NOT MEASUREMENT SENSITIVE

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DOE HANDBOOK
ELECTRICAL SAFETY

U.S. Department of Energy
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AREA SAFT

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1.0 INTRODUCTION

2.0 GENERAL REQUIREMENTS

3.0 HAZARD ANALYSIS

3.1 INTRODUCTION

This chapter provides tools for assessing electrical hazards (Step 2 of ISM), and provides the recommended controls for mitigating those hazards (Step 3 of ISM). The risk of a worker to an exposed electrical hazard is determined by (a) the classification of the electrical hazard due to its potential for injury, (b) the state of the electrical equipment, and (c) the distance of the worker from the exposed electrical hazard. Section 3.2 presents various types of electrical injury, Section 3.3 presents the 4 Modes of Work on electrical equipment, and Section 3.4 presents the boundaries associated with the distance of the worker from the exposed electrical hazard. Section 3.5 presents methods of shock and arc flash analyses for ac facility power and dc R&D power. Section 3.6 presents the types of controls used to protect the worker from exposed electrical hazards. Finally, Section 3.7 classifies electrical hazards as determined by the possible injury, and provides the recommended controls for mitigation of the hazard for the various Modes of Work on Electrical Equipment. This classification in Section 3.7 is not to be confused with the hazard risk categories for personal protective equipment defined in NFPA 70E.

3.1.1 Purpose

The purpose of this chapter is to provide qualified workers and others guidance for the "Analyze the Hazard" step of DOE's Integrated Safety Management (ISM), and to give recommendations for the controls to be implemented in the "Develop the Controls" step of ISM.

3.1.2 Scope

An assessment of the electrical hazards shall be performed for all work that requires employees to work on or near exposed electrical conductors or circuit parts. The assessment should be done by a qualified worker to determine the required safety-related work practices.

When an electrical hazard exists, the exposed circuit parts shall be placed into an electrically safe work condition unless it is infeasible to do so.

There are requirements for de-energization and verification for some classes of electrical hazards. If the work must be done with a hazardous circuit energized, safety-related work practices and procedures must be followed to eliminate or control the electrical hazards.

Hazard assessments must consider equipment failure modes, possible accidents, documentation inadequacies, procedural failure, and human error.

This chapter does not provide an exhaustive list of sources of electrical energy and their associated hazards and controls but provides the framework for categorizing those hazards to provide for enhanced worker safety.

3.2 ELECTRICAL HAZARDS

There are numerous injury mechanisms from exposure of a worker to electrical energy. This section briefly presents the various types of injury.

3.2.1 Electrical Shock

Electricity is one of the most commonly encountered hazards in any facility. Under normal conditions, safety features (engineering controls) built into electrical equipment protect workers from shock. Shock is the flow of electrical current through any portion of the worker's body from an external source. Accidents can occur in which contact with electricity results in serious injury or death.

Most electrical systems establish a voltage reference point by connecting a portion of the system to an earth ground. Because these systems use conductors that have electrical potential (voltage) with respect to ground, a shock hazard exists for workers who are in contact with the earth and exposed to the conductors. If a person comes in contact with a energized (ungrounded) conductor while also in contact with a grounded object, an alternate path to ground is formed in which current passes through his or her body.

The effects of electric current on the human body depend on many variables, including the following:

- amount of current
- waveform of the current (e.g., DC, 60 Hz AC, RF, impulse)
- current's pathway through the body (determined by contact location and internal body chemistry)
- duration of shock

The amount of current passing through the body depends on:

- voltage driving the current through the body
- circuit characteristics (impedance, stored electrical energy)
- frequency of the current
- contact resistance and internal resistance of the body
- environmental conditions affecting the body's contact resistance

The heart and brain are the parts of the body most vulnerable to electric shock. Fatal ventricular fibrillation (disruption of the heart's rhythmic pumping action) can be initiated by a current flow of as little as 40 milliamperes. Without immediate emergency resuscitation, electrical shock can cause fatality from direct paralysis of the respiratory system, disruption of rhythmic pumping action, or immediate heart stoppage. Severe injuries, such as deep internal burns, can occur, even if the current does not pass through vital organs or the central nervous system. Specific values for hazardous voltages and for hazardous current flow through the body are not completely reliable because of physiological differences between people.

There are four principal electrical waveforms of interest that cause various responses to electrical shock;

1. AC power frequencies
2. DC
3. radio frequencies (RF)
4. impulse shock (such as from a capacitor circuit)

The most dangerous are AC power frequencies, 50 or 60 Hz. Exposure to current at these frequencies causes ventricular fibrillation at the lowest thresholds and causes severe contraction of the muscles with a possible no-let-go response.

Exposure to DC electric currents can also cause a muscle response at first contact and when releasing, as well as heart fatigue and failure at high enough current levels. Radio frequencies (3 kHz to 100 MHz) have decreasing neurological effects with increasing frequency, but energy deposited results in tissue burning.

The resistance of the body is much less if the skin is punctured by a shock above the skin breakdown threshold (400 to 500 V). This allows higher current flow through the body, resulting in more damage. The amount and duration of current flow will determine the severity of the reflex action, the amount of damage to the heart, and neurological and other tissue.

Reflex action occurs when electric current causes a violent contraction of the muscles. Such contraction can result in violent recoil, resulting in falling from heights, recoiling into a nearby hazard, or violent muscle contractions resulting in broken bones, torn ligaments, or dislocated joints. Reflex action is enhanced by high voltage shock as the energy can be delivered more quickly from higher instantaneous currents.

A no-let-go response occurs when continuous shock current keeps the muscles violently contracting such that the victim is clutching the conductor without any ability to release. Because of the effects of the waveform on the body's response, the thresholds for acceptable shock vary depending on the form of the electricity. Acceptable means that below these thresholds there is no injury, and above these thresholds there could be injury. The thresholds are listed in Table 3-1 and are found imbedded in the Hazard Classification Charts in Section 3-6. Add explanatory note on classes

Table 3-1. Thresholds for defining shock hazards.

Source	Includes	Thresholds	Hazard Classes
AC	50 and 60 Hz, sub-RF 1 Hz to 3 kHz	≥ 50 V and ≥ 5 mA	1.2, 1.3, 1.4, 1.5 2.2b, 2.2c, 2.2d, 2.3, 2.4
DC	all	≥ 100 V and ≥ 40 mA	2.2c, 2.2d, 2.3, 2.4
Capacitors	all	≥ 100 V and ≥ 1 J	3.2b, 3.3b, 3.3c, 3.3d, 3.3e, 3.4b, 3.4c, 3.4d
Batteries	all	≥ 100 V	Could be in any Class, 4.0, 4.1, 4.2, 4.3
RF	3 kHz to 100 MHz	A function of frequency	5.2a, 5.2b

NOTES:

1. It is possible for a worker to be exposed to more than one shock hazard at any given location (e.g. multiple types of sources).
2. There may be other electrical hazards below the above shock thresholds (e.g., a thermal burn hazard). See Table 3-3.

3. Injuries may result from startle reactions due to contact with energized components, even though the source energy is too low to do physical damage, such as high voltage/low current circuits (e.g., Classes 2.1d and 3.1d).
4. Shock and burn hazards from induced and contact RF currents become negligible above 100 MHz (but radiated hazards still exist).

3.2.2 Electrical Burn

Burns suffered in electrical accidents are of three basic types: electrical burns, arc burns, and thermal contact burns. The cause of each type of burn is different, and prevention requires different controls.

3.2.2.1 Electrical Burns

In electrical burns, tissue damage (whether skin-level or internal) occurs because the body is unable to dissipate the heat from the current flow. Typically, electrical burns are slow to heal. Such electrical burns result from shock currents, and thus adhering to the shock current thresholds in Table 3-1 will prevent electrical burns.

3.2.2.2 Arc Flash Burns

Arc flash burns are caused by electric arcs and are similar to heat burns from high-temperature sources. Temperatures generated by electric arcs can melt nearby material, vaporize metal in close vicinity, and burn flesh and ignite clothing at distances of several meters, depending on the energy deposited into the arc. The arc can be a stable low-voltage arc, such as in an arc welder, or a short-circuit arc at higher voltage, resulting in an arc flash and/or arc blast. Such an expanding arc can ignite clothing and/or cause severe burns at a distance from centimeters (cm) to meters (m). The Flash Protection Boundary is defined to characterize the distance at which this injury mechanism is severe. Hazard Classes that include arc flash hazards are given in Table 3-2. The current values are the short circuit available currents, or fault currents.

Table 3-2. Thresholds for defining arc flash hazards.

Source	Includes	Thresholds	Hazard Classes
AC (facility)	50 and 60 Hz	Thresholds may be determined using formulas in IEEE Std 1584,Table E.1	1.2, 1.3, 1.4, 1.5
Sub RF	1 Hz–3 kHz	> 250 V and > 500 A	2.4
DC	all	> 250 V and > 500 A	2.4
Capacitors	all	> 100 V and > 10 kJ	3.4b, 3.4d
Batteries	all	> 250 V and > 500 A	4.3
RF	NA	Not Applicable (NA)	

3.2.2.3 Arc Blast Hazards

A rapid delivery of electrical energy into an arc can cause additional hazards not covered by arc flash hazards. The acoustical shock wave, or arc blast pressure wave, can burst eardrums at lower levels and can cause cardiac arrest at high enough levels. In addition, high currents (> 100 kA) can cause strong magnetic forces on current carrying conductors, which can lead to equipment destruction, or the whipping of conductors. Such arc blast hazards are of particular concern in high-energy facility power circuits (Classes 1.3d, 1.4, and 1.5) and large capacitor banks (Class 3.4d).

3.2.2.4 Thermal Contact Burns

Thermal contact burns are those that occur when skin comes into contact with the hot surfaces of overheated electrical conductors, including conductive tools and jewelry. This injury requires close proximity to a high-current source with a conductive object. Thermal burns can occur from low-voltage/high-current systems that do not present shock or arc flash hazards, and controls should be considered. The controls to prevent injury from shock and arc flash will also protect against thermal contact burn. High-current hazard classes with thermal burn hazards are given in Table 3-3.

Table 3-3. Thermal contact burn hazards, not included in shock and arc flash hazards.

Source	Includes	Thresholds	Hazard Classes
AC, R&D	1 Hz–3 kHz	< 50 V and ≥ 1000 W	2.2b
DC	all	< 100 V and ≥ 1000 W	2.2a, 2.2b
Capacitors	all	< 100 V and ≥ 100 J	3.2a, 3.3a, 3.4a
Batteries	all	< 100 V and ≥ 1000 W	4.2, 4.3
RF	NA	NA	

3.2.3 Delayed Effects

Damage to the internal tissues may not be apparent immediately after contact with electrical current. Delayed swelling and irritation of internal tissues are possible. In addition, imperceptible heart arrhythmia can progress to ventricular fibrillation. In some cases, workers have died two to four hours after what appeared to be a mild electrical shock. **Immediate medical attention may prevent death or minimize permanent injury. All electrical shocks shall be reported immediately.**

3.2.4 Battery Hazards

During maintenance or other work on batteries and battery banks, there are electrical and physical hazards that shall be considered. In addition, when working near or on flooded lead-acid storage batteries additional chemical and explosion hazards shall be considered. The hazards associated with various types of batteries and battery banks include the following:

- electric shock
- burns and shrapnel-related injuries from a short circuit
- chemical burns from electrolyte spills or from battery surface contamination
- fire or explosion due to hydrogen
- physical injury from lifting or handling the cells
- fire from overheated electrical components.

3.2.5 Other Hazards

Low-voltage circuits, which are not hazardous themselves, are frequently used adjacent to hazardous circuits. A minor shock can cause a worker to rebound into the hazardous circuit. Such an involuntary reaction may also result in bruises, bone fractures, and even death from collisions or falls. The hazard is due to the secondary effects of the reflex action.

An arc may form when a short circuit occurs between two conductors of differing potential, or when two conductors carrying current are separated, such as a safety switch attempting to interrupt the current. If the current involved is high enough, the arc can cause injury, ignite flammable materials or initiate an explosion in combustible or explosive atmospheres. Injury to personnel can result from the arc flash, or arc blast, resulting in severe burns to exposed skin, or ignition of clothing. Equipment or conductors overheat due to overload may ignite flammable materials. Extremely high-energy arcs can cause an arc blast that sends shrapnel flying in all directions.

R&D equipment is often unique. An uncommon or unique design can be difficult to analyze for hazard identification. The hazard analysis should include shock, potential arc or thermal sources. Acoustic shock wave, pressure shock wave and shrapnel are potential hazards.

Once the hazards have been identified, a risk mitigation plan should be developed. Personnel working on unique R&D equipment must be specifically qualified through training specific to the work to be done. The scope of such additional training depends on the hazards associated with the equipment.

3.3 MODES OF WORK ON ELECTRICAL EQUIPMENT

Under normal operation of listed or approved electrical equipment the user/operator is protected by engineering controls, including insulation, enclosures, barriers, grounds and other methods to prevent injury. When engineering controls are not yet in place, not approved, or removed for diagnostics, maintenance, or repair, the activity will fall into one of the following categories:

Mode 0 – Electrically Safe Work Condition

Mode 1 – Establishing an Electrically Safe Work Condition

Mode 3 – Energized Diagnostics and Testing

Mode 4 – Energized Work

3.3.1 Mode 0 – Electrically Safe Work Condition

An Electrically Safe Work Condition is a state in which the conductor (s) or circuit part (s) to be worked on or near have been (1) disconnected and isolated from a hazardous energized source or parts; (2) locked/tagged out (or equivalent) in accordance with established standards; (3) tested to ensure the absence of voltage; and (4) grounded if determined necessary. All work on hazardous electrical systems shall be done in a electrically safe work condition unless there is a compelling reason as defined in this chapter.

3.3.2 Mode 1 – Establishing an Electrically Safe Work Condition

To achieve Mode 0, an electrically safe work condition, a worker conducts Mode 1 work. If the Mode 1 process exposes the worker to any hazard, the activity must be covered by work control procedures, and a hazard analysis must be performed. The work is energized electrical work, as covered by Mode 1, until an electrically safe work condition is achieved (Mode 0). This Mode does NOT require an Energized Electrical Work Permit (EEWP). To establish an electrically safe work condition, a qualified person uses the following procedure:

1. Determine all sources of electrical supply to the specific equipment.
2. Check applicable drawings, diagrams, and identification tags, including equipment specific LOTO procedures.
3. Turn off equipment.
4. Don correct PPE and establish barricades as necessary for access control.
5. Open the disconnecting means (e.g., plug, breaker, or disconnect device).
6. If it is possible, visually verify that the plug is fully removed, all blades of the disconnecting devices are fully open, or that draw-out type circuit breakers are withdrawn to the fully disconnected position.
7. If applicable, test the controls and attempt to restart the equipment.
8. Apply lockout/tagout devices, assure that the plug is in total control of the worker, or use other engineering controls that are approved by the Authority Having Jurisdiction (such as capture key control systems that have been approved).
9. If grounds have not been applied, use a correctly rated voltmeter to test each normally energized conductor or circuit part to verify they are de-energized, Note: for high voltage or large capacitive systems using a correctly rated voltmeter may not be a safe procedure, skip this step for such systems and go to step 11.
10. If the possibility of induced voltages exists, apply grounds to the normally energized conductors or circuit parts before touching them.
11. If stored electrical energy exists (e.g., capacitors), discharge or remove the stored energy and apply grounds to the normally energized conductors.

3.3.3 Mode 2 – Energized Diagnostics and Testing

In Mode 2 measurements, diagnostics, testing, and observation of equipment functions are conducted with the equipment energized and with some or all of the normal protective barriers removed and interlocks bypassed. Verification of a safe condition with a voltage rated instrument is covered by the Mode 1 process and is not considered Mode 2.

Work is considered Mode 2 if proper voltage rated instruments are used to contact the energized conductors. If any portion of the worker's body passes the Restricted Approach Boundary then appropriate shock PPE must be worn. If any portion of the worker's body passes the Prohibited Approach Boundary then this is considered Mode 3, Energized Work, and the appropriate controls must be in place (see Section 2.4). If any portion of the worker's body passes the Arc Flash Boundary then the appropriate arc flash PPE must be worn.

An approved work control document may be required (see individual tables in Section 3.6). Authorization by the worker's safety-responsible line manager is required. The use of appropriate Personal Protective Equipment (PPE) may be required. Some examples of Mode 2 operations are:

- making voltage measurements with a multimeter on energized components
- performing tests while working in close proximity to exposed energized components
- following manufacturer's instructions for diagnostics and troubleshooting of energized circuits
- working on experimental facilities that operate in this mode.

Performing Mode 2 work does not require an EEWP.

3.3.4 Mode 3 – Energized Work

Mode 3 operations involve physically moving energized conductors and parts, or moving parts that are near energized conductors (within the Prohibited Boundary), and are conducted with the equipment fully energized and with some or all of the normal protective barriers removed.

Mode 3 work in Hazard Classification categories above X.0 and X.1 shall be treated as an electrical hazard that shall be permitted only when justified by a compelling reason. Tasks performed in this mode shall be conducted under close supervision and control. Work control with an approved EEWP is required, with exceptions as indicated in the hazard classification tables.

Energized Work is permitted only if:

1. Additional or increased hazards would exist due to establishing an electrically safe work condition;

2. Equipment design or operational limitations make it infeasible to perform the work in a deenergized state; or

3. If all exposed energized conductors and parts operate at 50 V or less with respect to ground.

An Energized Electrical Work Permit shall include, but not be limited to:

1. A description of the circuit and equipment to be worked on and their location;

2. Justification for why the work must be performed in an energized condition;

3. A description of the safe work practices to be employed;

4. Results of the shock hazard analysis;

5. Determination of shock protection boundaries;

6. Results of the arc hazard analysis;

7. The arc flash protection boundary;

8. The necessary Personnel Protective Equipment to safely perform the assigned task;

9. Means employed to restrict the access of unqualified persons from the work area;

10. Evidence of completion of a job briefing, including a discussion of any job-specific hazards; and

11. Energized work approval (authorizing or responsible management, safety officer, owner, etc.)

3.4 APPROACH BOUNDARIES

The risk to a worker from an exposed electrical source of energy is determined by the proximity of the worker to the hazard. Electrical shock is a function of voltage, as air breakdown distances increase with higher voltages. Arc flash injury is determined by the distance that the arc flash energy, including ionized gas and metal, can injure the worker. Burn injury from contact with hot conductors has no boundary, as contact, or near contact is required for injury.

There are three approach boundaries for shock protection:

1. the Limited Approach Boundary
2. the Restricted Approach Boundary
3. the Prohibited Approach Boundary.

As shown in Figure 3-1, and as defined in the 5efinitions (Appendix B), these three boundaries are encountered as a worker approaches an exposed, energized electrical conductor.

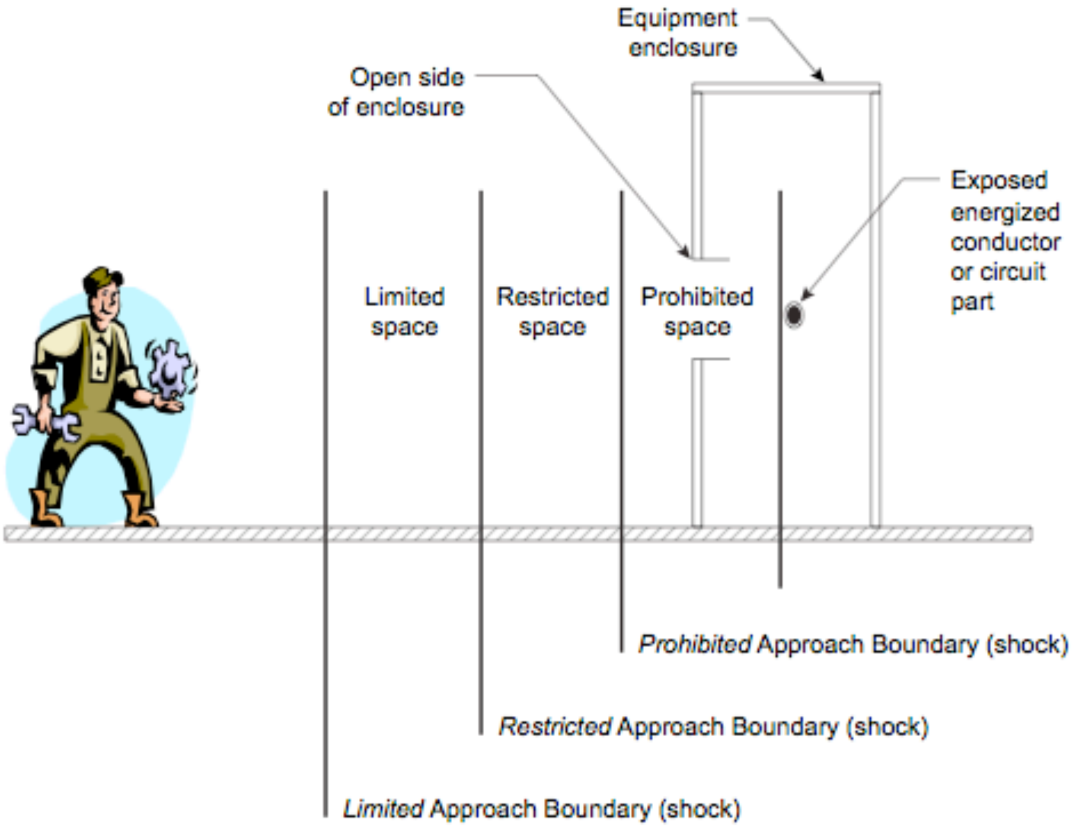


Fig. 3-1. Approach boundaries for an exposed, energized conductor.

