TABLE OF CONTENTS

D5010 ELECTRICAL SERVICE & DISTRIBUTION

RECORD OF REVISIONS

Rev	Date	Description	POC	OIC
0	11/18/02	General revision and addition of endnotes. Replaced Subsections 211, 214, 215, 232, 234, 241, 242, 243, 245, 246, and 247 in whole or in part.	David W. Powell, *FWO-SEM*	Kurt Beckman, *FWO-SEM*
1	5/27/05	Stated that utility distribution system components will typically be furnished and installed by the LANL SSS. Added installation requirements for indoor medium-voltage transformers. Updated references to LANL Specifications. Deleted requirement for isolated ground power for office building PC loads. Added provisions for sub-metering. Revised surge protection requirements. Changed basis for using draw-out circuit breakers to NIOSH lift calculation. Added requirements for space for future equipment additions in electrical rooms/spaces, zone-selective interlocking requirements, and requirement for lower impedance dry-type transformers to serve high-harmonic loads. Added ground cable enclosed in the concrete envelope for the underground electrical service conduit(s) as a grounding electrode for renovations. Added 5-year payback criteria for replacing feeders with excessive voltage drop.	David W. Powell, *ENG-DECS*	Gurinder Grewal, *ENG-CE*
2	10/27/06	Administrative changes only. Organization and contract reference updates from LANS transition. IMP and ISD number changes based on new Conduct of Engineering IMP 341. Master Spec number/title updates. Other administrative changes.	David W. Powell, *FM&E-DES*	Kirk Christensen, *CENG*
3	11/3/08	Updated to 2008 NEC. Added requirements to calculate ampacity of underground medium-voltage and low-voltage circuits in accordance with NEC Annex B. Added reference to LANL Standard Drawings ST-D5010-3, -4, and -5 for metering wiring and installation details. Eliminated separate requirements for power panelboards and lighting panelboards; deleted section that had addressed lighting and appliance branch circuit panelboards. Added requirement that dry-type transformer secondary be protected by a single overcurrent protective device. Changed conduit bend and length limits from requirement to guidance. Added aluminum as acceptable conductor in sizes 1/0 and above on ML-3 and ML-4 projects when terminated using approved compression terminals. Added design requirements for enclosed bus assemblies.	David W. Powell, *ES-DE*	Kirk Christensen, *CENG*

4	11/8/2011	Clarified concrete coverage requirements for underground conduits for MV and LV services and feeders; moved LV surge protection requirements to Section D5090; revised panelboard schedule for non-coincident loads and added description of calculations; added requirement to de-rate outdoor transformers exposed to summer mid-day sun.	David W. Powell, *ES-DE*	Larry Goen, *CENG-OFF*

D5010 ELECTRICAL SERVICE & DISTRIBUTION

1.0 MEDIUM-VOLTAGE SERVICE & DISTRIBUTION SYSTEMS

1.1 Utility Distribution System Characteristics

A. Nominal Distribution System Voltage: 13.2 kV, 3-wire, 60 Hz.

B. System Grounding: Solidly grounded[1] at the utility substation, but not multiple grounded.

C. Load Connections: Line-to-line.

D. Short-Circuit Current: Confirm the available short-circuit current with the LANL utilities electrical distribution engineer. *Guidance: LANL utility medium-voltage distribution system fault current can be as high as 18,000 amps RMS symmetrical, depending on the location and the distribution system configuration.*

E. System Configuration: *Guidance: Distribution circuits in highly developed LANL areas are generally underground with looped circuits controlled by pad-mounted sectionalizing switchgear. Major loads in such areas may have dedicated radial feeders from utility substations. Distribution circuits in less developed areas are typically aerial radial circuits.*

F. Utility distribution system components such as switchgear, transformers and cables will typically be furnished and installed by the LANL utilities organization. Ductbanks, equipment pads, and similar construction items to support or contain utility system components will typically be furnished and installed by the Project construction subcontractor.

1.2 Utilization System Characteristics

A. Use medium-voltage to serve large loads such as motors 500 HP and larger.

B. Nominal Utilization System Voltage: 4160Y/2400V, 3-wire, 60 Hz or as required by the utilization equipment.

C. System Grounding: Solidly Grounded

1.3 Indoor Medium-Voltage Switchgear

A. For facility-level medium-voltage switchgear lineups and unit substation primary switchgear provide metal-enclosed interrupter switchgear[2] conforming to IEEE C37.20.3, *IEEE Standard for Metal-Enclosed Interrupter Switchgear*, with current-limiting E-rated power fuses[3] conforming to IEEE C37.46, *American National Standard for High Voltage Expulsion and Current-Limiting Type Power Fuses and Fuse Disconnecting Switches*.

B. For facility-level medium-voltage switchgear applications that either exceed the current capacity of fused equipment or require complex or high-speed switching operations, use metal-clad switchgear with either vacuum or SF6 circuit breakers conforming to:

1. IEEE C37.20.2, *IEEE Standard for Metal-Clad Switchgear*

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1 System description is from 1.4.6 of IEEE Std 142™.

2 Interrupter switchgear with power fuses is a cost-effective and low-maintenance approach to protecting feeders and transformers where complex or high-speed switching is not required.

3 Current-limiting, E-rated power fuses are available for the range of short-circuit currents available on the LANL medium-voltage distribution system.

2. IEEE C37.04, *IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*
3. ANSI C37.06, *American National Standard on AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities*
4. IEEE C37.09, *IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis*

C. Select switchgear for 13.2 kV systems to have the following minimum ratings:

1. 60 Hz one-minute withstand voltage at 7500 ft elevation: 36 kV (42 kV at sea level; *this rating may be obtained through insulation coordination with surge arresters*[4])
2. Basic Insulation Level (BIL) at 7500 ft elevation: 95 kV (110 kV at sea level; *this rating may be obtained through insulation coordination with surge arresters* [4])
3. Short circuit rating: Provide equipment with a short circuit rating greater than the available short circuit current and not less than 25,000 amps RMS symmetrical.[5]

D. Select 5 kV medium voltage switchgear the following minimum ratings:

1. 60 Hz one-minute withstand voltage at 7500 ft elevation: 19 kV (22 kV at sea level; *this rating may be obtained through insulation coordination with surge arresters* [4])
2. Basic Insulation Level (BIL) at 7500 ft elevation: 60 kV (75 kV at sea level*; this rating may be obtained through insulation coordination with surge arresters* [4])
3. Short circuit rating: Greater than the available short circuit current.

E. Select intermediate-class, metal-oxide surge arresters for 13.2 kV medium-voltage switchgear conforming to IEEE Std C62.11, *IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits*, suitable for operation at an elevation of 6001 to 12000 ft, with an RMS duty-cycle voltage rating of 18 kV.[6] Apply arresters in accordance with IEEE Std C62.22, *IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems* or as recommended by the arrester manufacturer.

F. Refer to Section G4010 for requirements and guidance for selecting outdoor switchgear.

1.4 Indoor Medium-Voltage Power Transformers

1.4.1 Transformer Selection:

A. Select transformers with 13.2 kV primary with a basic impulse level (BIL) rating of 95 kV at 7500 feet elevation and a secondary BIL of 30 kV at 7500 feet elevation. De-rate all components and clearances affected by elevation for 7500 feet elevation.[7]

B. Use non-PCB "less-flammable liquid" insulated transformers conforming to IEEE Std C57.12.00, *IEEE Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers*, where liquid containment for transformer oil, structural fire rating, and fire

[4] Altitude de-rating information for medium-voltage switchgear is available from Table 5 in IEEE C37.20.3 and Table 8 in IEEE Std C37.20.2. 15.0 and 15.5 kV class switchgear is available with both 60 Hz one-minute withstand voltages and BIL ratings that are suitable for use at 7500 ft elevation.
[5] Minimum interrupting rating based on E-rated current-limiting fuses used in interrupter switchgear.
[6] Arrester voltage is from Table 7 in IEEE Std C62.22.
[7] Dielectric strength correction factors for transformers are available in Table 1 in IEEE Std C57.12.00 and Table 1 in IEEE Std C57.12.01.

sprinkler system (0.20 gpm/sq ft) are available.[8] Use transformers having a 55/65ºC average winding temperature rise over a 30ºC average, 40ºC maximum ambient.

C. Use dry-type transformers conforming to IEEE Std C57.12.01, *IEEE Standard General Requirements for Dry-Type Distribution and Power Transformers Including Those With Solid Cast and/or Resin-Encapsulated Windings*, where liquid containment is not practical.[8] Use dry type transformers having an 80ºC winding temperature rise over a 30ºC average, 40ºC maximum ambient. Use cast epoxy resin transformers to serve critical loads or where the transformer is in a dirty environment. Use vacuum pressure impregnated or cast epoxy resin transformers to serve non-critical loads and where the transformer is in a clean environment.[9]

D. Refer to Section G4010 for requirements and guidance for selecting outdoor transformers.

1.4.2 Transformer Capacity

A. Base transformer capacity on load calculations per the requirements in *NEC®* and this Chapter and loading guidance in the following IEEE standards as applicable:

1. IEEE C57.91-1981, *IEEE Guide for Loading Mineral-Oil-Immersed Transformers*
2. IEEE C57.96, *IEEE Guide for Loading Dry-Type Distribution and Power Transformers*.

B. Use the following loading factors:

1. Average ambient temperature: Refer to Transformer Installation part of this Section.
2. Elevation: 7500 feet
3. Transformers serving facilities having a significant daily load cycle may be operated with the peak load above the transformer nameplate rating so long as normal transformer life expectancy is maintained.

C. For single-ended services the calculated load (using *NEC®*) plus future load growth shall not exceed the calculated transformer peak loading capability. Base the secondary service conductors on the *NEC®* calculated load.

D. For double-ended services the calculated closed-tie load (using *NEC®*) plus future load growth shall not exceed the calculated forced-air peak loading capability of either transformer.

1.4.3 Transformer Overcurrent Protection

Select primary overcurrent protection devices to provide through-fault protection of transformer in accordance with IEEE Std 242™.[10]

1.4.4 Transformer Surge Protection

Select distribution-class, metal-oxide surge arresters in transformers with 13.2 kV primary that conform to IEEE Std C62.11, *IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits*, suitable for operation at an elevation of 6001 to 12000 ft, with an RMS duty-cycle voltage rating of 18 kV.[11] Apply arresters in accordance with IEEE Std C62.22, *IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems* or as recommended by the arrester manufacturer.

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8 Refer to FM Global *Loss Prevention Data Sheet 5-4* for guidance for locating and protecting transformers.
9 Transformer application information is from IEEE Std C57.12.01, Section 4.2.5.
10 Refer to Section 11.9.2.2.1 in IEEE Std 242™ for detailed information about "through-fault" protection of transformers. Similar information can also be found in IEEE Std C57.109.
11 Arrester voltage is from from Table 7 in IEEE Std C62.22.

1.4.5 Transformer Installation

A. Install installation indoor medium-voltage transformers in accordance with the *NEC*® and the FM Global Insurance Company *Loss Prevention Data Sheet 5-4*[12].

B. Design fire-resistive vaults or rooms for indoor medium-voltage transformers.

1. Provide transformer vaults with a fire resistance rating of not less than 3 hours for liquid insulated transformers[13].

