

**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).

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**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, NFPA, 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)
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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

### 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 RIV level @ 350kV line to ground)	450kV to 550kV 500kV nominal (typical "normal" voltages range from 515kV to 550kV)
Lightning Impulse Withstand Voltage w/o line entrance	300uV @ 1MHz
Lightning Impulse Withstand Voltage with line entrance arresters	1800kV
Switching Impulse withstand level (20)	1550kV
Typical Surge Arrester	1050kV
Circuit Breaker line closing switching surge factor	318kV MCOV Station Class (396kV duty cycle)
System Grounding	2.2 (i.e. closing resistors required & no restrikes, or line end arresters used to clamp switching)
Lightning trip out Performance (station)	Effectively Grounded Neutral (always)
<b>Fault performance (circuit failure, including momentary) all other causes</b>	1/100years Keraunic level =40 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 RIV level @ 350kV line to ground)	500 kV to 550kV 500kV nominal (typical "normal" voltages range from 515kV to 550kV)
Lightning Impulse Withstand Voltage w/o line entrance arresters	300uV @ 1MHz
	1,800 kV

Lightning Impulse Withstand Voltage <b>with</b> 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 3 second current (short circuit)	2000A (or as required at the connecting point) 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 <b>With</b> 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 3 second short circuit current	To match connecting point or 2000A 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 3 second short circuit current	To match connecting point or 2000A 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 3 second short circuit current	To match connecting point or 2000A 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 3 second short circuit current	To match connecting point or 2000A 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. There will be no load served, except for station service, from the transformer's tertiary.
8. 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 and equipment
- 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

## **Bus Configuration**

Stations may have the options for future expansion capabilities for future growth and expansion (e.g., converting ring bus to a breaker and a half as terminals are added). If the solution/ design include future expansion capabilities, the expansion should be outlined for potential evaluation.

For the bus configuration, an element is classified as a line or an equipment connection including transformers, capacitor banks, SVC, ect. The failure or maintenance of a transformer, SVC or capacitor bank cannot remove a transmission line from service for anytime increment.

All entities inside the substation must include a fault clearing device to limit the exposure of failures to only the affected line/ equipment. Isolation or maintenance of an entity should not affect the operation of another entity.

The bus design and configuration must meet the PJM criteria in terms of stability, voltage, maintenance and N-1 conditions on the system.

Voltages less than 200kV and below must at a minimum meet the criteria outlined above in the bus configuration. The below criteria for greater than 200kV could also be followed for less than 200kV but is not required.

Voltages greater than 200kV must be designed at a minimum based on the following parameters:

- 3 to 6 elements connected – requires a ring bus connection at a minimum
- 7 elements connected or more – requires a breaker and half design at a minimum

As the above are minimums, each project design can be designed to higher reliability and operating standards based upon the specific project needs.

Three terminal lines are not permitted in the PJM footprint.

## **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 lieu 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.

## **MAJOR EQUIPMENT:**

All major equipment shall be specified and procured in correspondence to the IEEE and ANSI standards that govern all aspects of the equipment. In addition to those standards, the Transmission and Substations Sub Committee of the (TSS) has requirements listed that should be used as a baseline for procurement of the equipment.

#### **ABOVE GRADE PHYSICAL:**

All design and working clearances shall meet the latest requirements of the NESC and IEEE 1427. Additional clearance consideration for safety should be considered in areas where foot and vehicular traffic may be. Phase spacing shall meet IEEE 1427 and NESC requirements at a minimum.

The physical design must be designed to accommodate any through fault condition that may be present. All switching and transient levels must be met in the design.

All connections utilized in stations 200KV and above must use either a welded, compression, or swage type fittings. Bolted connections must be limited to connections made on equipment itself. The system shall be designed per the latest IEEE 605 standard. All tubular bus work shall be designed and installed with the appropriate slide, rigid and expansion connections.