The arc flash boundary is the distance from an exposed, energized conductor that could result in a second degree burn to the worker, should an arc occur at that conductor. In general, the arc flash boundary is determined by the available fault current and the time to clear the fault, which determines the energy deposited into the arc. The arc flash boundary may be inside or outside the approach boundaries. Figure 3-2 shows an arc flash boundary that is outside of the Limited Approach Boundary, as is typical with many facility circuits, and Fig. 3-3 shows an arc flash boundary that is inside the Prohibited Approach Boundary, as is common with many high voltage, low energy R&D circuits.

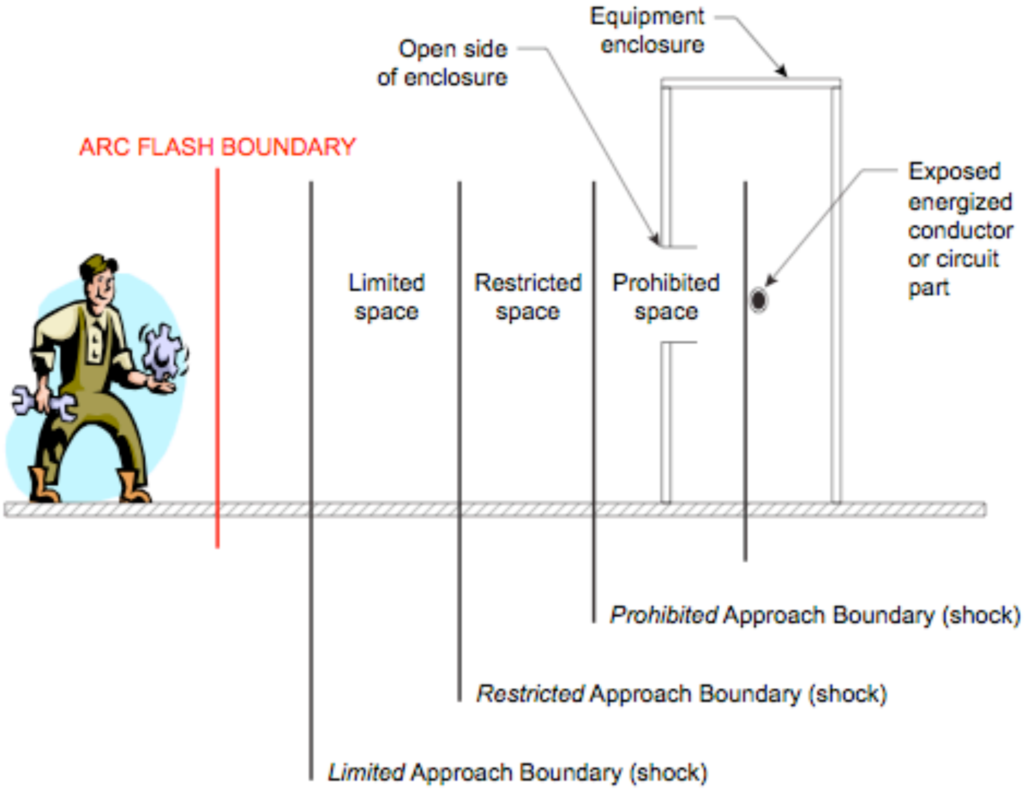


Fig. 3-2. Arc flash boundary outside of the limited approach boundary.

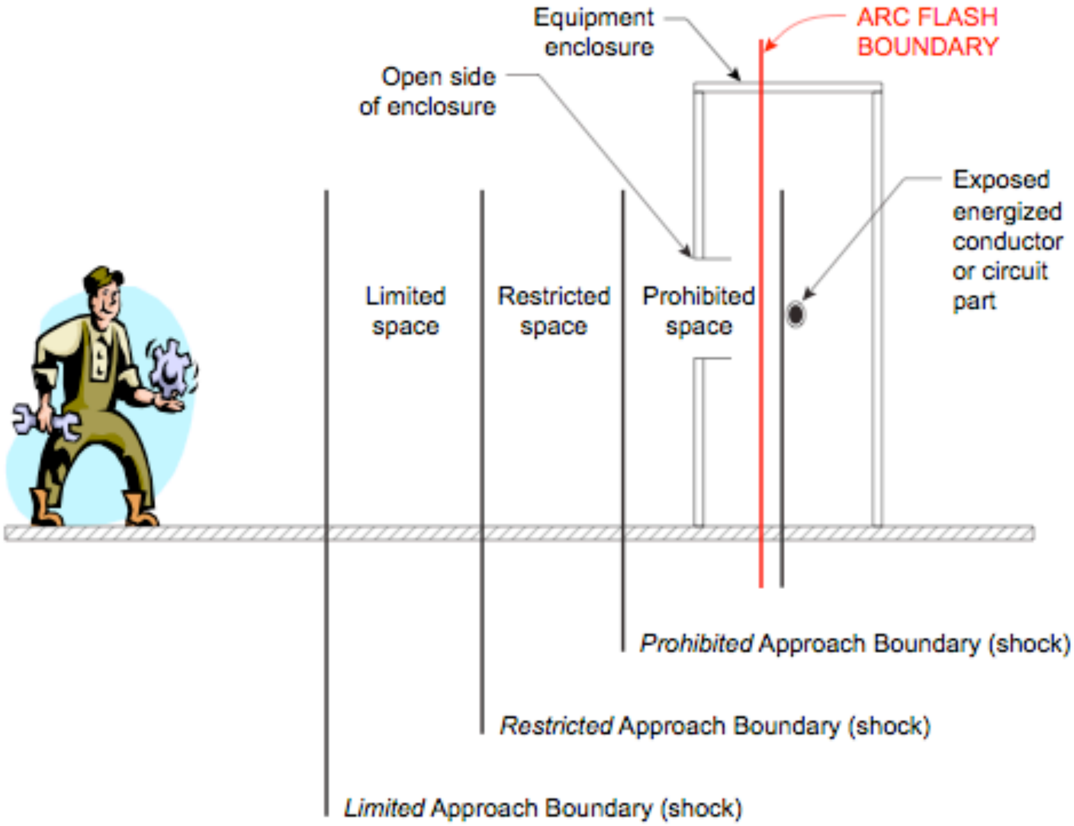


Fig. 3-3. Arc flash boundary inside of the prohibited approach boundary.

Shock and arc flash boundary analysis shall be done by a qualified person. For facilities, the principal reference for shock and arc flash boundary analysis is NFPA 70E, which covers facility shock and arc flash hazards. In addition, IEEE 1584, *Guide for Performing Arc Flash Hazard Calculations*, provides tools for calculating the arc flash boundary. Specialized system knowledge and methods may be necessary to calculate the shock and arc flash boundaries for R&D equipment, such as DC or capacitor systems, as methods are not available in existing codes and standards.

3.5 ELECTRICAL HAZARD ANALYSIS

3.5.1 Approach Boundary Analysis for 50/60 Hz AC

Approach boundary analysis (including the determination of the Limited, Restricted, and Prohibited Shock Boundaries) is based on the voltage of the exposed conductor relative to ground. Approach boundary tables are found in NFPA 70E for 60 Hz AC. Table 3-4 is taken from NFPA 70E, Table 130.2(C).

Table 3-4. Approach boundaries to energized electrical conductors or circuit parts for shock protection, 50/60 Hz AC.

(1)	(2)	(3)	(4)	(5)
Nominal System Voltage Range, Phase to Phase	Limited Approach Boundary		Restricted Approach Boundary	Prohibited Approach Boundary
	Exposed Movable Conductor[1]	Exposed Fixed Circuit Part[2]		
< 50	Not specified	Not specified	Not specified	Not specified
50 – 300 V	3.05 m (10’0”)	1.07 m (3’6”)	Avoid contact	Avoid contact
301 – 750 V	3.05 m (10’0”)	1.07 m (3’6”)	304 mm (1’0”)	25 mm (0’1”)
751 V – 15 kV	3.05 m (10’0”)	1.53 m (5’0”)	660 mm (2’2”)	178 mm (0’7”)
15.1 – 36 kV	3.05 m (10’0”)	1.83 m (6’0”)	787 mm (2’7”)	254 mm (0’10”)
36.1 – 46 kV	3.05 m (10’0”)	2.44 m (8’0”)	838 mm (2’9”)	432 mm (1’5”)
46.1 – 72.5 kV	3.05 m (10’0”)	2.44 m (8’0”)	1.0 m (3’3”)	660 mm (2’2”)
72.6 – 121 kV[3]	3.25 m (10’8”)	2.44 m (8’0”)	1.02 m (3’4”)	838 mm (2’9”)
138 – 145 kV	3.36 m (11’0”)	3.05 m (10’0”)	1.15 m (3’10”)	1.02 m (3’4”)
161 – 169 kV	3.56 m (11’8”)	3.56 m (11’8”)	1.29 m (4’3”)	1.14 m (3’9”)
230 – 242 kV	3.97 m (13’0”)	3.97 m (13’0”)	1.71 m (5’8”)	1.57 m (5’2”)
345 – 362 kV	4.68 m (15’4”)	4.68 m (15’4”)	2.77 m (9’2”)	2.79 m (8’8”)
500 - 550 kV	5.8 m (19’0”)	5.8 m (19’0”)	3.61 m (11’10”)	3.54 m (11’4”)
765 – 800 kV	7.24 m (23’9”)	7.24 m (23’9”)	4.84 m (15’11”)	4.7 m (15’5”)

NOTES:

[1] Exposed Movable Conductor means that the bare conductor can move (e.g., an overhead transmission line conductor). This is unlikely indoors.

[2] Exposed Fixed Circuit Part means that the bare conductor or other circuit part is stationary and will not move. This is the most common Limited Approach Boundary value used.

[3] It is unlikely that a worker will work near exposed conductors over 100 kV.

3.5.2 Approach Boundary Analysis for DC

Approach Boundary values for DC are not found in NFPA 70E, but can be inferred because the principles of air breakdown distance are similar. Differences in the physics of air gap break-down from 60 Hz AC to DC are small compared to the conservative values chosen for the boundaries. To determine a similar value for DC, the AC phase to phase voltage was converted to peak of a phase to ground. This would give a value that is 0.82 x value of the phase to phase voltage used in NFPA 70E. The higher voltage values from NFPA 70E were used and are more conservative. Table 3-5 gives approach boundaries to energized electrical conductors or circuit parts for DC, which are applicable to DC circuits, batteries, and capacitors. Notes help to explain the content and use of the table.

Table 3-5. Approach boundaries to energized electrical conductors or circuit parts for shock protection, DC.

(1)	(2)	(3)	(4)	(5)
Nominal Voltage Conductor to Ground	Limited Approach Boundary		Restricted Approach Boundary	Prohibited Approach Boundary
	Exposed Movable Conductor[1]	Exposed Fixed Circuit Part[2]		
< 100 V	Not specified	Not specified	Not specified	Not specified
100 – 300 V	3.05 m (10'0")	1.07 m (3'6")	Avoid contact	Avoid contact
301 V – 1 kV	3.05 m (10'0")	1.07 m (3'6")	304 mm (1'0")	25 mm (0'1")
1 kV – 5 kV	3.05 m (10'0")	1.53 m (5'0")	450 mm (1'7")	100 mm (0'4")
5 kV – 15 kV	3.05 m (10'0")	1.53 m (5'0")	660 mm (2'2")	178 mm (0'7")
15 kV – 45 kV	3.05 m (10'0")	2.5 m (8'0")	0.8 m (2'9")	0.44 m (1'5")
45 kV – 75 kV	3.05 m (10'0")	2.5 m (8'0")	1 m (3'2")	0.65 m (2'1")
75 kV – 150 kV[3]	3.4 m (10'8")	3 m (10'0")	1.2 m (4'0")	1 m (3'2"")
150 kV – 250 kV[3]	4 m (11'8")	4 m (11'8")	1.6 m (5'3")	1.5 m (5'0")
250 kV – 500 kV[3]	6 m (20'0")	6 m (20'0")	3.5 m (11'6")	3.3 m (10'10")
500 kV – 800 kV[3]	8 m (26'0")	8 m (26'0")	5 m (16'5")	5 m (16'5")

NOTES:

[1] Exposed Movable Conductor means that the bare conductor can move (e.g., an overhead transmission line conductor). This is unlikely indoors.
[2] Exposed Fixed Circuit Part means that the bare conductor or other circuit part is stationary and will not move. This is the most common Limited Approach Boundary value used.
[3] It is unlikely that a worker will work near exposed conductors over 100 kV.

3.5.3 Flash Hazard Analysis for Facility Power Systems

For Classes 1.2a, 1.2b, 1.2c, 1.3a, 1.3b, 1.3c and 1.4 (facility power systems) determine the Flash Protection Boundary as follows:

A. **Preferred method**: Calculate the Flash Protection Boundary using an appropriate method described in IEEE Std 1584a; include the clearing time considerations in §9.10.4. IEEE Std 1584a arc flash calculations related to facility power systems

B. **Alternate method**: Use 48 inches as the Flash Protection Boundary provided that the product of fault current and overcurrent protective device clearing time does not exceed 100 kA cycles (1,667 ampere seconds).

NOTE 1: § is a symbol for referring to a specific code section.

NOTE 2: An arc flash hazard need not be considered where all of the following conditions exist: (1) the circuit is rated 240 volts or less, (2) the circuit is supplied by one transformer, and (3) the transformer supplying the circuit is rated less than 125 kVA. Refer to §130.3, Exception 1, NFPA 70E, 2009.

NOTE 3: At locations immediately downstream of service entrance main circuit breakers and main circuit breakers in panel boards served by dry-type transformers, it is possible that the arc fault current will be in the circuit breaker long-time trip band instead of the instantaneous trip region. (This is because the arc fault current is significantly less than the bolted fault current in low-voltage systems.) Such a condition will result in a great increase in the Flash Protection Boundary because of the long time delay before the circuit breaker trips (e.g., 30 seconds (s) instead of 0.015 s). Refer to §9.14 in IEEE Std 1584a.

3.5.4 Flash Hazard Analysis for R&D Systems (supplement R&D)

Engineering supervision should be used to determine the DC arc flash boundary.

For R&D, capacitor, and battery systems, consider that an arc flash hazard potentially exists and perform a flash hazard analysis in accordance with either NFPA 70E or IEEE 1584a where any of the following conditions can exist on exposed parts:

NOTE: If the available energy is less than that listed below, an arc flash hazard analysis does not need to be performed.

A. alternating current (AC) systems up to 3 kHz: Available short-circuit energy exceeds:

1) 0.85 megavolt-ampere-seconds (MVA-seconds), 0.85 Megajoules (MJ) for an arc in open air

2) 0.53 MVA-seconds (0.53 MJ) for an arc in a cubic box.

NOTE 1: Systems such as this are placed in Hazard Class 2.4.

NOTE 2: 0.85 MVA-seconds will deposit approximately 5 J/cm2 (1.2 cal/cm2) on skin located 457.2 mm (18 in) from a 60Hz AC arc, assuming that the arc current equals the bolted-fault current. NFPA 70E uses a power factor of 0.5 in calculating the arc power.

NOTE 3: There is approximately 1.6 times the deposited energy from an arc in a cubic box than from an arc in open air due to reflecting and focusing effects of the box.

NOTE 4: Time of exposure is usually determined by the clearing time of the upstream overcurrent protection at the arc current. The arc current may be substantially less than the bolted fault current; hence, the clearing time may be substantially longer than that for the prospective bolted fault current.

B. direct current (DC) systems: available short-circuit energy exceeds:

1) 0.425 megawatt-seconds (MJ) for an arc in open air

2) 0.266 MJ for an arc in a cubic box.

NOTE 1: 0.425 MJ for a DC arc is extrapolated from the equations in NFPA 70E for a 60 Hz arc and assumes that the DC arc current equals the DC bolted-fault current.

NOTE 2: Analysis must be performed to determine the short circuit energy deposited in an arc. Such systems fall into hazard Classes 2.3 and 2.4.

C. Capacitor systems: stored energy exceeds: add Table ref

1) 131 kilojoules for an arc in open air

2) 80 kilojoules for an arc in a cubic box.

NOTE 1: 131 kJ is based on converting 100% of capacitor stored energy into radiant heat to deposit 5 J/cm^2 18 in from the arc.

NOTE 2: Large capacitor banks operating at high voltages (e.g., 1600 µF at 10 kV) would be required to approach these energy levels. Noise, pressure wave, and shrapnel hazards from an uncontrolled discharge will be the governing hazards with capacitors having stored energy less than the above values.

NOTE 3: A worker should never approach a charged capacitor or capacitor bank in excess of 10 kJ. The energy must be removed remotely before personnel access. Such systems fall into hazard Classes 3.4a, 3.4b, and 3.4d.

D. Battery systems: available short-circuit energy of battery string exceeds:

1) 0.425 MJ for an arc in open air

2) 0.266 MJ for an arc in a cubic box.

NOTE 1: 0.425 MJ for a DC arc is extrapolated from the equations in NFPA 70E for a 60 Hz arc and assumes that the DC arc current equals the DC bolted-fault current.

NOTE 2: Battery short-circuit current is determined by internal resistance and is often given in the battery manufacturer's product data. There are also rules of thumb used in the industry to compute short-circuit current: IEEE 946 uses 10 times the 1-min discharge current to 1.75 V per cell for a lead-acid cell.

NOTE 3: Time of exposure is usually determined by the clearing time of the upstream overcurrent protection at the arc current; with batteries there may be no upstream overcurrent protective device.

NOTE 4: Battery system arc flash hazards are present in relatively small UPS systems: A 480 V, 20 kW, 20 min UPS will have a 480 V battery bank consisting of about 240 50-A-hr cells capable of a short-circuit current of about 1500 A; the resulting arc power would be about 0.7 MW and the arc would persist for perhaps several seconds as the battery discharges.

NOTE 5: Hazards from contact with hot surfaces, molten metal, and corrosive chemicals will exist for battery short-circuit events even where energy levels are much lower than required to present an arc flash hazard.

NOTE 6: The 'short-circuit energy' of a battery is in Joules. That is the energy produced in each second. This is not the same as the total energy stored in a battery. For example, the 'short-circuit energy' of a car battery is about 10 kJ, but the battery stores a total of about 1 MJ.

3.6 ADMINISTRATIVE CONTROLS FOR ELECTRICAL WORK

Administrative controls to mitigate electrical hazards can be divided into four basic categories:

1. worker rules:
   - working alone rule
   - two-person rule
   - safety watch rule
2. qualification and training
3. work control (including EEWP)
4. personal protective equipment (PPE).

Each will be discussed briefly.

3.6.1 Working Alone, Two-Person, and Safety Watch Practices

Many sites use two-person and safety watch rules to provide a second person in case of emergency, or to provide a "second set of eyes".

Each electrical safety task should be analyzed to determine if risk of injury to a worker, while working alone, warrants a second person to be present. If the risk of injury from accidental contact with an electrical conductor is minimal, then a person may work alone.

If contact with an electrical conductor could result in ventricular fibrillation, serious burn, a no-let-go response, or other injury, the two-person practice should be followed. The second person should be a worker qualified to work on energized circuits, and should understand the work activities and the hazards present. The second person should know what to do in case of an electrical accident involving the other worker.

A safety watch is a more stringent hazard control measure than the two-person practice and should be implemented when there are grave consequences from a failure to follow safe work procedures. The safety watch should be a worker qualified to work on energized circuits who accepts responsibility for monitoring qualified worker(s) performing high-hazard electrical work.

Recommended working alone, two-person, and safety watch practices are provided for each of the four Modes of Work on electrical equipment for each of the 54 Electrical Hazard Classes.

3.6.2 Qualification and Training

Electrical safety training can be divided into three primary categories: (a) general classroom training, (b) specific classroom training, and (c) On-the-Job training (OJT).

General electrical safety classroom training can be broken into three basic types: (1) general awareness training, (2) non-Energized electrical worker, and (3) Energized electrical worker. Recommended general training requirements are given for each of the three Modes of Work on energized electrical equipment (Mode 1, 2, and 3) for each of the 54 Electrical Hazard Classes.