2. Provide transformer rooms with a fire resistance rating of not less than 1 hour for dry-type transformers[14].

C. Design medium-voltage transformer vaults or rooms with outward swinging fire-rated doors[15].

1. Equip doors with panic hardware.

2. Fire rating of doors shall match fire rating of room or vault.

3. Provide door opening adequate for moving largest equipment in the room or vault.

D. Locate transformers a minimum of 36 inches from building walls[16].

E. Provide ionization type smoke detectors and automatic sprinkler protection for indoor medium-voltage transformer vaults or rooms[17].

1. Connect ionization-type smoke detectors to the building fire alarm system.

2. Provide automatic sprinkler protection system with a discharge density of not less than 0.20 gpm/sq ft over floor area of the transformer vaults, rooms, or spaces[18].

F. Design containment systems for transformer insulating liquid[19].

1. Provide containment with capacity sufficient for the volume of liquid in the largest transformer plus the volume of 1 hour[20] of automatic sprinkler system discharge.

2. *Curbs and/or tanks may be used to obtain the required containment volume*.

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12 FM Global *Property Loss Prevention Data Sheet 5-4* provides transformer installation recommendations based on test data and loss experience. FM recommendations are made LANL requirements.

13 Refer to FM Global *Property Loss Prevention Data Sheet 5-4* clause 2.2.1.3.2.

14 Refer to *NEC*® Section 450.21(C); the *NEC*® minimum requirement for dry-type transformers over 35 kV is extended to all medium-voltage dry-type transformers at LANL.

15 Refer to *NEC*® Section 450.43; the *NEC*® minimum requirements for transformer vault doors are extended to all medium-voltage transformer rooms at LANL.

16 Refer to FM Global *Property Loss Prevention Data Sheet 5-4* clause 2.2.1.1.1.

17 Refer to FM Global *Property Loss Prevention Data Sheet 5-4* clause 2.2.1.1.4.

18 Refer to FM Global *Property Loss Prevention Data Sheet 5-4* clause 2.2.1.3.2.2; automatic sprinkler discharge density for vaults containing oil-filled transformers is extended to all transformer vaults and rooms.

19 Refer to FM Global *Property Loss Prevention Data Sheet 5-4* clause 2.2.1.1.2.

20 1 hour sprinkler discharge requirement is based on Tables 11.2.2.1 and 11.2.3.1.1 of NFPA 13, *Standard for the Installation of Sprinkler Systems*.

G. Design mechanical cooling or ventilation powered from a reliable source to maintain transformer vaults or rooms within temperature limits appropriate operation of transformers at 7500 ft elevation in accordance with the following guidance:

1. *Transformers may be operated based on rated kVA providing the average temperature of the cooling air does not exceed the following limits:*
   - *For self-cooled oil-filled transformers maintain an average ambient temperature not exceeding 81 ºF. The 81 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 99 ºF.*[21]
   - *For forced-air-cooled oil-filled transformers maintain an average ambient temperature not exceeding 77 ºF. The 77 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 95 ºF.*[21]
   - *For self-cooled dry-type medium-voltage transformers maintain an average ambient temperature not exceeding 77 ºF. The 77 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 95 ºF.*[22]
   - *For forced-air-cooled dry-type medium-voltage transformers maintain an average ambient temperature not exceeding 68 ºF. The 68 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 86 ºF.*[22]
2. *Transformers may be operated with average ambient temperature not exceeding 86 ºF (30 ºC) providing the transformer rating is reduced as described below; the 86 ºF average ambient temperature covers 24 hours, and the maximum cooling air temperature during the 24-hour period must not exceed 104 ºF:*
   - *For self-cooled oil-filled transformers reduce nameplate capacity by 5.1 percent*[23].
   - *For forced-air-cooled oil-filled transformers reduce nameplate capacity by 6.4 percent*[23].
   - *For self-cooled dry-type transformers reduce nameplate capacity by 3.8 percent*[24].
   - *For forced-air-cooled dry-type transformers reduce nameplate capacity by 6.4 percent*[24].
3. Power ventilation system from an emergency or standby power source if available[25].

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21 IEEE C57.91 Table E.1 gives oil-filled transformer ambient temperature correction factors for altitude greater than 3300 ft. At 7500 ft the ambient temperature obtained by interpolation is 27.2 ºC for self-cooled transformers and 25.2 ºC for forced-air cooled transformers. Paragraph 3.5.2 sets the maximum allowable temperature at 10 ºC above the 24-hour ambient.

22 IEEE C57.96 Table 2 gives dry-type medium-voltage transformer ambient temperature correction factors for altitude greater than 3300 ft. At 7500 ft the ambient temperature obtained by interpolation is 22.4 ºC for self-cooled 80 ºC rise transformers and 19.8 ºC for forced-air cooled 80 ºC rise transformers. Paragraph 1.7 sets the maximum allowable temperature at 10 ºC above the 24-hour ambient.

23 IEEE C57.91 Table E.2 gives oil-filled transformer capacity correction factors for altitudes greater than 3300 ft. At 7500 ft the capacity reduction is 5.09% for self-cooled transformers and 6.36% for forced-air cooled transformers. Paragraph 3.5.2 sets the maximum allowable 24-hour ambient temperature at 30 ºC and the maximum temperature at 10 ºC above the 24-hour ambient.

24 IEEE C57.96 Table 3 gives dry-type transformer capacity correction factors for altitudes greater than 3300 ft. At 7500 ft the capacity reduction is 3.82% for self-cooled transformers and 6.36% for forced-air cooled transformers. Paragraph 1.7.1 sets the maximum allowable 24-hour ambient temperature at 30 ºC and the maximum temperature at 10 ºC above the 24-hour ambient

25 Refer to FM Global *Property Loss Prevention Data Sheet 5-4* clause 2.2.1.1.3.

1.5 Medium-Voltage Power Cable

1.5.1 Shielded 15 kV Power Cable

A. Comply with the *NEC*®, IEEE C2™, and ICEA S-93-639/NEMA WC-74, *Shielded Power Cables 5-56 kV* requirements for medium-voltage power cable and its installation. Use shielded power cable for 15 kV systems in raceways, duct banks, manholes, and vaults. Use shielded power cable for interconnections within switchgear and equipment where sufficient space exists for bending and terminating shielded cables.

B. Use NRTL-listed Type MV105 power cable with copper conductors, 4/0 AWG minimum,[26] and selected so conductor temperature will not exceed its NEC temperature rating at 100 percent load factor[27]. Use the following factors in conjunction with *NEC*® Annex B, the Neher-McGrath formula[28], IEEE Std 835 – *IEEE Standard Power Cable Ampacity Tables*, IEEE Std 399 – *IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis*, or approved software to calculate the ampacity of conductors in parallel underground raceways having less than 5 ft separation between centerlines of the closest raceways or 4 ft separation between the extremities of the concrete envelopes[29]:

1. Concrete thermal resistivity (Rho) of 55 °C-cm/watt.
2. Native soil thermal resistivity (Rho) of 250 °C-cm/watt unless otherwise measured in accordance with ANSI/IEEE Std 442 *Guide for Soil Thermal Resistivity Measurements*.[30] *It may be cost-effective to design ductbank systems that use a select soil backfill to provide a lower Rho; review any such approach with the ESM Chapter 7 POC.*
3. Ambient earth temperature of 20°C outside the perimeter of a heated building.[31]
4. Ambient earth temperature of 30°C within the perimeter of a heated building.[32]

C. Terminate shielded 15 kV cables using cable terminations that meet Class 1A requirements of IEEE 48, *IEEE Standard Test Procedures and Requirements for High Voltage Alternating-Current Cable Terminators2.5 kV through 756 kV,* and are suitably de-rated for altitude.

D. Refer to LANL Master Specifications Section 26 0513, *Medium Voltage Cables*, for material and installation requirements.

1.5.2 Non-shielded 15 kV Power Cable[33]

A. Use non-shielded 15 kV power cables only for short jumpers within switchgear or transformer enclosures where it is not feasible to install shielded cables due to inadequate space for bending

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26 4/0 AWG medium-voltage cable with 5 mil tape shield is the minimum size that can carry the expected 15% of 14000 amp ground fault that will appear on the cable shield for the 0.2 seconds before the SM-149 substation breaker trips on ground fault. Source *IEEE Transactions on Industry*, Vol. IA-22, No. 6, November/December 1986 paper entitled "Are Cable Shields Being Damaged during Ground Faults?" by Paul S. Hamer and Barry M. Wood.

27 Operating temperature is limited to 90C because plastic power ducts are listed for 90C conductors.

28 Refer to *NEC*® Section 310.15(C) and associated discussion in the *NEC Handbook.*

29 Refer to *NEC*® Appendix B and associated discussion in the *NEC Handbook.*

30 Soil at LANL is typically dry welded tuff (volcanic ash) with a thermal resistivity of 250 to 500 °C-cm/watt; refer to Table 2.3.1 in The Geological Society of America special paper 408: "Tuffs – Their Properties, Uses, Hydrology, and Resources."

31 Refer to *NEC*® Table B.310.7. Soil not covered by a building will be cooled by nighttime radiation and exposed to the low average air temperature at LANL.

32 Refer to *NEC*® Table 310.16. Soil covered by a heated building will be effectively insulated by the warm building resulting in a higher ambient soil temperature.

33 Design/installation requirements for 15 kV unshielded cable is corrective action #3 to Occurrence Report LANL-1994-0013.

or terminating shielded cables. Obtain approval from the LANL Electrical Authority Having Jurisdiction for each installation of non-shielded 15 kV cable.

B. Use non-shielded 15 kV transformer cable with 220 mils of EPR insulation, chlorosulfonated polyethylene (Hypalon) jacket, and minimum 2 AWG copper conductor.

C. Support non-shielded cables by full voltage rated, flame-resistant, non-tracking insulating materials[34] of sufficient strength, size, and placement to maintain adequate clearances. *The following are guideline minimum clearances:*

1. *4.5 inches air separation between non-shielded cables.*
2. *4.5 inches air separation between non-shielded cables and grounded parts.*
3. *7 inches creepage distance between non-shielded cables.*
4. *7 inches creepage distance between non-shielded cables and grounded parts.*

1.5.3 Shielded 5 kV Power Cable

A. Comply with *NEC*®, IEEE C2™, ICEA S-93-639/NEMA WC-74, *Shielded Power Cables 5-56 kV* requirements for medium-voltage power cable and its installation. Use shielded power cable for 5 kV systems in raceways, duct banks, manholes, and vaults. Use shielded power cable for interconnections within switchgear and equipment where sufficient space exists for bending and terminating shielded cables. Use NRTL-listed Type MV105 power cable with copper conductors selected using its 90ºC ampacity[35].

B. Terminate shielded 5 kV cables using devices that meet Class 1 requirements of IEEE 48, *Test Procedures and Requirements for High Voltage Alternating Cable Terminations*.

C. Refer to LANL Master Specifications Section 26 0513, *Medium Voltage Cables*, for material and installation requirements.

1.6 Raceway Systems for Medium-Voltage Cables

A. Within the perimeter of buildings install aboveground medium-voltage conductors in rigid metal conduit or intermediate metal conduit.[36] Install voltage markers on conduits as required in LANL Master Specifications Section 26 0553, *Identification for Electrical Systems*. In areas protected with fire sprinklers terminate conduits entering equipment enclosures from above with water sealing fittings.[37] Refer to LANL Master Specifications Section 26 0533, *Raceways and Boxes for Electrical Systems*, for material and installation requirements.