The Physical layout and design must be conducted to ensure proper maintenance and access are accounted for in the design. The design must also allow for sufficient space to maintain OSHA minimum approach requirements, either with or without tools.

#### **INSULATION COORDINATION AND LIGHTNING PROTECTION:**

##### **GENERAL REQUIREMENTS**

Insulation coordination is the coordination of electrical insulation levels with overvoltage protection. It includes subjects of Shielding from lightning, Application of surge arresters, Insulator contamination, Switching surge mitigation, and temporary overvoltage control. The nominal voltage ratings of the effectively grounded transmission systems are defined as part of this standard in section Minimum Basic Insulation Levels (BIL). All insulation shall be capable of operating at these continuous voltages, and withstanding the transient over voltages allowed by the overvoltage protection. IEEE C62.82.1 “Standard for Insulation Coordination– Definitions, Principles 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.

##### **Shielding from Direct Lightning Strokes**

All facilities connected to the PJM system shall be shielded from direct lightning strokes to meet the design criteria in section II of these guides (verify where this will be located at). IEEE Standard 998 “IEEE Guide for Direct Lightning Stroke Shielding of Substations” should be used as guide in designing lightning shielding. Lightning Shielding may be accomplished through, masts, overhead ground wires, or other tall conducting structures. Static wires not connected to or associated with the incoming line terminations should avoid crossing over busses and other circuits.

IEEE C62.22 it recommends to maintain a 20% minimum margin of protection. This allows for insulation and surge arrester aging and contamination and higher incoming surge magnitudes and faster rise times. It is recommend to maintain 20% margin for breakers, switches and voltage transformers and 50% margin on power transformers.

Arrester shall be applied with adequate pressure relief or fault current withstand rating, and adequate energy capability.

### **Insulation Coordination Studies.**

Detailed studies including lightning traveling wave analysis, switching surge analysis, TOV analysis, Harmonic resonance, etc., need to be conducted to balance the number and location of surge arresters with proposed insulation levels. EMTP and similar tools can be used in these studies.

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 deserves special attention.

Generally, non-selfrestoring insulation is protected by a dedicated set of surge arresters at its terminals. In addition to power transformers this will include underground cable and accessories, Gas Insulated Switchgear (GIS), etc.

### **Specification of Surge Arresters**

All surge arresters shall meet or exceed the latest applicable ANSI, IEEE, NEMA, NESC and OSHA Standards.

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 environmental conditions.

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.

Studies for each Arrester application shall be performed.

Surge arresters shall be designed for an in service operating life, comparable to other electrical apparatus in the system to which it is applied.

Surge arresters, at a minimum, shall be designed to operate at ANSI required ambients of -30\_C to +40\_C (-22\_F to +104\_F). 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.

Local environmental conditions should be considered when selecting creep requirements for Surge arresters.

### **Application and Special Considerations**

Surge Arresters generally should be located as close as practical to the equipment they are primarily installed to protect. Both the lead length and the ground return length need to be kept as short and straight as possible.

For example, when possible, surge arresters protecting power transformers should be mounted on the transformer, and the grounded end solidly bonded to the nearest ground that grounds the transformer. Also, incoming transformer lead should be connected to the arrester BEFORE the transformer bushing.

### **AC STATION SERVICE:**

1. There must be two AC sources in which a single contingency cannot de-energize both the primary and back-up station services. An automatic throw-over switch with an auxiliary contact for SCADA alarm is required to provide notification of loss of primary station service.
2. Loads are generally categorized by electrical size in determining the appropriate supply voltage. Typical voltages would be 480Y/277V, 208Y/120V, and 240/120V.
3. Distribution lines shall not be used as a primary source.
4. Station service transformers shall be protected by surge arresters.
5. Emergency generators may be required where black start capability is required.
6. 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.
7. 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).