Specific classroom training can include courses such as Pulsed Power Safety, RF and Microwave Safety, Computer Safety, Battery and Battery Bank Safety, etc., and depends on the electrical hazard present. For certain electrical hazards specific classes are recommended. As appropriate, portions of the training may be provided using alternative methods such as self-study or computer-based training.

On-the-Job Training (OJT) may be important for certain classes of electrical hazards, or more specifically, for certain tasks with electrical hazards. Examples of relevant OJT include: how to use a personal safety ground (ground hook) to discharge a capacitor, how to use certain PPE, how to use a multimeter to diagnose a circuit while energized, etc.

3.6.3 Work Control

All hazardous electrical work shall follow documented work control procedures. The Electrical Hazard Classification control tables specify when an Energized Electrical Work Permit (EEWP) is required.

3.6.4 Personal Protective Equipment

Shock protection PPE is required whenever any portion of the worker's body passes the Restricted Approach Boundary. Arc flash PPE is required whenever any portion of the worker's body passes the Arc Flash Boundary. Recommended use of shock and arc flash PPE are given for each of the four Modes of Work on electrical equipment for each of the Electrical Hazard Classes. In many cases the shock and arc flash boundaries must be determined or obtained by the worker. In a few special cases additional PPE may be required, e.g., for capacitor discharging, or for working on lead acid batteries.

3.7 HAZARD ASSESSMENT TABLES AND RECOMMENDED CONTROLS

The hazard classification charts cover five broad areas, ranging from R&D, to capacitors, to batteries. These charts represent most of the electrical hazards found in electrical equipment. All charts and classes should be considered when identifying the hazards associated with any given piece of electrical equipment. A single piece of equipment may have multiple electrical hazard classifications, and the combination of hazards must be addressed by appropriate safety-related work practices. In order to aid hazard identification, each table has cross-reference notes in the upper right hand corner. For example, the R&D table has cross-reference notes to capacitance, battery, and facility hazard tables. Workers should have a thorough understanding of the equipment they are analyzing for hazards. Consulting manuals and schematics and speaking with factory service representatives and Electrical Safety Subject Matter Experts are ways to ensure that all of the hazards are fully understood and that all the pertinent charts and classes are taken into account. Some guidelines on use of the hazard classification charts are given. They are general, and there may be exceptions to each one:

1) If you do not understand these guidelines and your equipment, consult an electrical SME.
2) All equipment gets its power from the facility (Classes 1.x) or batteries (Classes 4.x). Thus, equipment starts with one of those classes.
3) Most small appliances, hand tools, and portable laboratory equipment plugs into Class 1.2. In general, if you can carry it, most likely it uses 120 to 240 V.
4) Larger facility and laboratory equipment may use up to 600 V (Class 1.3).
5) All electronic equipment and much other R&D equipment converts facility power into DC. All DC power supplies have some capacitance. Thus, DC power supplies have hazards in Classes 2.x and 3.x. Both must be evaluated.
6) All UPSs have hazards in Classes 4.x as well as 1.x, since they usually are tied into facility power (input), and produce facility type power (output).

The colors used in each hazard Class box are organized in increasing hazard: blue, green, yellow, red, and maroon. Some general statements can be made about each color. There may be exceptions. renumber

7) A blue Class (X.0) indicates no hazard, no engineering or administrative controls are needed.

8) A green Class (X.1) indicates little to no hazards, few or no engineering or administrative controls are needed.

9) A yellow Class (X.2) indicates injury or death could occur by close proximity or contact; often the hazard is shock or contact burn; engineering controls are necessary for operation (e.g., listing or equipment approval), and administrative controls are necessary for electrical work in this Class.

10) A red Class (X.3) indicates injury or death could occur by proximity or contact; often the hazard is shock, contact burn, or arc-flash burn; engineering controls are necessary for operation (e.g., listing or equipment approval), and administrative controls are necessary for electrical work in this Class.

11) A maroon Class (X.4 and X.5) is the highest level of risk; significant engineering and administrative controls are necessary to manage the hazard in these Classes.

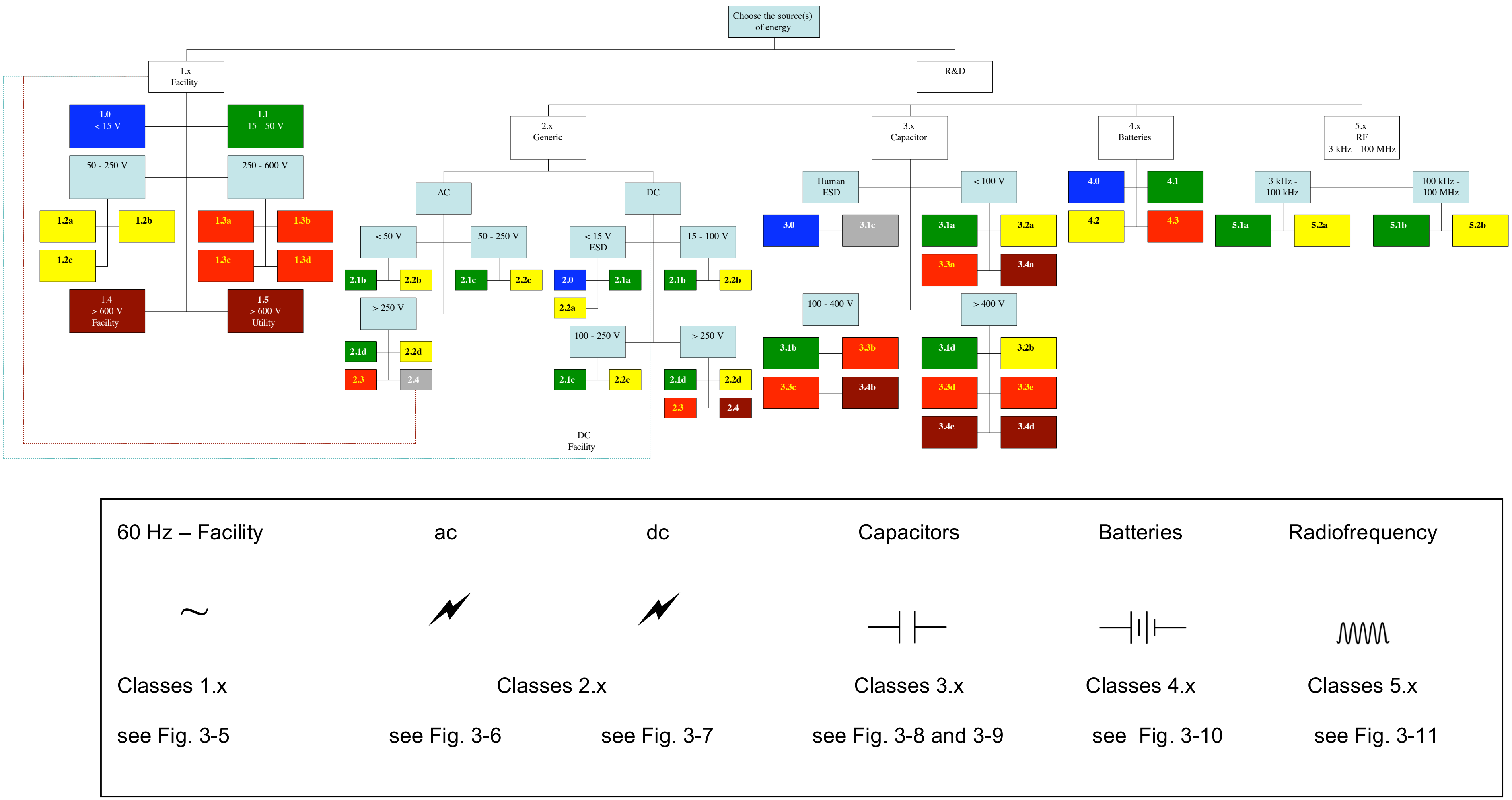


Fig. 3-4. Complete electrical hazard classification system showing 5 major groups and 54 classes.

Blue: (Class X.0) indicates no hazard; no engineering or administrative controls are needed

Green: (Class X.1) indicates little or no hazards; few or no engineering or administrative controls are needed

Yellow: (Class X.2) indicates injury or death due to shock or contact burn could occur by close proximity or contact. Recognized Testing Laboratory (RTL)

listing or approval by local inspection processes are required. Administrative controls are also required.

Red: (Class X.3) indicates injury or death due to shock, contact burn, or arc flash burn could occur by proximity or contact. Recognized Testing Laboratory (RTL)

listing or approval by local inspection processes are required. Administrative controls are also required.

Maroon: (Classes X.4 and X.5) indicates the highest level of risk. Significant Engineering and Administrative controls are required to manage hazards.

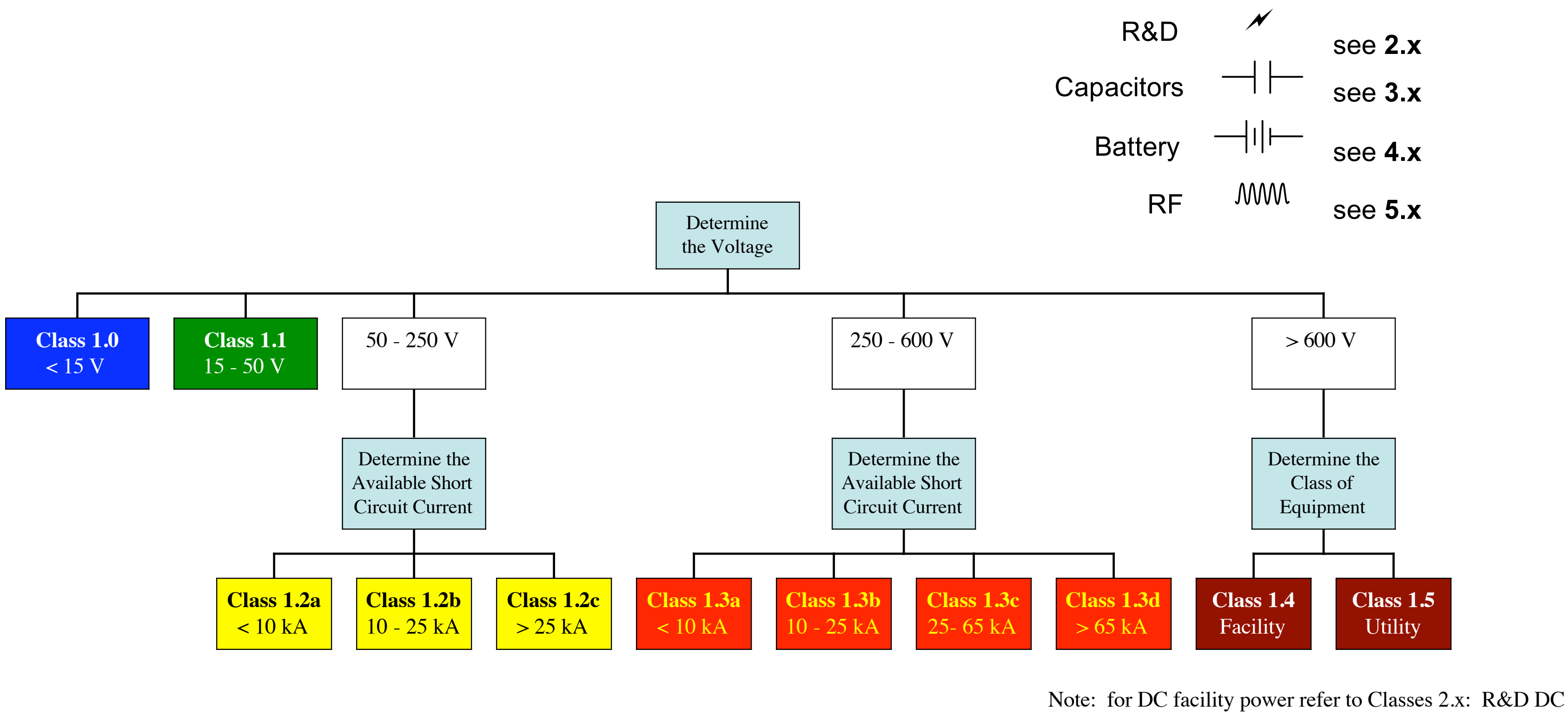


Fig. 3-5. Class 1.x: Hazard classes 1.x, for 60 Hz power.

Table 3-6. Controls for work in hazard Classes 1.x.

Class	Mode	Qualified Worker(s)	Training	Work Control	PPE
1.0	ALL	Alone	None	None	None
1.1	ALL	Alone	Non-Energized	None	None
1.2a	0-	Alone	Non-Energized and LOTO	None	None
	1	Alone	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	2	Alone	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	3[2]	Two person	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis[1]
1.2b	0	Alone	Non-Energized and LOTO	None	None
	1	Alone	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	2	Alone	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	3[2]	Two person	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis[1]
1.2c	0	Alone	Non-Energized and LOTO	None	None
	1	Alone	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	2	Alone	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	3[2]	Two person	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis[1]
1.3a	0	Alone	Non-Energized and LOTO	None	None
	1	Two person	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	2	Two person	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	3[2]	Two person	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis[1]
1.3b	0	Alone	Non-Energized and LOTO	None	None
	1	2nd	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	2	2nd	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis[1]

Class	Mode	Qualified Worker(s)	Training	Work Control	PPE
1.3c	0	Alone	Non-Energized and LOTO	None	None
	1	2nd	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	2	Safety Watch	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis[1]
1.3d	0	Alone	Non-Energized and LOTO	None	None
	1	Safety Watch	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	2	Safety Watch	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis[1]
1.4	0	Alone	Non-Energized and LOTO	None	None
	1	Safety Watch	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	2	Safety Watch	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis[1]
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis[1]
1.5	0	Alone	Non-Energized	YES	Refer to 29CFR1910.269
	1	Safety Watch	Lineman	YES	Refer to 29CFR1910.269
	2	Safety Watch	Lineman	YES	Refer to 29CFR1910.269
	3[2]	Safety Watch	Lineman	YES	Refer to 29CFR1910.269

[1] Perform a shock and arc flash analysis or see NFPA 70E tables (70E, pp. 29–34).

[2] This mode of work should be avoided.

Notes on use of hazard Classes and control Table 1.x:

(a) The voltage is the root mean square (rms) voltage for 60 Hz power.
(b) The current is the available fault current.
(c) The primary difference between subclasses a, b, c, and d in Classes 1.2 and 1.3 is the arc-flash hazard, since the arc fault current increases to the right.
(d) Class 1.4 is work on facility circuits above 600 V.
(e) Class 1.5 is work on utility circuits above 600 V.
(f) For R&D (AC or DC, not 60 Hz), use hazard Classes 2.x.
(g) For capacitors, use hazard Classes 3.x.
(h) For batteries, use hazard Classes 4.x.
(i) For ac frequencies above 3 kHz (rf) use hazard Classes 5.x.

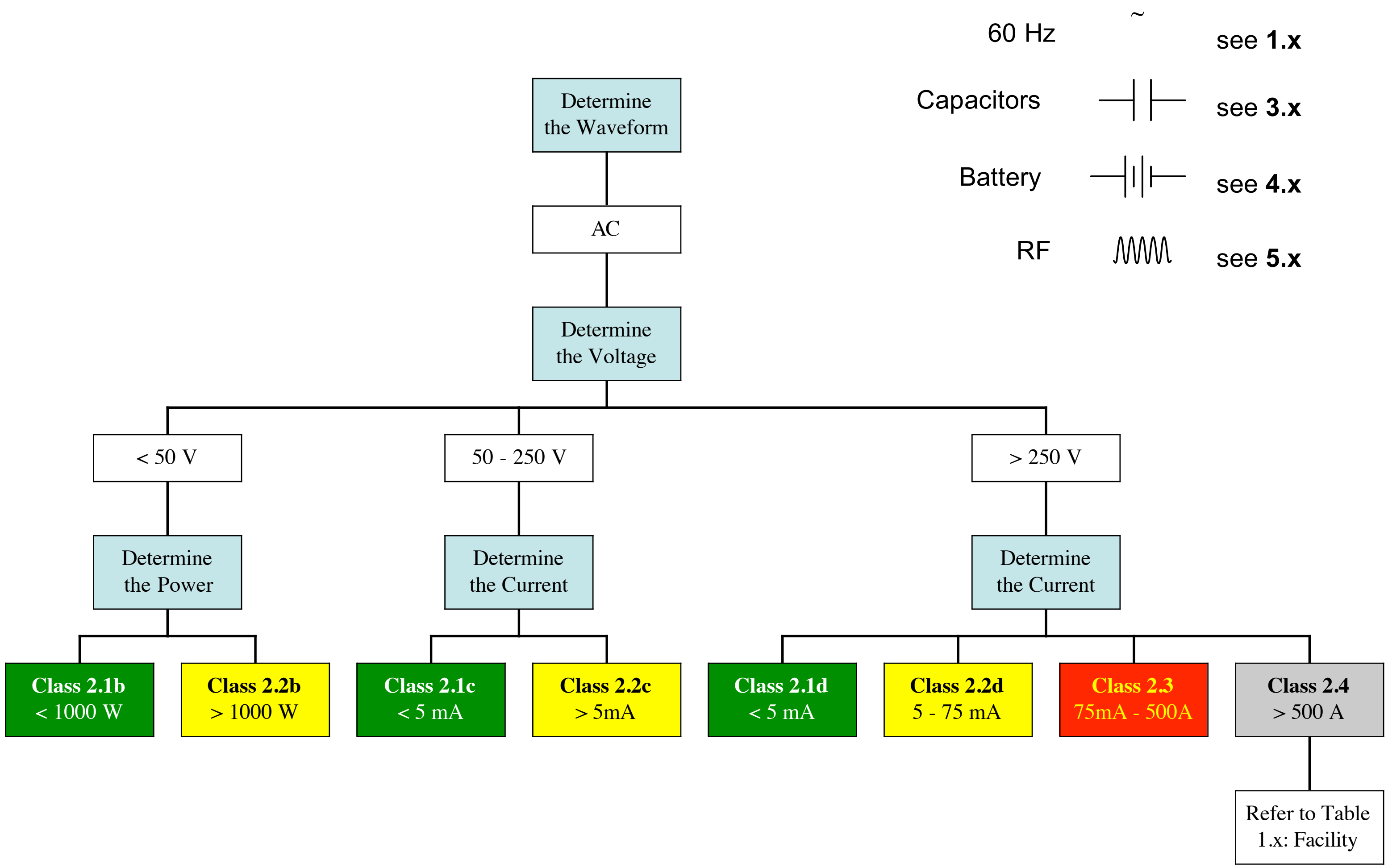


Fig. 3-6. Hazard Classes 2.x, AC R&D and electronic.

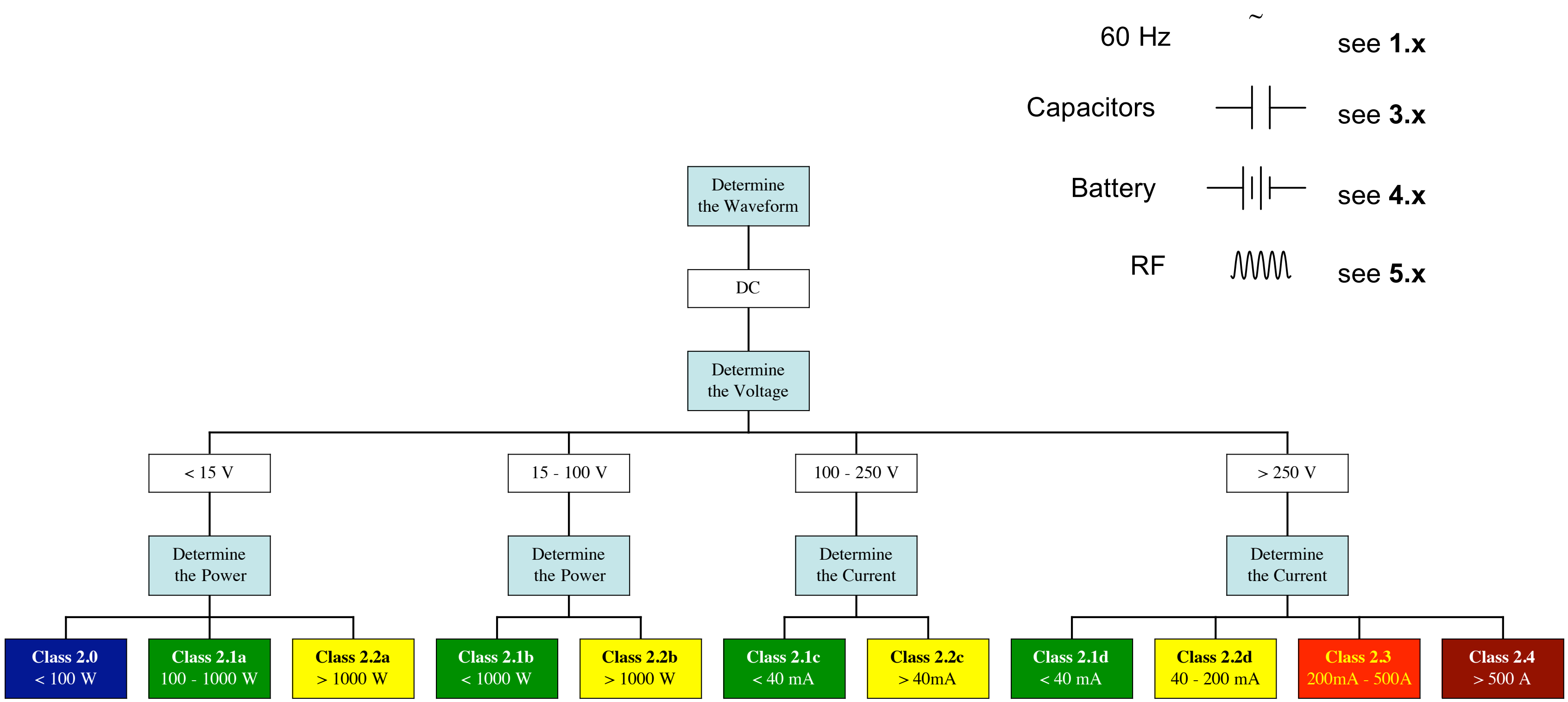


Fig. 3-7. Hazard Classes 2.x, DC R&D and electronic.

