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D5010 ELECTRICAL SERVICE & DISTRIBUTION

Please contact the ESM Electrical Standards Point of Contact (POC) for interpretation, variance, and upkeep issues.

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*

5	2/11/2019	Changed "13.2kV" to "15kV class"; added note that primary fault current is usually 9kA on a single feed, 18kA when tied; allowed for high-resistance grounded systems with POC approval; added that transformers 500kVA and larger will require special attention due to incident energy issues; substantial revisions to metering; edited voltage drop so that the overall voltage drop is no more than 5%; added concept to consider fuses when appropriate; added requirement that isolated ground systems may only be used with the permission of the POC; removed requirement for secondary protection of transformers; removed resistance requirements for grounding electrode systems; now only requiring concrete encasement of underground conduit where shown on drawings with warning tape everywhere else; edited color coding; allowed aluminum conductors in sizes 8 AWG and larger; removed conductor on rooftop rules to align with NEC changes.	Eric R. Stromberg, *ES-EPD*	Larry Goen, *ES-DO*

D5010 ELECTRICAL SERVICE & DISTRIBUTION

1.0 MEDIUM-VOLTAGE SERVICE & DISTRIBUTION SYSTEMS

1.1 Utility Distribution System Characteristics

A. Nominal Distribution System Voltage: 13.8 kV, 3-wire, 60 Hz.

B. Voltage class of distribution system: 15kV.

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

D. Load Connections: Line-to-line.

E. Short-Circuit Current: Confirm the available short-circuit current with the LANL utilities electrical distribution engineer by sending formal email to faultcurrent@lanl.gov. *Guidance: LANL utility medium-voltage distribution system fault current is typically around 9,000 amps but can be as high as 20,000 amps and varies as the distance to the supplying substation varies.*

F. 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.*

G. 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, after approval by ES-UI.

H. For the above situation and other ***direction to contact LANL Utilities or ES-UI*** *within this Section, send* ***an email to electrical_utilities@lanl.gov.***

1.2 Facility Medium Voltage

A. Use medium-voltage to supply 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; high-resistance grounded with the concurrence of the electrical standards Point of Contact.

D. Medium voltage equipment is operated and maintained by the LANL utilities and infrastructure group. All equipment and systems must be approved by the LANL UI group before purchase or installation.

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

[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.

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*
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 15 kV class 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).[4]
2. Basic Insulation Level (BIL) at 7500 ft elevation: 95 kV (110 kV at sea level).[4]
3. Short circuit rating: Provide equipment with a short circuit rating greater than the available short circuit current. Contact LANL utilities to obtain the available fault current in the system supplying the equipment by sending a formal email to faultcurrent@lanl.gov.

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

1. 60 Hz one-minute withstand voltage at 7500 ft. elevation: 19 kV (22 kV at sea level).[4]
2. Basic Insulation Level (BIL) at 7500 ft. elevation: 60 kV (75 kV at sea level).[4]
3. Short circuit rating: Greater than the available short circuit current. Send a formal email to faultcurrent@lanl.gov in order to obtain the available short circuit current.

E. Select intermediate-class, metal-oxide surge arresters for 15 kV class 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 12,000 ft, with an RMS duty-cycle voltage rating of 18 kV.[5] 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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3 Current-limiting, E-rated power fuses are available for the range of short-circuit currents available on the LANL medium-voltage distribution system.

4 Altitude de-rating information for medium-voltage switchgear is available from Table 8 in IEEE C37.20.3 and Table 9 in IEEE Std C37.20.2. **With the approval of the LANL electrical standards POC, this rating may be obtained through insulation coordination with surge arresters.**

5 Arrester voltage is from Table 7 in IEEE Std C62.22.

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

1.4 Indoor Medium-Voltage Distribution Transformers

1.4.1 Transformer Selection:

A. Select medium-voltage transformers with a basic impulse level (BIL) rating of 95 kV at 7500 feet elevation (110 kV at sea level) and a secondary BIL of 30 kV at 7500 feet elevation. De-rate all components and clearances affected by elevation for 7500 feet elevation.[6]

B. 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*.[7] Use dry type transformers having an 80ºC winding temperature rise over a 30ºC average, 40ºC maximum ambient. Use cast epoxy resin transformers to supply critical loads or where the transformer is in a dirty environment. Use vacuum-pressure impregnated or cast-epoxy resin transformers to supply non-critical loads and where the transformer is in a clean environment.[8]

C. 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, *IEEE Guide for Loading Mineral-Oil-Immersed Transformers and Step-Voltage Regulators.*

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 article of this Section below.

