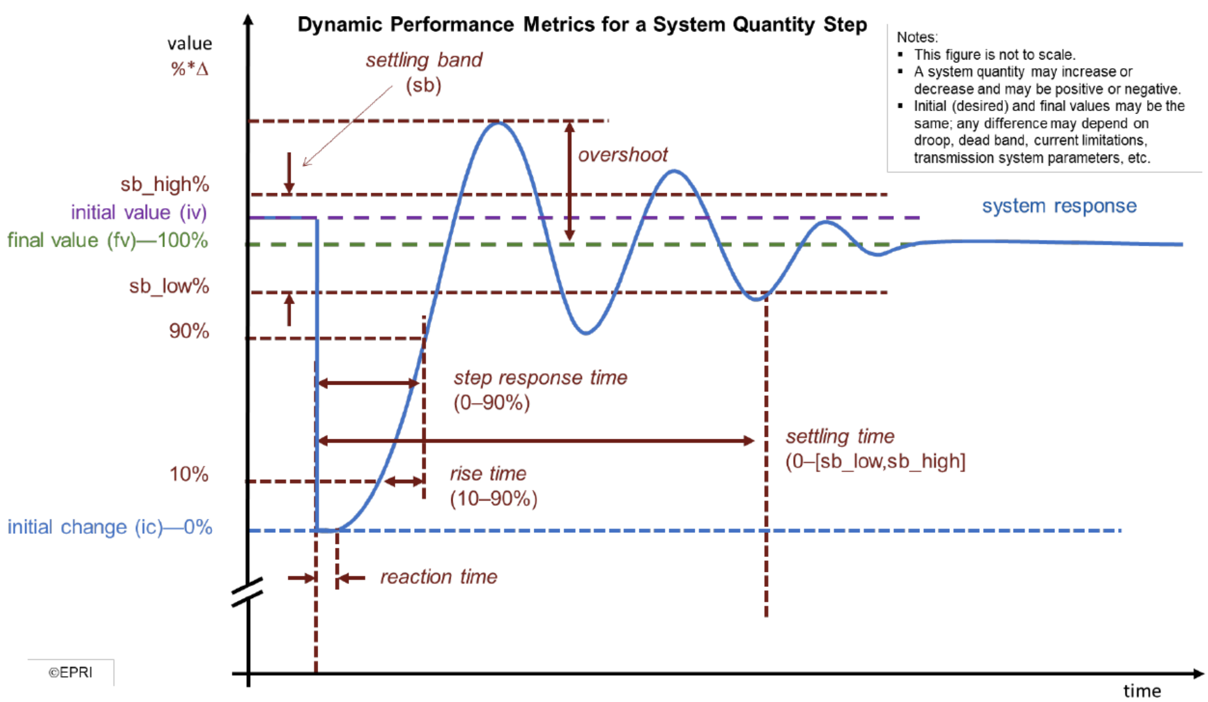
Parameter	Description (Refer to Figure 2 for illustration)	Performance Target	Units
Reaction Time	Time between the step change in voltage and when the resource reactive power output begins responding to the change	<0.50	Seconds
Rise Time	Time between a step change in control signal input (reference voltage or POI voltage) and when the reactive power output changes by 90% of its final value	1 to 30	Seconds
Overshoot	Percentage of rated reactive power output that the resource can exceed while reaching the settling band	< 5%	% of Change
Damping Ratio	The measure of how the oscillations in the response of a system decay over time after a disturbance.	>0.3	N/A

For large disturbance, the IBR should have the capability to meet or exceed the performance characteristics shown in Table 12.

Table 12 Large Disturbance Reactive Power-Voltage Performance.

Parameter	Description (Refer to Figure 2 for illustration)	Performance Target	Units
Reaction Time	Time between the step change in voltage and when the resource reactive power output begins responding to the change	<0.16	Seconds
Rise Time	Time between a step change in control signal input (reference voltage or POI voltage) and when the reactive power output changes by 90% of its final value	< 0.1	Seconds
Damping Ratio	The measure of how the oscillations in the response of a system decay over time after a disturbance.	>0.3	N/A

Figure 2 Dynamic Performance Metrics for a System Quantity Step (Voltage Regulations)



5.9 Black Start Requirements

This section is reserved for future use, as needed.