8. Transfer switches may be installed internal or external to their associated switchboards, however, if they are located externally, they shall be located adjacent to the switchboard to minimize the exposure of the single set of cables supplying the switchboard. For large electrical loads, such as a power transformer with oil pumps, dedicated transfer switches would be located at the power apparatus with primary and alternate power supplies. Electrical separation is required for this application and physical separation via separate cables at a minimum is required for the supplies routed to the switch.
9. 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.
10. AC station service system components must be installed in accordance with manufacturer's instructions and applicable industry standards.
11. All AC primary and backup station service supplies shall be adequately monitored and alarmed, for all voltage levels and sources, to assure that improper operation and abnormal conditions are reported for immediate corrective action.
12. AC station service systems shall be physically arranged to facilitate safe and effective inspection and maintenance.
13. Critical transmission facilities shall be provided with emergency engine-generator sets sized to carry essential loads considering a reasonable diversity factor, when alternate reliable sources are not available. If not, facilities shall be available for prompt connection of emergency generation. Remoteness of the location, adversity of weather conditions, refueling cycles, etc. must be considered in determining required fuel capacity.

#### Specification for AC Station Service

1. As a minimum requirement, AC station service systems and equipment shall be designed for the purpose intended and shall support Clause II (Transmission System Design Criteria) and be specified to meet latest requirements of all applicable industry standards, including but not limited to ANSI, IEEE, NEMA, OSHA and NESC.
2. AC station service equipment is available in varying degrees of quality. Equipment installed in a transmission facility shall be designed to operate reliably during the design life of the facility. This requires quality products and specifications that reflect this need.
3. Main distribution panels located on the load side of the fused safety disconnect switch shall have breakers rather than fuses. All devices shall be designed to coordinate with each other to ensure proper protection.
4. All copper electrical contact parts and conducting mechanical joints shall be silver surfaced. Aluminum electrical contact parts and conducting mechanical joints shall be tin surfaced.
5. AC station service cables may be run in the same tray systems as other AC circuits 480 volts and below and with 125vdc control circuits, however, they are not to be commingled with low voltage digital signal circuits and/or analog signal circuits.

6. AC circuits shall be adequately sized and designed to limit voltage drop to no more than 5% continuous and 10% momentary.

## **STATIONARY BATTERIES AND CHARGERS:**

1. Requirements for the battery design are to be incorporated on FERC based projects. These requirements are not required in projects required to support local distribution reliability and load as they are not governed by FERC. Stations 200kV and above whose configurations are designed to reinforce the flow of power on the transmission system, must follow the requirements outlined below.
2. Separate batteries for primary and back up protection are required. Each of these batteries must be fed by (1) independently supplied charger (each charger must have its own/ separate AC supply) in this application.
3. A single battery for all other requirements is acceptable. In this application, however, the battery must be supplied with two independently supplied chargers at a minimum.
4. The battery system shall 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 for a minimum duty cycle of no less than 8 hours with the most severe possible multiple breaker operation (usually bus differential operation) at the end of the cycle. It must be taken into consideration when sizing the battery the distance to the site in order to perform an emergency replacement. This distance may require a minimum duty cycle of more than 8 hours to be used.
5. Correction factors shall be included in battery sizing calculations to account for temperature conditions, battery aging and potential load increases.
6. Provisions must be made to facilitate the replacement of a failed charger or battery bank without interruptions to the DC system.
7. 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.

### Specification for Battery and Charger

1. As a minimum requirement, battery and charger systems must be designed for the purpose intended and shall be specified to meet the requirements of all latest applicable industry standards, including but not limited to ANSI, IEEE, NEMA, OSHA and NESC.
2. The charger shall be protected by automatic current limiting, and be self-protecting against transients and surge voltages, and be designed to prevent the battery from discharging back into the internal charger load.

### Application and Installation for Battery and Charger

1. When multiple battery and charger systems are provided to supply multiple relay systems (referred to as primary and backup or system one and system two), the batteries and

chargers, including all associated wiring, are to be kept physically and electrically separated to avoid a problem with one system affecting the other system.