Table 3-7. Control Table for work in hazard Classes 2.x.

Class	Mode	Qualified Worker(s)	Training	Work Control	PPE
2.0	ALL	Alone	None	None	None
2.1ALL	ALL	Alone	Non-Energized	None	None
2.2a	0	Alone	Non-Energized and LOTO	None	None
	1	Alone	Energized	YES	Shock Hazard Analysis
	2	Two person	Energized	YES	Shock Hazard Analysis
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis
2.2b	0	Alone	Non-Energized and LOTO	None	None
	1	Alone	Energized	YES	Shock Hazard Analysis
	2	Two person	Energized	YES	Shock Hazard Analysis
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis
2.2c	0	Alone	Non-Energized and LOTO	None	None
	1	Alone	Energized	YES	Shock Hazard Analysis
	2	Two person	Energized	YES	Shock Hazard Analysis
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis
2.2d	0	Alone	Non-Energized and LOTO	None	None
	1	Alone	Energized	YES	Shock Hazard Analysis
	2	Two person	Energized	YES	Shock Hazard Analysis
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis
2.3	0	Alone	Non-Energized and LOTO	None	None
	1	Two person	Energized	YES	Shock Hazard Analysis
	2[3]	Safety Watch	Energized	YES	Shock Hazard Analysis
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis
2.4[1]	0	Alone	Non-Energized and LOTO	None	None
	1	Safety Watch	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis
	2[2]	Safety Watch	Energized	YES	Shock Hazard Analysis and Flash Hazard Analysis
	3[2]	Safety Watch	Energized	YES, EEWP	Shock Hazard Analysis and Flash Hazard Analysis

[1] For AC, refer to Table 1.x: Facility.

[2] This mode of work should be avoided.

[3] DO NOT move probes while energized.

Notes on use of hazard Classes and control Table 2.x:

(a) This control Table is NOT to be used for 60 Hz power.
(b) The primary difference between Class 1.x and 2.x is the lack of available fault current in Class 2.x to create an arc-flash hazard. If significant fault current exists, Class 2.4, the worker must perform an arc-flash analysis, for ac or dc.
(c) AC R&D includes ac frequencies from 1 Hz to 3 kHz (sub RF AC), that is not 60 Hz power.
(d) Voltage is rms for AC, or DC voltage.
(e) Power is available short-circuit power.
(f) Current is available short-circuit current.
(g) For 60 Hz facility power use hazard Classes 1.x.
(h) For capacitors use hazard Classes 3.x.
(i) For batteries use hazard Classes 4.x.
(j) For AC frequencies above 3 kHz (RF) use hazard Classes 5.x.

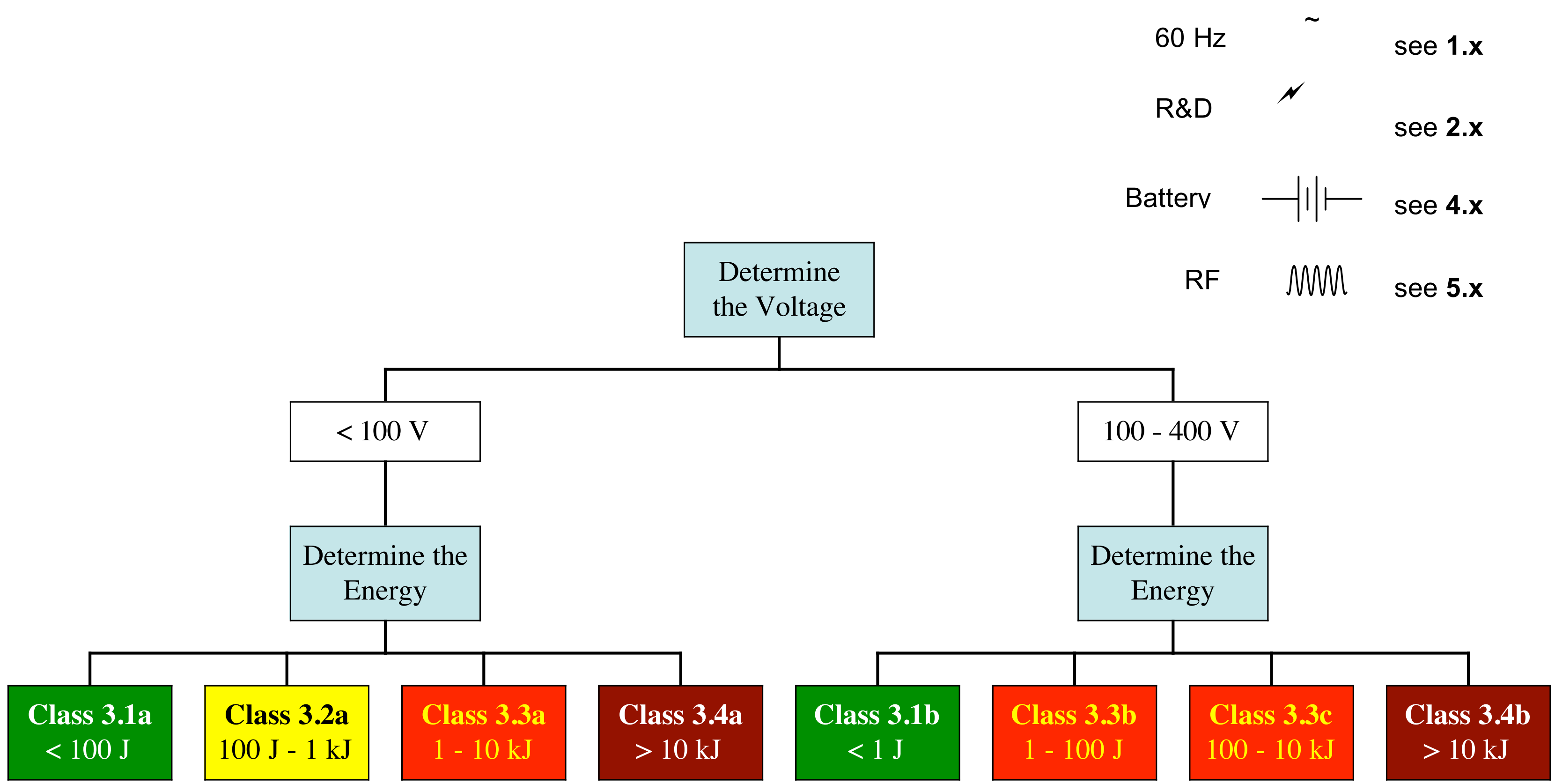


Fig. 3-8. Hazard Classes 3.x, capacitors, < 400 V

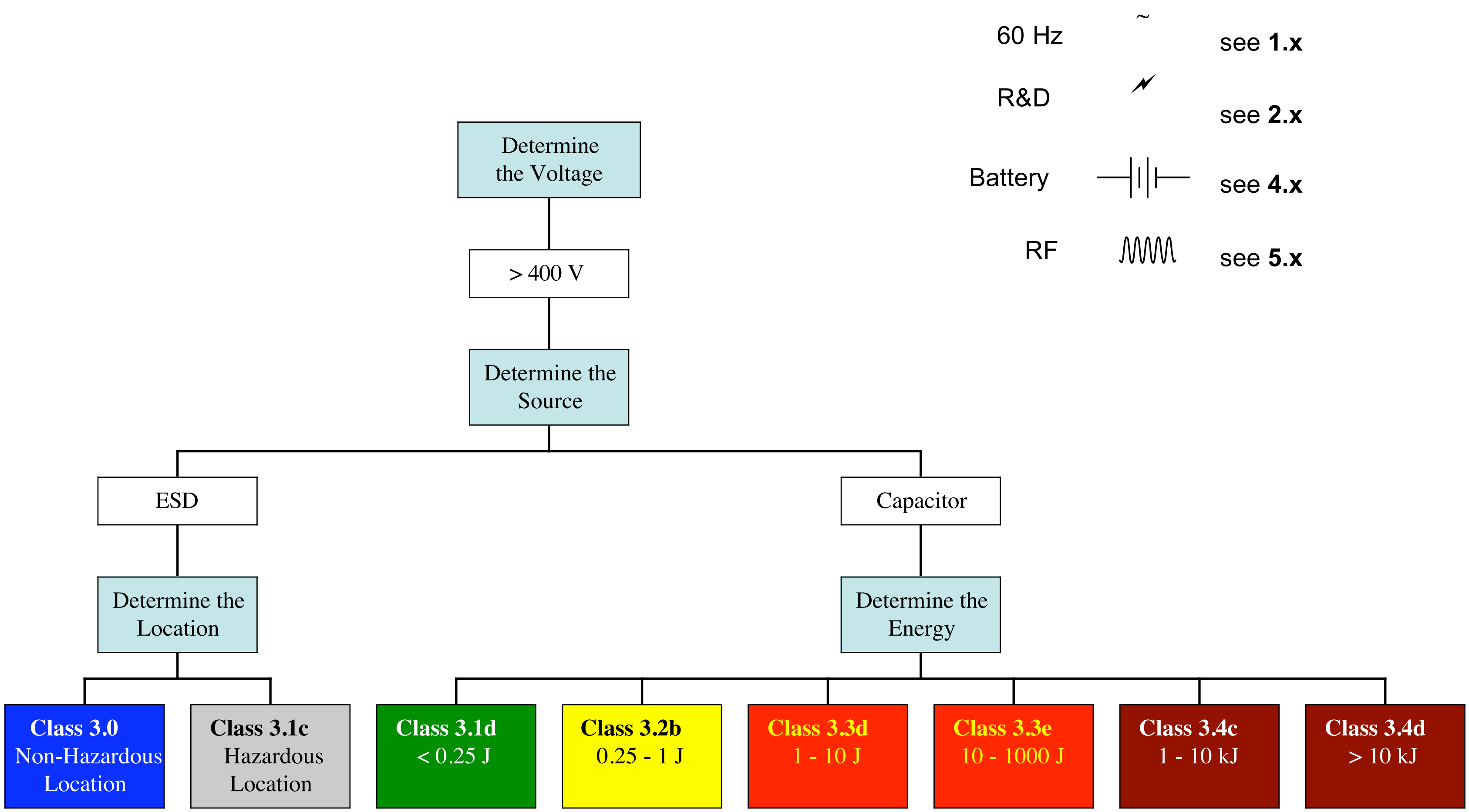


Fig. 3-9. Hazard Classes 3.x, capacitors, > 400 V.

Table 3-8. Control Table for work in hazard Classes 3.x.

Class	Mode	Qualified Worker(s)	Training	Work Control	PPE	Energy Removal
3.0	ALL	Alone	None	None	None	
3.1a,b,d	ALL	Alone	Non-Energized	None	None	
3.1c[3]	ALL					
3.2a	0	Alone	Non-Energized	None	None	
	1	Alone	Energized	YES	Eye, No Jewelry	Hard ground hook
	2	Two person	Energized	YES	Eye, No Jewelry	
	3	Two person	Energized	YES	Eye, No Jewelry	
3.2b	0	Alone	Non-Energized	None	None	
	1	Alone	Energized	YES	[1]	Hard ground hook
	2	Two person	Energized	YES	[1]	
	3	Two person	Energized	YES, EEWP	[1]	
3.3a	0	Alone	Non-Energized	None	None	
	1	Two person	Energized	YES	Eye, No Jewelry	Soft ground hook
	2	Two person	Energized	YES	Eye, No Jewelry	
	3	Safety Watch	Energized	YES, EEWP	Eye, No Jewelry	
3.3b	0	Alone	Non-Energized	None	None	
	1	Two person	Energized	YES	Eye,[1]	Hard ground hook
	2	Two person	Energized	YES	Eye,[1]	
	3[4]	Safety Watch	Energized	YES, EEWP	Eye,[1]	
3.3c	0	Alone	Non-Energized	None	None	
	1	Safety Watch	Energized	YES	Eye, Ear,[1],[2]	Soft ground hook
	2[5]	Safety Watch	Energized	YES	Eye, Ear,[1],[2]	
	3[4]	Safety Watch	Energized	YES, EEWP	Eye, Ear,[1],[2]	
3.3d	0	Alone	Non-Energized	None	None	
	1	Two person	Energized	YES	Eye,[1]	Hard ground hook
	2	Two person	Energized	YES	Eye,[1]	
	3[4]	Two person	Energized	YES, EEWP	Eye,[1]	
3.3e	0	Alone	Non-Energized	None	None	
	1	Safety Watch	Energized	YES	Eye, Ear,[1]	Hard or Soft[1] ground hook
	2[5]	Safety Watch	Energized	YES	Eye, Ear,[1]	
	3[7]					

Class	Mode	Qualified Worker(s)	Training	Work Control	PPE	Energy Removal
3.4a	0	Alone	Non-Energized	None	None	
	1	Safety Watch	Energized	YES	Eye, No Jewelry	Remotely
	2[5]	Safety Watch	Energized	YES	Eye, No Jewelry	
	3[4]	Safety Watch	Energized	YES, EEWP	Eye, No Jewelry	
3.4b	0	Alone	Non-Energized	None	None	
	1	Safety Watch	Energized	YES	Eye, Ear,[1],[2]	Remotely
	2[5]	Safety Watch	Energized	YES	Eye, Ear,[1],[2]	
	3[4]	Safety Watch	Energized	YES, EEWP	Eye, Ear,[1],[2]	
3.4c	0	Alone	Non-Energized	None	None	
	1	Safety Watch	Energized	YES	Eye, Ear,[1],[2]	Soft ground hook
	2[6]	Safety Watch	Energized	YES	Eye, Ear,[1],[2]	
	3[7]					
3.4d	0	Alone	Non-Energized	None	None	
	1	Safety Watch	Energized	YES	Eye, Ear,[1],[2]	Remotely
	2[6]	Safety Watch	Energized	YES	Eye, Ear,[1],[2]	
	3[7]					

[1] Determine by a shock hazard analysis.

[2] Determine by a flash hazard analysis.

[3] For Class 3.1c refer to explosive safety.

[4] This mode of work should be avoided.

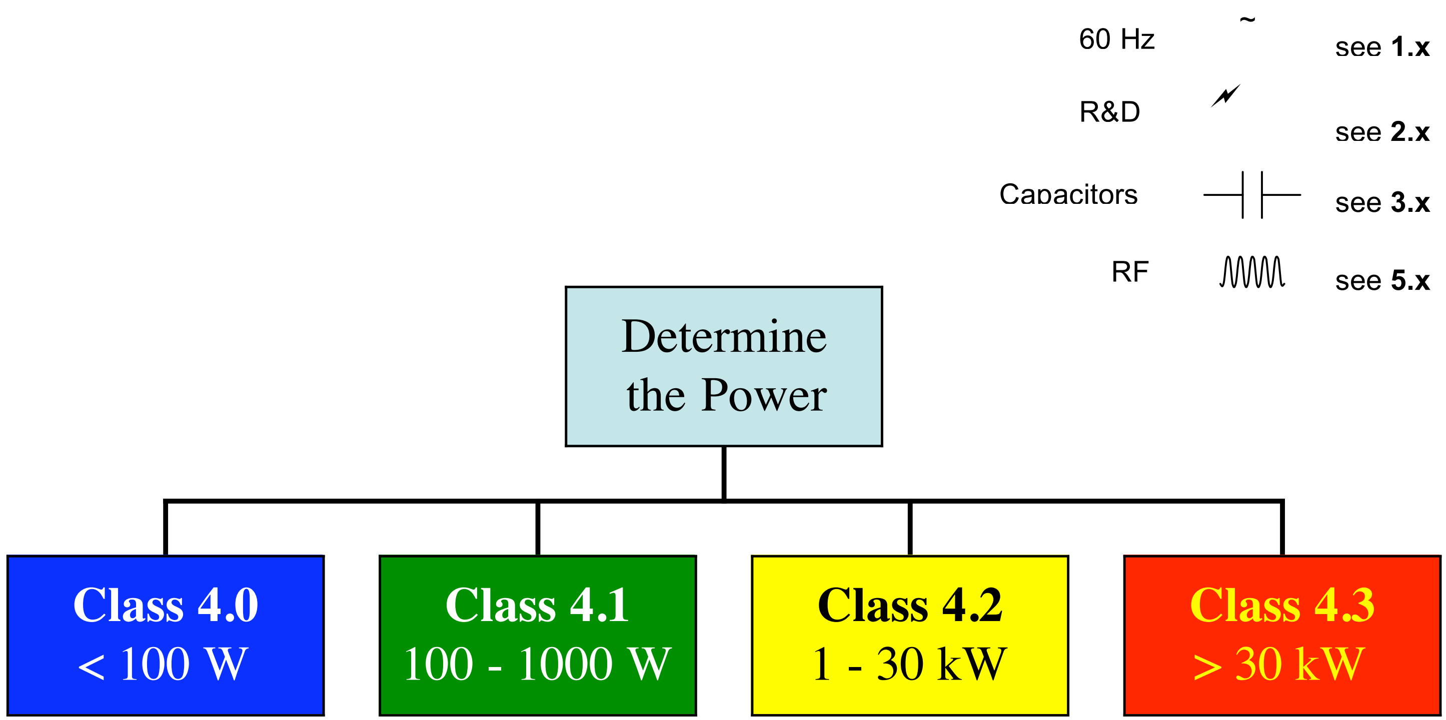
[5] This mode of work should be avoided or done remotely.

[6] Do this mode of work remotely.

[7] DO NOT do this mode of work.

Notes on use of hazard Classes and control Table 3.x:

(a) Voltage is AC rms or DC maximum charge voltage on the capacitor.
(b) Energy is maximum energy stored in the capacitor as determined by ½CV2.
(c) PPE – eye is proper eye protection, either goggles or a face shield, for higher energies.
(d) PPE – no jewelry for low-voltage capacitors, means no jewelry on the hands (e.g., rings, watches) and no dangling jewelry or other objects (e.g., badge).
(e) Column ‘Energy Removal’ is the method used to discharge lower-energy capacitors, or apply a safety ground on higher-energy capacitors. See definitions in Chapter 13 for definitions of hard and soft ground hooks.
(f) Performing ‘Energy Removal’ remotely means using engineering methods to discharge and verify the capacitors without worker presence (e.g., a capacitor “dump” system).
(g) Performing Mode 2 remotely means using sensors and instruments that are placed during a Mode 0 condition, then observed from a safe location during Mode 2 work.
(h) The hazards for less than 100 V, Classes 3.2a, 3.3a, and 3.4a, are high current through a short circuit, such as tools and jewelry.
(i) The hazards for 100 – 400 V, Classes 3.3b, 3.3c, and 3.4b, are high current through a short circuit, and a shock hazard.
(j) The hazards for greater than 400 V, Classes 3.2b, 3.3d, 3.3e, 3.4c, and 3.4d, are high current through a short circuit, and a shock hazard with a strong reflex action for Class 3.2d, and serious tissue injury and/or death for 3.3d and above.
(k) Classes 3.4b, 3.4c, and 3.4d have the added hazards of mechanical damage due to high currents and strong pulse magnetic forces during a short circuit.
(l) For 60 Hz facility power, use hazard Classes 1.x.
(m) For R&D (not 60 Hz), use hazard Classes 2.x.
(n) For Batteries use, hazard Classes 4.x.
(o) For AC frequencies above 3 kHz (RF), use hazard Classes 5.x.



Note: > 100 V also refer to Table 2.x: R&D DC to classify the shock hazard.

Fig. 3-10. Hazard Classes 4.x, batteries and battery banks.

Table 3-9. Control Table for work in hazard Classes 4.x.