2. Elevation: 7500 feet.

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 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.

E. Transformers 500 kVA and over require more attention because incident energies will often exceed 40 cal/cm^2. If the incident energy at the line side of the service disconnect exceeds 40 cal/cm^2, contact the electrical standards POC for direction

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6 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. **With the approval of the LANL electrical standards POC, this rating may be obtained through insulation coordination with surge arresters.**

7 Refer to FM Global *Loss Prevention Data Sheet 5-4* for guidance for locating and protecting transformers.

8 Transformer application information is from IEEE Std C57.12.01, Section 4.2.5.

on how to proceed. *Guidance. Some considerations for mitigating high incident energies are as follows:*

1. *Use transformers with internal sensing and contacts that will detect and mitigate a fault.*
2. *Use multiple transformers, where each has an incident energy less than 40 cal/cm^2 on the line side of the main, downstream of the transformer.*
3. *Compartmentalized main circuit breaker such that the line side energy is isolated to a smaller area. This arrangement should also include LED indicators, or measuring points, to allow for preliminary zero voltage checks without opening the cover.*

1.4.3 Transformer Overcurrent Protection

Select primary overcurrent protection devices to provide through-fault protection of transformer in accordance with IEEE Std 242™.[9]

1.4.4 Transformer Surge Protection

Select distribution-class, metal-oxide surge arresters in medium-voltage transformers 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.[10] 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.
Note: Refer to ESM Ch. 7 Section G4010 for requirements and guidance for selecting surge protection for transformers.

1.4.5 Transformer Installation

A. Install indoor, medium-voltage transformers in accordance with the *NEC®* and the FM Global *Loss Prevention Data Sheet 5-4.*[11]

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

  1. Provide transformer rooms with a fire resistance rating of not less than 1 hour for dry-type transformers.[12]

C. Design medium-voltage transformer vaults or rooms with outward swinging fire-rated doors.[13]

  1. Equip doors with panic hardware.
  2. Fire rating of doors shall be commensurate with the fire rating of room or vault. Confirm with Fire Protection as to the required rating for the doors.
  3. Provide door opening adequate for moving largest equipment in the room or vault.

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9 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.

10 Arrester voltage is from from Table 7 in IEEE Std C62.22.

11 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.

12 *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.

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

D. Locate transformers a minimum of 36 inches from building walls.[14]

E. Provide photoelectric-type smoke detectors and automatic sprinkler protection for indoor medium-voltage transformer vaults or rooms.[15]

1. Connect 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.[16]

F. Design mechanical cooling or ventilation powered from a reliable source to maintain transformer vaults or rooms within temperature limits appropriate to 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 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.*[17]

- *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.*[17]

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 dry-type transformers, reduce nameplate capacity by 3.8 percent.*[18]

- *For forced-air-cooled dry-type transformers, reduce nameplate capacity by 6.4 percent.*[18]

3. Power ventilation system from an emergency or standby power source if available.[19]

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14 FM Global *Property Loss Prevention Data Sheet 5-4* clause 2.2.1.1.1.

15 FM Global *Property Loss Prevention Data Sheet 5-4* clause 2.2.1.1.4.

16 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.

17 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.

18 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.

19 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,[20] and selected so conductor temperature will not exceed its NEC temperature rating at 100 percent load factor[21]. 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, use the following factors in conjunction with *NEC®* Annex B, the Neher-McGrath formula[22], IEEE Std 835 – *IEEE Standard Power Cable Ampacity Tables*, IEEE Std 399 – *IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis*, or LANL-approved software[23]:

1. Concrete thermal resistivity (Rho) of 55 °C-cm/watt.
2. Native soil thermal resistivity (Rho) of 225 °C-cm/watt unless otherwise measured in accordance with ANSI/IEEE Std 442 *Guide for Soil Thermal Resistivity Measurements*.[24] *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.[25]
4. Ambient earth temperature of 30°C within the perimeter of a heated building.[26]

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.

