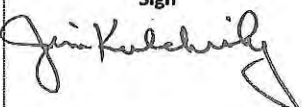




US/Canada TFO/ISO/RTO Minimum Substation Connection Technical Requirements

Issued to Client

Prepared By Jim Kulchisky, P.Eng.	Sign 	Date (YYYY-MM-DD) 2016-04-07	
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Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Table of Contents

1	Executive Summary	5
2	Background	6
3	Electric Utility/RTO/ISO Research Reference List	6
3.1	Overview	6
3.2	Research Reference List Table	6
3.3	NERC Baseline Evaluation Categories	9
3.4	Evaluation Categories Used by CANA	10
4	Technical Requirement Evaluations and Summaries	10
4.1	Definitions	10
4.2	General Requirements	12
4.3	Point of Connection Disconnecting/Isolation Devices	16
4.4	Environmental Factors	18
4.5	Insulation Levels and Insulation Coordination	19
4.6	Electrical Clearances	31
4.7	Surge Protection and Lightning Shielding	33
4.8	System Grounding and Neutral Shifts	39
4.9	Substation Grounding and Safety Issues	42
4.10	Substation Illumination	48
4.11	AC Station Service Supply	49
4.12	DC Station Service Supply	50
4.13	Structures/Structural Design Loads	54
4.14	Equipment Ratings - General	57
4.15	Equipment – Shunt Capacitors	62
4.16	Equipment – Circuit Breakers and Breaker Duty	68
4.17	Equipment – Circuit Switchers	75
4.18	Equipment – Power Transformers	76
4.19	Equipment – Potential Transformers/CVTs	78
4.20	Equipment – Current Transformers	81
4.21	Equipment – HV Switches	81
4.22	Equipment – HV Fuses	84
4.23	Equipment - Metering	85
4.24	Equipment – GIS	87
4.25	Equipment - Other	87
4.26	Physical and Cyber Security	87



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

4.27	System Voltage Ranges	88
4.28	Temporary/Transient Overvoltages.....	95
4.29	Applicable Codes, Regulations, and Standards.....	97
4.30	Reliability and Availability Criteria	98
4.31	Power Quality	99
4.32	Power Factor	103
4.33	Bus Configurations/Bus Design.....	104
4.34	Control Building	112
4.35	Substation Fencing.....	116
4.36	Parallel Operation of Transformers	116
4.37	Black Start Capabilities.....	116
4.38	Synchronizing.....	117
4.39	Audible Noise Levels	117
4.40	Oil Containment.....	118
4.41	Civil Works	118
4.42	Substation Land Requirements.....	119
4.43	Ferroresonance	120
4.44	Underground Cables	120
5	Conclusion.....	122
6	Appendices.....	123
6.1	NERC Rule FAC-001-1.....	123
6.2	Short Compilation of Substation Bus Configuration Documents	123
6.3	Hard Copy of CANA Slide Presentation.....	123
6.4	Substation Connection Minimum Technical Requirements Vol. 1 (Separate Binder)	123
6.5	Substation Connection Minimum Technical Requirements Vol. 2 (Separate Binder)	124
6.6	Substation Connection Minimum Technical Requirements Vol. 3 (Separate Binder)	125



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

1 Executive Summary

For development of AESO Transmission Substation Minimum Requirements Rule 502.11, the following question is addressed in this report:

What are other TFOs and ISOs/RTOs using as minimum transmission substation connection technical requirements?

The Transmission Connection Minimum Technical Requirements documents from 52 TFOs, ISOs/RTOs (Table 3-2 below) were collected, reviewed and summarized in this report.

The baseline minimum technical requirement categories are based on NERC Document FAC-001-1: *Facility Connection Requirements*. Each TFO/ISO/RTO expands these NERC categories into detailed technical requirements applicable to their particular Transmission Systems.

Of the nine(9) USA/Canada ISOs/RTOs (excluding AESO), the following four(4) had significant technical content related to minimum Transmission connection technical requirements. PJM (covering 14 TFO areas) offered the most extensive minimum technical requirements.

- IESO (Ontario)
- ISO-NE (ISO – New England)
- PJM
- SPP (Southwest Power Pool)

The other ISOs/RTOs had minimal technical design requirements and deflected the establishing of minimum technical requirements to the TFO involved with the connection.

The categories evaluated in this summary report are as described in Section 3.4 below.

The summary of category minimum requirement statements was done using the following criteria:

- a.) If more than one TFO/ISO/RTO had the same category requirement then the summary included that requirement only once as a common TFO/ISO/RTO requirement. (i.e. if 15 TFOs/ISOs/RTOs had the same category requirement, the requirement is listed only once in this summary report not 15 times).
- b.) If deemed to add technical value unique requirement statements were also captured under each category.

Three(3) Binders containing all the TFO/ISO/RTO documents used in this summary will form part of the Appendix part of this summary report, but submitted separately.

2 Background

AESO is developing Rule 502.11 for the Minimum Transmission Substation Technical Requirements for the Alberta Interconnected Electric System.

AESO (Alberta Electric System Operator) requested CANA High Voltage Ltd. to provide two reports:

- a) Complete a general research of the Transmission Minimum Substation Connection Technical Requirements documents of a representative number of TFOs, RTOs, and ISOs in the USA and Canada. The research summary would provide AESO with an industry practices baseline being used by others for Transmission Minimum Substation Connection Technical Requirements. Findings will assist AESO in assessing Rule 502.11 requirements in comparison to other TFO/RTO/ISO minimum requirements.
- b) Complete a general research and compile a list of new emerging technologies and their impact on Transmission substations in the years ahead.

This report will summarize current Transmission Minimum Substation Connection Technical Requirements.

3 Electric Utility/RTO/ISO Research Reference List

3.1 Overview

Informational documents from 52 TFOs, RTOs, and ISOs in the USA and Canada were obtained and reviewed.

3.2 Research Reference List Table

ID#	Utility/RTO/ISO	Location
1	Allegheny Power	Maryland/Pennsylvania/Virginia/West Virginia
2	Ameren	Illinois/Missouri
3	American Electric Power	Indiana/Kentucky/Michigan/Ohio/Texas
4	Atlantic City Electric	New Jersey
5	Austin Energy	Texas



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

6	AVISTA	Idaho/Oregon
7	BC Hydro	CANADA
8	Bonneville Power	Idaho/Montana/Nevada/Oregon/Utah/Washington/Wyoming
9	Chelan County Public Power	Washington
10	CLECO Power	Louisiana
11	Cleveland Public Power	Ohio
12	Consolidated Edison	New York
13	Dayton Power & Light	Ohio
14	Delmarva Power	Delaware
15	Dominion Resources/VEPCO	North Carolina/Virginia
16	Duke Energy	Florida/Indiana/Kentucky/North Carolina/Ohio/South Carolina
17	Duquesne Light Company	Pennsylvania
18	East Kentucky Power	Kentucky
19	Empire District Electric Company	Missouri
20	Entergy	Louisiana/Mississippi/Texas
21	Exelon	Illinois
22	First Energy	New Jersey/Ohio/Pennsylvania
23	FortisBC	CANADA
24	IESO-Ontario	ISO-CANADA
25	ISO-New England	RTO/ISO
26	LCRA (Lower Colorado River Authority)	Texas
27	Lincoln Electric	Nebraska



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

28	Lubbock Power & Light	Texas
29	Manitoba Hydro	CANADA
30	Memphis Light & Power	Tennessee
31	Mid-American Energy	Iowa/South Dakota
32	Montana-Dakota Utilities	Montana/North Dakota
33	National Grid	Massachusetts/New Hampshire
34	Newfoundland Power	CANADA
35	Niagara-Mohawk	New York
36	Nova Scotia Power	CANADA
37	ONCOR	Texas
38	Otter Tail Power	Minnesota/North Dakota/South Dakota
39	OMU-Owensboro Municipal Utilities	Kentucky
40	PacifiCorp	California/Idaho/Oregon/Utah/Washington/Wyoming
41	PEPCO	Washington DC/Washington
42	PG&E	California
43	PJM	RTO
44	PPL Electric Utilities	Pennsylvania
45	Public Service Electric and Gas (PSE&G)	New Jersey/New York
46	Quebec Hydro	CANADA
47	SaskPower	CANADA
48	Southern California Edison	California
49	Southwest Power Pool	RTO



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

50	Sunflower Electric	Kansas
51	USDA – Rural Utilities	
52	Xcel Energy	Michigan/North Dakota/South Dakota/Wisconsin

Table 3-2 List of Electric Utilities/RTOs/ISOs.

3.3 NERC Baseline Evaluation Categories

All researched references used in this report used NERC Document FAC-001-1: *Facility Connection Requirements* as the basis for establishing Transmission Connection Minimum Technical Requirements. See Appendix 1 for a copy of NERC Document FAC-001-1. The NERC FAC-001 was adopted by the AESO and forms the basis of the FAC-001-AB reliability standard.

The following partial excerpt from NERC Document FAC-001-1 lists the 16 technical categories covered in typical Transmission Connection Minimum Technical Requirements documents from the researched reference TFOs/ISOs/RTOs:

R3. Each Transmission Owner and each Generator Owner shall address the following items in its Facility connection requirements:

- 1. Procedures for coordinated joint studies of new Facilities and their impacts on the interconnected Transmission systems.*
- 2. Procedures for notification of new or modified Facilities to others (those responsible for the reliability of the interconnected Transmission systems) as soon as feasible.*
- 3. Voltage levels and MW and MVAR capacity or demand at point of connection.*
- 4. Breaker duty and surge protection.*
- 5. System protection and coordination.*
- 6. Metering and telecommunications.*
- 7. Grounding and Safety Issues.*
- 8. Insulation and Insulation Coordination.*
- 9. Voltage, Reactive Power, and power factor control.*
- 10. Power quality impacts.*
- 11. Equipment Ratings.*
- 12. Synchronizing of Facilities.*
- 13. Maintenance coordination.*



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

14. *Operational issues (abnormal frequency and voltages).*
15. *Inspection requirements for existing or new Facilities.*
16. *Communications and procedures during normal and emergency operating conditions.*

Note: Bold text above indicates the Substation categories covered in this report; along with additional categories specified by AESO. See Section 3.4 below.

3.4 Evaluation Categories Used by CANA

The findings for FAC-001-1 Technical Categories 3-4, 7-8, and 11 above, as well as the additional categories requested by AESO below, are summarized in this report.

3.4.1 Additional Categories Summarized:

- Definitions
- General Technical Statements (not in any specific category)
- Minimum Reliability and Availability Criteria
- Bus Design and Bus Arrangements
- ACSS Station Service
- DCSS Station Service
- Control Building
- Power transformers
- Circuit Breakers
- Capacitor Banks
- VTs/CTs
- Civil/Structural
- Environmental Factors
- Oil Containment

4 Technical Requirement Evaluations and Summaries

Evaluation was done by Technical Category with a reference back to the researched organizations ID# as listed in Table 3-2 above.

4.1 Definitions

4.1.1 [5]Good Utility Practice: Any of the practices, methods, and acts engaged in or approved by



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

a significant portion of the electric utility industry during the relevant time period, or any of the practices, methods and acts that, in the exercise of reasonable judgment in light of the facts known at the time the decision was made, could have been expected to accomplish the desired result at a reasonable cost consistent with good business practices, reliability, safety, and expedition. Good utility practice is not intended to be limited to the optimum practice, method, or act, to the exclusion of all others, but rather is intended to include acceptable practices, methods, and acts generally accepted in the region.

- 4.1.2 [8]Transmission – That part of the electric grid associated with bulk transfer of energy, at high nominal voltages (generally defined as 115 kV or above).
- 4.1.3 [13]Transmission System - The transmission facilities owned, operated or controlled by TFOs, including conductors, circuit breakers, switches, transformers and other associated equipment used to control and transfer energy from one place to another, and shall include any modifications, additions, or upgrades made to those facilities.
- 4.1.4 [21]Good Utility Practice – shall mean any of the applicable practices, methods and acts:
- Required by FERC, NERC, RTO, ISO, TFO or the successor of any of them, whether or not the party whose conduct is at issue is a member thereof,
 - Required by applicable law or regulation,
 - Otherwise engaged in or approved by a significant portion of the electric utility industry during the relevant time period, or any of the practices, methods and acts which, in the exercise of reasonable judgment in the light of the facts known at the time the decision was made, could have been expected to accomplish the desired result at a reasonable cost consistent with good business practice, reliability, safety and expedition. Good Utility Practice is not intended to be limited to optimum practice, method or act to the exclusion of all others, but rather is intended to include acceptable practices, methods, or acts generally accepted in the region.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

- 4.1.5 [7]Good Utility Practice – any of the practices, methods and acts engaged in or approved by a significant portion of the electric utility industry during the relevant time period, or any of the practices, methods and acts which, in the exercise of reasonable judgment in light of the facts known at the time the decision was made, could have been expected to accomplish the desired result at a reasonable cost consistent with good business practices, reliability, safety and expedition. Good Utility Practice is not intended to be limited to the optimum practice, method or act to the exclusion of all others, but rather to be acceptable practices, methods or acts generally accepted in the WECC region.
- 4.1.6 [7]Transmission –operating at voltages 60 kV and above
- 4.1.7 [46]Transmission –operating at voltages 44 kV and above
- 4.1.8 [47]Transmission –operating at voltages 72 kV and above