Class	Mode	Qualified Worker(s)	Training	Work Control	PPE
4.0	ALL	Alone	None	None	None
4.1[1]	ALL	Alone	Non-Energized	None	No Jewelry
4.2	2	Two person	Non-Energized	YES	Eye, No Jewelry
	3[2]	Safety Watch	Energized	YES, EEWP[3]	Eye, No Jewelry
4.3	2	Safety Watch	Energized	YES	Eye, No Jewelry
	3[2]	Safety Watch	Energized	YES, EEWP[3]	Eye, No Jewelry, Special Battery Tools

[1] Terminal voltage is less than 100 V.

[2] Break up bank for work.

[3] An EEWP is required if the terminals are exposed, or if the terminal voltage exceeds 100 V.

Notes on use of hazard Classes and control Table 4.x:

(a) Power is the short circuit available power from the battery. This can be obtained by multiplying the short circuit available current by the battery terminal voltage. The short circuit available current can be obtained from the manufacturer's specifications.
(b) There can be no Mode 0 or 1 for batteries, as they are always energized.
(c) Additional PPE is necessary for vented lead-acid batteries, depending on the work activity (e.g., chemical PPE).
(d) Although all work on Class 4.2 (e.g., automotive batteries) is Energized Work, some of this work (e.g., jump starting cars) is commonly done by the public. Caution should be used, however, and appropriate training and controls in place.
(e) Class 4.1 batteries (e.g., desktop UPS batteries) may have adequate engineering controls, such as recessed terminals, to reduce the need for controls.
(f) 'Energized Worker' training requires LOTO and CPR. Neither is necessary for low voltage battery work, unless the facility power source for a large UPS must be locked out and verified.
(g) For 60 Hz facility power, use hazard Classes 1.x.
(h) For R&D (not 60 Hz), use hazard Classes 2.x.
(i) For capacitors, use hazard Classes 3x.
(j) For ac frequencies above 3 kHz (RF), use hazard Classes 5.x.

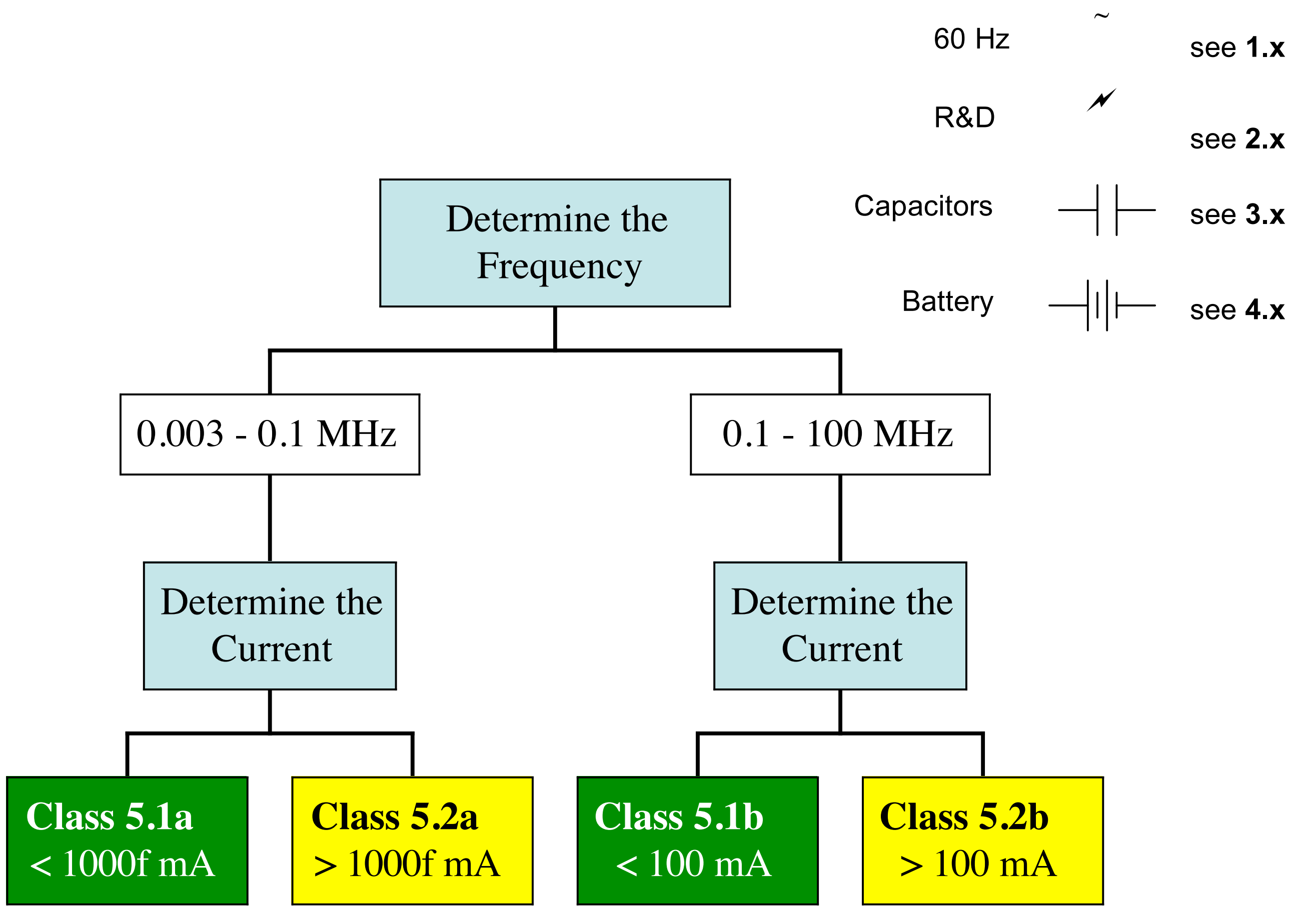


Fig. 3-11. Hazard Classes 5.x, RF circuits 3 kHz to 100 MHz (f is in MHz).

Table 3-10. Control Table for work in Classes 5.x.

Class	Mode	Qualified Worker(s)	Training	Work Control	PPE
5.1a,b	ALL	Alone	Non-Energized & RFMW	None	None
5.2a	0	Alone	Non-Energized & RFMW	None	None
	1[4]	Alone	Energized & RFMW	YES	[2]
	2[3]	Alone	Energized & RFMW	YES	[2]
	3[1]				
5.2b	0	Alone	Non-Energized & RFMW	None	None
	1[4]	Alone	Energized & RFMW	YES	[2]
	2[3]	Alone	Energized & RFMW	YES	[2]
	3[1]				

[1] DO NOT do this mode of work.

[2] No PPE is available for high current shock. Must avoid proximity.

[3] DO NOT move probes while energized.

[4] Must verify zero energy remotely.

Notes on use of Control Table 4.x:

(a) f in the Chart is frequency in MHz.
(b) Classes 5.x and control Table ONLY addresses the RF shock hazard. It does NOT address the exposure to electromagnetic fields.
(c) The allowable shock currents are much higher than 60 Hz (e.g., 100 mA is allowed for 100 kHz).
(d) There is no shock PPE for RF, thus Modes 1, 2, and 3 must NOT expose the worker to a shock hazard in Class 5.2..
(a) For 60 Hz facility power use hazard Classes 1.x.
(b) For R&D (not 60 Hz) use hazard Classes 2.x.
(c) For capacitors use hazard Classes 3x.
(d) For batteries use hazard Classes 4.x.

4.0 ELECTRICAL PREVENTIVE MAINTENANCE

5.0 GROUNDING

6.0 SPECIAL OCCUPANCIES

7.0 REQUIREMENTS FOR SPECIFIC EQUIPMENT

8.0 WORK IN EXCESS OF 600 VOLTS

9.0 TEMPORARY WIRING

10.0 ELECTRICAL SAFETY DURING EXCAVATION

11.0 ENCLOSED ELECTRICAL/ELECTRONIC EQUIPMENT

11.1 PURPOSE

This section provides guidelines to

1. complement existing electrical codes and recommend industry standards,
2. improve electrical safety in the work environment for personnel within the DOE complex,
3. eliminate the ambiguity and misunderstanding in design, construction and implementation requirements for electrical/electronic equipment,
4. assist the AHJ in providing information for acceptance of equipment within the scope of this document, and
5. To guide the use of typical vendor supplied equipment cabinet racks (i.e., 19" cabinet rack enclosure), and provide guidance for procurement requirements.

11.2 SCOPE

This section addresses enclosed electrical/electronic equipment electrical safety guidelines which are not specifically addressed elsewhere in the *Electrical Safety Handbook.* These types of equipment include: instrumentation and test consoles; enclosed electrical/electronic equipment; other laboratory diagnostic electrical/electronic equipment (stationary or mobile) mounted in or on an enclosure, rack or chassis; and special electrical/electronic equipment facility requirements.

11.3 GROUNDING AND BONDING

Many ground system types exist within electrical equipment. All metal parts of electrical equipment enclosures and chassis shall be bonded and grounded as per the NEC. The methods chosen to avoid ground loops and reduce noise shall meet the requirements of the NEC 250.6.

11.3.1 Objectionable Current over Grounding Conductors

Enclosed electrical/electronic equipment may have both power and signal conductors entering and leaving these enclosures. Objectionable currents and noise may be the result of the design or installation of conductors and equipment and their grounding locations. NEC 250.6 addresses these objectionable currents and noise (See Section 13.8.2.1).

NEC 250.6 must be used with care because it seems to give blanket authority to do whatever is necessary to stop objectionable currents from flowing in the grounding system. This is not the intent. NEC 250.6D specifically indicates that the introduction of noise or data errors in electronic equipment shall not be considered objectionable currents, as addressed therein. Therefore, such objectionable currents must be handled in other ways. NEC Section 250.6 principally deals with objectionable currents that can flow over grounding conductors due to severely unbalanced loads or improper installation practices. NEC 250.96(B) provides requirements for isolation of grounding circuits to reduce electrical noise (EMI). Because of the complexity and number of interconnections of most grounding systems, the NEC allows modifications of the grounding system and connections in order to address such problems. Those permitted:

1) Arrangement to prevent objectionable current. Grounding of electrical systems, circuit conductors, surge arresters, and conductive noncurrent-carrying materials and equipment shall be installed and arranged in a manner that will prevent an objectionable current over the grounding conductors or grounding paths. Use of a single-point grounding system, as well as meeting the other requirements of NEC Article 250, will usually overcome problems.

2) Alterations to stop objectionable current. If the use of multiple grounding connections results in an objectionable current, one or more of the following alterations are permitted to be made, provided that the requirements of NEC 250.4(A)(5)(B)(4), are met. Such permitted alterations are:

    1. Discontinue one or more, but not all, of the grounding connections;

    2. Change the locations of the grounding connections;

    3. Interrupt the continuity of the conductor or conductive path interconnecting the grounding connections; and/or

    4. Take other suitable remedial action satisfactory to the authority having jurisdiction.

3) Temporary currents not classified as objectionable currents. Temporary currents resulting from accidental conditions, such as ground-fault currents, that occur only while the grounding conductors are performing their intended protective functions shall not be classified as objectionable. This does not prohibit changes in the system to correct excessive current during a fault condition.

4) Limitations to permissible alterations. The intent of NEC 250.6 is not to permit electronic equipment to be operated on AC systems or branch circuits that are not grounded as required by NEC Article 250. Currents that introduce noise or data errors in electronic equipment are not considered to be the objectionable currents addressed in this Section.

Voltage differences and thus objectionable currents may exist because impedances to ground are not equal throughout a grounding system due to variations of the resistance of the earth, improper connections, or other problems.

Even though voltage differences allow unwanted currents to flow in the grounding conductors, and induced noise may travel over this path, it is not to be used as a reason to disconnect all grounding connections to any system component. At least one grounding connection must remain.

11.3.2 Equipment Grounding Conductor

The equipment grounding conductor of a power-supply cord or interconnecting cable shall be sized in accordance with NEC 250.122 and the associated NEC Table 250.122. The minimum size equipment grounding conductor is based on the total rating of the enclosed equipments in amperes. Note that the minimum size equipment grounding conductor may be smaller than the size for the current-carrying conductors; i.e., the grounded (neutral) and ungrounded conductors, which are sized per NEC Article 310.15 – usually following NEC Table 310.16.

11.3.3 Enclosure Grounding and Bonding

Enclosure grounding and bonding should comply with the following requirements: (See Figs. 11-1 thru 11-3)

1) Have a common grounding or bonding bus (normally a cabinet rail).
2) When the enclosure contains more than one bay, bond all grounding or bonding busses together.
3) All mounted chassis within rack cabinets shall have a grounding or bonding conductor attached to the common grounding or bonding bus when the chassis is not grounded or bonded through the power cord.
4) The grounding or bonding conductor shall be permanent and continuous.
5) Subassemblies mounted in other types of enclosures should be bonded by adequate preparation of the mounting surfaces or by the use of a bonding conductor.
6) To provide protection against grounding or bonding conductor breakage, conductors between the common grounding or bonding bus and moveable chassis should be braided cable or stranded wire.

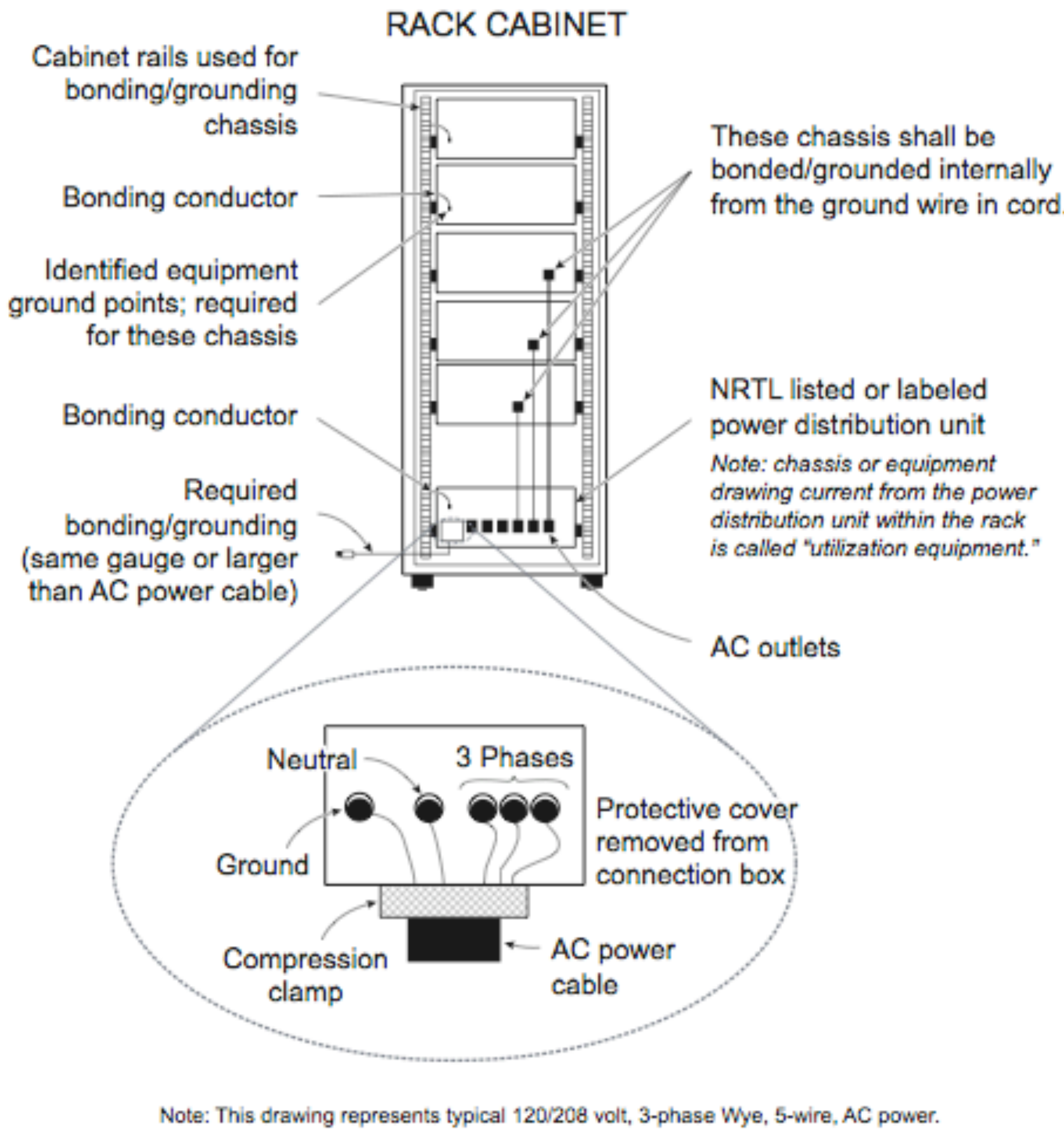


Fig. 11-1. Bonding and grounding in an equipment rack.

All grounding or bonding points should be tight for good continuity, identified by green color, permanently labeled, and properly prepared by cleaning metal surfaces to bare metal or by the use of serrated bushings. Anodized aluminum must be cleaned to bare metal.

The resistance across the bonding point should be very low, so that heating stress effects due to power loss across the bonding point are minimized. If a measurement is required, the method of measurement is to be determined by the user. The user may determine a maximum resistance, e.g., 0.1 ohm.

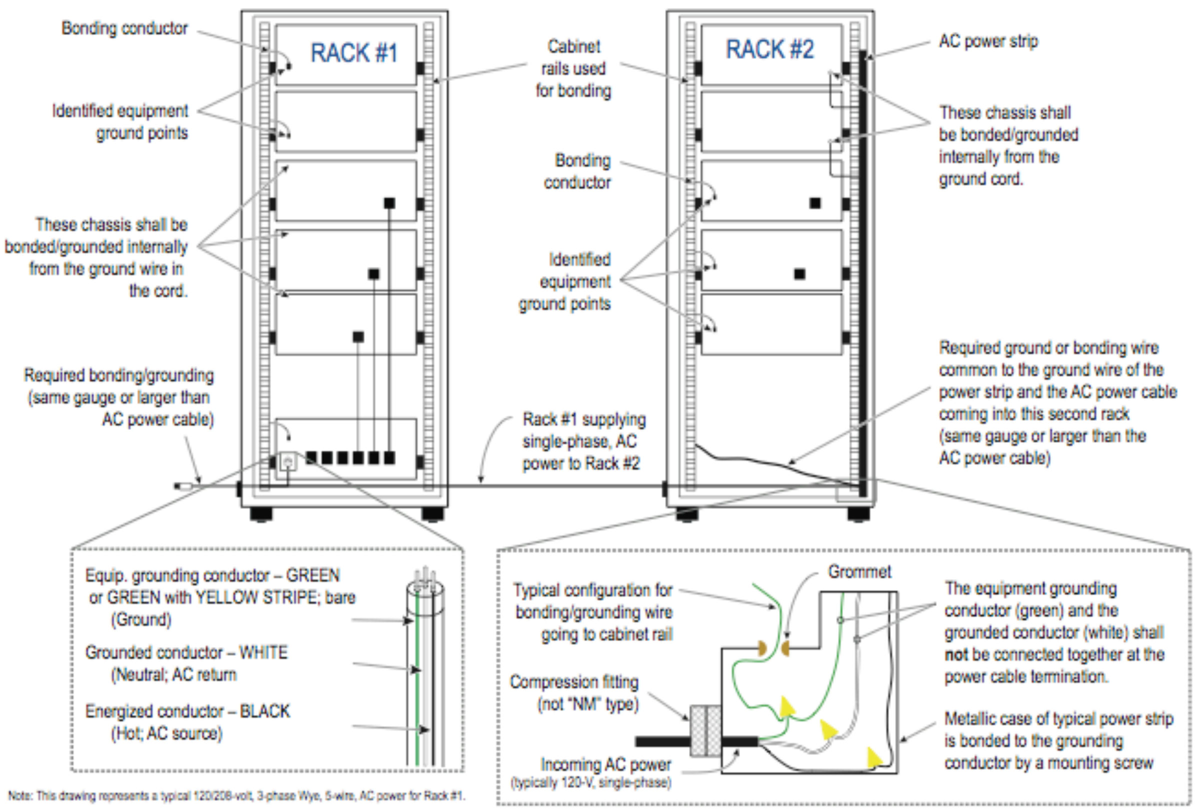


Fig. 11-2. Grounding of multiple independent racks.