2. Batteries shall be installed in facilities that assure that appropriate ambient temperatures are maintained and that the batteries are not exposed to **direct sunlight**.
3. Battery systems shall be installed in accordance with manufacturer's instructions and applicable industry standards, with special attention given to cell handling and cell connections and protection.
4. Before a battery and charger system is placed in service, appropriate acceptance testing shall be conducted and appropriate data, such as cell voltage and specific gravity, shall be recorded for future use.
5. Battery and charger systems shall be adequately monitored and alarmed to assure that improper operation and abnormal conditions are reported for immediate corrective action.
6. Batteries shall be physically arranged to facilitate safe and effective inspection and maintenance. This requires a 3ft. work area in front of the batteries for replacement and maintenance activities.

## DC STATION SERVICE

### Application and Installation of DC Station Service

1. DC station service system components shall be installed in accordance with manufacturer's instructions and applicable industry standards.
2. All devices connected to the dc station service system shall be capable of operating continuously and properly without malfunction or overheating in the voltage range specified by the designer of the system.
3. **The output cables from the battery to the first breaker or protective device in the main DC panel** shall be kept as short as possible; shall be separately routed to reduce the possibility of a short circuit between the positive and negative cables; shall be installed in non-metallic conduit to avoid grounding; and shall be sized in consideration of the available dc short-circuit current from the battery.
4. DC station service systems must be adequately monitored and alarmed to assure that improper operation and abnormal conditions are reported for immediate corrective action.
5. DC station service systems shall be physically arranged to facilitate safe and effective inspection and maintenance.

### Specification for DC Station Service

1. As a minimum requirement, DC station service systems and equipment shall be designed for the purpose intended and be specified to meet the requirements of all applicable industry standards, including but not limited to ANSI, IEEE and NEMA.
2. The typical nominal rating for this application is 125 VDC.



3. The DC system design must take into consideration the voltage drop between the battery and the load terminals. Under no circumstances should the voltage at each load terminal be less than the manufacturer specifications. Age, cell failures, and good engineering judgment must also be considered when designing and shall be considered in the initial voltage level of the batteries.
4. The maximum load terminal voltage shall not exceed the product of (the number of cells in battery) times (the maximum defined cell voltage).

## **GROUNDING:**

The station ground grid shall be designed in accordance with the latest version of IEEE Std. 80, Guide for Safety in AC Substation Grounding. The fault current calculations should include future improvements which would increase the fault current. It is recommended to use a growth factor of 20% if growth is expected and specific information is not available to include in the calculations.

## **RACEWAYS:**

### Design Considerations:

- Design of the raceway and conduit system shall be designed to accommodate all the anticipated station build out.
- All outdoor raceway components shall be designed for the environment which they are installed in.
- “Primary” and “Backup” systems cannot be in the same cable bundles.
- Long cable runs that parallel bus and transmission lines shall be avoided in the design of the trench system.
- All cables rated greater than 1kV shall not be installed in the same trench system as cables less than 1kV.
- All Conduits shall be installed to withstand protection from vehicular and element protection.
- Consideration of water flow must be considered when designing the conduit/ trench system to ensure excess water flow does not back up in the equipment, cabinets or control house.

### Below Grade:

- Typically the outdoor main runs of the raceway/ conduit system utilizes a surface mounted trench system installation. No direct buried cable is permitted.
- Proper drainage shall be included underneath the trench.
- Where vehicles will cross the conduits or trench system, suitable covers and design must be incorporated to protect the cables from the heaviest vehicles and equipment anticipated on crossing the roadway.
- Below grade conduits shall be used to complete the run from the main trench system to the equipment.
- No more than 360 degrees of bends should be installed in a conduit run.

- All steel conduit shall be bonded.

Above Grade:

- All cable trays and junction boxes shall be grounded.
- Fiber shall be routed and protected either in its own separate tray and/ or conduit.