4.2 General Requirements

- 4.2.1 [1] These requirements are applicable to all facilities interconnecting with the TFO transmission system, both Company owned as well as facilities owned by other parties.
- 4.2.2 [2]Connections shall comply with NERC Reliability Standards.
- 4.2.3 [2]TFO will perform coordinated joint studies of the new facilities to investigate their impacts on the Transmission System. The results of such studies will be provided as joint recommendations from all parties involved with the study.
- 4.2.4 [12]Checklist of Items for Transmission Substation Design:
- Primary and secondary voltage to be used
 - System Studies
 - Substation capacity, current and future
 - Future expansion needs
 - BIL rating of Equipment
 - Number of transmission feeder positions, initial and final.
 - Size and layout of station property
 - Air Insulated versus SF6 Bus (Momentary Rating of Bus)
 - Maintenance requirements
 - Electrical clearances
 - Light and Power requirements
 - Grounding Design
 - Control Room Layout
 - Cable and Trench Layout
 - Metering scheme

- Roadway Layout
- Primary and Secondary Voltage Relaying Schemes
- Aesthetic appearance of station
- Type of primary feeder cables
- Alarm Panel Design and requirements
- One Line High Tension drawing
- Accuracies of current transformers
- Lighting Design
- Security Protection
- Type of structure
- Number and location of Shunt / Series Reactors
- Environmental Aspects
- o Type of Circuit Switchers and Interrupters (Interrupting Rating)
- Type of Metal Clad Switchgear
- Environmental Aspects
- Transformer MVA rating and % Impedance
- Circuit Breaker (Continuous & Short Circuit Ratings)
- Phase Angle Regulators
- Breaker and A Half Bus Configuration
- Ring Bus Configuration
- Automation / SCADA / HMI
- Communication / IR Requirements
- Lightning / Surge Protection

4.2.5 [20] All the requirements identified as a result of transmission studies shall be incorporated into the design process. These requirements may include the following issues:

- SCADA
- Metering
- Equipment Ratings
- Short Circuit Conditions
- System Protection
- System Grounding

4.2.6 [12] The aesthetic and environmental impacts of the new or modified substation and PURS (Public Utility Regulating Substation) Facility toward its surrounding area shall also be considered. Structural design, lighting, architectural treatments, landscaping, noise emission, pollution prevention techniques, etc. should be included in the engineering design and environmental review process. In addition, the substation should present as low and



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

inconspicuous a silhouette as possible, consistent with good engineering practices.

- 4.2.7 [19] Transformers capable of serving load greater than or equal to 14MVA shall be controlled by a primary circuit switcher or circuit breaker with appropriate relaying.
- 4.2.8 [20] The Connection Facilities Study will provide the design specifications for the physical plant to be constructed in order to connect the facility, At a minimum, the study will address the following:
- Substation Layout
 - Station Service
 - Surge protection
 - System protection and coordination design
 - Metering and telecommunications
 - Grounding and safety issues
 - Insulation and insulation coordination
 - Equipment Ratings
- 4.2.9 [26] All interconnecting facilities, new or existing, requesting connection to the TFO transmission system shall be planned, designed and operated in accordance with the TFO Facility Connection Requirements, and any applicable requirements of ERCOT, the North American Electric Reliability Corporation (NERC), National Electric Code (NEC), the National Electric Safety Code (NESC), the Occupational Safety and Health Administration (OSHA) and the Public Utility Commission.
- 4.2.10 [27] TFO will conduct or review power system studies (at the expense of the connecting party) needed to substantiate system impact, reliability, and capability of the transmission system with the addition of the proposed connection. The studies may include, but not be limited to, power flow, system stability, short circuit, breaker duty, surge protection, insulation coordination, equipment ratings, system grounding, safety, voltage level, MW capacity, MVAR capacity and synchronizing studies. Evaluation of alternatives to the proposed interconnection, such as lower voltage construction, reactive support facilities, or upgrading facilities, may be requested or conducted. Analysis will include 10-year load or resource growth projections and the planned facilities needed to satisfy such requirements.
- 4.2.11 [27] The Connection Entity making the interconnection with the TFO shall provide written Standard Operating and Maintenance Coordination Procedures to the TFO for the interconnected facility.
- 4.2.12 [27] Since lines at higher voltage levels require the highest reliability, connection taps to transmission lines of voltages 345 kV and higher are not permitted.
- 4.2.13 [30] This document pertains to equipment and facilities that operate at or above 100kV.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Minimum requirements are defined for connecting transmission, end-user (load serving), or generation facilities to the Memphis Light, Gas and Water Division (MLGW) transmission system or to adjacent transmission systems when such interconnections have a material impact on the MLGW system. The requirements established in this document are intended to assure that facilities connected to the transmission system do not reduce the reliability or the operating flexibility of the Bulk Electric System (BES) and to assure that public safety is maintained.

- 4.2.14 [30] Any facility that operates at or above 100kV is subject to NERC (North American Electric Reliability Corporation) oversight.
- 4.2.15 [31] These Requirements specify the minimum technical requirements intended to ensure a safe, effective and reliable interconnection
- 4.2.16 [40] These technical requirements specify the minimum technical requirements intended to ensure a safe, effective, and reliable interconnection. These requirements are intended to supplement, but not replace, information contained in regulatory codes.
- 4.2.17 [40] The interconnection shall control the electrical real (MW) and reactive (MVar) power output such that it will not exceed the capacity of the interconnection facilities.
- 4.2.18 [40] The electric equipment shall meet IEEE C62.41 or C37.90.1, V&I Withstand Requirements.
- 4.2.19 [40] The interconnection shall be capable of withstanding electromagnetic interference environments in accordance with ANSI/IEEE Standard C37.90.2. The interconnection system and protection system shall not mis-operate due to electromagnetic interference, including hand-held communication devices.
- 4.2.20 [41] The design of the substation shall minimize the possibility of animal infestations and wildlife caused outages
- 4.2.21 [43] All facility connection designs must, as a minimum, account for single contingency (N-1) failures and:
- Minimize the magnitude and duration of system outages in the event of a component failure,
 - Minimize widespread system effects on voltage, dynamic stability, etc., that occur as a result of an unplanned event,
 - Facilitate the isolation of failed component(s) while maximizing the amount of transmission system equipment that can remain in service.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

- Include plans for expeditious restoration of failed facilities/components (dedicated spare equipment, etc.)

4.2.22 [48] Southern California Edison Company's (SCE) Interconnection Technical Requirements (Requirements) specify the typical minimum technical requirements to interconnect facilities with SCE's electric system. These requirements are necessary to ensure safe and reliable operation of SCE's electric system.

4.2.23 [49] These Southwest Power Pool (SPP) Minimum Transmission Design Standards ("MTDS") outline the minimum design standards to be used for Competitive RFPs.

The MTDS represent the minimum design standards by which a Competitive RFP must be designed unless the RFP specifies different values than those provided in the MTDS. The MTDS facilitate the design of transmission facilities in a manner that is compliant with NERC requirements and SPP Criteria; are consistent with Good Utility Practice; and are consistent with current industry standards specified herein, such as NESC, IEEE, ASCE, CIGRE, and ANSI, at the time the RFP is issued.

4.2.24 [49] Substations shall be designed to withstand the calculated available symmetrical fault current including predicted growth and expansion throughout the anticipated planning horizon. Design values will be determined from system models provided by SPP.

4.3 Point of Connection Disconnecting/Isolation Devices

4.3.1 [2] Provide a manually operated visible disconnecting device as a means of electrically isolating from the Transmission System. The manually operated disconnecting device shall have a means for locking the device in the open position with a TFO padlock.

4.3.2 [2] Provide automatic isolation of the Connection from the Transmission System for faults or abnormal conditions on the Connection so as to maintain network flow and reliability to the Transmission System.

4.3.3 [2] Provide automatic isolation of the Connection from the Transmission System for faults or abnormal conditions on the Transmission System so as to protect Connection from faults or abnormal condition on the Transmission System.

4.3.4 [2] Interrupting devices (i.e. circuit breakers) must have sufficient interrupting capacity to interrupt the ultimate fault current at each disconnecting/isolation location.

4.3.5 [8][9] For an interconnection to the TFO Grid, an isolating device, typically a disconnect



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

switch, shall be provided to physically and visibly isolate the TFO Grid from the connected facilities. All switchgear that could energize equipment shall be visibly identified, so that all maintenance crews can be made aware of the potential hazards. The following requirements apply for all isolating devices:

- Must simultaneously open all three phases (gang operated) to the connected facilities.
- Must be accessible by TFO.
- Must be lockable in the open position by TFO.
- Will not be operated without advance notice to affected parties, unless an emergency condition requires that the device be opened to isolate the connected facilities.
- Must be suitable for safe operation under all foreseeable operating conditions.

4.3.6 [52] A fully rated circuit breaker is normally required to be installed at the HV POI. Sync-check relay(s) must be installed with the circuit breaker to ensure synchronous closing. Breaker failure relaying shall also be included. Circuit breakers shall meet the latest applicable ANSI and IEEE standards and shall be suitable for the local environment and system operating conditions. Circuit breakers must be capable of interrupting present and future available fault current at the location at which they are being installed. Fault currents will increase on the Xcel Energy system over time, the Interconnection Party needs to periodically check fault levels to ensure their breaker meets these ever increasing values.

4.3.7 [7] At the Point of Interconnection, an isolating disconnect device shall be installed and shall meet the following requirements:

- It physically and visibly isolates the Transmission System from the connection
- It complies with safety and operating procedures of WorkSafeBC.
- It is rated for the voltage and current requirements of the particular application.
- It is gang operated.
- It is operable under all weather conditions in the area.
- It is lockable in both the open and closed positions.
- It is accessible to BC Hydro at all times.
- Its control and operation are governed by the operating agreements between the PG and



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

BC Hydro (normally in the form of "Local Operating Orders" (LOOs)).

The disconnect device is provided for isolation and cannot normally be used to interrupt load current or significant line charging current. Its location, capacity and operating rules must be carefully established and documented.

- 4.3.8 [13]The Connection Entity must provide a three-phase interrupting device(s) with appropriate relays and/or other protective equipment to isolate their facility from the TFO system for any faults, loss of supply from TFO or abnormal operating conditions, whether or not their facility is operating. This device shall fully comply with the latest ANSI/IEEE C37 collection of standards and be capable of interrupting the maximum available fault current at that location. The device shall interrupt all three phases simultaneously. The tripping control of the circuit interrupting device shall be powered independently of the utility ac source in order to permit operation upon loss of the TFO transmission system connection. Automatic reclosing of the Connection Entity facilities is not permitted unless a special agreement is worked out with the TFO. All gas insulated protective devices within the Connection Entity's facility having a direct connection to a TFO transmission line shall be equipped with a low gas pressure alarming/tripping/lockout scheme as appropriate for the particular device.
- 4.3.9 [32]A manual disconnect device shall be installed to isolate the Montana-Dakota System from the interconnection customer's Facility. This disconnect shall open all the poles except the neutral and shall provide a visible air gap to establish required clearances for maintenance and repair work of the Montana-Dakota system. A breaker that can be put into a visibly open position is also acceptable.

4.4 Environmental Factors

- 4.4.1 [8][9]The effects of windstorms, floods, lightning, elevation, temperature extremes, icing, contamination and earthquakes must be considered in the design and operation of the connected facilities. The Requester is responsible for determining that the appropriate standards, codes, criteria, recommended practices, guides and prudent utility practices are met for the equipment that they are installing.
- 4.4.2 [29]Any equipment that can impact the TFO TRANSMISSION SYSTEM shall be designed to function safely and reliably under the environmental conditions prevalent at the selected site. In particular, such equipment located outdoors and shall function reliably in extreme cold weather conditions with minimum temperatures as low as -50°C .
- 4.4.3 [43]Environmental Criteria for Substations:



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Ambient Temperature	-30(-40)°C to +40°C (-40°C minimum required N and W of Blue Mountain)
Wind loading Substations (no ice)	-per ASCE 7-98, Figure 6-1 depending on location [typically 90 to 110 mph]
Wind loading Lines (no ice) 138kV or less	per NESC Extreme Wind
Wind loading Lines (no ice) greater than 138kV	25psf or NESC Extreme Wind (whichever is greater)
Ice load 500kV, 345kV, 230kV lines (no wind)	38mm radial ice
Ice load substations (no wind)	25mm radial ice
Wind coincident with 13mm radial ice	40mph (64km/h)
Seismic Substations	per ASCE 7-98 0.2 s and 1.0s Spectral Response Acceleration (5% of Critical Damping), Site Class B.(Figure 9.4.1.1 (a) & (b)) Equipment qualification per IEEE 693-97. [Typically 0.2g some as high as 0.4g]
Line design	NESC Heavy (latest edition) and Clause IV A
Flood Plain	Structure ground line above 100yr flood where possible

4.5 Insulation Levels and Insulation Coordination

4.5.1 [2]BIL Levels should be coordinated with the TFO.