B. Within the perimeter of buildings install underground medium-voltage conductors in red-colored, concrete-encased duct banks providing not less than 3 inches concrete coverage on all sides and between ducts and not less than 7.5 inches center-to-center separation of ducts.[38] Refer to LANL Master Specifications Section 33 7119, *Electrical Underground Ducts and Manholes*, for material and installation requirements.

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[34] Refer to IEEE C37.20 for additional information about sheet, molded, or cast insulating materials.
[35] Operating temperature is limited to 90C because plastic power ducts are listed for 90C conductors.
[36] The greater wall thickness and threaded fittings of rigid metal conduit and intermediate metal conduit provide greater strength to contain the energy of a medium-voltage cable fault that EMT or PVC conduit.
[37] Water sealing fittings will provide a degree of protection for electrical equipment.
[38] Lesson learned from 1996 13.2 kV electrical accident at LANL. Red concrete will alert excavators that something other than a foundation is being encountered.

C. Design raceway systems for medium-voltage cables so calculated pulling tension and sidewall pressure will not exceed the cable manufacturer's recommendations. Lacking manufacturer's recommendations, use the following maximum values:[39]

1. Cable tension:
    - 0.008 lb/cmil for up to 3 conductors, not to exceed 10,000 pounds.
    - 0.0064 lb/cmil for more than 3 conductors, not to exceed 10,000 pounds.
    - 1000 lbs. per basket grip.
2. Sidewall pressure: 500 lbs/ft.

1.7 Medium-Voltage Metering

A. Where a large facility has a medium-voltage service,[40] provide an addressable, microprocessor based, multi-function digital electric meter.[41] This meter will be used for revenue metering as well as for facilities operation/maintenance purposes *Guidance: A group of buildings under the same facility management cost center may have a common primary electric meter.*

B. Provide metering equipment material and installation conforming to LANL Master Specifications Section 26 2713, *Electricity Metering*.

C. Provide current transformers and fused potential transformers, conforming to ANSI C12.11, 110 kV BIL, accuracy class 0.3, of suitable ratio and burden for the connected metering systems.[42] Provide a test switch in each potential circuit and a shorting type test switch in each current circuit for connecting portable power system analyzers.

1.7.1 Provisions for Future load Growth

A. Provide floor space in each medium-voltage electrical room or space for future additions of at least one medium-voltage switchgear section with dimensions not less than the largest section. *With double-ended switchgear assemblies it may be necessary to include empty section(s) as part of the initial installation.*[43]

B. Provide each switchgear assembly with spare bus capacity not less than the percentage of future electrical load growth specified under the "Calculations" heading in Section D5000.

C. Make provisions for future overcurrent protective devices to serve the electrical load growth specified under the "Calculations" heading in Section D5000. Provide not less than one <u>space</u> to accept a device equal to the largest overcurrent protective device. Provide additional <u>spaces,</u> as may be required, sized for protective devices of the predominant size.

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[39] Criteria from Chapter 7 of the *Southwire Power Cable Manual*, 2nd Edition and are traditional design practices.

[40] An example of such a facility is the LANL Strategic Computing Complex that has a medium-voltage service with medium-voltage and low-voltage utilization equipment.

[41] Recommended practice from IEEE Std 739. Refer to Chapter 6 for reasons for electrical metering and uses for the information obtained.

[42] ANSI C12.11, *American National Standard for Instrument Transformers for Revenue Metering 10 kV BIL Through 350 kV BIL*, covers the general requirements, metering accuracy, thermal ratings, and dimensions applicable to current and inductively coupled voltage transformers for revenue metering.

[43] Eventually, switchgear assemblies will become full, requiring the addition of new sections. This is true even for fairly new facilities and is especially prevalent in laboratory and science buildings. These future floor space provisions shall be shown on the design drawings so that space is reserved

2.0 LOW-VOLTAGE SERVICE & DISTRIBUTION SYSTEMS

2.1 System Characteristics

A. Design building service systems with appropriate voltage to cost effectively serve the load. *Refer to Clause 3.3 of IEEE Std 141™ and Clause 3.3 of IEEE Std 241™. Guidance: Select building service voltage based on estimated demand and load characteristic as follows:*

1. *Less than 50 kW demand and no 3-phase load: 120/240V, single phase.*
2. *Less than 250 kW demand and largest motor 20 HP or smaller: 208Y/120V.*
3. *More than 250 kW demand or largest motor larger than 20 HP: 480Y/277V.*
4. *Motor 500 HP or larger: Medium-voltage, refer to paragraph 1.2 in Section 5010.*

B. Unless otherwise required by the *NEC®* use solidly grounded building service and distribution systems (e.g. 120/240V, 208Y/120V, 480Y/277V). Convert existing facilities with ungrounded service systems to solidly grounded service systems during major renovations or service equipment replacements.[44]

C. Select the grounded conductor (neutral) for services and feeders as follows:

1. If the line-to-neutral connected load is 5 percent or less of the total connected load, size the grounded conductor based on *NEC®* minimum requirements.[45]
2. If the line-to-neutral load exceeds 5 percent of the connected load, make the grounded conductor ampacity no smaller than that of the phase conductors.[46]
3. If the line-to-neutral load exceeds 57 percent of the connected load, and the circuit serves high-harmonic loads, make the grounded conductor ampacity 200 percent that of the phase conductors.[47] Coordinate the size and quantity of neutral conductors with panelboard manufacturer's installation instructions; UL 67 requires that the cable terminations for 200 percent rated neutral bars match the rating of the neutral.[48]

D. Connect utilization equipment to the service in the following manner:

1. Connect major three-phase motor and power loads at the service line-to-line voltage[49]
2. Connect HID and fluorescent lighting at the service line-to-neutral voltage.[49]

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[44] Refer to Chapter 2 in the *Soares Book on Grounding*, 7th Edition, for a detailed discussion of the pros and cons of grounded and ungrounded low-voltage distribution systems. Solidly grounded systems effectively limit and stabilize the voltage to ground during normal operation, and prevent excessive line voltages due to lightning, line surges, or unintentional contact with higher line voltages.

[45] *NEC®* Article 250-24 establishes the minimum grounded conductor ampacity for services. If the service is grounded at any point, the minimum grounded conductor ampacity is 12.5% of the largest phase conductor.

[46] Triplen harmonics add in the neutral, so a 7% non-sinusoidal line-to neutral load could theoretically generate a neutral current of approximately 12% (5% x 1.732) of the phase current.

[47] Triplen harmonics add in the neutral, so a 57% non-sinusoidal line-to neutral load could theoretically generate a neutral current of approximately 99% (57% x 1.732) of the phase current. A 200% rated neutral path, busses, and termination/connection system is recommended practice in IEEE 1100™, Section 4.5.3.1.

[48] Refer to clause 12.1.6.1 in UL 67, *UL Standard for Safety for Panelboards Eleventh Edition; Contains Revisions Through and Including July 21, 2008*. For an example, refer to the Square D catalog section: "NQOD, NF, and I-Line Panelboards for Non-Linear Loads (200% Rated Neutral) Class 1630, 1670, 2110." Calling for neutral conductors with just 200% of the main bus rating may violate *NEC®* 110.3(B).

[49] Refer to clause 3.3.1 in IEEE Std 141™ for a discussion of low-voltage utilization voltages.

3. Connect 120V convenience receptacles, incandescent lighting, and 208V single-phase and three-phase equipment to separately derived 208/Y120V systems using dry-type step-down transformers if the service is 480Y/277V.[49]

4. Install one or more separately derived, isolated ground power systems as appropriate to cost-effectively serve groups of computer and electronic instrument loads that are susceptible to common-mode noise. [50] Derive each isolated ground power system using a K-factor rated, dry-type transformer with electrostatic shielding between primary and secondary windings served by dedicated feeders if the service is either 480Y/277V or 208Y/120V. Susceptible computer and electronic instrument loads include:

   - Equipment within an information technology equipment room as defined in NFPA 75, *Standard for the Protection of Electronic Computer/Data Processing Equipment.*
   - Laboratory instruments communicating through coaxial cable networks.
   - Other susceptible computer and electronic loads as identified in "functional and operational requirements" or design criteria.
   - *Isolated ground power systems are not typically required for office PCs that communicate over unshielded twisted pair cables (e.g. Cat 6A) or fiber-optic cables.*

5. Connect 120V and 208V computer loads in large raised floor computer rooms to isolated-ground, separately derived 208Y/120V systems using power distribution units served by dedicated feeders if the service is either 480Y/277V or 208Y/120V.[50]

E. Configure the low-voltage distribution system to facilitate safe work practices during maintenance and alterations[51] and to maximize power quality.

1. Connect large motor and power loads to separate services or feeders from sensitive loads.[52]
2. Provide a separate feeder for each panelboard; do not tap panelboards from a feeder riser.[53]
3. Configure system to minimize power interruptions during modifications and maintenance.[54]

2.2 Building Service Point Location

A. Locate the building service point and service equipment as close as feasible to the center of the load area. *Refer to IEEE Std 141™, Chapter 3 for additional guidance.* For LANL facilities, use the following definitions for electrical utility and service or service point, based on the configuration of the service system[55]:

1. **Pad Mounted Transformer:** The utility system includes the medium-voltage (13.2 kV) distribution system and the pad mounted transformer. The service point is at the low voltage (120/240V, 208Y/120V, or 480Y/277V) terminals of the pad-mounted transformer.

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50 Refer to clause 8.5.3.2 in IEEE Std 1100™ for a detailed description of the isolated ground power system as a means to reduce common-mode noise that may interfere with electronic equipment.

51 Refer to §2.3.1 in IEEE Std 141™ and also §5.3.2 and Chapter 9 in IEEE Std 902™ *Maintenance, Operation, and Safety of Industrial and Commercial Power Systems*.

52 Refer to Figure 8-1 in IEEE 1100™ for the recommended separation of electronic load power distribution from support equipment power distribution.

53 Tapping panelboards to a feeder riser increases the area of the building that must be shut down during maintenance to either the feeder or the panelboards.

54 Refer to Chapter 2 in IEEE Std 141™.

55 Definitions of supply points are necessary because a utility company does not individually serve LANL facilities. The LANL utilities organization serves the functions of a utility company, including operating and maintaining medium-voltage equipment up to the secondary terminals or the building supply transformers.

2. **Secondary Unit Substation:** The utility system includes the medium voltage distribution system, the unit substation medium-voltage switchgear, and the unit substation transformer. The service point is at the low voltage terminals of the secondary unit substation transformer. The secondary unit substation may be inside or outside the building.

3. **Overhead Low-Voltage Utility Service:** The utility system includes the medium voltage distribution system, the pole mounted transformer(s), and the low voltage service drop. The service point is at the building service entrance weatherhead (or equivalent).

4. **Underground Low-Voltage Utility Service:** The utility system includes the medium voltage distribution system, the pole mounted transformer(s), and the low voltage underground service lateral. The service point is at the line terminals of the first low voltage service disconnecting means. The low voltage service disconnect may be located on the utility pole, outside the building, or inside the building.