## **CONTROL HOUSE:**

### **GENERAL REQUIREMENTS**

The enclosure shall be suitably designed and constructed to contain all substation control and instrument panels, relay panels, metering panels, AC lighting and power panels, Annunciator, DFR, SCADA equipment, DC station batteries, DC Power Panels, battery chargers, toilet facilities (when required), office furniture, HVAC equipment, and local required telecommunications. Consideration shall be given to either sizing the enclosure to accommodate the needs of the ultimate station development or to allow for the expansion for such accommodation.

Control Enclosure shall not be part of the Substation fence.

All materials and equipment used in the control enclosure shall be noncombustible to the greatest extent practical.

### **SPECIFICATION**

The enclosure shall be designed and constructed in accordance with the latest revisions of all applicable codes including but not limited to:

- ACI – American Concrete Institute
- AISC – American Institute of Steel Construction
- AISI – American Iron and Steel Institute
- ANSI – American National Standards Institute
- ASCE – American Society of Civil Engineers
- ASTM – American Society for Testing and Material
- AWS – American Welding Society
- IBC – International Building Code
- IEEE – Institute of Electrical and Electronics Engineers
- MBMA – Metal Building Manufacturers Association
- NESC – National Electrical Safety Code (IEEE C2)
- NFPA – National Fire Protection Association
- All applicable state and local building codes and requirements.
- Wind and ice loading criteria as found in the structural section of this document

### **STRUCTURAL, ARCHITECTURAL AND MECHANICAL REQUIREMENTS**

The enclosure shall be as specified below:

1. The enclosure is not intended to be used as a shop.
2. The enclosure is not intended to be used as a storage location for spare parts.
3. The enclosure is not intended to be used for equipment assembly.

Enclosure design loads shall include live, snow, wind, and dead loads. In addition, enclosure must be designed to carry the auxiliary static loading from interior cable tray systems and air handling ductwork, and additional electrical equipment such as lighting, battery chargers, power panels etc.

Falling ice: Exterior of control enclosure shall be designed to resist damage by hail and falling ice from adjacent structures or overhangs.

Doors:

1. Typically, two exits with panic bar and door holder mechanism will be required. It is recommended that one exit be a double door and the second exit be a single personnel door. The double door needs to be high enough to accept delivery of control and power panels (usually > 8'-0" door height). A roll up garage door is acceptable in lieu of double doors.
2. Weather stripping shall be included around all edges.
3. Means for locking and securing all doors shall be included, and door shall automatically lock upon closing.

Enclosure ceiling and walls shall be insulated. Vapor barriers shall be provided.

Gutters, downspouts, and splash block diffusers shall be considered.

Consideration shall be given to separate cable entrances for the main and reserve AC station service feeders. Control cable entrances shall be sealed off to prohibit rodents from entering.

## HEATING, COOLING, AND VENTILATION

The enclosure shall be equipped with sufficient heating, cooling, and ventilation equipment to provide acceptable ambient temperatures within the enclosure so as not to impact the operation and life expectancy of the control equipment within.

Automatic temperature control equipment shall be installed. Microprocessor relay and control equipment and the control battery manufacturers should be consulted to establish proper ranges of operation.

Adequate ventilation shall be provided to prevent the accumulation of hydrogen gasses resulting from battery operation. Forced ventilation shall be used when required.

A redundant HVAC system shall be considered for the case of failure or maintenance of the primary HVAC system.

## ILLUMINATION

See Table 111-1 of the National Electrical Safety Code for minimum illumination levels.  
*Ref. <http://engineerboards.com/index.php?/topic/16992-nesc/>*

Emergency lighting shall be provided. Automatic initiation may be required. Illumination levels must meet the minimum requirements specified by the National Electrical Safety Code for egress.

Exterior lighting at doorways shall be provided to effect safe access to the enclosure.