4.5.2 [3]Equipment utilized in substations shall comply with the following BIL standard:

Description	Basic Lightning Impulse Insulation Level (BIL) (kV rms) at System kV listed			
	12.47	13.8	25	34.5
2Wdg Xfmr Internal BIL	110	110	150	200
2Wdg Xfmr Bushing BIL	110	110	150	200
Bus/Switch Support BIL	110	110	150	200
Circuit Breaker Bushing BIL	110	110	150	200
Auto Xfmr Internal BIL	110	110	150	200
Auto Xfmr Bushing BIL	110	110	150	200

Description	Basic Lightning Impulse Insulation Level (BIL) (kV rms) at System kV listed					
	69	115	138	161	230	345
2Wdg Xfmr Internal BIL	350	550	550	650	750	1050
2Wdg Xfmr Bushing BIL	350	650	650	750	900	1300



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Bus/Switch Support BIL	350	550	550	650	900	1300
Circuit Breaker Bushing BIL	350	650	650	750	900	1300
Auto Xfmr Internal BIL	350	550	550	650	750	1050
Auto Xfmr Bushing BIL	350	650	650	750	900	1300

- 4.5.3 [3]In areas classified as "Corrosive Environments," insulators and bushings will be supplied with high creep skirts. The BIL rating of the insulator need not be increased, but the total creepage must meet the following requirements:

Equipment Voltage Rating (kV)	BIL (kV)	Minimum External Creepage Distance (inch)	
		AEP Creepage Required	ANSI C37.01.06 (Reference Only)
15.5	110	17	9
25.8	150	26	15
38	200	-	22
72.5	350	72	42
121	550	-	70
145	650	133	84
169	750	-	93
242	900	-	140
362	1300	318	209

- 4.5.4 [10]34.5kV facilities shall be design for a Basic Impulse Insulation Level of 200kV.
138kV facilities shall be design for a Basic Impulse Insulation Level of 650kV.
230kV facilities shall be design for a Basic Impulse Insulation Level of 900kV.
- 4.5.5 [13]Equipment BIL application must meet requirements as determined by the latest IEEE C62 standards. TFO will provide the BIL for the system interconnection area.
- 4.5.6 [15]Basic Impulse Levels (BIL) for electrical equipment and high voltage substation buses shall meet or exceed TFO standard values listed below.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Nominal KV (phase to phase)	Basic Impulse Level (BIL)
115	550
138	650
230	900
500	1550

- 4.5.7 [22] The minimum required Basic Insulation Levels (BIL) are listed in Table 1. Substations in areas with significant airborne pollution may require a higher insulation level.

Table 1 - Substation Electrical Clearances and Insulation Levels

Table 1 Substation Electrical Clearances and Insulation Levels										
Rated Maximum Voltage Between Phases kVrms	Rated Basic Impulse Insulation Level (BIL) kVCrest	Electrical Clearances (inches) ^{1, 2}				Centerline-to-Centerline Phase Spacing (inches) ²			Vertical Clearance of Unguarded Live Parts ³	Horizontal Clearance of Unguarded Live Parts ³
		Ground		Live Part		Disconnect Switches		Horn Gap Switches (Vertical & Side Break)		
		Minimum	Design	Minimum Metal To Metal	Design Phase Spacing					
25.8	150	10	12	15	30	30	36	48	9'- 3"	3'- 9"
38	200	13	15	18	36	36	48	60	9'- 6"	4'- 0"
48.3	250	17	18	21	48	48	60	72	9'-10"	4'-4"
72.5	350	25	29	31	60	60	72	84	10'- 5'	4'-11"
121	550	42	45	53	84	84	108	120 ⁵	11'- 7"	6'- 1"
145	550	42	45	53	84	84	108	120 ⁵	11'- 7"	6'- 1"
	650	50	52½	63	96	96	132	144 ⁵	12'- 2"	6'- 8"
242	900	71	80	89	132	132	192	192 ⁵	13'- 9"	8'- 3"
362 ⁴	1300	104	106	119	174	174	Note ⁷	240 ⁵	17'- 2"	11'- 8"
550 ⁸	1800	144	152	222 ⁹	300	300	Note ⁷	324 ⁵	20'- 6"	15'- 0"



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Notes:

1. Clearances are given for rigid conductors and live parts. Non-rigid conductors (e.g., strain bus) must be located such that any possible movement will not create conditions which cause the clearances to be less than the minimum values shown.
2. These values are based on ANSI C37.32-1996 (except 550, 900 & 1800 BIL design ground clearances are based on the height of a station post insulator).
3. These values are based on the National Electrical Safety Code, Accredited Standards Committee C2-2002. These clearances are to any permanent supporting surface for workers. The vertical clearance to the unguarded bottom of any part of indeterminate potential (e.g., insulator or surge arrester) shall be not less than 8'-6".
4. Clearances for 362kV voltage are based on a per unit switching surge factor of 2.5.
5. Horn gap switches applied as disconnect switches should use the disconnect phase spacing.
6. FirstEnergy's standard is to use these values for center break switches.
7. Value not yet established.
8. Clearances for 550kV voltage are based on a per unit switching surge factor of 2.0.
9. Based on GPU accepted practice prior to merger.

4.5.8 [27]TABLE 1

MINIMUM BREAKER DUTY, SURGE PROTECTION AND EQUIPMENT RATING REQUIREMENTS FOR GENERATION, TRANSMISSION, AND END-USER FACILITIES

System Voltage (KV)	BIL (KV)	Arrester MCOV (KV)	Breaker Interrupting (KA)	Continuous Rating (A)
115	550	74	63	3000
161	750 ⁽¹⁾	98	40	2000
345	1300 ⁽¹⁾	212	40	3000

NOTES

1. Transformers have 1 level reduced insulation:
161kV - 650kV BIL 345k 1050kV BIL



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

4.5.9 [29] Insulation Levels used on the MH TRANSMISSION SYSTEM are:

Nominal Voltage (kVrms)	BIL (kVpeak)
66	350
115	550
138	550-650
230	900 -1050
500	1550-1800

4.5.10 [45] Standard spacing, minimum clearances and required BIL levels are provided in Table 1-3.

Table 1-3: Standard Spacing, Minimum Clearance and Insulation Coordination (BIL)

	Operating kV								
	500	345	230	138	69	26	18/20	11/13	4
Basic Impulse Insulation Level (BIL) kV									
Rigid Bus	1800	1300	900 ⁴	650	350	200	150	110	75
Disconnecting Switches	1800	1300	900 ⁴	650	350	200	150	110	75
Circuit Breakers	1800	1300	900 ⁴	650	350	200 ¹	150	110	75
Transformers	1550 ³	1050	750	550	350	200	150	110	75
Current Transformers	1800	1300	1050	650	350	200	150	110	75
Potential Transformers / CCVT	1800	1300	1050	650	350	200	150	110	75
Capacitor Banks	1800	1300	900	650	350	200	150	110	75
Spacings and Clearances²									
Phase-to-Phase (inches)	300	180	144	96	60	36	30	24	16
Phase-to-Phase Spacing for Side Break Circuit Switchers (feet)	25	NA	12	NA	NA	NA	NA	NA	NA
Minimum Clearance ² for Rigid Parts (inches)									
Phase-to-Phase	222	120	89	62	31	18	15	12	7



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Phase-to-Ground	144	108	71	50	25	13	10	7	5.5
Minimum Clearance ² for Rigid Parts (feet)									
to grade inside Substation	30	18	15	13	12	10	10	10	10
to Roadway inside Substation	30	30	27	23	23	22	22	20	20
to railways	41	41	35	31	30	30	30	28	28
to fence (*Per NESC)	*	*	*	*	*	*	*	*	*

Note: 1. Specially protected equipment's BIL may be reduced to 150 kV.

2. Clearance is the distance between conducting parts.

3. Arrester ratings are for metal oxide valve (**MOV**) types only. Stations with extensive underground cable or shunt capacitor banks shall be evaluated individually.

4. Use 1050 kV BIL tie bus insulators at old stations.

- 4.5.11 [49] Substation insulators, power transformer windings and bushings, potential transformer bushings, current transformer bushings, and power PTs shall meet the minimum BIL levels shown in the tables below. When placed in areas of heavy contamination (coastal, agricultural, and industrial), extra- creep insulators, special coatings to extra-creep porcelain insulators, or polymer insulators shall be used.

Nominal System L-L Voltage (kV)	BIL (kV Crest)	BIL (kV Crest) Heavy Contaminated Environment
115 - 138	550	650 (Extra Creep)
161	650	750 (Extra Creep)
230	750	900 (Extra Creep)
345	1050	1300 (Extra Creep)
500	1550	1800 (Standard Creep)
765	2050	2050 (Standard Creep)

Power Transformers, Potential Transformers and Current Transformers

Nominal System L-L Voltage (kV)	Power Transformer Winding BIL (kV Crest)	Power PTs (kV Crest)	PT and CT BIL (kV Crest)	Circuit Breaker BIL (kV Crest)
115	450	550	550	550
138	550	650	650	650
161	650	650	650	650
230	750	900	900	900
345	1050	1300	1300	1300
500	1425	N/A	1550 / 1800	1800
765	2050	N/A	2050	2050

- 4.5.12 [52]The Interconnection must ensure that all equipment is adequately protected from excessive system over-voltages. This includes selection of equipment Basic Impulse Insulation Level (BIL) and protective devices (e.g. surge arresters) to achieve proper insulation coordination and Surge Protections. The addition of new transmission facilities in general should be modeled, and Transient Network Analysis (TNA) or Electromagnetic Transients Program (EMTP) studies may be required. If so these studies should be completed before other major engineering work on the project commences.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

4.5.13 [52]The following table indicates voltage and BIL levels found on most of the Xcel Energy transmission system:

Voltage and BIL Levels Currently in Use in Typical Xcel Energy Substations:

NOMINAL SYSTEM VOLTAGE	MAXIMUM SYSTEM VOLTAGE	BASIC INSULATION LEVELS (kV BIL, <2 km/>2 km)*
34.5	36.2	200 / 200
46	48.3	250 / 250
69	72.5	350 / 350
88	92.4	450 / n/a
115	121	550 / 650
138	145	650 / 750
161	169	750 / n/a
230	242	900 / 1050
345	362	1050 / 1300
500	550	1800 / n/a

* Expressed in kV crest value of withstand voltage of a 1.2 x 50 microsecond full impulse wave. Values provided are for the non-arrester protected devices such as breaker bushings.

4.5.14 [34]Newfoundland BILs:

System Voltages kV (Ø-Ø) and BIL in parenthesis
15 (110)
25 (150)
69 (350)
138 (650)

4.5.15 [51]Outdoor Equipment Bushing BIL levels:

Nominal System Voltage kV	Apparatus Insulator BIL (Impulse Withstand) kV
7.5	95
14.4	110
23	150
34.5	200
46	250
69	350
115	550
138	650
161	750
230	900
230	1050
345	1050
345	1300

4.5.16 [30]Lines, buses, and other equipment shall be insulated for the respective voltage level, as shown in the Table below:

Nominal kV	Insulation BIL kV
161	750
115	550
23Y	150
12.47Y	110

4.5.17 [30]Insulation for power transformers shall be as listed in Table below:

Line Terminals:			Neutral Terminals:	
Nominal kV	Insulation BIL kV	Bushing BIL kV	Insulation BIL kV	Bushing BIL kV
161	650	750	450	550
115	550	550	350	350
23Y	150	150	150	150
12.47Y	110	150	110	150

4.5.18 [7]The transmission line lightning insulation level and line terminal station equipment insulation levels for BC Hydro voltage classes are listed in Table 3 and Table 4 below.

Table 3: BC Hydro Unshielded Transmission Line Lightning Insulation Levels

(Note: Lines are unshielded except for short lengths from station.)

Voltage Class (line to line kV)	Lightning Critical Flashover (CFO) (crest kV)	Shielding @ Station Minimum Number of Spans	Shielded Section Line Tower Footing R max (Low Frequency)
69	525	0	
138	860	0	
230	1265	2 (~0.5 km)	10 ohms
287	1345	2 (~0.5 km)	10 ohms
360	1665	2 (~0.5 km)	15 ohms
500	1985	2 (~0.5 km)	20 ohms

Table 4: BC Hydro Line Terminal/Station/TX Equipment Ratings (BIL and SIL)

(Note: Lines are unshielded except for short lengths from station.)

Voltage Class (line to line kV)	Terminal/Station/TX Equipment		Line/Station Surge Arrestors		Capacitance CCVT (nf minimum)
	BIL (kV)	SIL (kV)	V-rating	IEC-Class	
69	350/350/350	~290/290/290	72/60	2	10
138	650/550/550	~540/450/450	144/120	3	10



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

230	950/950/850	850/850/750	228/192	3	10
287	1050/1050/950	950/950/850	240/228	4	10
360	1300/1300/1175	1050/1050/950	300/288	4	10
500	1550/1550/1550	1175/1175/1175	396/396	5	10

4.5.19 [46]Table 2: Standard insulation and short-circuit levels for Hydro-Québec transmission system equipment

Nominal System Voltage kVrms	Equipment rated Voltage kVrms	Ground Insulation Level		Standard Short Circuit Levels kArms
		BIL kV peak	60Hz kVrms	
69	72.5	350	140	31.5
120	145	550	230	40
161	170	650-750	275-325	31.5 & 50
230	245	850-950	360-395	31.5 & 50
315	330	1050-1175	460	31.5 & 50

Table Notes:

1. Levels have not been standardized for 44-, 49.2- and 345-kV systems and must be confirmed on a case-by case basis.
2. Other requirements also apply to circuit-opening devices like circuit breakers and disconnects, whose
Terminal-to-terminal insulation must be higher than the ground insulation level.
3. The X/R ratio used for these voltage levels is 30.
4. The lower value applies to transformers and shunt reactors protected by surge arresters at their terminals; the higher value applies broadly to all other equipment.

4.5.20 [15]Interconnection facilities to be constructed in areas with salt spray contamination or other types of contamination shall be properly designed to meet or exceed the performance of facilities in a non-contaminated area. Typically this involves more insulation, higher leakage distances and/or non-standard insulating components and materials.

4.5.21 [22]The required station post insulator types are listed in Table 3 below. Substations in areas with significant airborne pollution may require a higher insulation level. Higher strength insulators are available and shall be used as needed to meet bus momentary short

circuit withstand values.