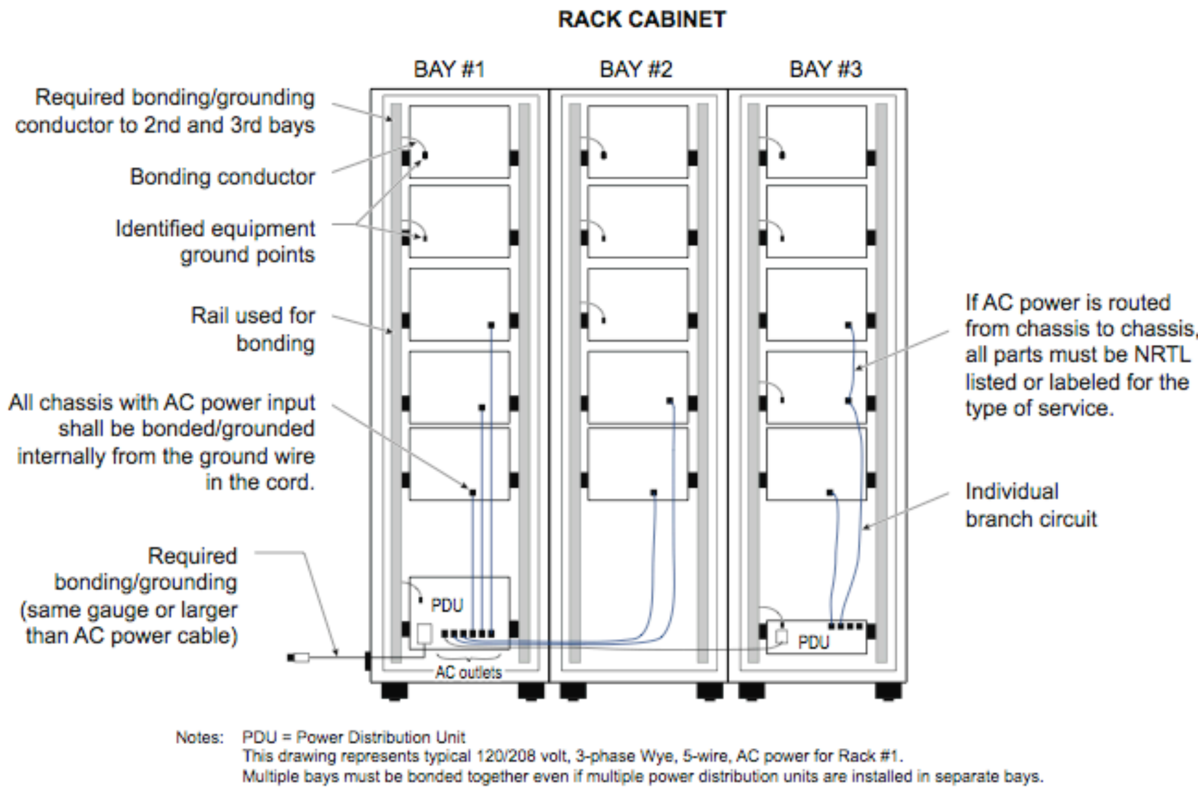


Fig. 11-3. Grounding multiple racks together.

11.3.3.1 Chassis Bonding and Grounding

Metal chassis shall be effectively bonded to a main grounding point in the rack cabinet where necessary to assure electrical continuity and shall have the capacity to conduct safely any fault current likely to be imposed on it. (NEC 250.96)

In a chassis with AC service connected to it, the grounding terminal of its receptacle shall be internally bonded to the chassis frame. (NEC 250.146)

If solder is used, the connection of the equipment grounding conductor shall not depend on solder alone. (NEC 250.8)

The leakage current of cord connected equipment should be very low.

11.3.4 Special Considerations

Systems feeding power isolation transformers must continue the equipment grounding conductor to the equipment or the ungrounded equipment must be guarded and labeled.

For two-wire cord connected equipment, an equipment grounding connector should be installed according to the manufacturer's instructions.

11.4 RACK POWER DISTRIBUTION

The following guidelines will provide the necessary information to correctly install power distribution equipment within instrumentation racks containing electrical and electronic equipment.

11.4.1 General Requirements Applying to All AC Power Equipment Within or Attached To Instrument Racks

11.4.1.1 Loads

Knowledge of the loads that will be connected within a rack cabinet is necessary and needs to be documented before starting design of a rack power distribution system. All components must be sized correctly for the loads and should provide for expansion.

Equipment enclosures may or may not contain a power distribution unit. A rack power distribution unit contains a main overcurrent protection device and multiple branch circuits that are individually protected against overcurrent. Without a power distribution unit, the power wiring is considered part of one branch circuit.

Branch circuit loading shall meet the requirements of NEC Article 210. (See NEC 210.21 through 210.23).

External convenience outlets should be connected to a separate circuit breaker.

Where three-phase, four-wire service is utilized, the loads should be evenly distributed on all phases and there should be consideration of sizing the neutral conductor for certain loads (such as computer equipment) due to the presence of harmonic currents. (See NEC 210.4 and 310.10)

11.4.1.2 Other General Equipment Requirements

Rack power distribution components or assemblies must be listed by an NRTL, or have AHJ approval (See Chapter 12) and UL 508 section 6, construction rack (enclosure)

11.4.2 Conductors, Cords and Cables Specific Requirements.

Each type of internal or external wiring for equipment or an accessory shall be acceptable for the particular application when considered with respect to (1) the current, ambient temperature, voltage, and other conditions of service to which the wiring can be subjected, and (2) exposure to oil or grease.

The term "cables" refers to groupings of wires typically used for control signals, data, or DC or AC power. The term "cords" refers to AC power cords that are attached to devices or extension cords.

The basic insulation on each wire shall be rated for at least the maximum voltage to which the wire is connected, and for at least the temperature it attains. Additionally, the insulation should be rated for the maximum voltage of nearby conductors and wire to which each wire may be exposed. Insulating tubing, sleeving, and tape shall be rated for at least the maximum voltage against which it insulates, and for at least the temperature it attains. Power and signal wires should be routed separately within a chassis.

Wires shall be routed away from sharp edges, screw threads, burrs, moving parts, etc. Holes through which wires are routed shall have smooth, well-rounded surfaces, or shall have a bushing. Clamps for guides used for routing or wiring shall have smooth, well-rounded edges. Pressures exerted by such clamps should not cause cold-flow or otherwise deform the basic insulation.

11.4.2.1 Flexible Cables

Flexible cables may be used:

1. Where flexible cables and attachment plugs are furnished by the manufacturer as part of the equipment to be mounted in the rack.
2. For connection of stationary equipment to facilitate their frequent interchange.
3. To prevent the transmission of mechanical vibration.
4. Where the fastening means and mechanical connections are specifically designed to permit ready removal for maintenance and repair.
5. For data processing cables approved as part of the data processing system.
6. For temporary wiring.

Where breaking or loosening of a circuit connection would render an electric shock or could result in a fire, such connection shall be made mechanically secure. Mechanical security of connections may be provided by crimped, closed ring or flanged lug, or a wrapping that forms at least an open U or by cable clamps, or by cable lacing, insulating tubing, or similar means.

11.4.2.2 Strain Relief

Wiring, cords, or cables shall be provided with strain relief as required to prevent damage.

Additional insulation may be required when the construction of the strain relief may damage the insulation. The use of type NM (Romex) cable clamps on flexible cords and cables is not permitted. Use listed or labeled clamps. The use of any metal clamp or other means that may cause undue stress on the cables within or external to instrument racks is not allowed. Cord and cable support for AC power cable or other heavy duty or large diameter cables must distribute the load over a large area of the outer covering of the cable.

11.4.2.3 Separation of Voltages

Insulated conductors of different circuits shall be separated or segregated from uninsulated energized parts connected to different circuits unless provided with insulation suitable for the highest voltage involved.

Segregation of insulated conductors may be accomplished by clamping, routing, or equivalent means that provide permanent separation from insulated or uninsulated energized parts of a different circuit.

Loose strands of stranded internal wiring, connected to a wire-binding screw, shall be prevented from contacting other uninsulated energized parts not always of the same potential and from contacting noncurrent-carrying metal parts. This may be accomplished by use of pressure terminal connectors, soldering lugs, crimped eyelets, or soldering all strands of the wire together.

11.4.2.4 Other Concerns

Conductors shall not be bundled together in such a way that the temperature rating of the conductors is exceeded. Bundled conductors may require derating of their ampacities. For example, see NEC 310.15(B)(2) and Table 310.15(B)(2)(a)

Flexible cord should be listed or labeled and used only in continuous lengths without splice or tap when initially installed.

Repairs are permitted if the completed splice retains the insulation, outer sheath properties, and usage characteristics of the cord being spliced. In most instances, the entire length of flexible cord should be replaced, in order to assure integrity of the insulation and usage characteristics.

In addition:

1. Conductors and cables shall be suitable for the conditions of use and location,
2. Provide mechanical protection where needed,
3. Consider the environment when choosing jacket for cord/cable, and
4. Recommend using yellow, orange or other bright cord where there exists potential for physical damage.

11.4.3 Power Switches and Interlock Devices Specific Requirements

For all electrical/electronic enclosures utilizing power switches or interlocks, the following should apply:

1. Interlocks should be utilized where exposed voltages (50 volts or greater) are present in equipment and access to the exposed energized parts is not controlled (See Section 11.6.4).
2. Ensure all line-side unprotected contacts are guarded on interlocking contactors or other switching equipment.
3. Be suitable for the conditions, use, and location.
4. Circuit breakers used for the equipment power switch shall be rated for switching under load.
5. Provide provisions for lockout/tagout requirements.

11.5 CHASSIS POWER DISTRIBUTION

Manufacturers are responsible for determining the safety of such chassis and/or enclosures and for providing documentation showing how that determination was made. Listed equipment should be selected by design when available. Unlisted commercial equipment and in-house fabricated equipment shall be approved by the local AHJ.

11.5.1 AC Power Distribution

11.5.1.2 Connections, Connectors, and Couplings

Input/output AC power connections to the chassis shall comply with NEC requirements.

The exposed, noncurrent-carrying, metal parts of panel mount connectors operating at 50 volts or greater shall be bonded to the chassis.

Plugs and sockets for connecting any AC power source shall be NRTL-listed for the application. (Ref. ISA-S82.01-1992, Section 6.10.3.a)

AC power plugs and sockets shall not be used for purposes other than the connection of AC power.

Connectors operating at 50 V or greater shall be listed, rated or recommended for their intended use.

Any connector used to provide power at 50 V or greater shall not allow personnel to make inadvertent contact with the power source.

If plug pins of cord-connected equipment receive a charge from an internal capacitor, the pins shall not be capable of rendering an electric shock or electric burn in the normal or the single fault condition 5 seconds after disconnection of the supply. Plug-in type connectors intended to be connected and disconnected by hand shall be designed so that the grounding conductor connection makes first and breaks last with respect to the other connections.

The following applies for all AC power connectors within or external to electrical/electronic enclosures:

1. There shall be no exposed current-carrying parts except the prongs, blades, or pins.
2. The connector shall prohibit mating of different voltage or current rating than that for the device intended.
3. All connectors must be protected against overcurrent in accordance with their rated ampacity. (NEC 240.5)
4. Connectors must be NRTL-listed for the application.
5. Use of MS, PT, or other non-approved connectors is not permitted except when justified to and approved by the AHJ.

If conditions require the use of a non-NRTL listed or labeled connector, such as an "MS" (military standard pin and socket type) or "PT" (similar to "MS" but smaller) type, for input/output AC power, a warning label should be affixed next to the connector stating: "WARNING - POWER MUST BE REMOVED BEFORE CONNECTING/DISCONNECTING."

11.5.1.3 Terminals/Energized Parts

All terminals/energized parts with a potential of 50 volts or greater shall be guarded to protect from accidental contact or bringing conductive objects in contact with them (NEC 110.27). Consult ANSI/ISA-S82.01-1988, Table 9-1 for spacing information regarding energized parts.

All energized switching and control parts shall be enclosed in effectively grounded metal enclosures and shall be secured so that only authorized and qualified persons can have access.

11.5.2 DC Power Distribution

Guidelines for DC power distribution include:

1. The metal chassis or cabinet shal not be used as a return path.
2. High-current analog or switching DC power supplies should use separate return paths from digital circuits.
3. All of the guidelines pertaining to AC power such as grounding, proper wire size, high voltage, etc. should apply to DC circuits as well.

An accessible terminal charged by an internal capacitor should be below 50 volts within 5 seconds after interruption of the supply.

As with AC power, avoid contacting DC parts when working on a energized chassis. The use of the appropriate class gloves should be considered when performing this type of work.

11.6 PROTECTIVE DEVICES FOR ENCLOSED ELECTRICAL/ ELECTRONIC EQUIPMENT

This section deals with the various protective devices commonly found in electrical/electronic equipment not discussed elsewhere.

11.6.1 Surge Arresters

The more common types of surge arresters used with electronic equipment are metal oxide varistors (MOV), avalanche diodes, and spark gap arresters. The type and electrical rating of the surge arrester is generally determined by the requirements of the circuit being protected, and by the amplitude and duration of the expected surge. (See ANSI/IEEE C62.11-1987.)

Metal oxide varistors and avalanche diodes are voltage-dependent devices whose impedance changes from a near-open circuit to a highly conductive level when subjected to transient voltages above their rated voltages. An MOV is considered "sacrificial" in that a portion of its material is literally burned off each time such a surge is encountered. The response time of an MOV is limited to approximately 500 picoseconds while avalanche diodes can respond in approximately 50 picoseconds. Lead lengths can greatly increase the response times of these devices. The normal failure mode of both devices is a short circuit although sustained voltages well beyond the rating of the MOV can cause the device to rupture and result in an open circuit. A surge arrester should be connected between each ungrounded conductor and ground.

For power line applications, MOV manufacturers recommend a varistor be used with a fuse that limits the current below the level that MOV package damage could occur. In general, circuit breakers are not recommended for this application since circuit breaker tripping is too slow to prevent excessive fault energy.

Consult the manufacturer's application data sheets for more information.

11.6.2 Fuses

Fuses are temperature-sensitive, current-sensing elements that are generally used as short circuit protective devices in individual electrical chassis. The fusing characteristic, or opening time versus current, must be within the safe time/temperature characteristic of the device being protected.

Designers must carefully consider the load requirements in the fuse selection process, particularly when high surge currents may be encountered during initial turn-on. Operating time/current characteristics of the various types available can usually be found in fuse manufacturers catalogs. A fuse's interrupting current capacity must also be considered when connected to a power distribution system having a significant fault current capacity.

The voltage rating on a fuse shall be equal to or greater than the device's operating voltage.

In general, cartridge fuses should have a disconnecting means on the supply side, (NEC 240.40), and shall not be connected in parallel unless factory assembled and listed as a unit (NEC 240.8).

11.6.3 Circuit Breakers

A chassis or cabinet shall not employ circuit breakers as “on/off” switches unless rated for the application by the manufacturer.

11.6.4 Power Interlock Devices

Cabinets and equipment having potentially dangerous currents and/or voltages present should have a means of controlling access, or a power interlock device designed to interrupt the power to the cabinet. Provisions should also be made to discharge any stored energy from capacitors or inductors to less than 50 volts within 5 seconds when the safety interlock is opened. Interlocks may not be used as a substitute for lockout/tagout. [29 CFR 1910.333(c)].

11.7 DISCONNECTING MEANS

All enclosed electrical/electronic equipment shall be provided with a means for disconnecting it from each external or internal operating energy source. This disconnecting means shall disconnect all current carrying conductors.

11.7.1 General

Interlock systems are not a recommended disconnecting means for cabinets and equipment having potentially dangerous currents and/or voltages present.

Permanently connected equipment and multi-phase equipment should employ a listed switch or circuit breaker as means for disconnection.

All cord-connected equipment should have one of the following as a disconnecting device:

1. A switch or circuit breaker,
2. Plug that can be disconnected without the use of a tool, or
3. A separable plug, without a locking device, to mate with a socket-outlet in the building

Where equipment is connected to the source of supply by flexible cords having either an attachment or appliance plug, the attachment or appliance plug receptacle may serve as the disconnect (NEC 422.33).

Where a switch is not part of a motor, motor circuit or controller, the disconnecting means shall be within 50 feet and in sight of the operator and marked as the disconnection device for the equipment.

Where a disconnecting means is not part of the equipment, the disconnecting means should be near the equipment, within easy reach of the operator during normal operation of the equipment, and marked as the disconnection device for the equipment.

If a disconnecting device is part of the equipment, it should be located as close as practical to the input power source.

11.7.2 Emergency Shutdown

The emergency shutdown switch should be within arm's reach of the operator, be easily identifiable, deenergize all power to all equipment associated with the system, be separate from the routine on/ off switch, and be located to protect the employee from moving parts. However, the emergency shutdown switch should not disconnect auxiliary circuits necessary for safety (such as cooling).

11.7.3 Special Considerations

The disconnecting means shall interrupt the source voltage for secondary or remote controlled equipment, such as that using thyristor controls. NOTE: Disconnecting the control voltage shall NOT be considered sufficient.

11.8 MARKING AND LABELING REQUIREMENTS

11.8.1 General Marking Requirements

For all chassis and rack cabinets (electrical, computer, power distribution, etc.), the manufacturer's name, trademark, or other descriptive marking of the organization responsible for the product should be identified.

Other markings for power requirements are:

1. Voltage
2. Maximum rated current in amperes
3. Wattage
4. Frequency
5. Duration
6. Duty cycle
7. Other ratings as specified in the NEC (NEC 110.21)

11.8.2 Hazard Marking Requirements

All enclosures containing exposed energized circuits over 600 volts nominal should be marked "Danger High Voltage Keep Out" with a label that is permanent. These areas shall be accessible to authorized personnel only. The label shall be placed in a noticeable location on the access panel to the enclosure. Mark all other hazards that are associated with the equipment.

11.8.3 Other Requirements

All equipment markings shall be of sufficient durability to withstand the environment involved and should be large enough to read.

To obtain the correct chassis load requirements for marking and labeling, monitor individual chassis while under load. Many chassis have components that are not energized except under certain conditions.

A normal current draw may be a few amperes, but when the chassis is sourcing current to a load, the current draw may be much higher. Individual loads, internal and external, may be tabulated and added to determine the chassis current labeling requirements.

For rack cabinets with internal power distribution units, the outside of the rack cabinet should be labeled with the input parameters of the internal power distribution system.

For rack cabinets without internal power distribution units, the outside of the rack cabinet should be labeled with the total current of the installed equipment.

11.9 WORKING CLEARANCES

Clear working space and headroom shall meet the NEC requirements (e.g., NEC 110.26 and 110.34, see Figs. 11-4 and 11-5). The clear working space and passageways to this space should not be used for storage. At least one entrance of sufficient area shall be provided to give access to working space above electrical equipment.

While maintenance, repair or calibration is being performed, personnel should identify clear working spaces via suitable means such as "Danger" or "Caution" barrier tape, or barricades to keep other personnel from entering the clear working spaces.

TOP VIEW

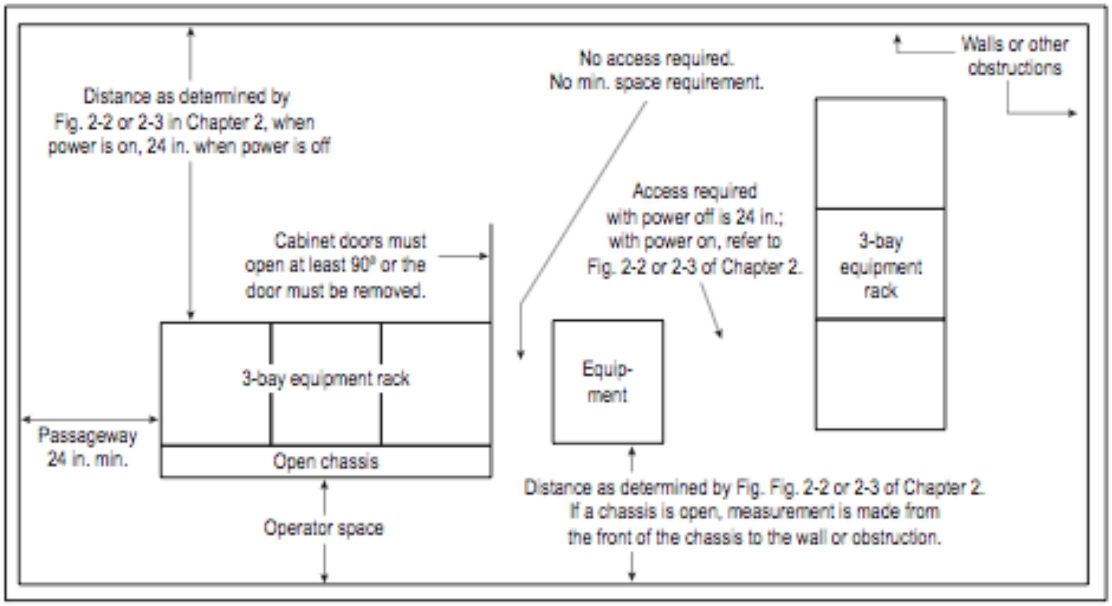


Fig. 11-4. Top view of equipment layout illustrating working clearances.