2.3 Disconnecting Means

A. The disconnecting means for each supply permitted by *NEC®* Section 225.30 or 230.2 shall consist of a single circuit breaker or a single switch.[56]

B. Outdoor service entrance equipment (unit substation, switchboard, panelboard, or a group of safety switches) dedicated and in close proximity (*within 20 ft*) to the served structure, is defined as "equipment" that is part of the served structure. *In this case the requirements in Part II of NEC® Article 225 do not apply to the feeders and branch circuits from the outdoor distribution equipment to the structure.*[57]

C. Outdoor distribution equipment (unit substation, switchboard, panelboard, or a group of safety switches) not dedicated or in close proximity (*20 ft*) to the served structure, is defined as "another structure." In this case the requirements in *NEC®* Article 225 apply.

2.4 Metering

2.4.1 General

Design electrical metering for each service entrance of each building.[58]

2.4.2 Revenue Meters

A. For 120/240-volt single-phase services up to and including 200 amperes, provide a self-contained, electro-mechanical, socket-mounted kWh meter.[59]

1. Refer to LANL Master Specifications Section 26 2713, *Electricity Metering*, for material and installation requirements.

2. Refer to LANL Standard Drawings ST-D5010-3, -4, and -5 for meter installation details and connection requirements.

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56 Service equipment with more than one main overcurrent device does not provide protection for the main bus.

57 The purpose for defining when equipment is "another structure" is to clarify the applicability of *NEC®* Article 225 requirements to feeders from outdoor distribution equipment.

58 Refer to DOE O 436.1 *Departmental Sustainability*, DOE/EE-0312 *Guidance for Electric Metering in Federal Buildings*, and EPAct 2005. EPAct 2005 directs that all Federal buildings be metered "...for the purposes of efficient energy use and reduction in the cost of electricity used in such buildings..." by October 1, 2012. Advanced meters or metering devices must provide data at least daily and measure the consumption of electricity at least hourly. These devices must be used to the maximum extent practicable.

59 Small services warrant energy metering only.

B. For three-phase services less than or equal to 800 amperes install a multi-function digital electric meter[60] that conforms to LANL Master Specifications Section 26 2713, *Electricity Metering*, for material and installation and displays:

1. Real time readings (voltage, current, real power, reactive power, power factor, frequency, current and voltage distortion)
2. Energy readings (real energy, reactive energy)
3. Demand readings (demand current, demand real power, demand apparent power).

C. For three-phase services greater than 800 amperes install a switchboard-mounted multi-function digital electric meter that conforms to LANL Master Specifications Section 26 2713 for material and installation that displays real time readings, energy readings, and demand readings plus provides waveform capture, event capture, and trend logging.[61]

2.4.3 Instrument Transformers:

Provide current transformers and fused potential transformers, conforming to ANSI C12.11, accuracy class 0.3, of suitable ratio and burden for the connected metering systems.[62] Provide a test switch in each potential circuit and a shorting type test switch in each current circuit for connecting portable power system analyzers to monitor the electrical service. Refer to LANL Master Specifications Section 26 2713 for material and installation requirements.

2.4.4 Metering Enclosures

A. If the service entrance equipment is not suitable to house meter, current transformers and potential transformers, locate a suitable metering enclosure(s) near the service entrance equipment and accessible for meter reading.

B. Provide a metal cabinet with hinged door to house the meter, test switches, fuse blocks, and terminal strips. Allow space for future installation of a telephone modem or Ethernet gateway.

C. Provide a metal cabinet for current transformers with the following minimum dimensions:

1. Service size from 300 to 600 amperes: 36” x 42” x 10”.
2. Service size from 800 to 1200 amperes: 42” x 48” x 12”.

D. Provide adequate space and access in the main electrical room for the metering enclosure(s).

E. Refer to LANL Master Specification Section 26 0713 for material and installation requirements.

2.4.5 Sub-Metering

A. Configure electrical power distribution system and include provisions for future installation of sub-metering of the following loads:[63]

1. HVAC

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[60] Medium size services warrant metering that provides information in addition to energy metering that the Facility Manager can use to more efficiently operate the building.

[61] Large services warrant metering that provides information related to power quality and event analysis.

[62] ANSI C12.11, *American National Standard for Instrument Transformers for Revenue Metering 10 kV BIL Through 350 kV BIL*, covers the general requirements, metering accuracy, thermal ratings, and dimensions applicable to current and inductively coupled voltage transformers for revenue metering.

[63] Heat loads and electrical loads for PC, process, and laboratory equipment are often significantly overestimated leading to grossly oversized mechanical and electrical equipment. This results in wasted first cost, and inefficient operation. Measured data will be used for estimating loads in future LANL buildings. Refer to *Labs21 Environmental Performance Criteria*, Energy and Atmosphere, Credit 9.

2. Lighting
3. Computers, including PCs
4. Process loads
5. Laboratory loads.

B. Provisions for future metering include space in panelboards or pull boxes sufficient for the safe temporary installation of clamp-on or split-core current transformers.[63]

2.5 Surge Protection

2.5.1 General

A. Provide surge protective devices (SPDs) for low-voltage service and distribution equipment[64] as described in Section D5090 of this Chapter.

B. *Where practical, SPDs should be factory installed and integrated into the distribution equipment*.

C. Refer to LANL Master Specification Section 26 4300 – *Surge Protective Devices* for material and installation requirements.

2.6 Switchgear, Switchboards, and Power Panelboards

2.6.1 General

A. Distribute low voltage power from one or more circuit breaker type switchgear assemblies, switchboards, or power panelboards located in dedicated electrical equipment rooms.[65]

B. For service entrance equipment, use low voltage switchgear, switchboards, or power panelboards that comply with *NEC*® requirements for service entrance equipment, have a single main circuit breaker[66], and are NRTL-labeled for service entrance use.

C. To compensate for the 7500-ft elevation, provide NEMA design switchboards, power panelboards, and circuit breakers rated at 600 VAC on 480V or 480Y/277V systems.[67] IEEE C37.20.1 switchgear rated 480V may be used on 480V or 480Y/277V systems.

D. Select low-voltage distribution system switchgear, switchboards, or power panelboards to cost-effectively serve the loads. Use the following criteria for selecting equipment:[68]

1. Mains equal to or less than 1200 amp main lugs or 800 amperes frame size main circuit breaker: NEMA PB-1, UL 67 front accessible power panelboard, front and rear aligned, branch and feeder circuit breakers panel mounted. Refer to LANL Master Specifications Section 26 2416 *Panelboards* for material and installation requirements.

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64 Refer to IEEE Std 1100 §8.6 and NFPA 780 §4.18.

65 LANL institutional preference is circuit breaker overcurrent protection because of its inherent capability of rapid service restoration.

66 Service equipment with more than one main overcurrent device does not provide protection for the main bus.

67 Voltage and current ratings for low-voltage equipment applied above 6000 ft must be de-rated due to the reduced insulating and heat removing properties of air. Table 11 in IEEE C37.20.1 indicates the following corrections at 7500 ft elevation: voltage – 0.9763, current – 0.9953. 480V switchboards and panelboard built to NEMA standards has a maximum rated voltage of 480V; 480V switchgear built to IEEE standards has a maximum rated voltage of 508V.

68 Equipment selection criteria are intended to promote the safe and cost-effective use of commercially available electrical distribution equipment. The criteria are intended to prevent the use of switchboards or switchgear for purposes that a power panelboard could accomplish.

2. Mains greater than 1200 amperes main lugs or 800 amperes frame size main circuit breaker but all feeder circuit breakers smaller than 800 amperes frame size: NEMA PB- 2 switchboard with branch and feeder circuit breakers panel mounted. For a main circuit breaker with a weight exceeding 42-lb., use a draw-out mounted circuit breaker with RMS sensing solid-state trip unit[69]. *Some manufacturers offer fixed-mounted 1200 ampere frame-size electronic trip circuit breakers that weigh less than 42 lb.* Refer to LANL Master Specifications Section 26 2413 *Switchboards* for material and installation requirements.

3. Any feeder circuit breaker 800 ampere frame size or larger with a weight exceeding 42-lb.: IEEE C37.20.1 low voltage metal-enclosed power circuit breaker (drawout) switchgear with a track-mounted hoist[70]. Use circuit breakers with RMS sensing solid-state trip units. Refer to LANL Master Specifications Section 26 2300 *Low Voltage Switchgear*, for material and installation requirements.

E. Provide enclosures suitable for the locations where the equipment will be installed. Provide “door-in-door” fronts for indoor power panelboards.[71]

F. Provide at least the *NEC*®-required working space behind rear-accessible switchgear, switchboards, and panelboards to facilitate thermographic examination of the equipment.[72]

G. Locate panelboards as close to the center of the load area and on the same floor as the branch circuit loads served to meet the following criteria:[73]

1. Maximum branch circuit voltage drop: 3 percent[74]

2. Maximum 208Y/120V system branch circuit length: 100 ft [75]

3. Maximum 480Y/277V system branch circuit length: 230 ft [76]

H. Where more than 50% of the panelboard connected branch circuit load is third harmonic-generating line-to-neutral connected equipment (such as PCs and monitors), provide panelboard with a 200% rated neutral bus.[77]

I. Arrange the single-phase loads between all phases of each panelboard to obtain phase currents balanced to within 15 percent of the average of the phase currents.[78]

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69 The weight-based threshold for draw-out circuit breakers is derived from the “NIOSH Lifting Guideline”. Using that guideline the calculated maximum weight for a circuit breaker that a worker should move from a dolly to a mounting position 44” above the floor is 42 lb.

70 Draw-out mounted circuit breakers that exceed the NIOSH lifting limits can be safely handled using a track-mounted circuit breaker hoist.

71 Door-in-door panelboard fronts eliminate the safety hazards associated with removing and installing panelboard fronts during troubleshooting, modification, and maintenance of panelboards.

72 Refer to LANL O&M Manual Criteria 504 – *Low-Voltage Electrical Equipment* for thermographic examination requirements and to Section 110.26(A) in the *NEC*® for working space requirements.

73 IEEE Std 141™, Chapter 3 establishes guidance and analysis methods for maximum circuit lengths.

74 Voltage drop criteria are mandatory provisions in ASHRAE/IESNA Standard 90.1.

75 100 ft is the approximate maximum circuit length serving a 120V 16-ampere, 0.95 pf line-neutral load through a magnetic conduit with 12 AWG conductors in a balanced multi-wire circuit or with 10 AWG conductors in a 2-wire circuit with 3% voltage drop.

76 230 ft is the approximate maximum circuit length serving a 277V 16-ampere, 0.95 pf line-neutral load through a magnetic conduit with 12 AWG conductors in a balanced multi-wire circuit or with 10 AWG conductors in a 2-wire circuit with 3% voltage drop.

77 Refer to Figure 8.5 and §8.4.2.3 in IEEE Std 1100™. The requirement for 200% rated neutral bus is driven by the effect that switched-mode power supplies have on transformers. With more than a small portion of the load being switched-mode power supplies, K-rated transformers with 200% neutral connections are needed.