Table 3 - FirstEnergy Standard Insulators

Table 3 FirstEnergy Standard Insulators Basic Impulse Insulation Levels, Insulator Technical Reference Numbers & Cantilever Strengths					
Reference Class kV	Standard BIL Level kV	Standard Strength		High Strength	
		Technical Reference No.	Cantilever Strength	Technical Reference No.	Cantilever Strength
23	150	208	2000	227	4000
34.5	200	210	2000	231	4000
46	250	214	2000	267	4000
69	350	216	1500	278	3000
115 & 138	550	286	1700	287	2600
230	900	304	950	308	1450
345	1300	324	1000	367	1450
500	1800	391	1450	-	1750

4.5.22 [1] Bus Supports – All bus supports shall be rated as follows:

115kV – 550kV BIL

138kV – 650kV BIL

230kV – 900kV BIL



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

4.5.23 [51] Altitude correction factors:

Altitude Meters (feet)	Correction Factors to Be Applied to BIL
1000 (3300)	1.00
1200 (4000)	0.98
1500 (5000)	0.95
1800 (6000)	0.92
2100 (7000)	0.89
2400 (8000)	0.86
2700 (9000)	0.83
3000 (10,000)	0.80
3600 (12,000)	0.75
4200 (14,000)	0.70
4800 (16,000)	0.65
5400 (18,000)	0.61
6000 (20,000)	0.56

4.6 Electrical Clearances

- 4.6.1 [3] AEP recommends new substation construction be designed to the bus heights and phase spacing presented in the table below. An exception to these recommendations is an addition to an existing substation where existing steel and bus heights may have to be matched. Matching existing steel is not mandatory, however.

System Voltage	BIL (kV)	Phase to Phase	High Bus	Low Bus
345 kV	1300	15'-0"(4.57)	36'-2"	23'-2"
345 kV	1050	15'-0"(4.57)	35'-0"	22'-0"
230 kV	900	14'-0"(4.27)	26'-0"	18'-0"
161 kV	650	12'-0"(3.66)	22'-0"	15'-0"
138 kV	550	10'-0"(3.05)	22'-0"	15'-0"
138 kV	650	10'-0"(3.05)	22'-0"	15'-0"
69 kV	350	7'-0"(2.13)	18'-0"	14'-0"

Recommended Bus Heights and Phase Spacing

- 4.6.2 [16] All insulation shall be capable of operating at power system continuous voltages, and withstanding the transient over-voltages allowed by the overvoltage protection. IEEE 1313.1 "Standard for Insulation Coordination Definitions Practices and Rules", and IEEE 1313.2 "Guide for the Application of Insulation Coordination" should be followed when selecting surge arrester ratings and station and equipment insulation levels.
- 4.6.3 [26] All structures and equipment in the substation shall be properly designed to meet clearances per standards outlined above. The minimum substation Basic Insulation

Levels (BIL) required are shown below per the National Electrical Safety Code C2-2012, Table 110-1 & Figure 110-1:

Table 110-1

Nominal voltage between phases	Typical BIL	Dimension "R"	
		m	ft
151-7200	95	3.0	10.0
13 800	110	3.1	10.1
23 000	150	3.1	10.3
34 500	200	3.2	10.6
46 000	250	3.3	10.9
69 000	350	3.5	11.6
115 000	550	4.0	13.0
138 000	650	4.2	13.7
161 000	750	4.4	14.3
230 000	825	4.5	14.9
230 000	900	4.7	15.4
345 000	1050	5.0	16.4
345 000	1175	5.3	17.3
345 000	1300	5.5	18.3
500 000	1550	6.0	19.8
500 000	1800	6.6	21.5
765 000	2050	7.1	23.4

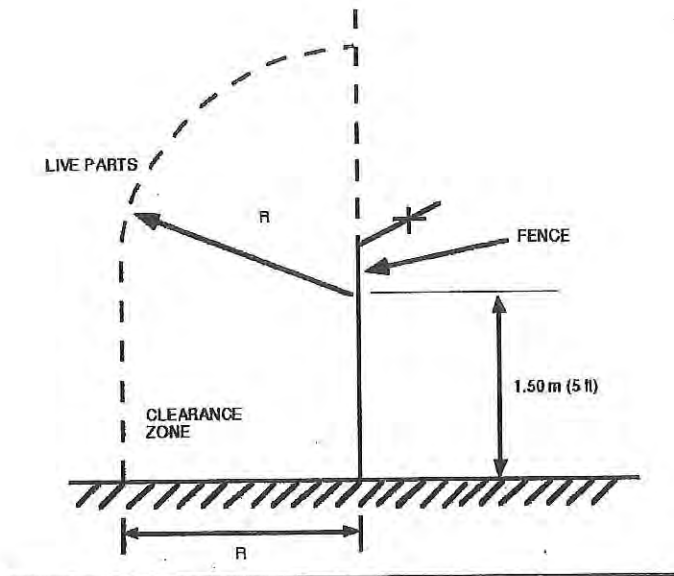


Figure 110-1

- 4.6.4 [37] Utility will meet the applicable requirements of the applicable IEEE Standards with respect to insulation, insulation coordination, and electrical clearances for its facilities including, but not necessarily limited to, IEEE Standards 1313.1, 1313.2, and 1427
- 4.6.5 [49] All design and working clearances shall meet the requirements of the NESC. Additional vertical clearance to conductors and bus shall be provided in areas where foot and vehicular traffic may be present. Phase spacing shall meet *IEEE C37.32* and NESC requirements.
- 4.6.6 [49] Sufficient space to maintain OSHA minimum approach distances, either with or without tools, shall be provided. When live-line maintenance is anticipated, designs shall be suitable to support the type of work that will be performed (e.g., insulator assembly replacement) and the methods employed (i.e., hot stick, bucket truck work, etc.). This requirement is not intended to force working clearances on structures not intended to be worked from.

4.7 Surge Protection and Lightning Shielding

- 4.7.1 [2] Entity transmission facilities shall be shielded from direct lightning strikes in accordance

with the latest version of IEEE Standard 998 "Guide for Direct Lightning Stroke Shielding of Substations".

- 4.7.2 [2] Substation non self-restoring insulation, if applicable, should be protected against incoming surges as per latest version of IEEE C62.22.
- 4.7.3 [3] The lightning arrester ratings recommended by AEP are shown in the table below. Arrester applications for 230 kV and above need to be evaluated on case-by-case basis because of the special duty placed on the arresters due to switching surge capabilities.

Standard Arrester Ratings (3)

<u>System kV</u>	<u>Duty-Cycle Voltage (kV)</u>	<u>Maximum Continuous Operating Voltage (MCOV) (kV)</u>
69	6	48
115	9	70
138	1	84
161	1	98
230	*	**
345	*	**
765	*	**

Arrester selection shall conform to IEEE STD C62.22.

- 4.7.4 [7] In general, stations with equipment operated at 15 kV and above, as well as all transformers and reactors, shall be protected against lightning and switching surges. Typically, this includes station shielding against direct lightning strikes, surge arresters on all transformers, reactors, and surge protection with arresters on the incoming lines.
- 4.7.5 [7] All BC Hydro stations are fully shielded while line shielding over short distances from the station are applied on lines operated at 230 kV and above. Furthermore, since BC Hydro line insulation levels are typically higher than line entrance equipment, surge arresters are applied at the line terminals to limit incoming lightning and/or switching over-voltage surges.
- 4.7.6 [8] Voltage stresses, such as lightning or switching surges, and temporary overvoltages may affect equipment duty. Remedies depend on the equipment capability and the type and magnitude of the stress. In general, stations with equipment operated at 15 kV and above, as well as all transformers and reactors, shall be protected against lightning and switching surges. Typically this includes station shielding against direct lightning strokes, surge arresters on all transformers, reactors, and surge protection with rod gaps (or arresters) on the incoming lines.
- 4.7.7 [10] Lightning Arresters shall be installed on the high and low side of all transformers. If



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

there are no transformers at the station, then each line terminal shall have arresters installed. The arresters shall be station class metal oxide varistor (MOV) type with a maximum continuous phase to ground (MCOV) rating of:

- 24kV to 25kV for 34.5kV systems
- 96kV to 100kV for 138kV systems
- 150kV to 154kV for 230kV systems

These ratings may be adjusted based on the Temporary Overvoltage Capability (TOC) of the proposed arrester to be used.

- 4.7.8 [10]Overhead shield wires and lightning masts installed on the take-off towers shall be provided for protection from direct lightning strikes. Freestanding lightning mast shall also be supplied, if required, to protect the substation. The shield system shall be tied into the substation ground grid. The lightning protection design shall be per IEEE 998 Guide.
- 4.7.9 [12]The surge protectors shall be coordinated with the substation's BIL levels and shall have a protective margin of 20% minimum. They shall be installed as close as possible to the equipment being protected.
- 4.7.10 [13]Shielding, and surge protective device application must meet requirements as determined by the latest IEEE C62 and IEEE 998 standards.
- 4.7.11 [16]All facilities connected to the transmission system shall be shielded from direct lightning strokes. IEEE Standard 998 "IEEE Guide for Direct Lightning Stroke Shielding of Substations" should be used as a guide in designing lightning shielding. Lightning shielding may be accomplished through masts, overhead ground wires, or other tall conducting structures. Overhead ground wires (static wires) crossing over busses and other circuits should be avoided.
- 4.7.12 [16]Detailed studies including lightning, traveling wave analysis, switching surge analysis, temporary overvoltage (TOV) analysis, harmonic resonance, etc., need to be conducted to balance the number and location of surge arresters with proposed insulation levels.
- 4.7.13 [16]Power transformers will require surge arrester protection on all terminals. Additionally, line entrance arresters are required. Any frequently open position will be a positive reflection point for fast front transients and deserve special attention.
- 4.7.14 [16]Generally, non self-restoring insulation is protected by a dedicated set of surge arresters at its terminals. In addition to power transformers this will include: underground cable, gas insulated switchgear (GIS), and metal clad or metal enclosed switchgear. Exceptions



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

- may include instrument transformers (column CTs, PTs, CVTs), outdoor circuit breakers, and capacitor banks.
- 4.7.15 [16] Compact line designs may require use of line type arresters. In any case, compact line designs require special insulation coordination studies to achieve desired transient overvoltage performance.
- 4.7.16 [26] Surge arresters must be placed at the transformer terminals and additional arresters must be applied to protect other equipment in the station.
- 4.7.17 [29] Lightning (Surge) Protection against direct lightning strokes shall be provided for protecting all outdoor equipment including transformers. Lightning protection shall be designed for a zero rate of failure (that is, all voltage stresses are at least three standard deviations less than the critical flashover voltage) taking into account the regional lightning stroke density (estimated from either the Canadian Lightning Detection Network (CLDN) data or the local keraunic map if CLDN data is not available) and tower footing resistances as applicable.
- 4.7.18 [30] The high voltage terminal of the surge arrester is to be connected to the terminal of the protected equipment by the most direct path possible. The ground terminal of the surge arrester is to be connected to the grounded portion of the protected equipment by the most direct path. The grounded portion of the protected equipment is to be connected directly to the grounding electrode.
- 4.7.19 [30] Substations and transmission lines should be shielded from direct lightning strokes. Surge arresters shall be applied at major components and systems.
- 4.7.20 [32] In general, stations with equipment operated at 15 kV and above, as well as all transformers and reactors, shall be protected against lightning and switching surges. Typically, this includes station shielding against direct lightning strokes, surge arresters on all wound devices, and arresters on the incoming lines.
- 4.7.21 [32] In general, all Montana-Dakota incoming lines shall be protected with surge arresters located on the line side of the disconnect switch for substation entrance protection.
- 4.7.22 [35] The substation structure shall be equipped with suitable lightning masts providing the necessary cone of protection. The "rolling sphere" method is acceptable for shielding against direct lightning strokes using a 250 ft. radius sphere. Other lightning protection measures may include shield wires, arrays, arresters, higher BIL levels, etc. However, overhead ground wires are not to be used over station equipment. For more information on direct stroke lightning protection, see NFPA 780.
- 4.7.23 [37] Transmission voltage facilities should meet the applicable IEEE Standards for direct lightning stroke shielding and surge arrestor protection including but not necessarily limited



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

to IEEE Standards 998 and C62.22.