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[20] 4/0 AWG medium-voltage cable with 5 mil tape shield is the minimum size that can carry the expected 15% of 14,000 amp ground fault that will appear on the cable shield for the 0.2 seconds before the TA-03-0149 Medium Voltage Switchgear 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.

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

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

[23] Refer to *NEC®* Appendix B and associated discussion in the *NEC Handbook*.

[24] 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."

[25] 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.

[26] 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.

1.5.2 Non-shielded 15 kV Power Cable[27]

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 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[28] of sufficient strength, size, and placement to maintain adequate clearances.
The following are guideline minimum clearances:

	air separation (in.)	***creepage distance (in.)***
between non-shielded cables	**4.5**	**7**
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.[29]

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*.

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.[30] Install voltage markers on conduits as required in LANL Master Specifications Section 26 0553, *Identification for Electrical Systems*. 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-

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27 Design/installation requirements for 15 kV unshielded cable is corrective action #3 to Occurrence Report LANL-1994-0013.
28 Refer to IEEE C37.20 for additional information about sheet, molded, or cast insulating materials.
29 Operating temperature is limited to 90C because plastic power ducts are listed for 90C conductors.
30 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.

center separation of ducts.[31] Refer to LANL Master Specifications Section 33 7119, *Electrical Underground Ducts and Manholes*, for material and installation requirements.

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:[32]

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,[33] provide an addressable, microprocessor based, multi-function digital electric meter.[34] *Guidance: This meter will be used for facilities operation/maintenance purposes. A group of buildings under the same facility management cost center may have a common primary electric meter.*

B. Send a formal email to umetering@lanl.gov for meter needs-determination and required characteristics.

C. Provide current transformers and fused-potential transformers conforming to ANSI C12.11, 110 kV BIL, accuracy class 0.3, and of suitable ratio and burden for the connected metering systems.[35] 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*.[36]

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31 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.

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

33 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.

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

35 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.

36 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

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 supply the electrical load-growth specified under the "Calculations" heading in Section D5000. Provide not less than one space to accept a device equal to the largest overcurrent protective device. Provide additional spaces as may be required sized for protective devices of the predominant size.

2.0 LOW-VOLTAGE SERVICE & DISTRIBUTION SYSTEMS

2.1 System Characteristics

A. Design building service systems with appropriate voltage to cost effectively supply 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. *For installations with no 3-phase loads: 120/240V single phase, or two 120V phases fed from a 208/120v three phase system*
2. *Less than 250 kW demand and largest motor 20 HP or smaller: 208Y/120V.*
3. *More than 250 kW demand, or has 460 volt motors: 480Y/277V.*
4. *Motor 500 HP or larger: Medium-voltage; refer to Article 1.2 herein.*

B. Use solidly grounded building service and distribution systems (e.g., 120/240V, 208Y/120V, 480Y/277V), or obtain Electrical Standards POC approval for alternative. Convert existing facilities with ungrounded systems to solidly grounded systems, or high-resistance grounded systems, during major renovations or main equipment replacements.[37]

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

1. If the load on the grounded conductor is less than that of the line conductors, size the grounded conductor based on *NEC*® minimum requirements.[38]
2. If the line-to-neutral load exceeds 57 percent of the connected load, and the circuit supplies high-harmonic loads, make the grounded conductor ampacity 200 percent that of the phase conductors.[39] 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.[40]

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37 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.

38 *NEC*® Section 250.24 establishes the minimum grounded conductor ampacity for services. NEC section 220.61 provides direction for sizing neutral conductors.

39 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.

40 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

D. Configure the low-voltage distribution system to facilitate safe work practices during maintenance and alterations[41] and to maximize power quality.