2.6.2 Provisions for Future load Growth

A. Provide floor/wall space in each electrical room or space for future additions of switchgear assemblies, switchboards, and power panelboards as follows:[79]

1. At least one switchgear or switchboard section with dimensions not less than the largest section. *With double-ended switchgear assemblies it may be necessary to include empty section(s) as part of the initial installation.*

2. At least one power panelboard with dimensions not less than the largest power panelboard.

B. Provide each switchgear assembly, switchboard, and power panelboard with a percentage of spare bus capacity not less than the percentage of future electrical load growth specified under the "Calculations" heading in Section D5000.

C. Make provisions for future overcurrent protective devices to serve the electrical load growth specified under the "Calculations" heading in Section D5000. Provide not less than one <u>space</u> to accept a circuit breaker with frame size equal to the largest feeder circuit breaker. Provide additional <u>spaces,</u> as may be required, sized accept circuit breakers of the predominant feeder circuit breaker frame size.

1. In each panelboard provide a percentage of spare single-pole 20-ampere circuit breakers not less than the percentage of future electrical load growth specified under the "Calculations" heading in Section D5000. Install circuits from each of the spare circuit breakers to accessible pull boxes located above the panelboard. Install not more than three circuits to each pull box. Schedule single pole spaces to fill out each panelboard to 24, 30, or 42 space units.[80]

2. In new switchboards provide spaces to accept the future circuit breakers.

3. In low-voltage power circuit breaker switchgear assemblies provide completely outfitted draw-out circuit breaker <u>cubicles</u> to accept the future circuit breakers.

2.6.3 Overcurrent Protection

A. Provide switchgear, switchboards, and power panelboards with bus bracing and overcurrent device interrupting ratings that exceed the calculated available short-circuit current.[81] Refer to the "Calculations" heading in Section D5000.

1. Where possible, use circuit breakers with the required NRTL-listed interrupting ratings.[82]

2. Where necessary, use current-limiting circuit breakers to obtain required interrupting ratings higher than those obtainable with "high-interrupting" circuit breakers. [83]

3. *Where current-limiting circuit breakers are not available, current-limiting fuses may be used to obtain the required interrupting rating.*

4. Do not use series-rated circuit breakers except to obtain an integrated short-circuit rating within a switchboard or panelboard.[84]

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[78] The purpose of load balancing is to keep voltage unbalance within 2 percent. Refer to clause 3.8 in IEEE Std 141™ for a discussion of phase-voltage unbalance in three-phase systems.

[79] Eventually, panels will become full, requiring the addition of new panels. This is true even for fairly new facilities and is especially prevalent in laboratory and science buildings. These future wall and floor space provisions shall be shown on the design drawings so that space is reserved

[80] Spare circuit breakers and open breaker spaces facilitate the orderly expansion of electrical use in the facility.

[81] Refer to section 110.9 in the *NEC*®.

[82] Circuit breakers can usually be re-set after the fault has been investigated and cleared; no spare parts, such as fuses, are required.

[83] Current-limiting circuit breakers are available with 200 kA interrupting rating from 20 to 600 amperes.

5. Use 600V two-pole or three-pole circuit breakers in 480V and 480Y/277V equipment. [85]

B. Provide individual overcurrent protection on the supply side of each switchgear, switchboard, and power panelboard. Overcurrent protection may be either a dedicated upstream feeder circuit breaker or a main circuit breaker.[86]

C. Provide selectively coordinated overcurrent protection.[87] Refer to the "Calculations" heading in Section D5000.

D. Use zone selective interlocking as described in IEEE Std 242™ within and between the following equipment:[88]
   1. Low-voltage power circuit breaker switchgear assemblies.
   2. Switchboards with electronic trip circuit breakers.

E. When ground-fault protection is required for the service disconnecting means on 480Y/277V services, provide an additional step of ground-fault protection in the next level of feeders.[89] Use the following guidance for selecting ground fault protection settings:
   1. *Service disconnect rated 1000 amperes*[90] *or more: Set ground fault pickup at 1200A, 0.5 second delay.* [91]
   2. *Feeder devices set at 100 amperes or less (long-time setting): ground fault protection not required.*[92]
   3. *Feeder devices set at over 100 amperes up to 1200 amperes (long-time setting): Set ground fault pickup equal to 0.8 times the feeder device trip setting, 0.3-second delay.* [91]
   4. *Feeder devices set at over 1200 amperes (long-time setting): Set ground fault pickup at 1000 amperes, 0.3 second delay.* [91]

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84 Manufacturers obtain series ratings through testing of specific circuit breaker designs; series ratings are not generally available for one manufacturer's circuit breaker with another manufacturer's product. Within a switchboard or panelboard it is possible to maintain the correct series-rated circuit breakers; it is unlikely that this control would be maintained beyond the switchboard or panelboard.

85 Voltage and current ratings for low-voltage equipment applied above 6000 ft must be de-rated due to the reduced insulating and heat removing properties of air. Table 11 in IEEE C37.20.1indicates the following corrections at 7500 ft elevation: voltage – 0.9763, current – 0.9953. 480V switchboards and panelboard built to NEMA standards has a maximum rated voltage of 480V; 480V switchgear built to IEEE standards has a maximum rated voltage of 508V.

86 The basic requirement in Section 408.36(B) of the *NEC*® is extended to switchgear, switchboards, and power panelboards to improve constructability, maintainability, and safety, and also to reduce the number of users disturbed when maintenance, repairs, or modifications are performed in distribution equipment.

87 Refer to Chapter 5 in IEEE Std 141™.

88 Zone selective interlocking provides improved personnel and equipment protection as follows: When a downstream breaker (feeder) detects a fault, it signals the upstream device (main) to shift to its preset time delay band, allowing the downstream device to clear the fault while the upstream device provides backup protection. If a fault occurs between two breakers equipped with zone selective interlocking, the upstream breaker would clear the fault on the minimum delay band because it receives no interlock signal from a downstream breaker, thus minimizing the duration that the fault would exist before being cleared.

89 Ground-fault protection on both the service and feeders is required to provide fully selectively coordinated ground-fault protection. A ground fault on a feeder should not cause the service ground fault interrupter to operate. Refer to FPN No. 2 in section 230.95 in the *NEC*®.

90 Ground fault protection is required on 480Y/277V system service disconnects rated 1000 amperes or more. Refer to section 230.95 in the *NEC*®.

91 Refer to 8.3.4 in IEEE Std 242™ for additional guidance in setting ground fault protection devices.

92 Electronic trip circuit breakers rated smaller than 70 or 100 amperes are not commonly available from commercial sources. It is anticipated that the available arcing ground fault current will be of sufficient magnitude to trip circuit breakers 100 amperes and smaller before the main ground fault protection operates.

5. *Consider using zone selective interlocking to minimize the arcing ground fault damage that may occur in the switchgear.* [91]

2.6.4 Identification

A. Identify each circuit breaker as to its specific purpose and use. Include sufficient detail to distinguish each circuit from all others. Identify spare circuit breakers as such.[93]

B. Provide two typed 8-1/2" x 11" circuit directories for each power panelboard as shown in Figure 5010-1. *Guidance: Panelboard schedules produced by commercial software may be used if the same information is provided.*

1. Use the panelboard schedule to tabulate the branch circuit loads. Categorize loads as continuous (e.g. general lighting), receptacle, power (non-continuous), or non-coincident loads (Refer to NEC Section 220.60 and ESM Chapter 7 Section D5000 paragraph 4.2 for additional requirements concerning accounting for non-coincident loads.).
2. Use the panelboard schedule to calculate the feeder connected load based on the sum of 100% of the continuous load, 100% of the receptacle load, 100% of the non-continuous load, and 100% of the non-coincident load.
3. Use the panelboard schedule to calculate an estimated feeder demand load based on the sum of 100% of the continuous load, the receptacle load after application of the NEC Section 220.44 demand factor, and 100% of the non-continuous load.
4. Use the panelboard schedule to calculate the feeder selection load based on the sum of 125% of the continuous load, the receptacle load after application of the NEC Section 220.44 demand factor, 100% of the non-continuous load, and not less than the spare capacity for future load growth required in paragraph 5.1 of ESM Chapter 7 Section D5000.
5. Provide a printed copy and an electronic copy to the Facility Manager.[94]
6. Mount a plastic laminated copy inside the panelboard door.[95]

2.6.5 Power Panelboard Feeders

A. Where more than 50% of the power panelboard branch circuit connected load is third harmonic-generating line-to-neutral connected equipment (such as PCs and monitors), provide feeder to panelboard with a 200% rated grounded conductor.[77]

B. Refer to Section D5020 for the number of PC stations and the unit loads that are to be included in feeder and service load calculations.

2.6.6 Isolated Ground Panelboards

A. Provide power for computer and electronic instrument loads susceptible to common-mode noise as described in 2.1 of this Section using dedicated isolated ground panelboards on a separately derived, isolated-ground power system.[96]

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[93] Refer to *NEC*® Section 408.4.

[94] The Facility Manager will use the circuit directory to keep up-to-date records of circuit changes for both configuration management purposes and to facilitate lock-out/tag-out procedures.

[95] The standard panelboard circuit directory card is too small to legibly record the purpose of each circuit breaker (type and location of each branch circuit load) as required in *NEC*® Section 408.4.

[96] Refer to clause 8.5.3.2 in IEEE Std 1100™ for a detailed description of the isolated ground power system as a means to reduce common-mode noise that may interfere with electronic equipment.

B. Isolated ground panelboards shall be 208Y/120V, 3-phase, 6- wire systems with an insulated isolated ground bus (IG), un-insulated equipment ground bus (EG), and a 200 percent rated grounded conductor (neutral) bus. The isolated ground bus shall have the same rating as the phase buses.[97]

[97] Refer to clause 8.4.2 in IEEE Std 1100™ for recommendations for panelboard bussing when serving high-harmonic loads.

Figure 5010-1 Panelboard Schedule

POWER PANEL "PP2"

MAINS: 100 AMP MAIN LUGS
VOLTAGE: 208Y/120V, 3 PH, 4 W.