- 4.7.24 [38] Install surge arresters for protection of transformers and other vulnerable equipment.
- 4.7.25 [40] Arresters shall be mounted in such a manner as to protect any part of facilities from surge voltages. In general, all incoming lines shall be protected with surge arresters located on the line side of the disconnect switch.
- 4.7.26 [40] The reference and resource documents for lightning strike and surge protection:
- IEEE Standard 998–1996, *IEEE Guide for Direct Lightning Stroke Shielding of Substations*
 - IEEE Standard 1313.2–1999, *IEEE Guide for the Application of Insulation Coordination*
 - IEEE Standard 1410–1997, *IEEE Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines*
 - Hileman, Andrew R., *Insulation Coordination for Power Systems*, Copyright 1999, Marcel Dekker, Inc.
- 4.7.27 [43] All Facilities connected to the PJM system shall be shielded from direct lightning strokes. IEEE standard 998 “IEEE Guide for Direct Lightning Stroke Shielding of Substations” should be used as guide in designing lightning shielding.
- 4.7.28 [43] All surge arresters shall be station class and shall meet or exceed the latest applicable ANSI, IEEE, NEMA, NESC and OSHA Standards. In case of conflict, these standards shall govern in the order stated.
- 4.7.29 [43] Surge Arresters shall be designed with adequate electrical and mechanical characteristics for the specific electrical system on which it is installed and for the application for which it is intended. These include but shall not be limited to: Maximum Continuous Operating Voltage (MCOV), Rated Duty Cycle Voltage, Energy Discharge Capability, Temporary Overvoltage Capability, and site environmental conditions.
- 4.7.30 [43] Energy discharge capability must be sufficient to survive line or capacitor bank discharge from at least one maximum energy restrike of any switching device in the substation.
- 4.7.31 [43] Studies for each arrester application shall be performed and special consideration shall be given to all Temporary Overvoltage Duties.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

- 4.7.32 [43] Surge arresters shall be designed for an in service operating life, comparable to other electrical apparatus in the system to which it is applied.
- 4.7.33 [43] All surge arresters shall be designed to operate satisfactorily in the ambients required by their installed location. Some locations in PJM have required -40°C capability. When surge arresters are mounted on Transformers, their high temperature ambient may easily reach 50°C.
- 4.7.34 [43] Local environmental conditions should be considered when selecting creep requirements for Surge arresters.
- 4.7.35 [45] For arresters mounted on transformer the incoming transformer lead should connect to the arrester BEFORE connecting to the transformer bushing.
- 4.7.36 [45] All line or cable entrance positions to a station shall have arrester protection installed on the line or cable side of the line or cable disconnect. Line entrance arresters located on cable circuits shall consider maximum voltages and energies that can result during cable operation and system restoration events.

All power transformers, autotransformers, reactors, shunt capacitor banks, and regulators or phase angle regulators shall have arrester protection for each winding and/or phase. 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.

Table 1-1: Protective Equipment – Surge

System Voltage	500 kV	345 kV	230 kV	138 kV
Lightning (Surge) Arrestors				
Nameplate rating ¹ in kV (duty cycle)	420	312	180	120
Equipment Protection				
Gaps in Inches (existing installations only)				
Bushings (where installed)	NA	NA	NA	NA
Line Terminals	None	None	42	None
CT's and PT's	None	50	40	26
Note: 1. Surge Arrester ratings are for Metal Oxide Varistor (MOV) types only. Stations with extensive underground cable or shunt capacitor banks shall be evaluated individually.				



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

- 4.7.37 [46] Surge arresters must be appropriately rated for the overvoltage constraints on the transmission system and on the facilities to which they are connected. If the customer substation has high voltage surge arresters, they must be of the zinc oxide type with no spark gap and must not be located on the supply side of the connection switch so that they can be isolated from the transmission system.
- 4.7.38 [49] All bus and equipment shall be protected from direct lightning strikes using the Rolling Sphere Method. IEEE Std. 998, Guide for Direct Lightning Stroke Shielding of Substations. Surge protection (with the appropriate energy rating determined through system studies) shall be applied on all line terminals and power transformers
- 4.7.39 [51] Because of the desire for high reliability and the high cost of equipment replacement, surge arresters are installed in various positions in transmission substations. Since power transformers are particularly sensitive to over-voltages, they normally have arresters on each phase of both the primary and secondary. Also install arresters on each ungrounded phase of the tertiary winding when it is brought out to provide service. The highest degree of equipment protection occurs with the surge arresters located as close as technically allowable to the equipment to be protected. Power transformers can usually be furnished with arrester mounting brackets adjacent to the transformer bushings.
- 4.7.40 [51] Surge arresters or other surge protective equipment are located at the line entrances and exits. In these instances, it is best to locate the arresters or other protective equipment on the line side of the substation equipment to be protected to limit the lightning and switching surges to acceptable levels as they enter the substation. Locating the arresters on the line side of the circuit breakers will also protect the gap in the breakers when in the open position.

4.8 System Grounding and Neutral Shifts

- 4.8.1 [8] Utilize appropriate transformer connections on the high-voltage side to make the system 'effectively grounded'. Effectively grounded is defined as a system $X_0/X_1 \leq 3.0$ and $R_0/X_1 \leq 1.0$.
- 4.8.2 [13] When various switching devices are opened on an energized circuit, its ground reference may be lost if all sources are not effectively grounded. This situation may cause over voltages that can affect personnel safety and damage equipment. This is especially true when one phase becomes short-circuited to ground. Therefore, the interconnected transmission power system is to be effectively grounded from all sources. Interconnection generators should provide for effective system grounding of the high-side transmission

equipment by means of a grounded high-voltage generation step-up transformer.

4.8.3 [15]The interconnected transmission power system is to be effectively grounded from all sources.

4.8.4 [28]A bus is considered to be "effectively grounded" when the following relationships are true:

- $X_0/X_1 \leq 3$ (ground)
- $R_0/X_1 \leq 1$ (lighting arresters)

If one or both of these relationships are not true, the effective grounding should be checked more precisely by referring to the curves found in the "*Westinghouse Transmission and Distribution Reference Book*". The proper relationship (curve) to use should be based on the actual R_1/X_1 ratio. Any set of ratios lying below the appropriate curve marked 80% will provide effective grounding for 80% lightning arresters standardly used on the Lubbock Power and Light.

4.8.5 [38]Neutral Shifts: When generation or a source of 'back-feed' is connected to the low-voltage side of a delta-grounded wye customer service transformer, remote end breaker operations initiated by the detection of faults on the high-voltage side can cause over voltages that can affect personnel safety and damage equipment. This type of overvoltage is commonly described as a neutral shift and can increase the voltage on the unfaulted phases to as high as 1.73 per unit. At this voltage, the equipment insulation withstand-duration can be very short. Several alternative remedies are possible:

- Provide an effectively grounded system on the high-voltage side of the transformer that is independent of other transmission system connections.
- Size the high-voltage-side equipment to withstand the amplitude and duration of the neutral shift.
- Rapidly separate the back-feed source from the step-up transformer by tripping a breaker using either remote relay detection with pilot scheme (transfer trip) or local relay detection of an overvoltage condition.

Effectively grounded is defined as an $X_0/X_1 \leq 3$ and $R_0/X_1 \leq 1$. Methods available to obtain an effective ground on the high-voltage side of the transformer include:

- A transformer with the transmission system side connected in a grounded-wye configuration and low voltage (Connection Point) side in closed delta.
- A three-winding transformer with a closed-delta tertiary winding. Both the transmission and distribution side windings are connected in grounded wye.
- Installation of a grounding transformer on the transmission system side.

Any of these methods result in an effectively grounded system with little risk of damage to surge arresters and other connected equipment.

- 4.8.6 [46] If the neutral point on the transmission system is effectively grounded under normal conditions and the customer facilities include motors that can temporarily maintain a voltage on the system and cause undue constraints (after grid circuit breakers open and the normal power supply is lost), then the grounding connection on the customer substation must be effectively grounded as seen from the high-voltage side. The Transmission Provider will analyze such constraints during the planning study.

To meet this requirement, the neutral of customer substation power transformer primary windings must be grounded or a grounding transformer must be inserted on the high-voltage side. Furthermore, the impedance of such transformers and winding connections must be such that the customer facilities themselves meet the criteria for effective grounding:

$$0 \leq X_0/X_1 \leq 3 \quad \text{and} \quad 0 \leq R_0/X_1 < 1$$

where:

X_1 = positive-sequence reactance of the customer facilities seen from the HV side

X_0 = zero-sequence reactance of the customer facilities seen from the high-voltage side

R_0 = zero-sequence resistance of the customer facilities seen from the HV side

If the motors are connected to the transmission system through existing customer facilities, the grounding connection criteria above still apply. The following means may then be used to meet those requirements:

- Adding grounding transformer(s) on the high-voltage side of the customer substation
- Modifying the connection type of existing transformer windings in the customer substation (i.e., YNd- or YNynd-connected windings)
- Taking into account the effect on the grounding connection of other transformers



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

connected to the same transmission line

- Adding a customer facility remote tripping system if grid characteristics so permit without overly degrading service to other customers

Depending on the characteristics of the transmission system near the connection point, it may also be necessary to add a reactor on the high-voltage side between the neutral of each transformer and ground to limit the contribution of customer facilities to zero-sequence current for transmission system faults. If such a neutral reactor is required, the Transmission Provider will determine its value at the time of the facilities study based on the criteria above.

4.9 Substation Grounding and Safety Issues

4.9.1 [2] Minimum grounding and safety requirements must meet National Electric Safety Code and Local Codes/Regulations for grounding safety.

4.9.2 [2] Design requirements for system grounding that should be addressed as appropriate for the connection include:

- *Grounding Study and Field Tests*
- Interconnection of grounding systems
- Transmission Line shield wire grounding
- Cathodic protection

4.9.3 [3] Personnel safety is the primary objective of an adequate grounding system. The ground grid must be designed to limit surface potential gradients to safe values in accordance with ANSI/IEEE 80.

4.9.4 [3] A substation grounding system shall be designed to fulfill the following requirements:

- Proper grounding of equipment, structures, and installation of an adequate earth ground grid for safety to personnel. Copper-clad steel conductors are strongly encouraged as grounds to reduce the risk of outages associated with copper theft.
- Grounding of system neutrals to stabilize circuit potentials with respect to earth ground, and to provide circuit relaying for clearing ground faults.
- Proper equipment grounding for lightning, surge protection, and low voltage faults.
- Contact the TFO to obtain ground fault values and clearing times.

4.9.5 [6] Each substation must have a ground grid that is solidly connected to all metallic structures and other non-energized metallic equipment. This grid shall limit the ground potential gradients to such voltage and current levels that will not endanger the safety of people or damage equipment in, or immediately adjacent to, the station under both



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

normal and fault conditions. The ground grid size and type are in part based on local soil conditions and available electrical fault current magnitudes. In areas where ground grid voltage rises beyond acceptable and safe limits (for example due to high soil resistivity or limited substation space), grounding rods and grounding wells may be required to reduce the ground grid resistance to acceptable levels. If a new ground grid is close to another substation, the two ground grids may be isolated or connected. If the ground grids are isolated, then no metallic ground connections are allowed between the two substation ground grids. Cable shields, cable sheaths, station service ground sheaths and overhead transmission shield wires can all inadvertently connect ground grids. All-dielectric type fiber optic cables are highly preferable for providing telecommunications and control between two substations while maintaining isolated ground grids. If the ground grids are to be interconnected, the interconnecting cables must have sufficient capacity to handle fault currents and control ground grid voltage rises. TFO must approve any connection to a TFO substation ground grid.

4.9.6 [6][8] Grounding must be in accordance with IEEE Standard 80.

4.9.7 [21] A safe grounding design must accomplish two basic functions:

- Ensure that a person in the vicinity of grounded structures and facilities is not exposed to critical levels of step or touch potential, and
- Provide a path for electric currents into the earth under normal and fault conditions without exceeding any operating and equipment limits or adversely affecting the continuity of service.

4.9.8 [21] Safety is of utmost importance. Strict adherence to established switching, Lock Out/Tag Out procedures, and grounding procedures is required at all times for the safety of personnel. Any work carried out within a facility shall be performed in accordance with all applicable laws, rules, and regulations and in compliance with Occupational Safety and Health Administration (OSHA), NESC, and good utility practice. Automatic and manual disconnect devices are to be provided as a means of removing all sources of current to any particular element of the power system. Only trained operators are to perform switching functions within a facility under the direction of the responsible dispatcher or designated person as outlined in the NESC.

4.9.9 [22] If the substation structure is to be wood-pole type construction, the transmission line overhead ground wire, all switch bases, fuse bases, insulator bases and other non-current carrying metal parts shall be grounded.

4.9.10 [23] Each interconnection substation must have a ground grid that solidly grounds all metallic structures and other non-energized metallic equipment. This grid and grounding system shall

be designed to meet the requirements of the latest Canadian Electrical Code and in accordance with IEEE Std. 80 & 81. The transmission line overhead ground wire (OHGW) shall be connected to the substation ground grid. If the interconnection substation is close to another substation, the two grids may be isolated or connected. If the ground grids are to be isolated, there shall be no metallic ground connections between the two substation ground grids. There must also be sufficient physical separation to limit soil conduction. If the ground grids are to be interconnected, the interconnecting cables must have sufficient capacity to handle the fault currents, duration, and duty. FortisBC must approve any connection to a FortisBC substation ground grid. Any exceptions to a continuous ground wire shall be supported by a system study. All ground wires and bond wires must be adequately sized to handle anticipated maximum fault currents and duty without damage. Transmission interconnections may substantially increase fault current levels at nearby substations and transmission lines. Modifications to the ground grids of existing substations and OHGWs of existing lines may be necessary. The Interconnection Study will determine if modifications are required and the scope and cost of the modifications.