6 Additional Interconnection Requirements for Transmission Facilities

This section is reserved for future use, as needed.

7 Additional Interconnection Requirements for End-User Facilities

This section is reserved for future use, as needed.

8 Modeling Requirements

The IC shall be responsible for submitting its required modeling data to PJM directly, following PJM's applicable timelines and procedures.

The modeling data required herein are needed for MAOD's facilities studies and/or for other studies that are not typically performed under PJM's Interconnection Process.

The IC shall provide MAOD with the following modeling data for its IF.

8.1 General Requirements

The following requirements shall be applicable to all types of modeling data requested. All requested model(s) shall:

- Provide, as accurate as possible, representations of all the IF's equipment that generate, absorb, or deliver active or reactive power (e.g., synchronous generator/motors, synchronous condensers, FACTS, IBR, two-winding/three-winding transformers, transformer winding connections, shunt capacitors/reactors, busbars, AC/DC transmission circuits, HVDC converters, filters, grounding impedances, etc.). This shall also include modeling the protective relays and all applicable station/substation/plant controllers. Mechanical parameters of synchronous machines and wind turbines also shall be modelled (e.g. turbines, flywheels, governors, pitch controller, etc.).
- Be up to date to represent the most recent parameters of the IF's power equipment, such as topology (e.g. transformer connections), ratings, maximum and minimum operating limits, impedances, settings, etc.
- Include as accurate as possible equipment settings (e.g., in-service status, transformer tap changer range/settings, generator voltage setpoints, voltage droop, frequency droop, gain(s), PLL, relay settings, controller settings, controlled bus, etc.).
- Utilize standard models that are available in the model library(ies) of commonly used commercial software tools (e.g. PSSE, PSCAD, ASPEN One-liner, etc.). User-Defined Models (UDMs) might be allowed under very limited circumstances when it is impossible to avoid them. ICs must seek PJM's approval prior to utilizing such UDMs.
- Not rely on approximations or simplifications of the IF unless it is permitted by commonly acceptable standards (e.g., IEEE 2800-2022). An example of acceptable approximation can include modeling a cluster of identical renewable generating units as a single generator.
- Be solvable and tested to initialize and compile as is without extensive intervention or trouble-shooting efforts from MAOD's personnel.
- Be accompanied by detailed and clear documentation, guides, and datasheets that explain all important controls and settings that need to be modelled.
- Be accompanied by reactive capability curves, particularly for onshore generating facilities or onshore HVDC equipment (e.g., VSC HVDC converters that support offshore wind projects) that will inject/absorb reactive power to/from the POI.

8.2 Positive Sequence (RMS) Simulation Models

The below requirements highlight the most important details to be included in the required positive-sequence models to be provided to MAOD by the IC.

For complete details of model requirements and modeling data submittal formats, refer to the latest version of PJM MOD-032 Data Requirements and Procedure, which can be downloaded from PJM's Planning Modeling Submissions (MOD-026, 027 & 032) webpage.

The modeling data shall be consistent with the most recent format and requirements of the Multiregional Modeling Working Group (MMWG) Procedural Manual. At the time of writing these Requirements, MMWG Procedural Manual V35 were posted.

8.2.1 Power (Load) Flow Case

A PSS/E (*.raw) file compatible with the latest PSS/E version acceptable to PJM including the following:

- A small PSS/E case in (*.raw or *.idv) file that depicts the entire IF.
- The power flow case shall model all equipment (e.g., generators, transformers, feeders, tie-lines)
- Each equipment model in the power flow case shall include a complete set of equipment parameters (e.g., continuous and emergency ratings, active and reactive power limits, tab changers, impedances, applicable kV base, and MVA base, etc.).
- The case shall report generators' active and reactive capabilities.
- Generators shall regulate the voltage at their respective POIs.
- Power transformers shall model their energized and/or de-energized load tab changers.
- An infinite bus with a swing generator can be used to represent the power grid.
- Unless specified differently by PJM, all bus numbers must be between 5 to 6 digits long and have descriptive bus names. Each bus must have a unique bus number. When possible, use bus numbers that do not conflict with existing bus numbers in the recent power flow cases provided by PJM or MMWG.
- Descriptive equipment identification numbers/names (e.g. W1 and W2 if two equivalent wind machines shall be modelled).