1. Connect large motor and power loads to separate systems, or feeders, from sensitive loads.[42]

2. Provide a separate feeder for each panelboard; do not tap panelboards from a feeder.[43]

Note: Multiple panelboards that are connected via bus feed-throughs and labelled with the same number are considered one panelboard (e.g., LP-1A, LP-1B).

3. Design systems to minimize power interruptions during modifications and maintenance.[44]

E. Use K-rated transformers to supply high-harmonic loads (e.g., switching power supplies, electronic lighting ballasts with high THD).

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 system. These service points may be defined at another location with the approval of Utilities and Infrastructure .[45]

1. **Pad Mounted Transformer:** The utility system includes the medium-voltage (15 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.

2. **Secondary Unit Substation:** The utility system includes the medium voltage equipment, 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. **(Pole) 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 weatherhead (or equivalent).

4. **(Pole) 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 low voltage service disconnecting means.

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).

41 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*.

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

43 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.

44 Refer to Chapter 2 in IEEE Std 141™.

45 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.

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.[46]

B. If a building or occupied structure has more than one supply, each supply must be labelled with the location of every other disconnect supplying the building or structure.

2.4 Metering

2.4.1 General

Design electrical metering for the supply of each building.[47]

2.4.2 Meters

A. For electrical systems that require a meter, provide an addressable multi-function, microprocessor-based, digital electrical meter.

1. Meter type shall be determined by LANL Utilities and Infrastructure. Send email to umetering@lanl.gov to request direction which may differ from LANL Master Specifications Section 26 2713, *Electricity Metering.*

2. Buildings or structures requiring metering:

   a. Buildings over 5000 square feet.

   b. Buildings 5000 square feet or less with substantial loads.

   Exception to 2: Where the cost of the metering exceeds the benefit of the metering and POC and UI approval is obtained, metering is not required.

B. Refer to Section 26 2713, *Electricity Metering*, for additional material and installation requirements.

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

D. For electrical systems that are connected to the LANL distribution system but are billed for electrical services by Los Alamos County, contact the County to determine the appropriate meter.

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.[48] Provide a test switch in each potential circuit and a shorting type test switch in each current

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

47 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.

48 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.

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 equipment is not suitable to house meter, current transformers and potential transformers, locate a suitable metering enclosure(s) near the service 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 2713 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:[49]

1. HVAC
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.[49]

2.5 Surge Protection

2.5.1 General

A. Provide surge protective devices (SPDs) for low-voltage service and distribution equipment[50] as described in Section D5090 of this Chapter.

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

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[49] 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.

[50] Refer to IEEE Std 1100 §8.6 and NFPA 780 §4.18.

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[51] type switchgear assemblies, switchboards, or power panelboards located in dedicated electrical equipment rooms, except with Chapter POC written permission.

B. For new buildings, locate electrical distribution equipment in dedicated electrical rooms, or in a dedicated space.[52]

C. For service equipment, use low voltage switchgear, switchboards, or power panelboards that comply with *NEC*® requirements for service equipment, have a single main circuit breaker.[53]

D. 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.[54]

E. IEEE C37.20.1 switchgear rated 480V may be used on 480V or 480Y/277V systems.[54]

F. Select low-voltage distribution system switchgear, switchboards, or power panelboards to cost-effectively supply the loads. Use the following criteria for selecting equipment:[55]

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.

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.[56] *Some manufacturers offer fixed-mounted 1200 ampere frame-size electronic trip circuit breakers that weigh less than 42 lb.* Refer to LANL Master

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[51] LANL preference is circuit breaker overcurrent protection because of its inherent capability of rapid service restoration.

[52] In warehouses it is not always necessary to build a dedicated room; it is often typical to mount panels on walls and paint the floor to indicate the required working space. Likewise, it may not be possible in existing facilities.

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

[54] 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.

[55] 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.

[56] 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.

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.[57] 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.

G. Provide enclosures suitable for the locations where the equipment will be installed. Provide "door-in-door" fronts for indoor power panelboards.[58]

H. Provide at least the *NEC*®-required working space behind rear-accessible switchgear, switchboards, and panelboards to facilitate thermographic examination of the equipment.[59]

I. Locate panelboards, and design branch circuits and feeders, such that the overall voltage drop from the service, or main, equipment to the furthest outlet is no more than 5%.[60]

J. 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.[61]

K. Design 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.[62]

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:[63]

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.