4.9.11 [26]The grounding conductor size is specified by the following table:

Structure/Equipment Ground Conductor (Copper) table:

kA	Grid Conductor	Tail Conductor
80kA	500MCM CU	750 MCM CU
63kA	4/0 CU	500 MCM CU
40kA	4/0 CU	500 MCM CU

Structure/Equipment Ground Conductor (Copper Clad) table:

kA (kV)	Tail Conductor
80 kA (345-kV)	19 No. 5 AWG
63 kA (138/345-kV)	19 No. 7 AWG
40 kA (138-kV)	19 No. 7 AWG

- 4.9.12 [26] Transmission lines connecting to a TFO facility are required to have proper overhead shields and adequate structure grounding for at least one mile out of the substation.
- 4.9.13 [27] The grounding design shall meet the requirements of IEEE 80 and the requirements of NESC. The grounding system shall use 4/0 copper wire, copper clad ground rods and exothermic welds. The fence shall be grounded and a ground grid conductor shall run around the perimeter, three feet beyond the fence.
- 4.9.14 [28] Generation integration may substantially increase fault current levels at nearby substations. Increased fault currents may exceed existing equipment ratings, interrupting ratings and/or through fault ratings. Modifications to the ground grids of existing substations may also be necessary to keep grid voltage rises within safe levels. The ground grid shall be designed to a minimum of ANSI/IEEE Standard 80-2000, *IEEE Guide for Safety in AC Substation Grounding*.
- 4.9.15 [29] Transmission connection facilities shall comply with safety requirements in the Canadian Electrical Code and all applicable safety standards mandatory within the Province of Manitoba.
- 4.9.16 [30] The measured soil resistivity values for the substation site, calculated and measured resistance of the substation to remote earth, available fault current and maximum substation ground grid current, calculated ground potential rise to remote earth, and maximum allowable and calculated step and touch potentials shall be noted on the grounding plan drawing(s). The ground grid shall extend a minimum of 5 feet outside the fenced area.
- 4.9.17 [30] Grounded systems shall adhere to IEEE 80 and NESC which include requirements for:
- Safety criteria: Calculated step and touch potentials shall be less than the maximum allowable voltages calculated in accordance with IEEE 80.
 - Design output: Maximum and allowable touch and step potentials, ground potential rise, soil model, maximum fault and grid current, and calculated grid resistance.
 - Connections: Only exothermic welds below grade and bolted connections above grade.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

- 4.9.18 [32]The interconnection customer shall submit the grounding system study and design for Montana-Dakota review and approval. At a minimum, the Interconnection Customers must follow IEEE 80 and IEEE 142 Standards
- 4.9.19 [32]Each generation site and/or Interconnection substation must have a ground grid that solidly grounds all metallic structures and other non-energized metallic equipment. This grid shall limit the ground potential gradients to such voltage and current levels that will not endanger the safety of people or damage equipment which are in, or immediately adjacent to, the station under normal and fault conditions. The size, type and ground grid requirements are in part based on local soil conditions and available electrical fault current magnitudes. In areas where ground grid voltage rises are not within acceptable and safe limits (due for example to high soil resistivity or limited substation space), grounding rods and wells can be used to reduce the ground grid resistance to acceptable levels.
- 4.9.20 [32]If the generation site is close to another substation, the two ground grids may be isolated or connected. If the ground grids are to be isolated, there may be no metallic ground connections between the two substation ground grids. Cable shields, cable sheaths, station service ground sheaths, and overhead transmission shield wires can all inadvertently connect ground grids. Fiber-optic cables are an excellent choice for telecommunications and control between two substations to maintain isolated ground grids. If the ground grids are to be interconnected, the interconnecting cables must have sufficient capacity to handle fault currents and control ground grid voltage rises. Montana-Dakota must approve any connection to a Montana-Dakota substation ground grid.
- 4.9.21 [32]The interconnection of lines and/or generation may substantially increase fault current levels at nearby substations. Modifications to the ground grids of existing substations may be necessary to keep grid voltage rises within safe levels.
- 4.9.22 [35]The substation ground grid design should conform to the requirements of IEEE Std. 80.
- The ground grid shall not be closer than 25 feet from any buried fuel lines. However, some instances may require greater distances. Consult the Company whenever buried fuel lines are in proximity to the station.
- The Customer shall install a ground grid of #4/0 bare stranded copper conductor connected to an earthing means such as driven ground rods or ground wells.
- Below grade connections shall be made with compression type connectors or by exothermic process connections.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

For outdoor installations the ground grid shall form one or more closed loops, 18 inches below grade, surrounding the Customer's service equipment structure. One loop must be installed 2'-6" outside of the fenced area and swing gate path(s).

A ground resistance test should be conducted in accordance with IEEE Std. 81.

All metallic structures, equipment supports, equipment tanks, switchgear, building frames, arresters, overhead shield wires, metallic conduits, cable sheaths, metallic cable trays, metallic fences, switch bases, metallic junction boxes, instrument transformer frames/bases, transformer neutrals, and insulator supports shall be solidly connected to the ground grid using #4/0 copper conductor minimum.

4.9.23 [38]Fiber-optic cables are an excellent choice for telecommunications and control between two substations to maintain isolated ground grids. If the ground grids are to be interconnected, the interconnecting cables must have sufficient capacity to handle fault currents and control ground grid voltage rises.

4.9.24 [45]Allswitchingstationandsubstationgroundinggridsshallbedesignedandconstructedto meet the requirements of IEEE 80, the IEEE Guide for Safety in AC Substation Grounding to establish safe step and touch potentials for a 155 lb. (70 kg) person wearing normal street clothing. A grounding grid study, which demonstrates the requirements of IEEE 80, is required, and the resistance to remote earth, of the completed ground grid, shall be tested.

Allswitchingandsubstationgroundinggridsshallbeconstructedwith4/0AWG,orlarger,BTN copper, and shall be installed a minimum of 18 in. below grade. All pigtail connections to equipment and structures shall be made with 350 kcmil BTN copper, and all equipment and structures shall be connected by at least two connections to the ground grid.

All below grade connections shall be either exothermically welded or utilize a "Swage" type ground connection system. All equipment and structure grounding connectors shall meet the requirements of IEEE 837, IEEE Standard for Qualifying Permanent Connections for use in Substation Grounding. All metallic fences, platforms, and railings within a station shall be grounded by cable connections and not rely on mechanical contact with supporting structures, all discontinuous pieces shall have two connections to the ground grid.

4.9.25 [45]Ground systems in high crime area shall make use of special materials and techniques to deter copper theft.

4.9.26 [48]If the substation ground grids are tied together, all cables may be landed without any protection. If the substation ground grids are not tied together, all cables shall have protection at both ends. The design of cable protection, if any, on circuits used for protective



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

relaying purposes shall be such that the operation of the protective relaying is not hampered when the cable protection operates or fails.

4.9.27 [46] All ground grids shall be designed in accordance with good engineering practice and judgment. Presently the recognized standard for grounding is IEEE 80 "IEEE Guide for Safety in AC Substation Grounding." All ground grid designs should meet or exceed the requirements listed in this standard. If local governmental requirements are more stringent they shall prevail. Appropriate tests shall be performed, including soil resistivity tests, to demonstrate that ground grid design meets the standard.

4.9.28 [48] Grounding studies shall be performed with industry recognized software to determine if ground grids should be separate or tied together. This study will determine the maximum safe fault current for the ground grid design. It is suggested that the grid be designed for the maximum fault currents expected over the life of the facility. If for any reason the worst-case fault current exceeds the design maximum fault current value due to changes in the connection facilities or changes on the power system, new grounding studies shall be conducted.

4.10 Substation Illumination

4.10.1 [3] Service Lighting (2.0FC minimum) shall be provided at all equipment locations and wired to a dedicated 240VAC circuit(s). With Service Lighting, personnel shall be able to observe and effectively control the operation and maintenance of various substation equipment and processes.

4.10.2 [3] Security lighting (0.5FC minimum) shall be provided at all equipment locations and wired to a dedicated 120VAC or 240VAC circuit(s). With Security Lighting, personnel shall be able to observe equipment locations from outside the station fence, and such lighting shall serve as a deterrent to keep people from trespassing and/or tampering with equipment.

4.10.3 [32] Substation lighting shall meet the requirements of the NESC

4.10.4 [35] Appropriate minimum lighting levels for various circumstances of indoor, outdoor, and roadway areas are given in the latest editions of NFPA 70 and ANSI C2.

4.10.5 [35] Emergency lighting shall be provided in attended areas in accordance with local codes and regulations.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

4.11 AC Station Service Supply

- 4.11.1 [3] The standard station service voltage preferred is 120/240VAC.
- 4.11.2 [3] Primary and backup station service shall be provided from two unique busses/sources.
- 4.11.3 [3] Receptacles are needed in the substation yard adjacent to equipment for various AC needs.
- 4.11.4 [32] Appropriate provisions for station service and alternate station service shall be established for the interconnection. Generally, a distribution transformer or station service voltage transformer (SSVT) within the substation will be the preferred methods of primary station service. The interconnection must provide metering for station service and alternate station service.
- 4.11.5 [43] Two independent sources with automatic transfer (emergency generators may be required where black start capability is required)
- 4.11.6 [45] In addition to specific equipment or task lighting, the overall yard area shall be illuminated as required in the National Electric Safety Code. Over all lighting shall meet local municipality requirements. Switched upwardly directed lighting shall be provided for all disconnects, ground switches, circuit switchers or any other device where visible verification of operation or position is needed.
- 4.11.7 [45] All interconnection facilities shall be equipped with two independent separate sources of AC auxiliary power (auxiliary power transformer derived, main transformer tertiary derived, distribution source, diesel / natural gas back-up generator, etc.)
- 4.11.8 [49] Two sources of AC substation service, preferred and backup shall be provided. This shall be accomplished by using the tertiary winding of an autotransformer, power PTs connected to the bus, distribution lines or a generator. Distribution lines shall not be used as a primary source unless no other feasible alternative exists. Generators shall not be used as a primary source.
- 4.11.9 [41] Two independent main station service supplies are required for the switchyard. An emergency diesel engine generator shall be provided in the event of loss of primary and emergency station service supplies to the switchyard. The engine generator will start automatically and will be sized to completely supply the station service requirements of the switchyard for 72 hours.
- 4.11.10 [43] All devices connected to the AC station service system must be capable of operating continuously and properly without malfunction or overheating in the voltage range specified by the designer of the system.

4.11.11[43]AC station service system components must be installed in accordance with manufacturer's instructions and applicable industry standards.

4.11.12[43]All AC station service systems shall be adequately monitored and alarmed all voltage levels to assure that improper operation and abnormal conditions are reported for immediate corrective action.

4.11.13[43]AC station service systems should be physically arranged to facilitate safe and effective inspection and maintenance.

4.12 DC Station Service Supply

4.12.1 [3]DC station service for a substation is needed to supply critical station loads. These station loads include circuit switchers, breakers, motor operated switches, switchgear, RTUs, relays, DC/AC inverters and communications facilities. The DC system voltage is obtained from a station battery and the associated charging system. The standard battery voltages are 48 VDC and 125 VDC. Each substation must have a properly sized battery and charger to carry the DC station loads during an AC power failure.

4.12.2 [3]The DC station service system shall be no smaller than that determined by IEEE 485 calculations.

4.12.3 [7]Batteries shall be suitable for station applications, having a long life when on float charge with no load cycling. In general, this requires the use of lead calcium batteries.

4.12.4 [7]Shall ensure that the continuous DC supply voltage rating of any relay or its associated power supply is not exceeded due to sustained over-voltages on the DC supply bus. Common causes of high, sustained over-voltages are:

- Battery chargers at their equalize setting,
- Battery chargers connected to the DC supply bus without the station batteries, and
- Battery chargers set in the constant current charging mode.

If there is any possibility that the DC rating of a relay will be exceeded, a passive voltage regulator of suitable rating shall be applied to each relay to limit the DC voltage to within that relay's DC rating.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

4.12.5 [7]Dual station batteries may be required for power protection and control equipment for connecting to the Main Transmission System.

4.12.6 [7]The DC supply shall:

- Supply power circuit breaker control circuits from dedicated and independently protected DC circuits,
- Supply those physically separated protection systems that are intended to back each other up from dedicated and independently protected DC circuits, Provide one under-voltage relay, with time delay, to provide an alarm for battery charger failure or loss of AC supply, and
- Provide one under-voltage relay with adjustable setting capability in a scheme⁴ that:
 - Operates at least 5 VDC above the minimum acceptable voltage to operate the circuit breaker and associated protection and control circuitry,
 - Operates to shut down the generator and open the HV circuit breaker to disconnect the PGF from the Transmission System, and
 - Has delayed trip initiation, not to exceed 1 minute, to override temporary voltage dips.

4.12.7 [30]Batteries shall be sized, installed, and maintained in accordance with the latest version of IEEE Std 485, ANSI/IEEE Std 450, and ANSI/IEEE Std 484. Batteries shall be maintained in the fully charged state by being continuously connected to a suitably sized charger that derives its energy from a station service supply source. The charger shall be sized to charge a fully discharged battery in 12 hours, in addition to carrying the substation's continuous DC load. The charger shall have a "battery eliminator" option, which allows for serving the DC load even if the battery is removed.

4.12.8 [44]125V batteries shall be provided to supply control system load. Batteries shall be sized to carry all control system load for a minimum of 24 hours and have ability to operate all circuit breakers and motor operated switches simultaneously, at the end of the 24 hour period. Two (2) independent battery chargers shall be provided. The battery shall be 60 Cell flooded lead acid type. Battery should be arranged in a 2 tier arrangement with a mid-point circuit breaker having an auxiliary contact. In some cases 2- 125V batteries will be required one for primary protection and one for Back – up protection. In such cases 2



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

independently supplied chargers are required for each battery.

In any case, 2 dc panel boards are required one for primary protection and one for back up protection. The dc panels shall be of the fused switch type, negative leg with slug.

- 4.12.9 [44] Provisions must be provided to connect an emergency "portable" battery
- 4.12.10 [45] Batteries for operating 12 hours without external electric power (500 kV Stations shall be equipped with primary and backup batteries). All DC Power Systems shall be equipped with two 100% Capacity Chargers fed from separate AC sources.
- 4.12.11 [29] Station battery for stations with a system restoration plan must be able to with stand a 12 hour outage to the battery chargers and must:
- be able to serve all normal dc loads,
 - survive the largest credible station event at the beginning of the 12 hour period,
 - survive one open-close-open operation on each station device during the 12-hour period with some margin.
- Stations without a restoration plan may have a 16 hour battery capability.
- 4.12.12 [41] The 125V dc system will consist of two batteries and two chargers. The chargers and associated battery set will be capable of providing emergency operation and continuous load for the station. The battery will be sized using IEEE Std 485- Recommended Practice for Sizing Large Storage Batteries for Substation, and the following criteria.