SERVED BY: 3-410-XFMR2 LOCATION: TA-3-410-123 FAULT CURRENT AVAILABLE: 8250 AMPS, RMS, SYMMETRICAL

LOCATION: TA-3-410-120 MOUNTING: SURF SECT. 1

SERVES	C/B	CONT	RCPT	PWR	NON-C	CKT	PHASE	CKT	CONT	RCPT	PWR	NON-C	C/B	SERVES
LIGHTS RM 103, 105	1P20	1260				1	-A-----	2	1460				1P20	LIGHTS RM 102, 104
LIGHTS RM 107,109	1P20	1320				3	---B---	4	1380				1P20	LIGHTS RM 106, 108
RCPT RM 103	1P20		1440			5	-----C-	6		1440			1P20	RCPT RM 102
RCPT RM 105	1P20		1440			7	-A-----	8		1440			1P20	RCPT RM 104
RCPT RM 107	1P20		1440			9	---B---	10		1440			1P20	RCPT RM 106
RCPT RM 109	1P20		1440			11	-----C-	12		1440			1P20	RCPT RM 108
	3P /			2105		13	-A-----	14				1667	3P /	
CONDENSING UNIT #1	/			2105		15	---B---	16				1667	/	DUCT HEATER #1
	/ 20			2105		17	-----C-	18				1666	/ 20	
FAN-COIL UNIT #1	2P/			1100		19	-A-----	20					1P20	SPARE
	/15			1100		21	---B---	22					1P20	SPARE
SPARE	1P20					23	-----C-	24					1P20	SPARE
SPARE	1P20					25	-A-----	26					---	SPACE
SPARE	1P20					27	---B---	28					---	SPACE
SPACE	---					29	-----C-	30					---	SPACE

TOTAL CONNECTED PHASE VOLT-AMPS: A: 10472 B: 10452 C: 9531

CONNECTED LOAD:		ESTIMATED DEMAND LOAD:		FEEDER SELECTION LOAD:	
CONTINUOUS LOAD (CONT):	5420 VA	CONTINUOUS LOAD @ 100%:	5420 VA	CONTINUOUS LOAD @ 125%:	6775 VA
RECEPTACLE LOAD (RCPT):	11520 VA	RECEPT. LOAD PER NEC 220.44:	10760 VA	RECEPT. LOAD PER NEC 220.44:	10760 VA
NON-CONTINUOUS LOAD (PWR):	8515 VA	NON-CONTINUOUS LOAD @ 100%:	8515 VA	NON-CONTINUOUS LOAD @ 100%:	8515 VA
NON-COINCIDENT LOAD (NON-C):	5000		---		---
	---		---	FUTURE LOAD GROWTH CAPACITY:	5210 VA
TOTAL CONNECTED LOAD:	30455 VA	ESTIMATED DEMAND LOAD:	24695 VA	FEEDER SELECTION LOAD:	31260 VA
	84.6 AMPS		68.6 AMPS		86.8 AMPS

2.6.7 Power Distribution Units

Provide power for computer equipment in raised floor computer rooms using factory-fabricated power distribution units. Power distribution units are free-standing cabinets that are located on the raised floor and contain one or more isolated ground panelboards, an electrostatic shielded transformer, surge protection devices, and metering and control apparatus.[98]

2.7 Low-Voltage Dry-Type Transformers

2.7.1 General-Purpose Dry-Type Transformers

A. Use dry-type transformers as described below to derive system voltages for general-purpose loads where the switched-mode power supply load is less than 20% of the total connected load.[99]

1. Where the average daily load will be less than 50% of the transformer nameplate rating use a transformer certified to have Class 1 efficiency in accordance with NEMA TP-1, *Guide for Determining Energy Efficiency for Distribution Transformers*.[100] *Class 1 efficiency transformers will typically be used for loads in office buildings and similar occupancies.*

2. Where the average daily load will be 50% or more of the transformer nameplate rating use a low temperature rise dry-type transformer (115 °C rise or less).[100] *Low temperature rise transformers will typically be used for process loads in laboratory buildings.*

B. Refer to LANL Master Specifications Section 26 2213, *Low Voltage Distribution Transformers*, for material and installation requirements.

2.7.2 Transformers for Switching Mode Power Supply Loads

A. Where more than 20% of the transformer connected load is harmonic-generating line-to-neutral connected equipment (such as PC switch mode power supplies), provide K-Factor rated, shielded isolation, dry-type distribution transformers specifically designed for non-linear loads such as office equipment and PC switched-mode power supplies.[99, 101]

B. Select K-factor based on manufacturer's recommendations and the following guidance:[102]

1. *Use K-4 rated transformers when load is a large number of non-linear single-phase electronic equipment. An example is an isolated ground separately derived system serving 20 or more personal computer stations in an office environment.*

2. *Use K-13 rated transformers when connected loads are comprised of single, large electronic loads, or small numbers of comparatively large single-phase loads. Examples*

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98 Refer to clause 8.5.3.2 in IEEE Std 1100™ for a detailed description of the isolated ground power system as a means to reduce common-mode noise that may interfere with electronic equipment.

99 Refer to Figure 8-5 in IEEE Std 1100™. The capacity of conventional transformers must be de-rated when the switched-mode power supply load becomes more than a small part of the transformer connected load.

100 Executive Order 13123, *Greening the Government through Efficient Energy Management*, Sec. 403 (b.1) directs agencies to select, where life-cycle cost-effective, ENERGY STAR and other energy efficient products when acquiring energy-using products.

101 Refer to clause 8.4.1 in IEEE Std 1100™ for recommended practice for use of electrostatically shielded and K-factor rated dry-type transformers to serve electronic load equipment. K-factor relates a transformer's ability to serve non-linear load without exceeding the rated temperature-rise limits.

102 K-factor guidelines lifted from manufacturers' recommendations and former NAVFAC Specification Section 16400, Service and Distribution.

are mainframe computers, on-line single-phase UPS systems, and isolated ground separately derived systems serving less than 20 personal computer stations.

3. *Caution should be used in specifying K-ratings above K-13, as the impedance generally decreases as the K-ratings increase. This low impedance can result in unexpectedly high line-to-line and line-to-ground fault currents.*
4. *K-factor rated transformers should never be used for three-phase non-linear loads such as motor drives, three phase UPSs, or any three-phase device with SCR phase-control or static-diode input circuits.*

C. Select transformer impedance based on the following:[103]

1. Where more than 20% of the panelboard connected load is harmonic-generating line-to-neutral connected equipment (such as PC switch mode power supplies), provide transformers with impedance not exceeding 6%.
2. Where more than 50% of the panelboard connected load is harmonic-generating line-to-neutral connected equipment (such as PC switch mode power supplies), provide transformers with impedance not exceeding 5%.

D. Refer to LANL Master Specifications Section 26 2213, *Low Voltage Distribution Transformers*, for material and installation requirements.

2.7.3 Transformers for Three-Phase Converter Loads

A. Use dry-type transformers as described below to derive system voltages or to provide isolation for three-phase converter loads such as UPS loads, solid-state motor drive loads, and similar loads that generate high 5th and 7th harmonics or the current pulse stresses of three-phase converter loads.

B. Provide transformers that are specifically compensated and tested per UL 1561 procedures for the typical harmonic spectrum of phase converters defined in IEEE-519, *Standard Practices And Requirements For General Purpose Thyristor Drives.*[104]

C. Drive isolation transformers must be capable of supplying the drive overload requirements defined as Class B in IEEE-597, and be suitable for 150% load for one minute occurring once per hour.[104]

2.7.4 Transformer Loading

A. Provide each transformer with spare capacity not less than the percentage of future electrical load growth specified under the “Calculations” heading in Section D5000.

B. Select dry-type transformers based on the design load, including future load growth capacity, and adjust rating for altitude and ambient temperature using IEEE Std C57.96, *IEEE Guide for Loading Dry-Type Distribution and Power Transformers*.

C. Further de-rate dry-type transformers located outdoors and exposed to the summer mid-day sun based on IEEE Std C37.24, *IEEE Guide for Evaluating the Effect of Solar Radiation on Outdoor Metal-Enclosed Switchgear*[105] or instructions from the transformer manufacturer.

[103] Refer to IEEE Std 1100™ for recommended practice for low-voltage dry-type transformer impedances. Low impedance transformers are required to minimize voltage waveform distortion due to nonlinear load equipment.

[104] Information about special requirements for transformers serving three-phase converter loads is from the 1996 Square D “Dry-Type Transformers Selection Guide”.

[105] While IEEE Std C37.24 does not directly apply to transformers, it does provide useful information for evaluating the increase in outdoor equipment temperature caused by solar radiation.

Use a solar radiation value[106] of 950 W/m^2 coincident with a July normal maximum temperature of 80.6 ºF.

D. Include transformer selection calculations in the project design file and with the design review submittals.

2.7.5 Transformer Installation

A. Locate transformers as close as practicable to the switchboard, panelboard, or loads served.[107]

B. Provide primary and secondary overcurrent protection for each transformer as described in the *NEC*®; protect the transformer primary and secondary conductors at their ampacity.[108] Protect transformer secondary with a single circuit breaker.[109]

C. Design transformer secondary conductors and connections so they can be safely installed, tested, and maintained.[110]

D. Provide adequate space for ventilation around transformers. Provide not less than 6 inches separation between any transformer ventilation opening and any obstruction. Do not locate transformers above heat-producing equipment unless positive and reliable compensating measures are provided.[111]

2.8 Grounding

2.8.1 General

Install the grounding systems in accordance with *NEC*® Article 250, IEEE Std 142™, IEEE Std 1100™, LANL Master Specifications Section 26 0526 *Grounding and Bonding for Electrical Systems,* and as described in this section. Electrical Drawings ST-D5010-1 and ST-D5010-2 illustrate the grounding system requirements.

2.8.2 Grounding Electrode System

A. Install the grounding electrode systems having calculated ground resistance not exceeding the following values:

1. Aggregate service rated 50 kVA and less: As required by the *NEC*®.[112]
2. Aggregate service rated more than 50 kVA but less than 2500 kVA: 5 Ohms[113]

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[106] Refer to Los Alamos Climatology (LA-11735-MS).

[107] IEEE Std 1100™, section 8.3.2.2.3 recommends that transformers be located as close as practicable to the branch circuit panelboard and the loads served.

[108] The primary overcurrent protection provides short-circuit protection for the primary conductors and a degree of overload protection for the transformer, and the secondary overcurrent protection prevents the transformer and secondary conductors from being overloaded. Without secondary overcurrent protection, primary overcurrent protection must be not more than 125% of the rated transformer primary current—refer to *NEC*® Table 450.3(B); such a low overcurrent device will sometimes trip on the transformer magnetizing inrush current.

[109] Using a single secondary overcurrent protective device improves worker safety by reducing arc-flash energy that would be available during a short circuit on the main bus. Also, main lug power panelboards do not inherently limit the number circuit breakers that can be installed as secondary protection to the NEC limit of six or the sum of multiple breaker ratings to the total that would be permitted for a single circuit breaker.

[110] Lesson learned form several LANL design-build construction projects.

[111] Clearance data is collected from manufacturer's installation instructions.

[112] Refer to *NEC*® article 250.

[113] 5 Ohms is indicated in clause 4.1.2 of IEEE Std 142™ as suitable ground electrode system resistance for industrial plants and large commercial installations.

3. Aggregate service rated 2500 kVA and larger: 1 Ohm[114]

B. Perform calculations of grounding electrode resistance using methods outlined in IEEE Std. 142™.[115] Since soil resistivity at LANL ranges from 1,800 to 140,000 Ohm-cm within one mile[116], the design professional must investigate and determine the soil resistivity for each site.[117] *Guidance: A recommended method is to have soil resistivity measurement part of the geotechnical report, using the Wenner four-electrode method and procedures described in ASTM G57.*

C. For new structures install a concrete-encased main grounding electrode in the lower part of the perimeter strip footing or grade beam to form a complete loop around the building.[118] Use one of the following materials for the electrode:

1. Use a bare copper ground cable not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG.[119]
2. Use bare or galvanized perimeter concrete reinforcing bars that are made electrically continuous. Use reinforcing bars not smaller than the following based on the total length of the interconnected and paralleled reinforcing bars[120]:

Total length of reinforcing bars	Minimum reinforcing bar
112 ft	1 3/8” (#11 bar)
150 ft	1” (#8 bar)
192 ft	3/4” (#6 bar)
223 ft	5/8” (#5 bar)
268 ft	1/2” (#4 bar)

Interconnect reinforcing bars using bare copper jumpers that are either exothermically welded to the reinforcing bars or connected using hydraulically compressed tap fittings that meet requirements of IEEE 837, *Standard for Qualifying Permanent Connections Used in Substation Grounding*.[121] Use jumpers that are neither smaller than the required *NEC*® grounding electrode conductor nor smaller than 4 AWG.[119]

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114 1 Ohm is indicated in clause 4.1.2 of IEEE Std 142™ as suitable ground electrode system resistance for large industrial plants, substations, and generating stations.