SIDE VIEW

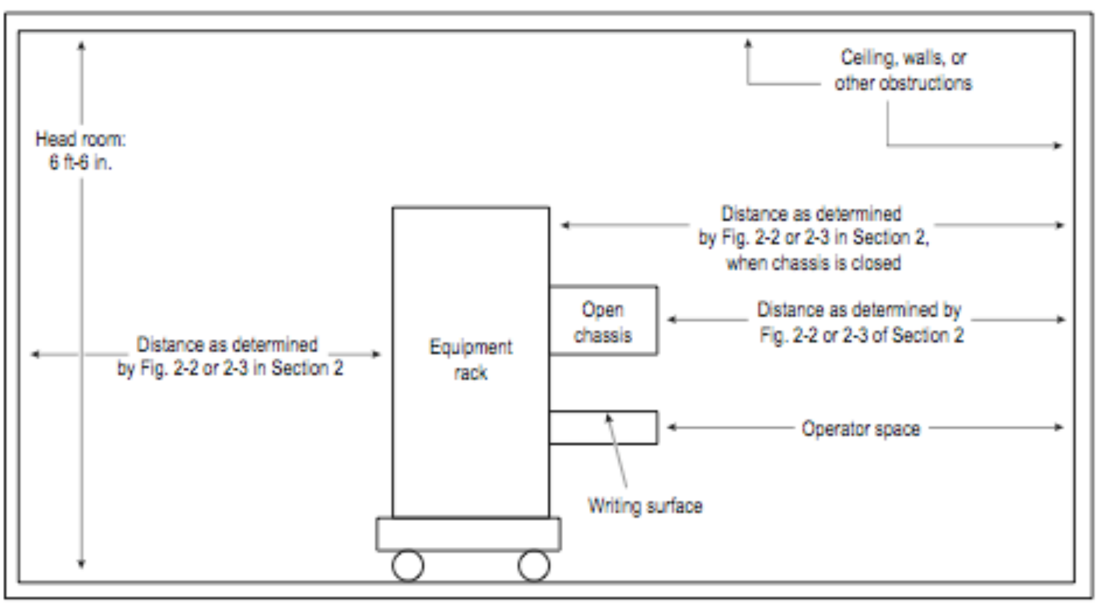


Fig. 11-5. Side view of equipment layout illustrating working clearances.

11.10 CABLE/UTILITY MANAGEMENT SYSTEM

11.10.1 Definitions

Cable Tray - a mechanical support system used to provide cable routing and protection for electrical cables.

Power Cable Tray - a cable tray containing DC cables supplying magnet loads and/or AC cables for utilization equipment.

Premises Wiring Cable Tray - a cable tray containing conductors associated with the premises wiring system.

Signal - a voltage or current of low energy associated with equipment or process monitor and control. Such signals are typically associated with, but not limited to, accelerator and experimental control and data acquisition systems and their connective networks. This definition must not be confused with the NEC definition for a signaling circuit which refers to alarm (fire alarm) or security (burglar alarm) systems or with controllers that deliver electric power to equipment such as motors.

Utility Cable Tray - a cable tray containing signal (as defined above) cables .

11.10.2 Usage with Enclosed Electrical/Electronic Equipment

In certain locations cable supports and/or enclosures are installed for dedicated use with enclosed electrical/electronic equipment. In such cases, the use of a cable/utility management system is a part of custom-made equipment. (See Figure 11-6) It is acceptable for these cable/utility management systems to be used to support bundles of cables, hoses, and tubing that run from the equipment console to the unit under test.

In cable/utility management systems where cables other than those of the custom equipment exist, steps shall be taken to assure that no damage to the existing cables can occur, and that the colocation of the cables creates no additional hazard.

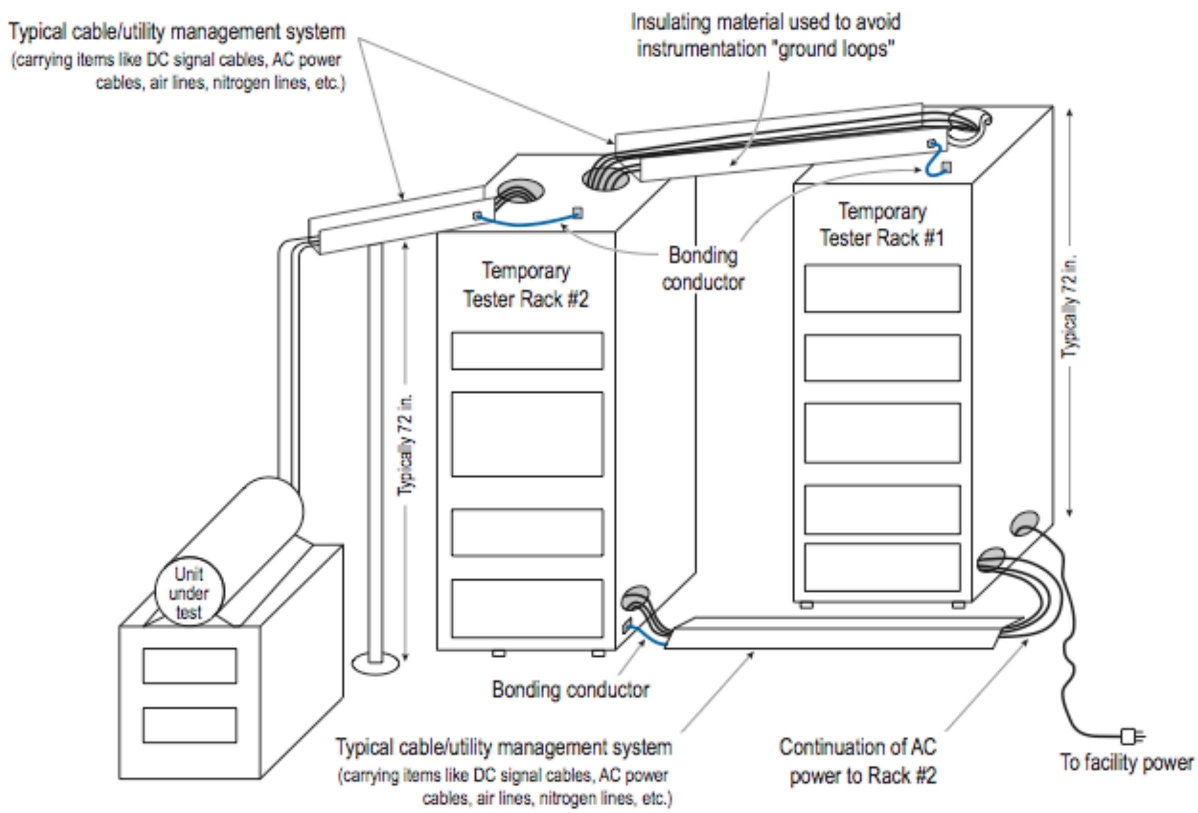


Fig. 11-6. Example of cable management in laboratory.

11.10.3 Requirements

1. The following requirements and recommendations relate to installation and use of Utility Cable Tray systems.
    a. Cable tray systems shall be grounded.
    b. Cable tray systems shall be engineered and properly installed so as to preclude mechanical failure under anticipated load conditions.
    c. Cable tray systems shall present a minimum of sharp edges to installed cables.
    d. Caution must be exercised when adding cables or other services to existing trays to insure that installed cables are not crushed, abraded, or otherwise damaged.
    e. Mechanical fastening of cables to the cable tray structure or to other cables in the cable tray system should be minimized. Excessive fastening unnecessarily constrains the addition or removal of cables at future times. It is recognized, however, that mechanical fastening of certain cable installations is necessary to limit movements associated with electromagnetic forces.
    f. It is strongly recommended that all unused cables be removed from existing cable tray systems. It is recognized, however, that such removal may be precluded if existing operational cables would be adversely affected by the removal process.

g. Cable trays should not be utilized for storage of excessive lengths of installed cables. Cables should be dressed to suitable lengths upon installation.

h. It is recognized that in many locations, due to limited space, the cable tray system offers the best means of bringing services to support experimental devices. In all cases, neither the mechanical loading nor the ventilating capability of the installed cable tray system shall be significantly compromised by addition of such services.

i. Flammable gas lines are not permitted to be located in cable trays.

j. Utilization equipment shall not be located in cable tray.

k. For instances of where premise wiring is to be installed in a utility cable tray, such wiring shall be installed in accordance with the National Electrical Code. The installation of premise wiring shall be segregated through the use of tray dividers.

l. For installations of signal cable into a power cable tray, the responsible engineer shall consider the cable for thermal and electrical properties in consideration of the specific installation and the cable tray for structural integrity. All installations in power cable tray shall follow the NEC guidelines for cable tray fill.

m. For installations of cable into a utility cable tray, the responsible engineer shall take into account the structural load capability of the cable tray system and the durability of the existing cables. 100% cable fill of the tray is permitted. The nature of signal circuits is such that the energy carried by the cables is relatively low. Accordingly, the resultant losses in signal cables are of a sufficiently low level that heat dissipation is not a problem.

n. Non-flammable gas lines which are neatly bundled and secured may be installed in utility cable tray or attached to the utility cable tray supports (not attached to the tray itself).

o. Cable trays should be made of corrosion-resistant material or adequately protected from corrosion that may be encountered in use. Refer to manufacturers' literature.

p. Verify that the building structure has adequate capacity to support the fully loaded cable tray(s). An appropriate safety factor should be applied to account for stresses during installation of cables, stresses during seismic events, and uncertainties about the building structure.

q. Provide protection for cables from deteriorating agents. (See NEC 392.5(C))

2. The following requirements and recommendations relate to installation and use of Cable Tray systems in pulsed power applications.

   a. Cable tray systems shall be grounded in a way such that inductive effects are minimized during a fault condition so that voltage rise along the ground path is also minimized.

   b. The cable tray should be designed and installed to minimize inductive effects during a fault condition.

An assessment of any hazards identified with the equipment and the operation with which it is involved should be performed to assure safe operation of components in the cable/utility management system. Where any cable/utility runs include hazardous fluids or pressurized gases, the utilization of these utilities with the cables involved must be determined to be safe.

Metallic cable/utility management systems that support electrical conductors shall be grounded or bonded to the equipment. Grounding integrity should be checked by inspection by a qualified worker for all components with exposed metal parts. This inspection should be documented. Where cable/utility management systems are installed exclusively for electrical/electronic equipment usage and where these trays are metallic and not grounded or bonded, approved documentation shall exist stating the reason for not grounding or bonding the system (See Section 11.3).

Equipment cable/utility runs installed in cable/utility management systems should be visually inspected periodically. These inspections should be performed at the time of installation and any interval specified in the equipment documentation. Any inspection should, as a minimum, consist of:

1. A visual check for the integrity of cable jackets and visible shields;
2. A check for the integrity of all utility hoses by looking and listening for leaks;
3. A visual check on all securing devices used to hold the bundle on the tray to assure the bundle is positioned properly and no damage has occurred;
4. A visual inspection on all bends for signs of pinching, cutting, exceeding minimum cable bending radius, or other damage; and
5. Documentation of all results of any inspection.

Supports shall be provided to prevent stress and physical damage to cables where they enter or exit cable/utility management systems.

11.11 ELECTRICAL SAFETY REQUIREMENTS FOR TESTER FACILITIES

The following is not intended to encompass all of the electrical design requirements which must be considered in planning electrical systems for facilities intended to accommodate testers. The information provided should, however, provide a guide to understanding for personnel who would be tasked with specifying facility electrical safety necessary to the testing environment.

Provisions for an adequate number of receptacle outlets and associated branch circuits to accommodate cord and plug connected equipment, testers, etc., in a facility must also be considered in specifying the electrical requirements.

For equipment that cannot tolerate power interruption, consideration should be given to the use of a continuously operating or standby uninterruptible power supply (UPS) or a generator.

11.11.1 Ampacity of Facility Wiring and Distribution Equipment

Consideration must be given to accommodating the anticipated load demand which may occur as a result of power supplied to the various possible combinations of electrical equipment connected to a particular branch circuit.

11.11.2 Facility Grounding at Temporary or Remote Sites

Proper grounding is considered crucial to providing the safest possible electrical installation, from the standpoint of maximizing the safety of facility occupants and minimizing property damage and loss.

Designs for equipment to be used at temporary or remote sites must take into consideration the same grounding issues which may not be accommodated in the same manner as for permanent facility power wiring (See Section 11.3).

11.11.3 Facility Lightning Protection

Lightning protection is required for facilities which will house enclosed electrical/electronic equipment involved with radioactive, explosive, and similarly hazardous materials or for facilities that are considered valuable or house valuable contents.

11.11.4 Surge Protection

In addition to facility lightning protection, the effects of surges resulting from lightning strikes to power distribution systems may be lessened by the use of lightning arrestors and suppressors installed at strategic points in the supply system to the facility. An assessment is necessary, addressing the consequences of lightning-induced surges, in order to determine the degree to which protection should be provided.

11.12 ENCLOSED POWER ELECTRONICS

Power electronics equipment is equipment that uses electronic components and subsystems to control significant amounts of electrical energy. Examples of power electronics systems include:

1. Power supplies and modulators for laser systems;
2. Accelerators, magnets, x-ray systems, and other research equipment;
3. Radio and radar transmitters;
4. Variable speed motor drives; and
5. Induction heating systems.

All applicable portions of this section should be addressed due to the hazards involved with this type of equipment.

11.12.1 Enclosures

Power electronics equipment should be constructed in all-metal enclosures for containment of fire, high energy, and electromagnetic radiation hazards.

The enclosures should support the housed equipment, provide strength to brace conductors against short circuit forces, and protect housed equipment against physical damage.

It is usually easier to provide barriers to protect the electronics enclosure from collision and missile hazards rather than to strengthen the enclosure itself.

11.12.2 Component Clearances

Enclosures must provide adequate clearance from energized parts. The required clearances depend on the shape of the conductor, the surface characteristics of the conductor and enclosure, the voltage characteristics, environmental conditions, and creepage. Larger clearances may be required around support insulators due to their surface breakdown characteristics.

All power electronics enclosures shall provide adequate room for access to parts and subsystems for expected maintenance and modification. Consideration should be given to handling provisions for heavy parts and subsystems, access to test points and calibration adjustments, and work clearances for safe access to enclosure interiors.

Safe work on high-voltage equipment requires installation of manual grounding devices on exposed high-voltage conductors. Enclosure size shall provide adequate room to safely apply and remove grounding devices, and permit grounding devices to remain in place without interfering with expected work. (See Section 13.10.1.2)

Enclosures shall be sized to allow cables to be installed and routed without infringing on required clearances from high-voltage conductors.

Subassemblies, circuits, and related equipment should be segregated to the extent possible to minimize the possibility of a fault in one device damaging another.

11.12.3 Instrumentation

Power electronics systems can involve fast pulses, high frequencies and high currents and it is common for the voltage difference between ground in one circuit and ground in another circuit to differ substantially. This difference can be hundreds or thousands of volts. Wire and cable shall be insulated to withstand these potentials. Surge arrester and capacitor protection may be used to control these potentials. DC circuits connected to coils, solenoid valves and other inductive components should be tested for induced voltages and appropriate protection for circuits should be provided.

11.12.4 General

Test points needed for adjustment and diagnosis should be installed on the front panel or other appropriate location of power electronic systems to facilitate their use without exposure hazard to employees in the area.

Currents generated only during fault conditions or those introducing noise or data errors shall not be considered objectionable currents. However, bonding and grounding may be altered to reduce the noise or data errors, in accordance with provisions of NEC 250.96(B). Conductors, bus bars, and internal wiring should be insulated in the event objects are dropped into the equipment.

Automatic discharge devices are not a substitute for grounding devices used for personnel protection. Grounding points shall be located in the system and physically arranged to permit the attachment of adequate grounding devices for the protection of personnel working on the system.

These grounding points shall be capable of carrying the short-circuit current to which they may be subjected and applied using methods appropriate for the voltages or currents involved.

11.13 NON-IONIZING RADIATION

11.13.1 Electromagnetic Radiation

Human exposure to electromagnetic (EM) radiation at certain power-density levels can be hazardous. The hazards are associated with the heating of biological tissue, which occurs when EM radiation is absorbed by the body. This heating is essentially similar to the cooking process in a microwave oven. Use caution where EM sources are being used with the shielding altered or removed.

When working with EM radiation, it is recommended that calculations be performed to estimate the emitted radiation levels and actual levels be measured by radiation monitors.

EM radiation-safe levels have been established by the Institute of Electrical and Electronics Engineers and are documented in the IEEE standard - C95.1-1999. See Section 13.7.4.

Exposure to hazardous levels of EM radiation can be lessened by maintaining as much distance as possible from the source. Power density is reduced by a factor of $1/\text{distance}^2$ from the source.

11.13.2 Electromagnetic Radiation Threat to Electroexplosive Devices

Designers of enclosed electrical/electronic equipment must consider the possible effects on nearby Electro Explosive Devices (EED) of electromagnetic radiation (EMR); i.e., radio frequency (RF) energy, emitted by that equipment.

Energy induced into an EED by the electromagnetic field resulting from such emissions may be adequate to cause the device to detonate.

Factors which should be taken into account in assessing concerns for possible EMR emissions are:

1. Wiring, shielding, and sensitivity
2. Proximity
3. Frequency of the emissions
4. Power density

5. Type of emission modulation

Possible measures to mitigate the threat of EMR emissions include:

1. Enclosure and signal line shielding and grounding to prevent leakage of EMR from the equipment.
2. Designed-in physical separation or barrier that would ensure that the power density of the electromagnetic field is inadequate to cause detonation of an EED at the closest possible distance to the emission source within the equipment.
3. Filter, or provide ferrite beads for, signal lines from the equipment which may conduct EMR emissions into EED circuitry or secondarily radiate EMR in the proximity of an.
4. Ensure that the minimal power necessary is used to operate circuitry capable of producing EMR.
5. Label the equipment capable of emitting EMR to indicate the minimum separation distance to be maintained between the equipment and an EED or EEDs.
6. Use a safety factor in design for EMR reduction; e.g., only 1/10 of the energy that would initiate an EED is allowed.

11.14 AMPACITY INFORMATION FOR WIRE SIZING

The following information is useful for designing wiring for electronic equipment.

11.14.1 Ampacity Information

Sources of information for determining ampacity of wiring and cable include:

IEEE Standard 835, IEEE Standard Power Cable Ampacity Tables

IEEE Standard 848, Procedure for the Determination of the Ampacity Derating of Fire Protected Cables

ICEA P-54-440, NEMA Pub. No. WC 51 - Ampacities of Cables in Open-Top Trays.

The National Electrical Code [NEC] requires their own cable sizing for premises wiring. Refer to the NEC rules to determine building wiring, as this page relates to electronic equipment wiring. For reference, the ampacity of copper wire at 30^0C for common wire sizes

14 AWG may carry a maximum of 20 Amps in free air, or 15 Amps as part of a 3 conductor cable.

12 AWG may carry a maximum of 25 Amps in free air, or 20 Amps as part of a 3 conductor cable.

10 AWG may carry a maximum of 40 Amps in free air, or 30 Amps as part of a 3 conductor cable.

8 AWG may carry a maximum of 70 Amps in free air, or 50 Amps as part of a 3 conductor cable.

As appropriate, refer also to the tables in NEC Article 310 and Overcurrent Protection in NEC 240.4.

Cable manufacturers will provide different current carrying numbers based on the insulation used for the wire.

Table 11-1 below lists copper wire with a Teflon [TFE] insulation. Teflon insulation has a higher operating temperature range then other insulators such as PVC. The table below is based on data derived from MIL-STD-975, using 70^0C as the operating temperature. To derate based on number of wires in a bundle:

$I_{BW} = I_{SW} \times (29 - \#_{wire}) / 28$ @ [1 to 15 Bundled wires]

$I_{BW} = I_{SW} \times (0.5)$ @ [more then 15 Bundled wires]

I_{SW} = Single wire

I_{BW} = Bundled wires

To derate by temperature use; derate by 80% at 150^0C, 70% at 135^0C, or 50% at 105^0C

Table 11-1. Ampacity for TFE insulated copper wire.

Copper Wire TFE Insulated			
AWG	**Current Carrying**	**AWG**	**Current Carrying**
00	169	**0**	147
2	108	**4**	81
6	60	**8**	44
10	33	**12**	25
14	19	**16**	13
18	9.2	**20**	6.5
22	4.5	**24**	3.3
26	2.5	**28**	1.8
30	1.3	**-**	-

11.14.2 Color Coding Guidelines

This page describes wire insulation color coding as defined by current military specifications. Insulation color coding is used to indicate wire function or the voltages present.

The **National Electrical Code** [NEC] specifies the color coding system for premise and facility wiring as described in NEC 200.6, 200.7, 210.5, 250.119, et al.

The **National Fire Protection Association** [NFPA] specifies insulation colors for industrial machinery [machine tools]. The NFPA 79 color scheme uses a solid color with another color strip for a number of applications. For details, see NFPA 79: Electrical Standard for Industrial Machinery.

Table 11-2 below provides hook-up wire color coding for chassis and interconnecting wiring. The Military Standard color identification number is not addressed on this page. Table 11-3 provides an alternate system of color codes. The Military Standard color identification number is not addressed here.