1. Nominal battery voltage	130V dc
2. Number of cells	58
3. Emergency operating time	8 hours
4. Minimum cell voltage	1.81 V
5. Lowest expected electrolyte temperature	65 degree F
6. Specific gravity at rated capacity	1.215
7. Plate type	Lead calcium
8. Recharge time at design load	12 hours

- 4.12.13 [42] Battery sizing calculation based on IEEE Std 485-1997 (IEEE recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations) and minimum 8 hours discharge rate using manufacturer software (to ensure proper discharge curve is used) using aging factor of 1.25 and design margin of 1.1 to be clearly shown on the calculation.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Charger sizing calculation based on battery size with recharge time of 12 hours assuming charger will support the continuous load and recharging of the battery at the same time.

- 4.12.14 [42] Because of serious reliability, safety and reduced life concerns with sealed (also called Valve Regulated Lead Acid – VRLA) batteries industry-wide, PG&E has stopped the use of sealed batteries in substation or any switchgear installations or interconnection using these batteries. Flooded lead acid (calcium, antimony) are the only batteries acceptable in these installations.
- 4.12.15 [43] Separate batteries for primary and back up protection are desired. 8 hour capacity required for all control batteries, and they should be fed with 2 independently supplied chargers
- 4.12.16 [43] DC station service system components should be installed in accordance with manufacturer's instructions and applicable industry standards.
- 4.12.17 [43] All devices connected to the dc station service system should be capable of operating continuously and properly without malfunction or overheating in the voltage range specified by the designer of the system.
- 4.12.18 [43] The output cables from the battery to the first breaker or protective device should be kept as short as possible; should be separately routed to reduce the possibility of a short circuit between the positive and negative cables; should be installed in non-metallic conduit to avoid grounding; and should be sized in consideration of the available dc short-circuit current from the battery.
- 4.12.19 [43] DC station service systems must be adequately monitored and alarmed to assure that improper operation and abnormal conditions are reported for immediate corrective action.
- 4.12.20 [49] For new substations greater than 200 kV, redundant battery systems shall be installed.

At all voltage levels, battery system(s) of sufficient capacity to support station requirements for a minimum duration of 8 hours without AC power shall be installed. DC systems shall be designed in accordance with NERC standards and SPP Criteria.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

4.13 Structures/Structural Design Loads

- 4.13.1 [1]Dead-End Structures: Line dead-end structures shall be designed to withstand the following tensions: 7000 lbs per phase conductor. 7000 lbs per static conductor.
- 4.13.2 [3]The line dead-end structure shall be designed with the specific quantity, size and type of phase conductors and overhead ground wire(s) as determined by TFO. The approximate take-off or dead-end tension for each phase conductor and each overhead ground wire must be in accordance with Rule 250 of the National Electrical Safety Code (NESC). The exact take-off tensions will be determined after the facility plans are finalized.
- 4.13.3 [3]Dead-end structures must be designed to the conductor, wind, and ice loading conditions and strength requirements described in Part 25 of the NESC. A minimum of three loading conditions shall be satisfied:
1. NESC Heavy Loading, Grade B Construction
 2. Extreme Wind, using the basic wind speed of 90 mph or 135 mph as appropriate for the geographical area in which the facility will be located
 3. Combined Wind and Ice, as defined in Part 25 of the NESC
- 4.13.4 [3]Structures shall be designed to resist all applied loads including, but not limited to, conductor tension, wind, ice, and short circuit forces. In addition to strength requirements, structures shall be designed such that the load-induced deflections do not hinder the functionality of the structure and the equipment it supports. All design parameters shall follow the rules set forth by the NESC; ASCE 7, "Minimum Design Loads for Buildings and Other Structures"; ASCE Manuals and Reports on Engineering Practice No. 113, "Substation Structure Design Guide"; and other accepted industry standards.
- 4.13.5 [15]Rigid bus structures shall be designed to meet the latest revision to IEEE 605. Current carrying conductors and tubing shall be braced and supported for the expected worst case, short circuit currents, ice loading and wind loading.
- 4.13.6 [23]Transmission and substation structures for facilities connected to the FortisBC transmission system shall be designed in compliance with the latest version of Canadian Standards Association standard for Overhead System CAN/CSA C22.3 No.1 which forms a part of the Canadian Electrical Code Part III.
- 4.13.7 [41]The bus, insulator, switch, and equipment supports shall be designed to withstand the loads resulting from the following loading cases:



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

- Loading Case 1 – NESC Heavy

Structure will be loaded with all equipment loads and the weight of the structure. A wind pressure of 4 psi will be applied to the structure and equipment mounted thereon, with the wind load being applied in the most severe direction. Loads for radial ice one-half inch in thickness will simultaneously be applied to the structure, all rigid bus and conductor.

Under this condition, structure stresses will remain below yield stresses specified in the appropriate ASTM steel specification. Overload factors of 2.5 for transverse wind, 1.65 for wire tension, and 1.5 for vertical loads will be applied. The deflections will be limited as specified in NEMA SG- 6-36.05. No overload factor will be applied for deflection.

- Loading Case 2 – Extreme Ice

Structure will be loaded with all equipment loads and the weight of the structure. A wind pressure of 4 psi will be applied to the structure and equipment mounted thereon, with the wind load being applied in the most severe direction. Loads for radial ice 1 inch in thickness will simultaneously be applied to the structure, all rigid bus and conductor.

Under this condition, structure stresses will remain below yield stresses specified in the appropriate ASTM steel specifications. Overload factors of 1.10 will be applied for all loads. The deflections will be limited as specified in NEMA SG-6-36.05. No overload factor will be applied for deflection.

- Loading Case 3 – Extreme Wind

Structure will be loaded with all equipment loads and the weight of the structure. A wind of 80 mph (with appropriate gust and shape factors) will be applied to the structure and equipment mounted thereon, with the wind load being applied in the most severe direction. Under this condition, structure stresses will remain below yield stresses specified in the appropriate ASTM steel specifications. Overload factors of 1.25 will be applied for all loads. The deflections will be limited as specified in NEMA SG-6-36.05. No overload factor will be applied for deflection.

- Loading Case 4 - Short Circuit and High Wind

A horizontal loading of 100 percent of the cantilever strength of the insulator stack will be applied at the bus elevation to simulate the short circuit force, unless less severe short circuit loading forces are calculated for the particular bus geometry and substation fault current.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Wind loads will be applied according to Loading Case 3, except, wind load need not be applied to the bus or insulators. Under this loading condition, structure stresses will remain below yield stresses specified in the appropriate ASTM steel specification. Overload factors of 1.00 will be applied for both cantilever strength and wind pressure. The deflections will be limited as specified in NEMA SG-6-36.05.

- 4.13.8 [42]The Load Entity or Transmission Entity shall supply the structure at which PG&E shall dead-end or terminate its transmission conductors. The entity's dead-end structure shall meet the specifications of Table L3-1 below.

Table L3-1

DEAD-END STRUCTURE SPECIFICATIONS

VOLTAGE	MINIMUM PHASE SEPARATION	MINIMUM CLEARANCE (live part to structure)	MINIMUM CLEARANCE phase-to- ground (per GO 95)*	MINIMUM CONDUCTOR SIZE	TENSION PER PHASE IN FT•LB.
60 kV	7 ft.	2 ft. 6 in.	32 ft.	#4/0 al	1520
				715 kcmil al	2700
70 kV	7 ft.	2 ft. 6 in.	32 ft.	#4/0 al	1520
				715 kcmil al	2700
115 kV	10 ft.	3 ft. 9 in.	34 ft.	#4/0 al	1520
				715 kcmil al	2700
230 kV	18 ft.	7 ft. 3 in.	34 ft.	954 kcmil ACSR	2700-6800
				1113 kcmil AACC	2700-6800

* The actual minimum height at which the conductor lands on the structure shall be such that the conductor height at mid span meets these requirements.

- 4.13.9 [49]Structures, insulators, hardware, bus, and foundations shall be designed to withstand the following combinations of gravity, wind, ice, conductor tension, fault loads, and seismic loads (where applicable). The magnitude of all weather-related loads, except for NESC or other legislated loads shall be determined using the 100 year mean return period and the basic wind speed and ice with concurrent wind maps defined in the ASCE Manual of Practice (MOP) 113. The load combinations and overload factors defined in ASCE MOP 113 or a similar documented procedure shall be used.

- 4.13.10[49]Structures and foundations shall be designed to the requirements of the applicable



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

publications:

- ⌘ *ASCE Standard No. 10, Design of Latticed Steel Transmission Structures*
- ⌘ *ASCE Standard No. 48, Design of Steel Transmission Pole Structures*
- ⌘ *ASCE Standard No. 113, Substation Structure Design Guide*
- ⌘ *AISC 360 Specification for Structural Steel Buildings*
- ⌘ *ACI 318 Building Code Requirements for Structural Concrete and Commentary*

Deflection of structures shall be limited such that equipment function or operation is not impaired, and that proper clearances are maintained. The load combinations, overload factors, and deflection limits defined in ASCE MOP 113 or a similar documented procedure shall be used.

4.13.11[49] A site-specific geotechnical study shall be the basis of the final foundation design parameters.

4.14 Equipment Ratings - General

- 4.14.1 [2]Applicable industry standards (ANSI/IEEE) shall be used to determine ratings of the equipment. TFO general design parameters and practices shall be identified and adhered to. Any special equipment rating requirements due to atmospheric, geological, seismic, or environmental conditions should also be addressed.
- 4.14.2 [7]The station and transmission equipment facilities, including but not limited to all current transformers, potential transformers, secondary cabling, DC system/battery charger, switchboard wiring and protective relays, shall be designed for the ultimate fault duty.
- 4.14.3 [10]Equipment ratings shall be suitable for the ambient temperature range of -40° C to 50°C. Equipment ratings shall be sized for load and system expansion for the 20 year time frame. Equipment ratings shall comply with the latest ANSI, IEEE, NEMA, and NERC requirements and shall be in accordance with the TFO methodology for determining facility ratings.
- 4.14.4 [11]Substation equipment shall have interrupting and momentary ratings adequate for the short circuit conditions provided. Fault interrupting devices shall have the open-close duty cycle ratings necessary to accommodate their required open-close sequences.
- 4.14.5 [11]All gas insulated interrupting devices within the substation shall be equipped with a low gas pressure alarming/tripping/lockout scheme (as appropriate for the particular device) in order to minimize the possibility of a transmission fault resulting from a loss of insulating



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

gas.

4.14.6 [12] In order to provide a common set of guidelines for operation during contingency conditions, emergency ratings (time and current) are established for various equipment and conductors. The durations of these emergency ratings are based on an assumed life expectancy of the installation of 40 years. Emergency ratings are divided in two categories:

- Long Term Emergency Ratings (LTE)
- Short Term Emergency Ratings (STE)

Long Term Emergency Rating is defined as a 4-hour rating by the New York ISO on the Tie Line Ratings. For other components the LTE rating is defined as a 3-hour rating.

Short Term Emergency Rating is defined as a 15-minute rating by the New York ISO on Tie Line Ratings and 20 minutes for other components of the system. The STE conditions should not exceed an aggregate of 12½ hours over the life of the equipment. The LTE conditions should not exceed 300 hours.

The equipment should, therefore, be selected to withstand the above contingency conditions.

4.14.7 [33] Equipment Thermal Ratings

Thermal ratings of each load carrying element in the system are determined such that maximum use can be made of the equipment without damage or undue loss of equipment life. The thermal ratings of each transmission circuit reflect the most limiting series elements within the circuit. The existing rating procedures are based on guidance provided by the NEPOOL System Design Task Force (SDTF) in Planning Policy 7 (PP 7 Procedures for Determining and Implementing Transmission Facility Ratings in New England), the NYPP Task Force Report on Tie Line Ratings (1995), and industry standards. Similar rating procedures have been developed for rating National Grid facilities in New England and New York. The applicable National Grid procedure will be applied to all new and modified facilities. The principal variables used to derive the ratings include specific equipment design, season, ambient conditions, maximum allowable equipment operating temperatures as a function of time, and physical parameters of the equipment. Procedures for calculating the thermal ratings are subject to change.

Equipment ratings are summarized in the following table by durations of allowable loadings for three types of facilities. Where applicable, actions that must be taken to relieve equipment loadings within the specified time period also are included.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

Equipment	RATINGS			
	Normal	Long Time Emergency (LTE)	Short Time Emergency	Drastic Action Limit (DAL) ⁴
Overhead Transmission	Continuous	Loading must be reduced below the Normal rating within 4 hours ²	Loading must be reduced below the LTE rating within 15 minutes	requires immediate action to reduce loading below the LTE rating
Underground Cables ¹	Continuous	Loading must be reduced below the 100 hr or 300 hr rating within 4 hours ²	Loading must be reduced below the 100 hr or 300 hr rating within 15 minutes	requires immediate action to reduce loading below the LTE rating
Transmission Transformers	Continuous	Loading must be reduced below the Normal rating within 4 hours ²	Loading must be reduced below the LTE rating within 15 minutes ³	requires immediate action to reduce loading below the LTE rating

¹ Ratings for other durations may be calculated and utilized for specific conditions on a case-by-case basis. Following expiration of the 100 hr or 300 hr period, loading of the cable must be reduced below the Normal rating. Either the 100 hr or the 300 hr rating may be utilized after the transient period, but not both. If the 100 hr rating is utilized, the loading must be reduced below the Normal rating within 100 hr, and the 300 hr rating may not be used.