Exit lights shall be provided in accordance with local codes. These lights may be required to be connected to the emergency lighting circuit.

## GROUNDING

Structural enclosure steel, raceways, relay and control panels, AC and DC distribution panels (not the DC control voltage itself) shall be bonded to the station ground grid in accordance with the NEC and NESC.

Each control and relay panel shall be equipped with a ground bus to which instrument transformer secondary circuits or other equipment such as relay case grounds can be grounded.

Cable tray system shall be provided with a continuous run of copper wire for grounding purposes. All cable tray and cable ladder sections shall be adequately bonded.

## APPLICATION & SPECIAL CONSIDERATIONS

### RACEWAYS

Control cables are to be installed in overhead cable tray raceway, or under the floor if a raised computer floor is used, or in under floor cable troughs. Raceways are to be suspended from enclosure ceiling. Cable tray shall be aluminum or galvanized steel construction and be sized adequately for anticipated cable loads. Mechanical protection may be needed on vertical raceway sections to a height of 7'-0" in high traffic areas.

Nonmetallic jacketed cables below 7 feet above the floor level not in ladder tray or otherwise suitably protected shall be enclosed in conduit.

## WORKING SPACE

A minimum of 3 feet working clearance shall be provided in front of all panels/batteries and 3 feet in back of panels where rear connected equipment access is required. See NESC Rule 125 for additional information.

A desk and Filing cabinet should be considered for operational support purposes.

## SAFETY EQUIPMENT

Signage as required by NESC, OSHA, and other applicable organizations shall be provided. Signage is to be in accordance with ANSI Standards Z535.1, Z535.2, Z535.3, Z535.4, and Z535.5, latest revision.

Fire detection and extinguishing equipment shall be installed in accordance with all applicable national and local codes.

Face shields and eyewash stations, if installed, shall meet applicable OSHA requirements.

Provisions for containing acid spillage from the control battery shall be included in design of the facility.

## SECURITY

Security monitoring shall be properly designed and operated per applicable regulatory requirements.

## METERING, SYSTEM PROTECTION, ANNUNCIATOR, DFR, SCADA, AND TELECOMMUNICATIONS

The local telecommunications provider shall be consulted for their requirements for space, access, conduit size and routing, working clearances, auxiliary power, grounding, and other aspects of the installation. Isolation equipment may be required to protect telephone equipment from voltage rises.

Free standing or rack mounted panels are acceptable.

Controls panels and equipment shall be arranged in such a manner to allow for safe and reliable operation and maintenance activities of the substation.

## **SECURITY:**

A barrier with access points must be provided to protect the substation and its equipment. Many various forms and methods have been done to accomplish this. The station must have adequate signs for public safety according to the latest NESC. The physical protection must adhere to the

latest version of IEEE 1402. In addition to the physical security, the station must meet NERC CIP-006 for cyber security and the protection requirements outlined within the document.

## **STRUCTURAL:**

### **Structural Design Loads**

Structures, insulators, hardware, bus, and foundations shall be designed to withstand the following combinations of gravity, wind, ice, conductor tension, construction, maintenance, 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 recurrence interval (MRI). and the basic wind speed and ice with concurrent wind maps defined in the ASCE Manual of Practice (MOP) 113.

### **Line Structures and Shield Wire Poles**

Design of transmission line type structures shall be designed per the requirement of the PJM Line Design Document.

### **Equipment Structures and Shield Poles without Shield Wires**

Substation structures shall have sufficient strength to resist all loads as defined in ASCE MOP 113 and the load combinations defined below. The effects of gravity, wind, ice, wire tension, short circuit, seismic, construction & maintenance and operating loads shall be included as applicable.

The following load combinations apply to the substation equipment, equipment supports, bus supports, and rigid bus. It does not apply to buildings, lightning masts, strain bus structures, or transmission line dead-end and suspension structures. Structure design shall be ultimate strength using the methodology set forth in the ACSE Guide for Design of Substation Structures (ASCE Guide).