115 Chapter 4 of IEEE Std 142™ describes methods for calculating ground electrode resistance.

116 In 1999 soil resistivity measurements were made at LANL using the Wenner Four-Point method on roughly a one-mile grid. Measurements at the 4-ft depth ranged from 2,100 to 93,000 Ohm-cm. There was no consistent relationship of soil resistivity to location.

117 Clause 4.1.4 in IEEE Std 142™ strongly recommends that the resistivity of the earth at the desired location of connection be investigated.

118 The concrete encased electrode used at LANL is based on that described in clause 4.2.3 of IEEE Std 142™.

119 Section 250.52(A)(3) in the *NEC*® sets 4 AWG as minimum size concrete-encased grounding electrode and Table 250-66 establishes the minimum size grounding electrode conductor (or rebar jumper) based on service conductor size. The concrete-encased ground electrode (or rebar jumper) is made the same size as the electrode conductor because it is considered the main grounding electrode.

120 Minimum sizes for concrete-encased electrode rebars are based on Table 4-7 in IEEE Std 142™ and assuming a 5-cycle clearing time for a 30 kA ground-fault or lightning event. Size of rebar is critical to ensure that high magnitude ground currents do not damage the concrete surrounding the rebar.

121 These methods of making grounding electrode connections are described in clauses 4.3.3 and 4.3.5 in IEEE Std 142™.

D. For new structures bond each perimeter structural steel column to the main grounding electrode described above.[122]

1. Use bond conductors that are not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG.[119]
2. Make bonding connection to either directly to the steel column or a column anchor bolt using either an exothermic weld or a hydraulically compressed fitting that meets IEEE 837 requirements.[121]

E. For modifications to existing structures measure the ground resistance of the existing main grounding electrode and verify that the electrode system is adequate and substantial.

1. Verify that the main grounding electrode is a separate electrode from that used for lightning protection.[123]
2. Install one or more of the following supplemental grounding electrode(s) to obtain the required ground electrode system resistance or to establish a main grounding electrode that is separate from the lightning protection ground:
   - A bare copper ground cable not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 2 AWG, not less than 20 feet long, and buried not less than 30 inches deep adjacent to the building foundation in a Bentonite[124] slurry backfill.[125]
   - One or more electrolytic ground rods installed in accordance with the manufacturer's instructions.
   - A bare copper ground cable, not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG, not less than 20 ft long where outside the building perimeter, and enclosed in the concrete envelope for the underground electrical service conduit(s).[126]

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122 This method of bonding to perimeter building columns is described in clause 4.2.3 of IEEE Std 142™.

123 Section 250.60 in *NEC*® requires that the electrical system grounding electrode be separate from (but bonded to) the lightning protection grounding electrode.

124 Refer to IEEE Std 80-2000, clause 14.5: Bentonite is a natural clay containing the mineral montmorillionite, which was formed by volcanic action years ago. It is noncorrosive, stable, and has a resistivity of 2.5 Ohm-m at 300% moisture. The low resistivity results mainly from an electrolytic process between water, Na2O (soda), K2O (potash), CaO (lime), MgO (magnesia), and other mineral salts that ionize forming a strong electrolyte with pH ranging from 8 to 10. This electrolyte will not gradually leach out, as it is part of the clay itself. Provided with a sufficient amount of water, it swells up to 13 times its dry volume and will adhere to nearly any surface it touches. Due to its hygroscopic nature, it acts as a drying agent drawing any available moisture from the surrounding environment. Bentonite needs water to obtain and maintain its beneficial characteristics. Its initial moisture content is obtained at installation when the slurry is prepared. Once installed, bentonite relies on the presence of ground moisture to maintain its characteristics. Most soils have sufficient ground moisture so that drying out is not a concern. The hygroscopic nature of bentonite will take advantage of the available water to maintain its as-installed condition. If exposed to direct sunlight, it tends to seal itself off, preventing the drying process from penetrating deeper. It may not function well in a very dry environment, because it may shrink away from the electrode, increasing the electrode resistance

125 Supplemental electrode based on clause 14.10.4.11.G in the 2008 New Mexico Electrical Code adapted to LANL site specific requirements.

126 Modifications to existing structures often include installation of new underground electrical service.

F. Install a main grounding electrode bar adjacent to the service entrance equipment; use the main grounding electrode bar as a point for bonding all grounding electrodes, power systems, separately derived systems, communications systems, piping systems, and structural steel.[127]

1. Refer to LANL Master Specifications Section 26 0526 *Grounding and Bonding for Electrical Systems* for ground bar material and installation requirements.
2. Connect the grounding electrode bar to the main grounding electrode using unspliced copper cable and irreversible connections. Irreversible connections are either exothermic welds or IEEE Std 837 compression lugs attached with tamper-proof nuts and bolts.[128]
3. Install main grounding electrode bar extensions at additional locations in reinforced concrete structures for grounding separately derived systems that are remote (more than 50 ft) from the main grounding electrode bar.[129] Establish main grounding electrode bar extensions by installing ground bars connected to the main ground electrode bar using unspliced 4/0 AWG copper cable with irreversible connections.[130]
4. Connections to the main grounding electrode bar (or extensions) will be considered direct connections to the main grounding electrode. [128]
5. Label each connection to the main grounding electrode bar or extensions.[131]

G. Bond building structural steel, interior metallic piping systems, and exterior metal water piping systems to the main grounding electrode bar using copper cable, listed pipe clamps, exothermic welds, and compression lugs that meet requirements of IEEE Std 837.[127] Use bonding conductors that are not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG.

H. Bond the lightning protection grounding counterpoise to the building grounding electrode system at the main grounding electrode bar using 600V insulated 4/0 AWG ground cable and compression lugs that meet IEEE Std 837 requirements.[132]

2.8.3 Circuit and System Grounding

A. Connect the service entrance equipment ground bus to the main grounding electrode bar with unspliced grounding conductor sized per *NEC*® Table 250.66.[133]

B. In the service entrance equipment, connect the system grounded conductor bus to the equipment ground bus with a bonding jumper sized per *NEC*® Table 250.66; do not use a factory furnished bonding screw. [133]

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[127] Interconnection of building grounding electrodes and other systems is described in clause 8.5 and figure 8-6 in IEEE Std 1100™.

[128] The intent of the requirement for irreversible connections is so connections to the main grounding electrode bar can be considered the same as direct connections to the main grounding electrode.

[129] Reinforced concrete structure buildings do not have electrically continuous structural steel for grounding separately derived systems as required in Section 250.30 of the *NEC*®.

[130] The intent of the requirement for 4/0 AWG cable with irreversible connections is so connections to the main grounding electrode bar extensions can be considered the same as direct connections to the main grounding electrode bar.

[131] Labels on connections to the main grounding electrode bar will reduce the possibility of disconnecting the wrong system ground during facility maintenance or modifications.

[132] Clause 3-14.1 requires that main size lightning conductors be used to interconnect the grounding electrode systems. 4/0 AWG is used for the lightning protection counterpoise conductor. Conductor insulation is to prevent uncontrolled interconnection of electrodes.

[133] Section 250.24(A)(4) in the *NEC*® permits connecting the grounding electrode conductor to the equipment ground bar if main bonding jumper is a wire or bus bar.

C. Separately Derived Systems (transformers, generators, computer power distribution units, UPSs, etc.):

1. Ground separately derived systems in the vicinity (within 50 ft) of the main electrical room to the main grounding electrode bar.
2. Ground separately derived systems remote from the main electrical room to the nearest effectively grounded building structural steel or metal water pipe within 5 ft of the point of entrance into the building.[134] If neither grounding electrode is available, install a main grounding electrode bar extension near the separately derived system disconnecting means. [129]
3. Connect the separately derived system equipment ground bus at the first system disconnecting means or overcurrent device to the ground described above using un-spliced grounding conductor sized per *NEC®* Table 250.66, based on the derived system conductor size.[135]
4. At the separately derived system disconnecting means or overcurrent device, connect the system grounded conductor bus to the equipment ground bus with a bonding jumper sized per *NEC®* Table 250.66; do not use only a factory furnished bonding strap or bonding screw. [135, 133]
5. Bond the grounded conductor to all interior metallic piping systems in the area served by the separately derived system in accordance with *NEC®* requirements.[136]

2.8.4 Enclosure and Equipment Grounding

A. Install an NRTL-listed equipment ground bar or ground lug in each item of electrical equipment and bond it to the equipment enclosure.[137]

B. Install a 600 volt insulated (green) equipment ground conductor in each feeder raceway.[138] An equipment-grounding conductor is not required in a service entrance raceway if the service includes a system grounded conductor.

C. Provide feeder and plug-in busways with integral low-impedance grounding conductor having an ampacity not less than 50 percent of the busway and with plated, low-resistance contact areas at busway joints and connection points.[139]

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134 Refer to *NEC®* Section 250.30(A)(7).

135 LANL institutional preference is to make the connection between the separately derived system grounded conductor and the equipment-grounding conductor in the enclosure for the first overcurrent device. This was codified in AHJ Interpretation No. 003 dated January 24, 1995. The connection point in the first disconnect or overcurrent device is the preferred location because these enclosures are more likely to have standard arrangements incorporated into their design for this connection. Required inspection and testing of the ground on an energized system can be accomplished with less risk to personnel in the overcurrent device enclosure than in the transformer enclosure.

136 The bonding requirement in *NEC®* Section 250.104(A)(4) to bond metallic water piping systems is extended to all metallic piping systems in the area served by the separately derived system to provide additional safety.

137 A listed ground bar or ground lug provides an acceptable place to terminate the equipment grounding conductor(s). In many instances at LANL mounting screws or sheetmetal screws have been used to terminate equipment grounding conductors; thus creating potential electrocution hazards.

138 Installation of an insulated equipment-grounding conductor is recommended practice in clause 8.5.3 of IEEE Std 1100™. Clause 2.2.3 of IEEE Std 142™ indicates that the use of a metal raceway as a grounding conductor supplemented by an equipment grounding conductor achieves both minimum ground fault impedance and minimum shock hazard voltage.

2.8.5 Isolated Grounding System

A. Install isolated grounding systems for computer and laboratory instrument power systems that are susceptible to common-mode noise.[140] Refer to Section 2.1 of this Chapter for guidance in establishing isolated ground power systems.