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

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

59 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.

60 Incorporates VAR-10234, *Circuit Length Requirements for Voltage Drop*

61 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.

62 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.

63 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

C. Make provisions for future overcurrent protective devices to supply the electrical load growth specified under the "Calculations" heading in Section D5000. Provide not less than one space to accept a circuit breaker with frame size equal to the largest feeder circuit breaker. Provide additional spaces, as may be required, sized to 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. Schedule single-pole spaces to fill out each panelboard to 24, 30, or 42 space units.[64]
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 cubicles 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.[65] Refer to the "Calculations" heading in Section D5000.

1. For circuit breakers with incident energy greater than 40 cal/cm^2 on the line side, provide circuit breakers that are capable of operation with an 'umbilical cord' remote operator.[66]
2. Where necessary, use current-limiting circuit breakers to obtain required interrupting ratings higher than those obtainable with "high-interrupting" circuit breakers.[67]
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.[68]
5. Use 600V two-pole or three-pole circuit breakers in 480V and 480Y/277V equipment.[69]
6. *Consider the use of fuses for the following:*
   a. *Fused disconnects*
   b. *Arc-flash reduction – Current-limiting fuses can mitigate arc-flash on the load side of the fuse*

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64 Spare circuit breakers and open breaker spaces facilitate the orderly expansion of electrical use in the facility.
65 Refer to section 110.9 in the *NEC®*.
66 LANL P101-13, *Electrical Safety Program*
67 Current-limiting circuit breakers are available with 200 kA interrupting rating from 20 to 600 amperes.
68 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.
69 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.

c. *Maintenance reduction – Fuses are not subject to the same maintenance as are circuit breakers.*

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.[70]

C. Provide selectively coordinated overcurrent protection.[71] 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:[72]

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.[73] Use the following guidance for selecting ground fault protection settings:

1. *Service disconnect rated 1000 amperes*[74] *or more: Set ground fault pickup at 1200A, 0.5 second delay.*[75]
2. *Feeder devices set at 100 amperes or less (long-time setting): ground fault protection not required.*[76]
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.*
4. *Feeder devices set at over 1200 amperes (long-time setting): Set ground fault pickup at 1000 amperes, 0.3 second delay.*
5. *Consider using zone selective interlocking to minimize the arcing ground fault damage that may occur in the switchgear.*

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70 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.

71 Refer to Chapter 5 in IEEE Std 141™.

72 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.

73 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*®.

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

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

76 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.

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.[77]

B. Provide two printed, 8-1/2” x 11” circuit directories for each power panelboard as shown in Figure 5010-1.

Guidance: Panelboard schedules produced by other methods, such as commercial software, if the same information is provided.

Guidance: On Square-D I-Line panels, the schedule shown in Figure 5010-1 may not be adequate. On these panels, the sequence of ABC might not be the same on both sides and the circuit numbering might not be clear. Coordinate circuit numbering with the responsible facility system engineer.

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 that portion of the non-coincident loads that will be used at one time.[78]

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 ESM Section D5000 (*Para. 5.1*) or that has been determined in the project documents.

5. When a construction drawing package is being produced (e.g., new building or panel), include panel schedules on a sheet of the package.

6. *When modifying existing panels, the design should include a redline of the existing panel schedule. This redline could be a hand-sketch in a work package for a very simple job, a DCF sketch if that is the form of the design, or on a drawing sheet if the project is producing drawings.*

7. At turnover to operations, provide a printed 8 ½” x 11” copy and an electronic copy to the Facility Engineering Manager.[79]

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[77] Refer to *NEC®* Section 408.4.

[78] Incorporates VAR-2010-013, *Approved Alt Method for Load Calculations with Non-Coincident Loads*.

[79] The Facility Engineering 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. Drawing versus 8.5x11 considerations implement VAR-10016 for ESM.