### **Loading Combination 01: Wind and Ice**

- 4psf wind, 0.5 inch radial ice
  - Load factors:
    - o 2.50 on wind loads
    - o 1.50 on vertical loads (live and dead)

### **Loading Combination 02: Extreme Wind**

- 90 mph wind (3 second gust), no radial ice
- Pressure determination per ACSE Guide
  - Load factors:

- o 1.40 on wind loads
- o 1.10 on vertical loads (live and dead)

### **Loading Combination 03: Short Circuit**

- No wind or ice
- Short circuit loads
  - Load factor
    - o 1.0 on all loads
  - Short circuit loads shall be calculated using the equations of IEEE 605.

### **Loading Combination 04: Short Circuit with Wind**

- 4psf wind
- Short circuit loads
  - Load factor
    - o 0.75 on all short circuit forces
    - o 1.00 on all other loads
  - Short circuit loads shall be calculated using the equations of IEEE 605.

### **Loading Combination 05: Earthquake**

- Per ASCE Guide
- No wind or ice loading
  - Load factor 1.0
- Seismic Site Soil Class: Per geotechnical report
- USGS Design Information: <https://earthquake.usgs.gov/designmaps/us/application.php?>

### **Loading Combination 06: NESC**

The NESC Heavy, Grade B design parameters are the governing body for any application in a region where the NESC Heavy loading case is greater than those found in the previous 5 cases stated above.

### **Foundations**

Foundation reactions shall be determined from the load cases and load combination defined above. Load Factors shall be a minimum of 1.0.

Structures and foundations shall be designed to the requirements of the applicable publications:

- ACI 318: Building Code Requirements for Structural Concrete and Commentary
- ACI 336.3R-14: Report on Design and Construction of Drilled Piers
- TMS 402/602 Building Code Requirements and Specifications for Masonry Structures
- ACI 543R-12: Guide to Design, Manufacture and Installation of Concrete Piles
- AISC 360: Specification for Structural Steel Buildings
- ASCE/SEI 7-10: Minimum Design Loads for Buildings and other Structures
- ASCE 10-15, Design of Latticed Steel Transmission Structures
- • ASCE/SEI 48-11: Design of Steel Transmission Pole Structures
- • ASCE 113: Substation Structure Design Guide
- ASCE Manual No. 91, Design of Guyed Electrical Transmission Structures
- ASCE Manual No. 74, Guidelines for Electric Transmission Structural Loading
- ASCE Manual No. 104, Recommended Practice for Fiber-Reinforced Polymer Products for Overhead Utility Line Structures
- ASCE Manual No. 123, Pre stressed Concrete Transmission Pole Structures
- ANSI 05-1, Specifications and Dimensions for Wood Poles
- IEEE Std. 691, Guide for Transmission Structure Foundation Design and Testing
- IEEE Std. 751, Trial-Use Design Guide for Wood Transmission Structures

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 and this document shall be used.

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

## **CIVIL**

The substation shall be developed in accordance with all the local requirements. These requirements can consist of public safety, zoning, noise levels, poor drainage, wetlands, and aesthetic requirements. Site grading shall be completed to ensure excess runoff is accounted for in the design and ponding does not occur inside the substation. The grading design shall also consider the minimum of 5' berm required outside the perimeter substation fence. Stormwater management and erosion control shall be designed with reference to the state and local permitting requirements.

Roadways shall be designed for large truck and trailer deliveries. Consideration should be given to ease of ingress and egress. Minimum turning radii for equipment shall be considered in the design. Special consideration shall be considered for vehicular access related to transformer hauling equipment, which may include the use of enlarged turning radiuses. Consideration should also be given to access transmission structures located outside the fence within proximity to the substation yard.

## **RATING GUIDES:**



The rating of equipment, cable tube, and conductor must adhere to the PJM rating philosophy.