B. In addition to the equipment ground bar, install an insulated isolated ground bar in switchboards and panelboards supplying isolated ground circuits. [141]

C. At the first isolated ground system phase conductor overcurrent device or disconnecting means, bond the isolated ground bus to the equipment ground bus with a bonding jumper sized per *NEC*® Table 250.66; do not use a factory furnished bonding strap or bonding screw. Make no other isolated ground to equipment ground connections. [135, 133]

D. In addition to the equipment-grounding conductor, install a dedicated 600-volt insulated (green/yellow) isolated ground conductor for each isolated ground feeder. [141]

1. Make isolated ground conductors the same size as the phase conductors.[142]
2. Connect the isolated ground conductors to the isolated ground bars in switchboards and panelboards. [141]

2.9 Raceway Systems

A. Use raceway systems to contain low-voltage service and feeder wiring systems.

B. Design raceway systems with consideration given to all conductor adjustment factors required by the *NEC*®.

C. Design raceway systems for low-voltage conductors so calculated installation pulling tension and sidewall pressure will not exceed the following values:[143]

1. Cable tension:
   - 0.008 lb./cmil for up to 3 conductors, not to exceed 10,000 pounds.
   - 0.0064 lb./cmil for more than 3 conductors, not to exceed 10,000 pounds.
   - 1000 lbs. per basket grip.
2. Sidewall pressure: 500 lbs./ft.

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139 An integral ground conductor that completely enclose the busway conductors have a lower 60 Hz impedance than provided by internal ground

140 The purpose of isolated ground power systems is to reduce common mode noise that may interfere with sensitive electronic equipment. Isolated ground power systems are described in clause 8.5.3.2 of IEEE Std 1100™.

141 Recommended practice for isolated ground systems is provided in clause 8.5.3.2 of IEEE 1100™.

142 Clause 8.5.3 in IEEE Std 1100™ indicates that the isolated ground conductor is the sole grounding path from electronic load equipment to the power system or the separately derived system. To provide a low ground fault impedance and minimum shock hazard voltage, LANL institutional preference is to make the isolated ground conductor the same size as the phase conductors.

143 Criteria are from Chapter 7 of the *Southwire Power Cable Manual*, 2nd Edition and traditional conservative design practices.

3. *Guidance: Conduit runs within the following limits of bends and conduit length between pull points will not exceed the above installation pulling tension and sidewall pressure limits:*
    - *Three (3) equivalent 90 degree bends: not more than fifty feet (50') between pull points,*
    - *Two (2) equivalent 90 degree bends: not more than one hundred feet (100') between pull points,*
    - *One (1) equivalent 90 degree bends: not more than one hundred fifty feet (150') between pull points,*
    - *Straight pull: not more than two hundred feet (200') between pull points.*

D. Indicate sizes of conduits, wireway sections, and cable tray sections on the construction or record as-built drawings.

E. Refer to LANL Master Specification 26 0533, *Raceways and Boxes for Electrical Systems*, for raceway material and installation requirements.

F. Provide concrete-encasement and warning tape for underground low-voltage service and feeder conduit outside the perimeter of the building. Provide warning tape for underground low-voltage service and feeder conduit inside the perimeter of the building. Provide not less than 7.5 inches center-to-center separation of conduits.[144] Provide not less than 3 inches concrete coverage on all sides and between conduits. *Guidance: Low-voltage service and feeder conduits inside the perimeter of the building need not be concrete-encased.*

G. Refer to LANL Master Specification 26 0533, *Raceway and Boxes for Electrical Systems*, for material and installation requirements for junction and pull boxes.

H. In addition to locations required by the *NEC*®, provide conduit sealing fittings with approved sealant at the following locations:
    1. Where conduits cross the boundary of a radiological area.[145]
    2. Where conduits pass between areas where air pressure differential must be maintained.

I. Install raceways penetrating radiation shielding or permanent contamination zones with sufficient bends, curvature, or shielding to prevent radiation streaming through the void.[146]

2.10 Conductors

2.10.1 Wiring Color Codes

A. Identify all wiring system conductors at each accessible location using color-coding that is consistent throughout the building.[147] *Guidance: For minor work[148] in existing facilities use wiring color codes that match existing color codes so long as National Electrical Code® requirements for identifying grounded and grounding conductors are satisfied[149].*

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[144] Refer to Figure 310.60 in the *NEC*®.
[145] The purpose of sealing raceways crossing radiological areas is to prevent the spread of contamination.
[146] DOE 6430.1A, section 1300-6.2, Shielding Design, states that straight-line penetration of shield walls shall be avoided to prevent radiation streaming.
[147] Color coding of phase conductors will facilitate identification of system voltages and correct installation of equipment that requires a particular phase rotation, such as motors.
[148] Refer to ESM Chapter 7, D5000, 1.0-E.4.
[149] Refer to *NEC*® Sections 200.6 and 250.119.

B. Refer to LANL Master Specifications Section 26 0519, *Low Voltage Electrical Power Conductors and Cables*, for the wiring color codes.

C. Install a permanent placard on the enclosure for each switchgear assembly, switchboard, panelboard, motor control center, dry-type transformer, safety switch, and motor controller. On the placard indicate the color code for each conductor in the enclosure by phase and voltage.[150]

2.10.2 Building Wire and Cable

A. Select building wire and cable based on NEC ampacity tables and adjustments such as voltage drop, ambient temperature, mutual heating of adjacent raceways, number of current-carrying conductors per raceway, effects of harmonics, and future load growth.[151]

B. For power wiring, use minimum 12 AWG conductors.[152]

C. For power and control wiring on ML-3 and ML-4 systems, use copper conductors except:

1) For size 1/0 AWG and larger, AA-8000[153] compact stranded aluminum conductors[154] terminated with circumferential crimp compression aluminum terminals or adapters are also allowed.

D. For power and control wiring on ML-1 and ML-2 systems, use only copper conductors.

E. Before using conductors larger than 500 kcmil copper or 750 kcmil aluminum, consult with the ESM Electrical POC.[155]

F. Indicate on the construction drawings and the record as-built drawings the number, size, and type of conductors in conduit runs, wireway sections, and cable tray sections.

G. Refer to LANL Master Specifications Section 26 0519, *Low Voltage Electrical Power Conductors and Cables*, for materials and installation methods.

H. For new construction work size service and feeder conductors to limit the total voltage drop from the service point to the most remote outlet to 5%.

1. Use voltage drop calculation methods outlined in Chapter 3 of IEEE Std 141™.
2. Design branch circuit conductors for a maximum voltage drop of 3% at full design load.
3. Design feeder conductors for a maximum voltage drop of 2% at full design load.[156]
4. Include voltage drop in service conductors in the 5% total voltage drop.

I. For renovation work replace service and feeder conductors that otherwise meet *NEC*® requirements if the energy savings from meeting the above voltage drop limits will yield a simple 5-year payback of the replacement costs.[157]

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[150] The requirement for placards indicating conductor color codes is extended from multi-wire branch circuits in *NEC*® Section 210.5 (D) to all conductors at LANL.

[151] Adjustments for raceway fill, ambient temperature, and harmonics are required in *NEC*® Article 310-15.

[152] The use of minimum 12 AWG on branch circuits limits voltage drop.

[153] Refer to ASTM B801 *Standard Specification for Concentric-Lay-Stranded Conductors of 8000 Series Aluminum Alloy for Subsequent Covering or Insulation.*

[154] Construction cost analysis indicates total installed cost of AA-8000 aluminum feeders to be 14-31 percent less than equivalent copper feeders, including the larger conduits required for the aluminum conductors. In the dry environment at LANL, AA-8000 aluminum feeders are expected to have the same reliability as copper feeders.

[155] 500 kcmil is the largest conductor that can be terminated in copper circuit breaker lugs.

[156] ASHRAE/IESNA Standard 90.1 requires the stated voltage drop design criteria.

J. Use the following factors in conjunction with *NEC*® Annex B, the Neher-McGrath formula[158], IEEE Std 835 – *IEEE Standard Power Cable Ampacity Tables*, IEEE Std 399 – *IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis*, or approved software to calculate the ampacity of conductors in parallel underground raceways having less than 5 ft separation between centerlines of the closest raceways or 4 ft separation between the extremities of the concrete envelopes[159]:

1. Concrete thermal resistivity (Rho) of 55 °C-cm/watt.
2. Soil thermal resistivity (Rho) of 250 °C-cm/watt unless otherwise measured in accordance with ANSI/IEEE Std 442 *Guide for Soil Thermal Resistivity Measurements*.[30] *It may be cost-effective to design ductbank systems that use select soil backfill to provide a lower Rho; review any such approach with the ESM Chapter 7 POC.*
3. Ambient earth temperature of 20°C outside the perimeter of a heated building.[160]
4. Ambient earth temperature of 30°C within the perimeter of a heated building.[161]
5. Load factor of 100 percent unless determined by measurement or approved calculations.

K. For conduits exposed to sunlight on roofs, apply the temperature adders in NEC Table 310.15(B)(2)(c) to an outdoor temperature of 100F. [162]

L. Size feeders serving switchgear, switchboards, motor control centers, and panelboards to at least match the load bus or load circuit breaker rating.[163]

M. In areas where the total integrated gamma dose for the useful life of the facility is calculated to be 10^6 rads or greater, such as hot cells, provide conductor insulation such as cross-linked copolymer, polyvinyl chloride, or polyethylene. Radiation doses will be specified in the project design criteria.[164]

2.10.3 Enclosed Bus Assemblies

A. Consider enclosed bus assemblies for circuits rated 800 amperes and larger.[165]

1. *Use life-cycle cost comparison to conduit and wire circuits.*
2. *Address factors such as installation costs, access requirements, maintenance costs, voltage regulation, and energy savings.*

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157 Lesson learned from LANL construction projects. 5 years simple payback is a common acceptance criterion for energy-saving investments.

158 Refer to *NEC*® Section 310.15(C) and associated discussion in the *NEC Handbook*.

159 Refer to *NEC*® Appendix B and associated discussion in the *NEC Handbook*.

160 Refer to *NEC*® Table B.310.7. Soil not covered by a building will be cooled by nighttime radiation and exposed to the low average air temperature at LANL.

161 Refer to *NEC*® Table 310.16. Soil covered by a heated building will be effectively insulated by the warm building resulting in a higher ambient soil temperature.

162 Refer to LANL Climatology: Extremes for White Rock.

163 Matching the load bus to the feeder ampacity reduces uncertainty in the field about the true capacity available at panelboards, switchboards, transformers, etc.

164 Gamma radiation can cause deterioration of the physical and electrical properties of polymers used in conductor insulation materials. Refer to IEEE 1205, *IEEE Guide for Assessing, Monitoring, and Mitigating Aging Effects*.

165 Feeder busway can be advantageous for transmitting large blocks of power due to its very low and balanced circuit reactance. Plug-in busway can provide a very flexible distribution system to accommodated re-arrangement of load. Refer to IEEE Std 141 Chapter 13.

B. Select enclosed bus assemblies (busways) considering available short-circuit current, voltage drop, ambient temperature, effects of harmonics, and future load changes.[166]

   1. Use copper busway conductors for ML-1 and ML-2 systems.
   2. Use copper or aluminum busway conductors for ML-3 and ML-4 systems.

C. Refer to LANL Master Specifications Section 26 2500, *Enclosed Bus Assemblies*, for materials and installation methods.

D. Select feeder busways, plug-in busways, and any associated feeders to limit voltage drop to 2% at the most remote point at full design load.[156]

E. Select busway and design installation in accordance with *NEC*® Article 368.

F. Design installation of enclosed bus assemblies to provide sufficient vertical and horizontal clearance so each joint will be accessible for inspection and each joint bolt will be accessible for re-torquing using a standard torque wrench. Provide access doors as required.[167]

[166] IEEE Std 141 Section 13.8.
[167] Refer to NFPA 70B section 24.4.