Substation Subgroup Members: Please update the sections below you volunteered to review using the track changes option or highlight your changes. Once done, email your updated document to Scott Herb (SEHerb@pplweb.com) and Ron Wellman (rjwellman@aep.com).

- INTRODUCTION

- General Design Criteria
  - (include charts from Section 2 of TSS)

- Functional Criteria
  - (from TSS section 3)

- Accessibility and Layout
  - (from TSS section 3)

- Above Grade Physical
  - Design
  - Construction

- Lightning
  - Insulation Coordination
  - Design
  - Construction

- AC Station Service
  - Design
    - Type, quality, quantity
  - Construction

- DC Station Service
  - Design
    - Type, quality, quantity
  - Construction

- Grounding
  - Design

    - Below grade
    - Above grade
    - Construction

- Raceways
    - Design
    - Below grade
    - Above grade
    - Construction

- Control House
    - Design
    - Construction

- Security
    - Fence
    - NERC
    - Signage

- Fire Protection

- Major Equipment
    - Transformers
    - Circuit Breakers
    - Circuit Switchers
    - Manual and Motor Operated Disconnect Switches
    - Shunt Capacitors
    - Instrument Transformers
    - Line Traps
    - Arresters
    - SVCs (future)
    - GIS (future)
    - DC Inverters (future)

- Rating Guides

- Civil
    - Location
    - Grading
    - Drainage

    - Erosion (EDS)
    - Roadways
    - Spill Prevention

- Structural
    - Foundations
    - Structures

- Installation and Commissioning

- Inspection, Testing and Acceptance

INTRODUCTION:

The PJM Designated Entity Design Standards Task Force (DEDSTF) were formalized by PJM to conform in part to FERC Order 1000. They are intended to apply to facilities proposed/requested in accordance with the process defined in the Open Access Transmission Tariff ("OATT"). They are intended to provide common PJM transmission provider criteria concerning design philosophy, design requirements and operating practices for Transmission Facility Owners. These guidelines are intended to be the minimum guidelines to which any entity must design and built to in the PJM territory. Transmission Owners ("TO's") traditionally have additional more specific requirements based on the needs of their systems and to ensure the reliability of the Transmission System, which may be greater than these Technical Requirements referenced throughout this documentation.

The user of these Technical Requirements must review all PJM criteria and documents referenced throughout these sections to ensure proper detail and knowledge of the guidelines is considered. Also noting that these standards must comply with all PJM Transmission, Substation and Protection and Control Standards as indicated. While this document describes details, criteria and philosophy, it is also understood that all other standards shall be followed at a minimum, including, but not limited to IEEE, FERC, NERC, NESC, ect.

GENERAL DESIGN CRITERIA:

These design criteria have been established to assure acceptable reliability of the Bulk transmission system facilities. These set forth the service conditions, and establish insulation levels for lines and substations, and short circuit levels for substations. Specific component requirements are listed in their own sections (in addition to NESC the IEC 61936 provides a solid reference).

Environmental Conditions:

Ambient Temperature	-30(-40)°C to +40°C (-40°C minimum required N and W of Blue Mountain)
Wind loading Substations (no ice) Wind loading Lines (no ice) 138kV or less Wind loading Lines (no ice) greater than 138kV	-per ASCE 7-98, Figure 6-1 depending on location [typically 90 to 110 mph] per NESC Extreme Wind 25psf or NESC Extreme Wind (whichever is greater)
Ice load 500kV, 345kV, 230kV lines (no	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

765 kV Substations Electrical (copy from 500 kV)

Line Terminal and Equipment Continuous	3000A
3 second current (short circuit)	40kA (X/R 25) DC time constant 60ms
Operating Voltage (Transformer must accommodate the voltage range expected at the point of	450kV to 550kV 500kV nominal (typical "normal" voltages range from 515kV to 550kV)
RIV level @ 350kV line to ground	300uV @1MHz
Lightning Impulse Withstand Voltage w/o line entrance	1800kV
Lightning Impulse Withstand Voltage **with** line entrance arresters	1550kV
Switching Impulse withstand level (20)	1050kV
Typical Surge Arrester	318kV MCOV Station Class (396kV duty cycle)
Circuit Breaker line closing switching surge factor	2.2 (i.e. closing resistors required & no restrikes, or line end arresters used to clamp switching
System Grounding	Effectively Grounded Neutral (always)
Lightning trip out Performance (station)	1/100years Keraunic level =40
Fault performance (circuit failure, including momentary) all other causes	1/40 years/breaker position

500kV Substations Electrical

Line Terminal and Equipment Continuous	3000A
3 second current (short circuit)	40kA (X/R = 25) DC time constant 60ms { higher duties required at some locations usually < 63kA}
Operating Voltage (Transformer must accommodate the voltage range expected at the point of	500 kV to 550kV 500kV nominal (typical "normal" voltages range from 515kV to 550kV)