8.2.2 Dynamic Models

A PSS/E (*.dyr) file compatible with latest PSS/E version acceptable to PJM, shall include:

- Complete dynamic models of the entire IF equipment including its protective relays (e.g., under-voltage, over-frequency, etc.) and controllers for each equipment.
- All dynamic models are based on generic PSS-E model library. For unavoidable UDMs, the necessary compiled Dynamic Link Library (DLL) file(s) shall be provided.
- All dynamic models must utilize matching bus number and equipment IDs included in the corresponding power flow case(s).

Refer to the most recent version of NERC's Dynamic Modeling Recommendations to determine which models are not acceptable.

8.3 Harmonics Models

For IBR IFs, IC must provide the necessary harmonics data to model the harmonics injected by the converter into MAOD's facility, at the POI. At a minimum, the IC must provide the following:

- The IBR converter type (i.e., VSC or LLC)
- The converter impedance based on the fundamental frequency, as seen at the POI. If the impedance is provided in per unit, use the POI voltage as the base voltage and 100 MVA base.
- For VSC (i.e., voltage source):
  - The magnitude of each voltage harmonic, including the fundamental frequency harmonic, up to the 50th harmonic.
- For LLC (i.e., current source):
  - The magnitude of each current harmonic, including the fundamental frequency harmonic, up to the 50th harmonic.

8.4 Short-Circuit Models

IC must provide an ASPEN OneLiner model of the entire IF equipment, which shall include:

- Equipment positive-sequence, negative-sequence, zero-sequence data.
- The winding connections of each transformer (either two-winding or three-winding) shall be modelled as planned/built (e.g., delta, solidly grounded wye, impedance grounded wye, ungrounded, etc.). Grounding impedances, if any, shall be modeled.
- The short-circuit model must utilize matching bus number and equipment IDs in the corresponding power flow case.

8.5 Electromagnetic Transient (EMT) Models Modeling Requirements for Inverter-Based Resources (IBRs)[3]

IC must provide an EMT model in PSCAD (version 5) for the entire IF equipment. including its power plant controller, if applicable, that shall consider all the following aspects:

8.5.1 Model Details

- If permitted by the inverter's Original Equipment Manufacturer (OEM), the EMT models shall embed the actual control firmware codes presented in black box models accompanied by their associated complied binary DLL files.[4] The models shall include the detailed actual inner control loops of the inverter.

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[3] Most of the EMT modeling requirements listed here are based on the "Requirements for the Connection of Facilities to the AES Ohio Transmission System" – September 2023.

[4] If actual code models are not employed, or if essential control features are approximated with generic representations, further validation might be necessary. Avoid using a three-phase sinusoidal source representation. Additionally, do not manually translate models block-by-block from control block diagrams, as this can introduce inaccuracies.

- Models shall provide access to all relevant controls and tuning settings such as plant-level controllers, inverter controls, and external voltage controllers, preferably based on actual hardware codes.
- The models shall include all relevant electrical systems such as harmonic filters, specialized transformers, transformer saturation curves, transmission line frequency dependent models/traveling wave models, and detailed and actual representation of the converter/inverter's power electronic bridges.
- The models shall include all relevant protection systems such as fault ride-through protective relays[5] (e.g., over/under voltage protection, over-current protection, over/under frequency protection, etc.) based on the actual settings recommended by the OEM and that will be implemented in the field.

8.5.2 Usability and Practicality

Models shall provide and/or conform to the following:

- Models shall provide access to all hardware parameters (e.g., priority modes, active current, power ramp rates, voltage references, voltage droop, frequency droop, dispatchable active power, and the ease of independently scaling up or down the active and reactive plant capacities and its equipment ratings (e.g. transformers), etc.).
- Models shall provide access to simulation time steps. By default, the single time step shall be between 10 to 20 microseconds.
- Access to troubleshooting/diagnostic flags (e.g., protective relaying actions).
- Straightforward initialization of the model, with minimal intervention of MAOD engineers to troubleshoot the initialization issues.
- The model shall initialize to a stable state in five seconds or less.
- The model shall support multiple instances of itself in the same simulation.