8. Mount a plastic laminated copy inside the panelboard door, or, if the door has a plastic sleeve for this purpose, place a copy inside the sleeve.[80]

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.[61]

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. Isolated Ground Panelboards may only be used with the concurrence of the electrical standards point of contact.[81]

B. When isolated ground systems are installed, the following shall be considered:

1. Harmonics on the system, possibly requiring a larger neutral
2. Sizing of the isolated ground bus.[82]

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[80] 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.

[81] Restriction on isolated ground incorporates VAR-10139. Sometimes, manufacturers of equipment will request that the equipment be supplied by an isolated ground system. “Isolated ground,” however, has different definitions. For this reason, each request for an isolated ground system must be carefully considered as to the underlying concerns.

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

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

Figure 5010-1 Panelboard Schedule

2.6.7 Power Distribution Units (PDUs)

Provide power for computer equipment in raised floor information technology equipment rooms using factory-fabricated PDUs. *PDUs 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.*
Note: Although the PDUs come from the factory with isolated ground bars, they are not used. Isolated ground systems may only be installed with the concurrence of the LANL Electrical Standards POC.

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.[83]

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*.[84] *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).[84] *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.[83, 85]

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[83] 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.

[84] 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.

[85] 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 supply electronic load equipment. K-factor relates a transformer's ability to supply non-linear load without exceeding the rated temperature-rise limits.

B. Select K-factor based on manufacturer's recommendations and the following guidance:[86]

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 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:[87]

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.*[88]

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.[88]

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

87 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.

88 Information about special requirements for transformers serving three-phase converter loads is from the 1996 Square D "Dry-Type Transformers Selection Guide".

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*[89] or instructions from the transformer manufacturer. Use a solar radiation value[90] 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 supplied.[91]

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.[92]

C. Design transformer secondary conductors and connections so they can be safely installed, tested, and maintained.[93]

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.[94]

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*

89 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.
90 Refer to Los Alamos Climatology (LA-11735-MS).
91 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 supplied.
92 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.
93 Lesson learned from several LANL design-build construction projects.
94 Clearance data is collected from manufacturer's installation instructions.

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 grounding electrode systems that meet the requirements of the NEC.

B. For new structures with concrete footing, install a concrete-encased main grounding electrode in the lower part of the perimeter strip footing or grade beam for a minimum of 20 feet in length.[95] Use one of the following materials for the electrode:

1. Use a bare-copper conductor not smaller than 4 AWG.[96]
2. Use bare or galvanized perimeter concrete reinforcing bars that are made electrically continuous, per NEC 250.52(A)(3).
3. For new structures without a concrete-encased electrode, install a grounding electrode system per the New Mexico Electrical code.
4. For new structures bond each perimeter structural steel column to the main grounding electrode described above.[97]
   a. Use bond conductors that are not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG.[96]
   b. Make bonding connection directly to the steel column using an exothermic weld or a hydraulically compressed fitting that meets IEEE 837 requirements.[98]
5. For modifications to existing structures, check to see if an electrical grounding electrode system exists.
   a. If there does not appear to be an electrical grounding electrode system, contact the LANL Electrical Standards POC for further direction.
   b. If the structure has a lightning protection system, verify that the main grounding electrode is a separate electrode from that used for lightning protection.[99]

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

96 Section 250.52(A)(3) and 250.66 in the *NEC*® sets 4 AWG as minimum size concrete-encased grounding electrode

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

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

99 Section 250.60 in *NEC*® requires that the lightning protection electrical system grounding electrode system be separate from (but bonded to) the electrical system lightning protection grounding electrode system. The bonding between the two systems should occur on the outside of the building.

6. Install a main grounding electrode bar adjacent to the service, or main, equipment; use the main grounding electrode bar as a point for bonding the grounding electrode system, power systems, separately derived systems, communications systems, piping systems, and structural steel.[100]

   a. Refer to LANL Master Specifications Section 26 0526 *Grounding and Bonding for Electrical Systems* for ground bar material and installation requirements.

   b. Connect the grounding electrode bar to the grounding electrode system using unspliced copper cable and irreversible connectors. (either exothermic welds or IEEE Std 837 compression lugs).

   c. 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.[101] 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.[102]

   d. Label each connection to the main grounding electrode bar or extensions.[103]

7. Bond building structural steel, interior metallic piping systems, and exterior metal water piping systems to the main grounding electrode bar using copper conductors, listed pipe clamps, exothermic welds, and compression lugs that meet requirements of IEEE Std 837.[100] Use bonding conductors that are not smaller than the grounding electrode conductor required in the *NEC*® and not smaller than 4 AWG.