RIV level @ 350kV line to ground	300uV @1MHz
Lightning Impulse Withstand Voltage w/o line entrance arresters	1,800 kV
Lightning Impulse Withstand Voltage **with** line entrance arresters	1,550 kV
Switching Impulse withstand level (20)	1,050 kV
Typical Surge Arrester	318 kV MCOV Station Class (396kV duty cycle)
Circuit Breaker line closing switching surge factor	2.2 (i.e. closing resistors required & no restrikes, or line end arresters used to clamp switching overvoltages.)
System Grounding	Effectively Grounded Neutral (always)
Lightning trip out Performance (station)	1/100years Keraunic level =40
Fault performance (circuit failure, including momentary) all other causes	1/40 years/breaker position

345kV Substations Electrical

Line Terminal and Equipment Continuous	2000A (or as required at the connecting point)
3 second current (short circuit)	40kA (X/R 25) DC time constant 60ms { higher duties required at some locations usually < 63kA}
Operating Voltage (Transformer must accommodate the voltage range expected at the point of application)	325kV to 362kV 345kV nominal (typical "normal" voltages range from 345kV to 362kV)
RIV level @ 230 kV line to ground	300uV @1MHz
Lightning Impulse Withstand Voltage w/o line entrance	1300 kV
Lightning Impulse Withstand Voltage **With** line entrance arresters	1050 kV
Switching Impulse withstand level (20)	750kV
Typical Surge Arrester	209kV MCOV Station Class (258kV duty cycle)
Circuit Breaker line closing switching surge factor	2.2 (i.e. closing resistors required & no restrikes, or line end arresters used to clamp switching overvoltages.)
System Grounding	Effectively Grounded Neutral (always)
Lightning trip out Performance (station)	1/100years Keraunic level =40
Fault performance(circuit failure, including momentary) all other	1/40 years/breaker position

230kV Substation Electrical

Line Terminal & Equipment Continuous	To match connecting point or 2000A
3 second short circuit current	40kA (X/R=20) DC time constant 48ms { higher duties required at some locations usually < 63kA}
Operating Voltage (Transformer must accommodate this range)	220kV to 242kV 230kV nominal
Lightning Impulse Withstand Voltage	900kV BIL

Typical Surge Arrester	144kV MCOV Station Class (180kv Duty Cycle)
Lightning trip out Performance (station)	1/100 years Keraunic level =40
Fault performance (circuit failure, including momentary) all other	1/40 years/breaker position
System Grounding	Effectively Grounded Neutral (always)

138 kV Substation Electrical (new section)

Line Terminal & Equipment Continuous	To match connecting point or 2000A
3 second short circuit current	40 kA (X/R=20) DC time constant 48ms { higher duties required at some locations usually < 63 kA }
Operating Voltage (Transformer must accommodate this range)	131 kV to 145 kV 138kV nominal (*)
Lightning Impulse Withstand Voltage	650 kV BIL
Typical Surge Arrester	98 kV MCOV Station Class (120 kV Duty Cycle)
Lightning trip out Performance (station)	1/100years Keraunic level =40
Fault performance (circuit failure, including momentary) all other causes	1/40 years/breaker position
System Grounding	Effectively Grounded Neutral (always)

115 kV Substation Electrical

Line Terminal & Equipment Continuous	To match connecting point or 2000A
3 second short circuit current	40kA (X/R=20) DC time constant 48ms { higher duties required at some locations usually < 63kA }
Operating Voltage (Transformer must accommodate this range)	109 kV to 121 kV 115 kV nominal
Lightning Impulse Withstand Voltage	900kV BIL
Typical Surge Arrester	144kV MCOV Station Class (180 kv Duty Cycle)
Lightning trip out Performance (station)	1/100years Keraunic level =40
Fault performance (circuit failure, including momentary) all other	1/40 years/breaker position
System Grounding	Effectively Grounded Neutral (always)

69 kV Substation Electrical

Line Terminal & Equipment Continuous	To match connecting point or 2000A
3 second short circuit current	40kA (X/R=20) DC time constant 48ms { higher duties required at some locations usually < 63kA }
Operating Voltage (Transformer must accommodate this range)	66kV to 73 kV 69 kV nominal
Lightning Impulse Withstand Voltage	350 kV BIL
Typical Surge Arrester	57 kV MCOV Station Class (66 -72 kV Duty Cycle,)
Lightning trip out Performance (station)	1/100years Keraunic level =40 (recommended)

Fault performance (circuit failure, including momentary) all other	1/40 years/breaker position (recommended)
System Grounding	Effectively Grounded Neutral (always)

FUNCTIONAL CRITERIA:

When evaluating a proposed electrical interconnection the designated entity should consider physical as well as electrical characteristics. This can be done to a certain degree by evaluating the arrangement using the following criteria:

1. The clearing of failed Transmission Owner facility equipment, should not adversely affect any other TO's facilities. This generally means that there could be one or more intertie breakers. While this breaker need not be located at the POI, it should be the first element in the adjacent stations. No load, circuits, transformers, or other elements shall be tapped off the interconnection facility prior to its isolation.
2. The arrangement of circuits and breaker bays should be such that a stuck breaker operation will not trip two circuits on the same double circuit tower line.
3. Multiple ties should be provided between buses for all conditions, including situations where at least one transmission line or station breaker is out of service for maintenance.
4. Every attempt should be made to lay out stations such that a transmission conductor or a static wire that drops within the switchyard area should not cause another transmission circuit to trip. This means that line crossings within the switchyard fence should be avoided and there should be adequate spacing between bays to minimize the possibility of a falling wire contacting another line's phase conductor. If this cannot be accomplished the configuration should be evaluated to assure no unacceptable conditions could result from the postulated failure.
5. Electrical equipment within the station must be adequately spaced to:
    - Facilitate equipment replacement
    - Facilitate maintenance activities and associated maintenance equipment
    - Minimize the likelihood that catastrophic failure of an item of equipment will adversely impact adjacent equipment.
6. Consideration should be given to the distribution of supply and load connection within the station. The connection of circuits and transformers into the station should be arranged to balance flows throughout the station bus. This can be accomplished by alternating the connection of elements anticipated to inject flow with those anticipated to supply load from the station. The objective is to balance flows in the station to reduce bus loading.

7. In addition to these criteria the following factors must be reviewed and weighed appropriately in performing the assessment of a substation configuration:
    - Operational complexity and flexibility
    - Reliability for the load
    - Reliability for transmission lines
    - Component reliability
    - Generator interface
    - Line Maintenance
    - NERC, MAAC requirements/criteria
    - Expandability/Adaptability
    - Safety
    - Changes in technology
    - Cost (capital and O&M)
    - Availability of spare equipment

<u>Bus Configuration (From the SPP Min. Transmission Design Upgrades Doc. Dated May 2016)</u>

Substations shall be designed using the bus configurations shown in the table below or as specified by SPP. All stations shall be developed to accommodate predicted growth and expansion (e.g., converting ring bus to a breaker and a half as terminals are added) throughout the anticipated planning horizon and as defined by SPP. For the purposes of this table, terminals are considered transmission lines, BES transformers, generator interconnections. Capacitor banks, reactor banks, and non-BES transformer connections are not considered to be a terminal.

Voltage (kV)	Number of Terminals	Substation Arrangement
100 - 200	One or Two	Single Bus
	Three to Six	Ring Bus
	More than Six	Breaker-and-a-half
201 - 765	One to Four	Ring Bus
	More than Four	Breaker-and-a-half

ACCESSABILITY AND LAYOUT:

Adequate space and firm vehicular surface must be provided on at least one side of each item of major electrical equipment to permit O&M vehicles, including bucket trucks and cranes, to access electrical equipment and to maneuver without requiring the de-energization of any adjacent electrical equipment in order to conduct maintenance or to remove and replace equipment. In a breaker bay this access must be provided the full length of the bay and must not be encumbered by overhead electrical equipment or conductors. Appropriate stone or asphalt roadway must be provided.. For indoor GIS equipment a bridge crane may be used in lue of roadways as long as this approach provides a feasible means to conduct maintenance including the removal and replacement of all major equipment.

Electrical equipment must be arranged with adequate clearance for maintenance activities and for associated maintenance equipment, such that only the equipment to be maintained, including its isolating devices, needs to be operated and/or de-energized for the maintenance work to be performed. Depending on the criticality of the facility, Each Transmission lines and Transformer may need to be equipped with a switch to isolate it from the substation such that the station bay or ring bus can be re-energized during maintenance of that Transmission lines or Transformer.

Electrical equipment must be arranged with adequate clearances such that a catastrophic failure of equipment associated with one circuit would be unlikely to adversely affect equipment associated with another circuit.

A corridor, typically 15 – 25 feet in width, must be provided around the inside perimeter of the substation for vehicle movement. The corridor must be adequate for the weight of vehicles transporting the heaviest item of electrical equipment installed in the substation. If the corridor is required to be paved, it must meet this same functional requirement and might typically be constructed with a 6” crushed stone base covered with 4” of asphalt, which is covered with a 2” top layer of cover asphalt.

Twenty-four hours, unobstructed access must be provided for the substation. Typically asphalt paving is required from the driveway entrance to the relay/control house with parking for several vehicles. The entrance gate must be double roadway width with the yard’s safety grounding covering the open gate area.