IC shall provide detailed documentation and datasheets on how to achieve all the above.

8.6 Modeling of FACTS

Positive sequence dynamic model, short-circuit model, detailed EMT models, and steady-state power flow models of Flexible Alternating Current Transmission System (FACTS) must be provided to MAOD.

Refer to Section 8.5 for the similar detailed EMT model requirements.

8.7 Special Considerations

The IF shall prioritize providing MAOD with modeling data for portions of the IF that will have the strongest impact on MAOD's Facility and the grid.

For example, for connection of offshore wind generation at the Larrabee Collector Station, the AC system of the onshore portion of the IF (i.e., the IF's HVDC converter) that is connected to MAOD's Facility at the

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[5] By default, Momentary Cessation is not allowed inside the No Trip Zone as defined in PRC-024-3.

POI is separated from the AC system of the offshore portion of the IF (i.e., the offshore wind park) by the DC link in between the two AC systems (i.e., the HVDC underground and submarine cables). Therefore, due to this DC separation between the two AC systems, the IF shall prioritize providing the required detailed modeling data of the onshore portion (i.e., the HVDC converter) of the IF since this has the strongest impact on MAOD's Facility and the grid.

8.8 Modeling of Loads

Depending on load characteristics (e.g., asynchronous motors, data center, etc.), MAOD will determine the load modeling requirement specifications on a case-to-case basis. In general, the IC shall provide power flow, positive sequence dynamic, and EMT model(s) as needed.

9 Procedure for New Interconnection Requests

In the PJM transmission system, primary responsibility for interconnection processes and requirements is with the PJM RTO. The PJM Open Access Transmission Tariff (OATT) and PJM Manual 14 series address the interconnection process, planning study requirements, and development of facility connection requirements. All generation, transmission, and end-user interconnection requestors should review PJM's Queue Point tool website prior to submitting an interconnection request.

PJM Queue Point tool website: https://www.pjm.com/planning/service-requests/application-and-forms

9.1 Facility Studies

One of the PJM RTO functions is to coordinate joint studies of new facility interconnections for generation, transmission, and end-user facilities to assess the reliability impacts to the interconnected transmission system. PJM Manual 14H: New Service Requests Cycle Process identifies the studies to be performed by request type and data required. PJM studies comply with NERC Reliability Standards, PJM regional transmission criteria, and facility interconnection requirements. The preliminary studies, System Impact Study, and Facility Study document the assumptions regarding the Interconnection Request relative to pending requests and planned transmission system expansion projects to identify necessary facilities and upgrades for construction. The study results will be shared with the transmission planners, Interconnection Customer, and impacted transmission owners.

MAOD will furnish all requested updated modeling data for its hosting Facility to PJM to allow PJM to conduct joint studies for new interconnection requests.

9.2 Notification

MAOD will assess the potential impact of the modifications and contact the appropriate point of contact of the affected entity(ies). MAOD may require engineering study(ies) involving PJM and affected entities based on impacts to operating limits, power flow, power quality, electromagnetic transient stability, electromechanical dynamic stability, and modifications to MAOD facility(ies) or construction of new facility(ies). The PJM studies and potential engineering study will help identify facility interconnection requirements for new interconnection requests.

9.3 Provision of Facility Interconnection Requirements

MAOD shall update these Requirements as necessary, publish the Requirements on MAOD's website, and provide the Requirements to PJM for publishing on PJM's website. MAOD also shall provide a copy to the affected entities' points of contact and the IC upon request.

9.4 Balancing Authority Area Confirmation

All new interconnection requests for generation, transmission, and end-user facility(ies) are submitted directly to PJM and processed through PJM's Queue Point tool. PJM, as a registered Balancing Authority, is responsible for assessing the facilities within its Balancing Authority Area's metered boundaries in accordance with the OATT, Manual 14B and 14H.