8. Bond the lightning protection grounding electrode system to the building grounding electrode system at the main grounding electrode bar using a 600V insulated 4/0 AWG conductor and compression lugs that meet IEEE Std 837 requirements.[104]

2.8.3 System Grounding

A. Connect the service equipment ground bus to the main grounding electrode bar with unspliced grounding conductor sized per *NEC*® Table 250.66.[105]

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

101 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*®.

102 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.

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

104 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.

105 NEC Section 250.24(A)(4) permits connecting the grounding electrode conductor to the equipment ground bar if main bonding jumper is a wire or bus bar.

B. In the service equipment, connect the system grounded conductor bus to the equipment ground bus with a system bonding jumper sized per *NEC®* Table 250.102(C)(1), or use the factory furnished bonding screw or strap.

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.[106] If neither grounding electrode is available, install a main grounding electrode bar extension near the separately derived system disconnecting means.[101]
3. Connect low-voltage distribution transformer's ground terminal bus to the ground described above using un-spliced grounding conductor sized per NEC® Table 250.66, based on the derived system conductor size.[107]
4. Connect low-voltage distribution transformer's grounded conductor to the transformer's ground terminal bus with a system bonding jumper sized per NEC® Table 250.102(C)(1).
5. Bond the grounded conductor to all interior metallic piping systems in the area supplied by the separately derived system in accordance with *NEC®* requirements.[108] *Guidance: If this is already done at the service location, there is no need to repeat this at each separately derived system. Repeating these connections will cause circulating currents (objectionable current) resulting in power quality issues.*

2.8.4 Enclosure and Equipment Grounding

A. Install an NRTL-listed equipment ground bar or ground lug in each item of electrical equipment. The ground bar must be listed as a component of the panel or equipment and must be installed per the manufacturer's instructions. All connections must be per NEC 250.8.[109]

B. Install a 600 volt insulated (green) equipment ground conductor in each feeder raceway.[110] An equipment-grounding conductor shall not be installed in a service raceway.

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.[111]

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

107 The 2014 NEC first required the installation of a ground terminal bar in the transformer enclosure. Because of this new requirement the system bounding location is now to be in the transformer

108 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 supplied by the separately derived system to provide additional safety.

109 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.

110 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. Isolated grounding systems may only be installed with the concurrence of the electrical standards POC.

1. Install isolated grounding systems for computer and laboratory instrument power systems that are susceptible to common-mode noise.[112] Refer to Section 2.1 of this Section for guidance in establishing isolated ground power systems.
2. In addition to the equipment ground bar, install an insulated isolated ground bar in switchboards and panelboards supplying isolated ground circuits.[113]
3. 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.[105]
4. In addition to the equipment-grounding conductor, install a dedicated 600-volt insulated (green/yellow) isolated ground conductor for each isolated ground feeder.[113]
   a. Make isolated ground conductors the same size as the phase conductors.[114]
   b. Connect the isolated ground conductors to the isolated ground bars in switchboards and panelboards.[113]

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:[115]

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 lbs.

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

112 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™.

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

114 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.

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

- 1000 lbs. per basket grip.

2. Sidewall pressure: 500 lbs/ft.
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 raceways and cable tray sections on the construction and project record (or as-built) drawings.

E. Provide concrete-encasement for underground low-voltage service and feeder conduits where indicated on drawings. Provide warning tape for underground low-voltage conduits that are not concrete-encased. For concrete-encased duct banks, provide not less than 7.5 inches center-to-center separation of conduits. 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.*

F. When penetrating radiation shielding or permanent contamination zones, install raceways with sufficient bends, curvature, or shielding to prevent radiation streaming through the void.[116]

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. *Guidance: For minor work[117] in existing facilities use wiring color codes that match existing color codes, if possible, so long as National Electrical Code® requirements for identifying grounded and grounding conductors are satisfied.[118] Some facilities have multiple color schemes and so matching is not possible.*

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

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116 DOE 6430.1A, Section 1300-6.2, Shielding Design, stated that straight-line penetration of shield walls shall be avoided to prevent radiation streaming.