The switchyard should be appropriately graded to facilitate water runoff and to direct spilled dielectric fluid away from other major electrical equipment and toward planned containment.

ABOVE GRADE PHYSICAL:

Electrical Clearances (From the SPP Min. Transmission Design Upgrades Doc. Dated May 2016)

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.

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.

AC STATION SERVICE:

There must be two AC sources in which a single contingency cannot de-energize both the primary and back-up station services. An automatic throwover switch with an auxiliary contact for SCADA alarm is required to provide notification of loss of primary station service.

Distribution lines shall not be used as a primary source.

Station service transformers shall be protected by surge arresters.

Emergency generators may be required where black start capability is required.

Due to the large auxiliary loads in 765kV and large EHV stations, multiple station service load centers may be required. The relay protective scheme must be selective and remove from service only the faulted station service transformer.

All station service transformers shall have high side overcurrent protection (via a fuse or a bus protection scheme if the transformer is solidly connected to the bus).

DC STATION SERVICE:

Separate batteries for primary and back up protection are required. An 8 hour capacity is required for all control batteries, and they must be fed with 2 independently supplied chargers. Provisions must be made to facilitate the replacement of a failed charger or battery bank. The station batteries are to be sized in accordance with the latest version of IEEE-485 Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications or IEEE-1115 Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications. The battery charger shall be able to supply the station DC power requirement and at the same time to bring the station battery to “fully charged” condition in less than 24 hours following a prolonged discharge period due to an AC power failure.

GROUNDING:

Grounding and Shielding (From the SPP Min. Transmission Design Upgrades Doc. Dated May 2016)

The substation ground grid shall be designed in accordance with the latest version of IEEE Std. 80, Guide for Safety in AC Substation Grounding, using the fault currents defined in the Minimum Design Fault Current Levels section.
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.
Southwest Power Pool, Inc.
Minimum Transmission Design Standards for Competitive Upgrades 12

STRUCTURAL:

Structural Design Loads (From the SPP Min. Transmission Design Upgrades Doc. Dated May 2016)
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.

Line Structures and Shield Wire Poles (From the SPP Min. Transmission Design Upgrades Doc. Dated May 2016)
• NESC Grade B, Heavy Loading
• Other legislated loads
• Extreme wind applied at 90 degrees to the conductor and structure
Southwest Power Pool, Inc.
Minimum Transmission Design Standards for Competitive Upgrades 11
• Extreme wind applied at 45 degrees to the conductor and structure
• Ice with concurrent wind
• Extreme ice loading, based on regional weather studies

Equipment Structures and Shield Poles without Shield Wires (From the SPP Min. Transmission Design Upgrades Doc. Dated May 2016)
• Extreme wind, no ice
• Ice with concurrent wind
• Forces due to line tension, fault currents and thermal loads
In the above loading cases, wind loads shall be applied separately in three directions (two orthogonal directions and at 45 degrees, if applicable).

Structure and Foundation Design (From the SPP Min. Transmission Design Upgrades Doc. Dated May 2016)
Structures and foundations shall be designed to the requirements of the applicable 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.

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

RATING GUIDES:

Rating of Bus Conductors (From the SPP Min. Transmission Design Upgrades Doc. Dated May 2016)

The minimum amperage capability of substation bus conductors shall meet or exceed the values shown below, unless otherwise specified by SPP. If otherwise specified by SPP, the SPP value shall govern. The amperage values shown in the table shall be considered to be associated with emergency operating conditions.

The emergency rating is the amperage that the circuit can carry for the time sufficient for adjustment of transfer schedules, generation dispatch, or line switching in an orderly manner with acceptable loss of life to the circuit involved. Conductors shall be selected such that they will lose no more than 10 percent of their original strength due to anticipated periodic operation above the normal rating.

Voltage (kV)	Emergency Rating (Amps)
100 - 200	~~1,2~~2,000
230	2,000
345	3,000
500	3,000
765	4,000

Normal circuit ratings shall be established by the Respondent such that the conductor can operate continuously without loss of strength. Consideration shall be given to electrical system performance (voltage, stability, losses, impedance, corona, and audible noise), and for the effects of the high electric fields when selecting the size and arrangement of phase conductors and sub-conductors.

For bare, stranded conductors, the conversion from conductor ampacity to conductor temperature shall be based on IEEE Publication No. 738, Standard for Calculating the Current-Temperature Relationship of Bare Overhead Conductors, SPP Criteria 12.2.2, or other similar documented approaches.

For rigid bus conductors, the conversion to conductor operating temperature shall be based on IEEE Std. 605, Guide for Bus Design in Air Insulated Substations, SPP Criteria 12.2.2 as applicable, or other similar documented approaches."