10 Procedure for Existing Interconnection Facility(ies) Seeking to Make a Qualified Change Request

The following information, from PJM's Manual 14B: PJM Region Transmission Planning Process Attachment G.12, Revision 56, Effective 06/27/2024, defines a qualified change for a facility interconnection. PJM's Manual 14 series documents and Queue Point website should be referenced for the most current definitions, processes, and questions related to qualified change requests.

PJM Queue Point tool website: https://www.pjm.com/planning/service-requests/application-and-forms

Qualified Change for End-User Facilities	
Description	Examples
Facility changes leading to a change in: 1. End-User Facility topology, or 2. Protection system changes impacting contingency definition, or 3. The electrical characteristics of the facility, or 4. Facility ratings that either of which may impact the Bulk Electric System performance.	• Increase or decrease in load • Changes to the number of feeds in an existing End-User Facility

Qualified Change for Transmission Facilities	
Description	Examples
Facility changes lead to a change in: 1. Transmission system topology, or 2. Protection system changes impacting contingency definition, or 3. The electrical characteristics of the facility, or 4. Facility ratings that either of which may impact BES performance	• Increase or decrease in rating. • Change in facility impedance. • Reconfiguration

Qualified Change for Generation Facilities	
Description	Examples
GO reports anticipated changes of the electrical characteristics following execution of the applicable interconnection agreement. PJM evaluation of changes requires more detailed analytical studies.	• Change in generator electrical characteristics. • Change in turbine type.

All qualified changes to an existing interconnection are required to submit an upgrade request to PJM's Queue Point tool. It is recommended that all upgrade request customers review PJM's Queue Point tool website prior to submitting an upgrade request.

10.1 Facility Studies

PJM RTO will coordinate joint studies of qualified changes to existing facilities for generation, transmission, and end-user facilities to assess the reliability impacts to the interconnected transmission system. PJM Manual 14H: New Service Requests Cycle Process identifies the studies to be performed by request type and data required. PJM studies comply with NERC Reliability Standards, PJM regional transmission criteria and facility interconnection requirements. The System Impact Study and Facility Study document the assumptions regarding the upgrade request, relative pending requests, and planned transmission system expansion projects to identify necessary facilities and upgrades for construction. The study results will be shared with the transmission planners, Interconnection Customer, and impacted transmission owners.

MAOD will furnish all requested updated modeling data for its hosting Facility to PJM to allow PJM to conduct joint studies for qualified changes to existing facilities.

10.2 Notification

MAOD will assess the potential impact of the modifications and contact the appropriate point of contact of the affected entity(ies). MAOD may require an engineering study(ies) involving PJM and affected entities based on impacts to operating limits, power flow, power quality, electromagnetic transient stability, electromechanical dynamic stability, and modifications to MAOD facility(ies) or construction of new facility(ies). The PJM studies and potential engineering study(ies) will help identify updates to facility interconnection requirements for qualified changes to existing facility(ies) upgrade requests.

10.3 Provision of Facility Interconnection Requirements

MAOD shall update these Requirements as necessary, publish the Requirements on MAOD’s website, and provide the Requirements to PJM for publishing on PJM’s website. MAOD also shall provide a copy to the affected entities’ points of contact and the IC upon request.

10.4 Balancing Authority Area Confirmation

All upgrade requests for generation, transmission, and end-user facility(ies) are submitted directly to PJM and processed through PJM’s Queue Point tool. PJM, as a registered Balancing Authority, is responsible for assessing the facilities within its Balancing Authority Area’s metered boundaries in accordance with the OATT, Manual 14B and 14H.

11 Additional References

In addition to the applicable NERC, IEEE standards, and PJM Manuals and Technical Specifications, listed in Section 1.4., MAOD consulted the most recent applicable Facility Interconnection Requirements of the following utilities for similar requirements:

- **AES Ohio (Dayton Power & Light Co)**

  Requirements for the Connection of Facilities to the AES Ohio Transmission System, 2023-09.

- **FirstEnergy (FE)**

  Requirements for Transmission Connected Facilities (TPP-REF-004), 2023-01-18.

- **American Electric Power (AEP)**

  Requirements for Connection of New Facilities or Changes to Existing Facilities Connected to the AEP Transmission System, 2023-12-31.