117 Refer to ESM Chapter 7, D5000, 1.0-E.4.

118 Refer to *NEC*® Sections 200.6 and 250.119.

Note: Color codes are essential for installation[119] (e.g., to distinguish different voltage systems); however, they are not meant to endure for the life of the facility, nor can color codes in existing facilities be expected to match current requirements.

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.[120]

B. For power wiring, use minimum 12 AWG conductors.[121]

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

1. copper conductors, or

2. where 8 AWG or larger, AA-8000[122] compact stranded aluminum conductors.[123] *Guidance: If aluminum conductors are used, care must be taken to ensure all installation requirements of the NEC are met. For example, bending space inside equipment, compliance with equipment markings, and appropriate terminations.*

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

E. Before using conductors larger than 600 kcmil copper or 750 kcmil aluminum, consult with the ESM Electrical POC.

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

G. 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%.[124]

1. Use voltage drop calculation methods outlined in Chapter 3 of IEEE Std 141™.

H. 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.[125]

I. Use the following factors in conjunction with *NEC*® Annex B, the Neher-McGrath formula[126], IEEE Std 835 – *IEEE Standard Power Cable Ampacity Tables*,

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[119] LANL uses brown/orange/yellow for 480/277 volt systems and black/red/blue for 208/120 volt systems.
[120] Adjustments for raceway fill, ambient temperature, and harmonics are required in *NEC*® Article 310-15.
[121] The use of minimum 12 AWG on branch circuits limits voltage drop.
[122] Refer to ASTM B801 *Standard Specification for Concentric-Lay-Stranded Conductors of 8000 Series Aluminum Alloy for Subsequent Covering or Insulation.*
[123] 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. NMAC limits use to 8 AWG and larger.
[124] Reflects NEC recommendation/ASHRAE 90.1 req't; incorporates VAR-10200.
[125] Lesson learned from LANL construction projects. 5 years simple payback is a common acceptance criterion for energy-saving investments.
[126] Refer to *NEC*® Section 310.15(C) and associated discussion in the *NEC Handbook*.

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:[127]

1. Concrete thermal resistivity (Rho) of 55°C-cm/watt.
2. Soil thermal resistivity (Rho) of 225°C-cm/watt unless otherwise measured in accordance with ANSI/IEEE Std 442 *Guide for Soil Thermal Resistivity Measurements*.[24] *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.[128]
4. Ambient earth temperature of 30°C within the perimeter of a heated building.[129]
5. Load factor of 100 percent unless determined by measurement or approved calculations.

J. For raceways exposed to sunlight on roofs, the raceways shall be a minimum of 7/8 inch above the roof surface.[130]

K. Size feeders supplying switchgear, switchboards, motor control centers, and panelboards to at least match the load bus or load circuit breaker rating.[131]

L. 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.[132]

2.10.3 Enclosed Bus Assemblies

A. Consider enclosed bus assemblies for circuits rated 800 amperes and larger.[133] *Note: Refer to LANL Master Specifications Section 26 2500, Enclosed Bus Assemblies, for materials and installation methods.*

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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127 Refer to *NEC®* Appendix B and associated discussion in the *NEC Handbook*.
128 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.
129 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.
130 Raceways installed closer than 7/8 inch to the roof surface are subject to an addition derating of ampacity for the enclosed conductors.
131 Matching the load bus to the feeder ampacity reduces uncertainty in the field about the true capacity available at panelboards, switchboards, transformers, etc.
132 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*.
133 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 accommodate 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.[134]

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

D. 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-torqueing using a standard torque wrench. Provide access doors as required.[135]

[134] IEEE Std 141 Section 13.8.
[135] Refer to NFPA 70B section 24.4.