² The summer LTE rating duration is 12 hours in New England. The winter LTE rating duration in New England, and the summer and winter LTE rating duration in New York is 4 hours. The time duration does not affect the calculated value of the LTE rating. The duration difference reflects how the LTE ratings are applied by the ISO in each Area.

³ The transformer STE rating is based on 30 minute duration to provide additional conservatism, but is applied in operations as a 15 minute rating.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

⁴ The DAL rating is only calculated only in New England based on historical ISO requirements.

- 4.14.8 [13] All current carrying equipment and devices shall be designed to not limit the rating of the transmission line to less than the rating of the transmission circuit without the interconnection. Loads exceeding nameplate or normal design capacities are acceptable only when allowed by Manufacturers' design documentation or standard industry practice. Equipment must meet all applicable ANSI/IEEE standards.
- 4.14.9 [18] For tap and looped connections, the high voltage bus and associated equipment, such as breakers, switches, connectors, and other conductors shall have continuous, long-term emergency, short-term emergency, and momentary asymmetrical current ratings which: (1) do not limit the TFO transmission system network capability and (2) have adequate capability for the initial and future system conditions identified by TFO.
- 4.14.10 [18] All substations connected to the TFO system must be designed to the applicable requirements of NESC, ANSI, and IEEE Standards.
- 4.14.11 [18] All interrupting devices, such as circuit breakers shall have interrupting capability sufficient to satisfactorily interrupt the maximum short-circuit currents that may occur at the location of the interconnection, including margin for circuit-breaker duty and DC offset.
- 4.14.12 [18] For transmission lines interconnecting into TFO facilities, transmission line ratings shall meet the requirements of TFO transmission line design standards, including MVA, operating voltage, ampacity, insulation critical flashover, insulation clearances, shielding, tower grounding, and short circuit withstand requirements. In all cases the National Electric Safety Code (NESC) and OSHA requirements shall be satisfied.
- 4.14.13 [22] The Connecting Party's high voltage bus and associated equipment, such as switches, connectors, and other conductors shall have a minimum continuous current carrying rating and a momentary asymmetrical current rating as listed in Table 2 below.

Table 2 - Equipment Ratings

Table 2 Equipment Ratings							
System	Current Carrying Equipment			Surge Arresters			
Nominal System Voltage (kV)	(1) Continuous Amps	Momentary Asymmetrical Withstand	Switch Rated Maximum Voltage	(3) MCOV	(3) Duty Cycle	Class	P. Relief kA Sym.
500	N/A	N/A	550 kV	318 kV	396 kV	Station	65
345	N/A	61 kA	362 kV	209 kV	258 kV	Station	65



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

230	1200	61 kA	245 kV	140 kV	172 kV	Station	65
138	600	40 kA	145 kV	84 kV	108 kV	Station	65
115	600	40 kA	123 kV	70 kV	90 kV	Station	65
69	600	40 kA	72.5 kV	48 kV	60 kV	(2)	(2)
46	600	40 kA	48.3 kV	31.5 kV	39 kV	(2)	(2)
34.5	600	40 kA	38 kV	24.4 kV	30 kV	(2)	(2)
23	600	40 kA	27 kV	17 kV	21 kV	(2)	(2)

Table 2 Notes: 1. For tap supplied connection only. Looped supplied connection must not limit through line rating.
2. Station or Intermediate Class may be used but pressure relief rating must be greater than maximum future Isc.
3. Minimum sized arresters for effectively grounded systems only.

4.14.14 [26] For Station upgrades equipment (circuit breakers, circuit switches, wave traps, jumpers, connectors, current transformers, relays, relay settings, etc.) connected in series with the conductor shall be upgraded (independent of a conductor upgrade) if either of the following two conditions are met:

a. The continuous rating of the station equipment is less than or equal to 50 percent of the continuous rating of the conductor; or

b. The loading through the station equipment during normal or single-contingency conditions is greater than or equal to 80 percent of the continuous rating of the station equipment.

4.14.15 [27] Equipment ratings shall be suitable for the ambient temperature range of -40° C to 50°C.

4.14.16 [27] Equipment ratings shall be sized for load and system expansion for a 15-20 year time frame.

4.14.17 [30] All current-carrying equipment shall be designed to carry the maximum loads that are predicted and used in load flow analysis. Facility loading exceeding "nameplate" design capabilities is only acceptable when allowed by manufacturer's design documentation or standard industry practices. TFO shall have the express right to review Customer design and specifications to verify that equipment ratings are consistent with TFO criteria. Equipment ratings must meet requirements identified in system studies, latest industry standards (ANSI, NEMA, IEEE), and TFO equipment specifications.

4.14.18 [35] Spacing of oil filled equipment: The Connection Entity should use NFPA 850 as a guide and consult their insurance carrier for separation requirements.

4.14.19 [45] PSE&G requires that the minimum interrupting rating of all equipment be a minimum of 63 KA. At a minimum bus supports/bracing and ground systems shall be designed for 63 KA, and shall consider



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

the current split factor provided by PSE&G.

In certain situations and locations within the PSE&G transmission system, maximum fault currents have been identified as being currently greater than 63 KA Symmetrical or having the high probability of exceeding 63 KA Symmetrical within a short period of time. In these cases as identified by the PSE&G Planning Department, the Interconnection Customer shall be required to install equipment with a rating of 80 KA Symmetrical.

- 4.14.20 [45] All interconnecting station equipment shall have the minimum interrupting and momentary ratings adequate for the currents involved but in no case shall these ratings, or the continuous current rating be less than those in Table 1-4 below.

In certain situations and locations within the PSE&G transmission system, maximum fault currents have been identified as being currently greater than 63 KA Symmetrical or having the high probability of exceeding 63 KA Symmetrical within a short period of time. In these cases as identified by the PSE&G Planning Department, the Interconnection Customer shall be required to install equipment with a rating of 80 KA Symmetrical.

If the Generation/Interconnection Customer facility has the ability of increasing fault duties above 80 KA, extraordinary means may be required to hold the line at 80 KA. These means may include reactors, high impedance transformers or HVDC equipment.

Table 1-4: Minimum Interrupting and Momentary Ratings¹

System Voltage (kV)	Interrupting Duty (kA)	Momentary Duty (kA)	Continuous Current (A)
500	63	101	3,000
230	63	101	3,000
138	63	101	3,000

Note: 1. Table is of minimum values, higher ratings may be required.

All interconnecting substation equipment including circuit breakers, transformers, disconnect switches, bus, strain bus, current transformers, line traps, and equipment connecting leads shall have temperature sensitive ratings calculated per PJM rating methodologies and applied for system operation

4.15 Equipment – Shunt Capacitors

- 4.15.1 [4][14] Capacitor banks on systems 69kV and below are ungrounded wye and use neutral voltage sensing for unbalance detection. Capacitor banks on systems 138kV and above are



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

grounded wye and use voltage differential unbalance detection.

- 4.15.2 [4][14] Capacitor Bank shall be designed such that a single can failure does not cause more than 110% of rated voltage on the other cans.
- 4.15.3 [41] Capacitor bank shall be connected double-wye with neutral ungrounded but solidly tied together, in two equal sub-banks, each sub-bank being one-half of total MVAR rating of the bank.
- 4.15.4 [39] Capacitor banks, and all their components shall be designed, installed, and maintained in accordance with the latest version of:
- IEEE 18 - Standard for Shunt Power Capacitors
 - IEEE 1036 – Guide for Application of Shunt Power Capacitors
 - IEEE C37.99 - Guide for Protection of Shunt Power Capacitor Banks
 - ANSI C2 – National Electrical Safety Code
- 4.15.5 [39] Capacitor banks installed on the transmission system, whether utilized for VAR support or voltage control, shall be connected wye or double-wye, and may be grounded or ungrounded.
- 4.15.6 [39] The capacitor shall be sized so that when energized, the maximum voltage rise on the bus to which the capacitor bank is connected shall be limited to the value for that voltage class.
- 4.15.7 [39] Capacitor bank switching devices shall have either pre-insertion resistors or synchronized closing in order to provide an effective means of reducing transients associated with switching.
- 4.15.8 [40] Voltage fluctuation values applied to shunt reactive devices and switching capacitors are shown in Table 2 below.

Table 2—Shunt Reactive Switching Limits

Shunt reactive devices switched regularly	±3.0%
Shunt reactive devices switched seasonally	±4.5%
Shunt reactive devices switched only during emergencies for voltage support	±6.0%

- 4.15.9 [43] At 500 kV, the capacitor bank shall be arranged in a single wye (or multiple wye if fuseless) with the neutral solidly grounded at a single point. Since the 500 kV system operates well above 525 kV, it is recommended that the capacitor banks be designed with

a nominal voltage rating of at least 550 kV.

- 4.15.10[43] Below 500kV, the capacitor banks shall be arranged in a single or double-wye (or multiple wye if fuseless) with the neutral solidly grounded at a single point. It is recommended that the capacitor banks be designed with a voltage rating factor of at least 1.05.
- 4.15.11[43] Each capacitor bank step shall be switched with a device which has the capability to make and break capacitive current a sufficient number of times so that the switching device will not require maintenance more than once a year. The switching devices capable of this duty utilize vacuum or SF₆. Switching devices shall not be reclosed before any trapped charge on the capacitor bank has decayed to an acceptable level (usually 5 minutes). The current rating of the switching device shall include the effects of overvoltage (1.1 pu), capacitor tolerance (1.15 pu) and harmonic component (1.1 pu). The recommended multiplier is 1.25, rather than the 1.35 which assumes simultaneous application of the maximums of the three factors. Transient current limiting devices may be required.
- 4.15.12[43] Dedicated SF₆ gas insulated circuit breakers are recommended for use in switching 500 kV capacitor banks. In addition to transient current limiting reactors, the circuit breakers shall be equipped with adequately sized pre-insertion resistors or use controlled closing, or a combination. The pre-insertion resistors shall not limit the reclosing capability of the circuit breakers.
- 4.15.13[43] When capacitor banks are installed in substations, the circuit breakers on existing power transformers or transmission lines should be checked to ascertain their respective momentary, close-and-latch, outrush capabilities when closing into a fault and capacitor switching capabilities for a short-circuit on the protected equipment. In addition, the associated disconnecting switch momentary ratings should be checked. Oil circuit breakers are particularly vulnerable to outrush di/dt.
- 4.15.14[43] TNA studies of a typical 230 kV system with 300 mVar connected to the bus have shown that the reclosing of a 230 kV transmission line with a one per unit trapped charge would result in somewhat higher switching surge voltages at the remote end when the remote end power transformer is out of service. With the power transformer connected, no trapped charge would be present on the transmission line and the switching surge voltage would be essentially the same with and without the 300 Mvar of capacitance. Based on these studies, the installation of capacitor banks of the 230 kV system should not cause switching surge problems. One method for minimizing switching surges is to re-energize a transmission line from a terminal which does not have capacitor banks. This also applies to the 500 kV system. It is recommended that a transient switching study be conducted for any new capacitor installation.



Transmission Connection Minimum Technical Requirements

Version: Re-Issued For Review

Revision Date: Mar 22, 2016

4.15.15[43] When capacitor banks are in parallel and are switched back-to-back, transient currents of high magnitude and high frequency will flow between energized banks and the one being energized. This high magnitude transient current is limited by:

- The impedance of the capacitor banks and of the circuit between them.
- The instantaneous voltage difference between the banks just prior to the instant of energization of the subsequent capacitor bank.

The magnitude will be greatly reduced by the use of series reactors or a capacitor switching device utilizing properly sized pre-insertion resistors, or controlled closing. Pre-insertion inductors may also be considered. The thermal capability of the pre-insertion resistors should be checked to ascertain at what time intervals a capacitor bank can be re-energized. The capacitor bank inrush and discharge currents should not exceed the ratings of the switching devices.

4.15.16 [43]Capacitor overvoltage protection from lightning or switching transients with surge arresters should be considered. Existing surge arresters should be checked for adequate thermal capability during capacitor bank discharge. High energy metal oxide arresters should be applied to protect the capacitor bank and any gapped arrester in the same substation.

4.15.17[43] When CTs are used in the detection/protection scheme for the capacitor bank, the voltage class of the current transformer should be suitable for its location in the circuit. High magnitude currents can saturate and/or thermally overload the transformer causing mis-operation of the relays. Suitable ratios and primary and secondary surge protection will tend to reduce the problems associated with high primary currents. Transient inrush currents through a circuit breaker may cause secondary flashover of bushing current transformers (CT) or voltages damaging to protective relays. CT voltage crest should be determined by calculation.

4.15.18[43]When voltage sensing is used in the detection/protection scheme, the voltage devices can be transformers or CCVTs, and should be suitable for the proposed location. Because the capacitor banks can be subjected to lightning/switching surges, the primary and/or secondary of the voltage device should be provided with suitable protection. If intermediate tap point voltages and bus voltages are used for unbalanced protection for single bank design, it is recommended that mid-tap and dedicated bus CCVTs be used.

4.15.19[43]Two industry recognized grounding methods, single point and peninsula, are acceptable. Each method requires that the neutral of each step be brought to a common point and connected to the station ground grid at only one point. This will minimize the severity of the recovery voltage across the switching device and also minimize the severity of the