Table 11-2. Color codes for chassis and interconnecting wires.

Colors for chassis and interconnecting wiring system by function				
Function	**Base Color**	**Identification #**	**Alternate color code**	**Identification #**
Grounds, Grounded elements	Green	5	Green	5
Heaters or filaments	Brown	1	White/brown	91
Power Supply B+	Red	2	White/red	92
Screen Grids Clock	Orange	3	White/orange	93
Transistor Emitters	Yellow	4	White/yellow	94
Transistor Bases	Black	0	White/black	90
Transistor Collectors	Blue	6	White/blue	96
Power Supply, minus	Violet	7	White/violet	97

Table 11-3. Wiring color code for interconnecting by voltage.

Wiring Colors for Interconnecting by Voltage		
Voltage	**Color**	**Identification #**
+151 to +500	Red	2
+61 to +150	White/Red	92
+26 to +60	White/Brown/Red	912
+7 to +25	White/Red/Orange	923
+2 to +6	White/Red/Yellow	924
-26 to -60	Violet	7
-11 to -25	White/Violet	97
-2 to -10	White/Violet/Yellow	47
Ground	Green	5

Table 11-4 specifies optical fiber cable color coding according to EIA Standard 598-A. EIA Standard 598 specifies color codes of the cables when they are grouped into bundles.

Table 11-4. EIA598 Fiber Color Chart.

EIA598 Fiber Color Chart	
Position Number	Color & Tracer
1	Blue
2	Orange
3	Green
4	Brown
5	Slate

6	White
7	Red
8	Black
9	Yellow
10	Violet
11	Rose
12	Aqua
13	Blue with Black Tracer
14	Orange with Black Tracer
15	Green with Black Tracer
16	Brown with Black Tracer
17	Slate with Black Tracer
18	White with Black Tracer
19	Red with Black Tracer
20	Black with Yellow Tracer
21	Yellow with Black Tracer
22	Violet with Black Tracer
23	Rose with Black Tracer
24	Aqua with Black Tracer

Table 11-5 specifies optical fiber cable color coding when there is more than one type of cable in the jacket.

Table 11-5. Color coding of premises fiber cable.

Color coding of Premise Fiber Cable		
Fiber Type / Class	Diameter (µm)	Jacket Color
Multimode 1a	50/125	Orange
Multimode 1a	62.5/125	Slate
Multimode 1a	85/125	Blue
Multimode 1a	100/140	Green
Singlemode IVa	All	Yellow
Singlemode IVb	All	Red

Table 11-6 below specifies the Military standard for AC wiring Color Coding

Table 11-6. Color coding for AC wiring per military standard.

Color Coding for AC Wiring					
Service	**Phase A**	**Phase B**	**Phase C**	**Neutral**	**Ground**
115v 60Hz 1 ϕ	Black	---	---	White	Green
208v 60Hz 3 ϕ "Y"	Black	Red	Orange or Blue	White	Green
230v 60Hz 3 ϕ Delta	Black	Red	Orange or Blue	---	Green
115v 400Hz 3 ϕ Delta	Black	Red	Orange or Blue	---	Green
208v 60Hz 3 ϕ "Y"	Black	Red	Orange or Blue	White	Green

Table 11-7 below specifies color coding standards for commercial AC wiring including flexible power cords.

Table 11-7. Commercial color code for AC wiring.

Commercial Coding for AC Wiring			
Service	**US**	**Europe**	**UK**
115v/240v 60Hz	Black	Brown	Brown
Common	White	Blue	Blue
Ground	Green	Green/Yellow	Green/Yellow

12.0 APPROVAL OF UNLISTED ELECTRICAL EQUIPMENT

12.1 INTRODUCTION

The use of unlisted and unapproved electrical equipment that contains or produces hazardous energy must be NRTL listed/labeled or approved by an Equipment Inspector prior to use. Listed equipment that has been modified or is used outside its use defined by its listing or manufacturer's instructions must also be approved by an Equipment Inspector prior to use.

An Equipment Inspector is a qualified worker who has been approved by the electrical AHJ to inspect and approve electrical equipment for its intended use.

Site management must:

- Ensure that all employees working in areas they are responsible for use only NRTL-listed or Equipment Inspector-approved electrical equipment.
- Ensure NRTL-listed equipment is purchased and utilized if available.

This chapter provides an example program for examining and approving unlisted electrical equipment at DOE sites, that would be acceptable for an AHJ to use to evaluate unlisted, in-house built, or modified listed equipment.

12.1.1 Scope

Field Evaluation and approval of unlisted electrical equipment applies to electrical equipment used by employees and employees of subcontractors or organizations. All *unlisted* or *modified NRTL- listed* electrical equipment requires Field Evaluation and approval prior to use. These requirements apply as follows:

- New equipment must be approved by an equipment inspector before use following the provisions of this document.
- Equipment previously accepted as approved without field examination must be approved following the provisions of this document.
- Re-approvals of equipment previously approved under a previous program that did not meet the requirements within this document should follow the provisions of this document. Re-approvals may include previously approved equipment that has been modified or is used outside of its original intent.
- Equipment that was previously evaluated, labeled and documented under a previous program that did not meet the requirements of this document does not need to be approved again to meet these requirements.
- *Exception:* Unlisted equipment in use when a site first adopts its field examination program may be used for a period of up to 60 months (5 years) after the program is adopted with the following restrictions:
  - The existing equipment at the site must be examined with proportional progress towards completion within the 5 year time period, and
  - Existing equipment that exhibits any observed external serious defects (e.g. frayed power cord, ungrounded metal chassis) that would result in a failure to pass examination or that is involved in an electrical incident must be removed from service and subsequently discarded or repaired and approved before further use.

The following types of electrical equipment **do not require field evaluation and approval**:

- Equipment that is not being used (e.g., in storage, staged for salvage/excess, etc.) Equipment that is not being used should be located or labeled so it is clear it is not in use.
- Nationally Recognized Testing Laboratory (NRTL) listed as defined in this document and used in accordance with such NRTL listing. Salvaged equipment is an exception and must be field evaluated (see section 12.4.4).
- Low Hazard (Classes X.0 and X.1) equipment as defined in this document (see Chapter 3).
- Prototype equipment (e.g., test chassis, bench top experiment) built to test the validity of a design that is under the exclusive control of the designer if used for less than three months. An Equipment Inspector should be consulted at the beginning of the development stage and as necessary to ensure that all appropriate electrical safety requirements are being met (e.g., guarding, work control [EEWP], etc.). Equipment being developed that exceeds a three-month period may be acceptable as long as a Equipment Inspector is informed of the equipment and the status of the design/development and safety continues to be covered by adequate work control.

The following equipment **does not need to be disassembled/opened for approval.** However, no hazard should be present to the worker, as can best be determined by external Field Evaluation. Other evaluations must be substituted for the inability to visual inspection e.g. review of schematics, assembly drawings etc.

- Equipment that will be rendered inoperative as a result of Field Evaluation.
- Equipment that will void the manufacturer's warranty upon opening.
- Equipment manufactured by a reputable manufacturer as defined in this document.
- Equipment that could present additional hazards to the EQUIPMENT INSPECTOR upon opening, e.g., radiological hazards.
- Equipment containing classified components requiring a "need to know".

12.1.2 Purpose

The purpose of this document is to provide standard criteria for: evaluation, labeling, and documentation of unlisted electrical equipment. The Occupational Safety & Health Administration (OSHA) requires explicit approval of all electrical equipment in the workplace so it is free from recognized hazards that are likely to cause death or serious physical harm to employees. To improve and maintain electrical safety at DOE Facilities, only electrical equipment that has been approved as safe for the intended use must be utilized. Unlisted electrical equipment must be examined for safety before use as required by OSHA 29 CFR 1910.303(b).

12.1.3 NRTL-Listed Equipment

NRTL-listed equipment must be purchased and utilized if available. For new or replacement equipment, an NRTL-listed product must be purchased instead of an unlisted product if both exist. All NRTL-listed equipment must be used for its intended purpose in accordance with the manufacturer's instructions. **Otherwise the equipment must be treated as unlisted and approved per the requirements in this document.**

12.1.4 Definitions

Approved Equipment – Equipment acceptable to the AHJ consisting of:(1) NRTL-listed equipment being used in accordance with its listing or labeling for the manufacturer's intended purpose; or (2) equipment that is inspected and approved by an Equipment Inspector as safe for its intended purpose.

Electrical Equipment – Equipment that uses electrical energy for electronic, electro-mechanical, or chemical operations; heating; lighting; or similar purposes. Electrical equipment includes equipment used in laboratory research and development (R&D) as well as utility, facility, and shop equipment.

Equipment Inspector – A qualified electrical worker who has been determined by his/her AHJ or designee to have the skill, knowledge, and abilities to safely perform the work to which they are assigned. In addition they must have knowledge of the applicable electrical safety requirements as well as demonstrated field experience in the design, installation, and/or operation of facility or R&D electrical systems. Performs field evaluations, approves, labels and documents electrical equipment installations and work.

Facility Electrical Equipment – Electrical equipment that is considered an integral part of a facility or building and is generally not under direct control by research and development or office personnel. Examples include building pumps, compressors, HVAC equipment, fixed general lighting fixtures permanently attached to the building structure, and facility power distribution equipment such as transformers.

Field Evaluation – The process used for one-of-a-kind, limited production, used, or modified products that are not listed or labeled under a full listing and certification program. The process is completed at the point of manufacturing, interim points of distribution, in the evaluating company's facilities or at the final installation site or a combination of the above.

In-House-Built Equipment – Electrical equipment designed and/or fabricated by employees of a DOE facility, including employees of subcontractors, other research organizations, including universities, other labs, and other research institutions.

Low Hazard Equipment – Class X.0, X.1 equipment that contains only negligible or low hazards as defined in Chapter 3 of this document.

Modified Equipment – NRTL-listed or Approved electrical equipment that has been modified or is being used for a purpose other than intended by the manufacturer/builder. Modification means that a change has been made that affects the safety of the equipment or is not in accordance with the manufacturer's/builder's installation, use, or maintenance instructions.

Nationally Recognized Testing Laboratory (NRTL) – An organization (e.g., UL, CSA):

- That is recognized by OSHA in accordance with Appendix A of 29 CFR 1910.7;
- That tests for safety;
- That lists, labels, or accepts equipment or materials that meet all of the criteria in 29 CFR 1910.7(b)(1)-(b)(4);
- That is concerned with the evaluation of products or services;

- That maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services; and
- Whose listing states that the equipment, material, or services either meet appropriate designated standards or have been tested and found suitable for a specified purpose.

Other than Reputable Manufacturer – A manufacturer that does not meet the criteria for "Reputable Manufacturer" as defined in this document.

NRTL-Listed Equipment – Equipment, included in a list published by an NRTL and used in accordance with any instructions included in the listing/labeling for its intended purpose by the manufacturer.

Reputable Manufacturer – Manufacturers that meet the following criteria:

- At least two pieces of unlisted electrical equipment from the manufacturer have been examined and approved by an EQUIPMENT INSPECTOR. Field Evaluation should be done according to the requirements for in-house built/modified equipment as required in this document.
- The manufacturer has a North American office/distributor (e.g., Thomas Register®)
- The manufacturer services their products and can provide technical support.
- The manufacturer provides adequate documentation in English (acceptable to the approving EQUIPMENT INSPECTOR), and
- The site AHJ or designate decides to approve the manufacturer as reputable.

Each site or group of sites should maintain a list of reputable manufacturers as a reference for its equipment inspectors. Note: *Manufacturers originally meeting this criteria should no longer be considered reputable when the manufacturer no longer exists. The age of equipment should be considered when determining the level of field examination with equipment made by a reputable manufacturer.*

System – A combination of components integrated into a unit to perform a specific task that is unlikely to change.

Unlisted Equipment – Equipment that has not been listed by an NRTL.

12.2 FIELD EVALUATION/DOCUMENTATION CRITERIA

Field Evaluation of unlisted electrical equipment must be documented. The documentation and Field Evaluation criteria as applicable must be done as specified in this section. Documentation may be kept in paper and/or a computer format (e.g. computer database).

It is recommended that each site or group of sites adopt a standard form (paper or computer based) for each of the four types of examinations used by all EQUIPMENT INSPECTORS that meets the requirements of this chapter and is appropriate to site equipment. Examples of such forms appear in Section 12.6.

12.2.1 In-House Built/Other Than Reputable Non-NRTL/Modified NRTL-Listed Electrical Equipment

Documentation (See Example in Section 12.6,1) must include as appropriate:

- Equipment Owner name (optional), Badge # (optional), group/organization

- Equipment Name
- Equipment Manufacturer
- Equipment model number
- Equipment serial number and property number if applicable
- Equipment location (optional)
- Equipment status: new, modified, not previously approved, in-use, etc.
- Equipment Type(optional):
    - Stand-alone custom built, or non reputable
    - System
    - Powered rack
    - Appliances and electrical tools
    - Powered Workbench
    - Extension cords and relocatable power taps
    - Other
- Function
- Usage:
    - Operating Environment
- Conditions of Usage/comments
- EQUIPMENT INSPECTOR tracking number if equipment is approved.
- Date examined and approved/rejected
- Name of EQUIPMENT INSPECTOR who examined and approved/rejected the equipment

Other than reputable non-NRTL or modified NRTL-listed electrical equipment must be examined at a minimum, checking for the following items as appropriate:

- External Inspection:
    - Enclosure
        - Operator not exposed to any hazard
        - Not damaged
        - Appropriate material
        - Protects contents from operating environment
        - Will contain any arcs, sparks, electrical explosion
    - Power Source
        - Cords and Plugs
            - Proper voltage and ampacity rating for plug and cord
            - Grounding conductor included if required
            - Not frayed or damaged
            - Proper wiring of plug
            - Strain relief on cord
        - Direct wired into facility power
            - Proper voltage and ampacity rating for wiring method
            - Installation according to NEC
            - Proper loading and overcurrent protection in branch circuit
    - Grounding
        - Ground from cord or other is properly terminated
        - All non-current-carrying exposed metal is properly bonded
        - All non-current-carrying internal subsystems are properly bonded
        - Equipment ground is run with circuit conductors
        - Auxiliary ground permitted
            - Check termination
    - Foreign Power Supplies and Equipment

        - Connected to facility power with appropriate NRTL listed adapters
        - Correct voltage, frequency, and phasing
        - Correct wire ampacity for U.S. use
    - Overcurrent Protection
        - Adequate overcurrent protection? in equipment, or branch circuit
    - Marking Requirements
        - Hazards, including stored energy
        - Power requirements (Voltage, current or power, frequency)
        - Make/model/drawing number
        - Restrictions and limitations of use
    - Other Requirements
        - Documentation adequate
        - Procedures to use
    - Secondary Hazards
        - RF hazards
        - DC electric or magnetic fields
        - IR, visible, or UV
        - X-rays
        - Fire, electrical explosion
- Internal inspection:
    - Internal Wiring
        - Polarity
        - Phasing
        - Landing of ground
        - Separation of line voltage and high voltage from low voltage
        - Wiring terminals and leads
        - Wire size
        - Proper dielectric
        - Clearance/creepage distances for high voltage
        - Listed conductors, if applicable
    - Other Internal Issues
        - Neat workmanship
        - Listed components used, if applicable
        - Free of sharp edges
        - Proper cooling
        - Automatic discharge of high voltage capacitor
- Tests performed as deemed appropriate by Equipment Inspector
    - Ground continuity (less than an ohm)
    - Polarization of cord and plug
    - Auto discharge of high voltage capacitor
    - Functional Tests (e.g. GFCI, emergency shut-off etc.)
- Failure Analysis
    - Effect of ground fault
    - Effect of short circuit
    - Effect of interlock failure
    - Effect of overload
    - Effect of incorrect setting
- Maintenance
    - Any safety issues with access and maintenance

12.2.2 Facility Electrical Equipment

Note: It is recommended that unlisted facility equipment be examined by an equipment inspector who has background and experience working with and/or on facility equipment or who is a registered professional engineer.

Documentation (See Example in Section 12.6.2) must include at a minimum:

- Equipment Owner name (optional), Badge etc.#(optional), group/organization
- Equipment name
- Equipment manufacturer
- Equipment model number
- Equipment serial number and property number if applicable
- Equipment location (optional)
- Equipment function
- The 8 items checked
- Conditions of use/comments
- EQUIPMENT INSPECTOR tracking number if equipment is approved.
- Date examined and approved/rejected
- Name of EQUIPMENT INSPECTOR who examined and approved/rejected the equipment

Facility unlisted electrical equipment must be examined (See Appendix C, Part 2), at a minimum, checking for the following items:

- Suitability for installation and use in conformity with 29 CFR 1910 Subpart S and/or NEC
- Mechanical strength and durability, including for parts designed to enclose and protect other equipment, the adequacy of the protection thus provided
- Wire bending and connection space
- Electrical connections and insulation
- Heating effects under normal condition of use and also under abnormal conditions likely to arise in service
- Arcing effects
- Classification by type, size, voltage, current capacity, and specific use
- Other factors that contribute to the practical safeguarding of persons using or likely to come in contact with the equipment

12.2.3 Reputable Manufacturer Electrical Equipment

Documentation (See Example in Section 12.6.3) must include at a minimum:

- Equipment Owner name (optional), Badge etc.#(optional), group/organization
- Equipment name
- Equipment manufacturer
- Equipment model number
- Equipment serial number and property number if applicable
- Equipment location (optional)
- Equipment function
- The 6 items checked (itemized below)
- Conditions of use/comments
- Equipment Inspector tracking number if equipment is approved.
- Date examined and approved/rejected

- Name of Equipment Inspector who examined and approved/rejected the equipment

Electrical Equipment manufactured by a reputable manufacturer must be examined, at a minimum, checking for the following items:

- The case is grounded through the power cord to the grounding pin on the plug, if applicable (less than one Ohm resistance).
- The plug is polarized, if applicable.
- The equipment input voltage and frequency match those of the power source (e.g., building's electrical system, etc.).
- The equipment construction is suitable for the intended operating environment.
- The equipment is in its original, unmodified, and undamaged condition.
- The equipment has externally accessible overcurrent protection (e.g., fuses) that are properly sized, if appropriate. (Equipment not having externally accessible overcurrent protection needs further evaluation to determine if the equipment is safe for use.)

12.2.4 System

To examine a group of components as a system, the EQUIPMENT INSPECTOR must first confirm that it meets the definition of a system as defined in this document. If not, each component must be examined and approved separately but the inspector should consider the interactions and connections among the components in performing the evaluation.

Documentation (See Example in Section 12.6.4) for the system should include at a minimum:

- The items required to be evaluated for system Field Evaluation in this section
- Conditions of use/comments
- System description
- Subsystems
- System name
- Manufacturer
- Date built
- Date last modified
- Number of pieces of equipment (e.g., 3 power supplies, 2 modulator racks)
- System status
- System Owner name (optional), Badge etc.#(optional), group/organization
- Equipment location (optional)
- Specific tests performed for approval
- Immediate improvements, required modifications (with a due date) and compensatory measures taken in the meantime.
- Name of Division and Group EQUIPMENT INSPECTOR(S) who examined and approved/rejected the system.
- EQUIPMENT INSPECTOR tracking number if equipment is approved. Site organizations may approve unlisted electrical equipment as systems. Systems must be examined at a minimum as follows:

- Hazard Assessment to include:
    - Electrical hazard classification (see Chapter 3 of this document)
    - Stored electrical energy in capacitors (E and V)
    - Batteries, including UPSs
    - Electromagnetic fields produced (dc to 300 GHz, pulsed)
    - Infrared, optical, and UV

- X-rays
- Heat and sparks
- Acoustic energy
- Other (e.g., chemical high pressure, cryogen, etc. This may require other SME review)

- Evaluation For Operation to include:
  - Enclosure, isolation. No exposed hazardous energized conductors, no unused openings.
  - Grounding. All conductive enclosures exposed to personnel that may become energized must be properly grounded.
  - Overcurrent protection. Overload protection, ground fault, and short circuit protection.
  - Failure analysis. Adequate electrical and fire protection systems for failure modes. (e.g. wiring, component failures etc.)
  - Operation safety analysis and controls documented.
  - System is labeled appropriately.
- Evaluation For Working on System to include:
  - Method(s) of energy isolation (e.g., plug control, LOTO, Kirk key)
  - Automatic methods of stored energy removal
  - Proper design for the manual removal and/or verification of capacitively stored energy
  - Documentation for entry and work on system

12.2.5 Multiple Identical Model Units

For approving multiple units of identical model units the following may be done:

- At least two units must be Field Evaluated and documented in accordance with the appropriate sections of this chapter as follows:
  - *For Non-NRTL/modified NRTL-listed electrical equipment,* follow in-house built/modified NRTL-listed electrical equipment requirements (Section 12.2.1).
  - *For reputable manufactured electrical equipment,* follow reputable manufacturer requirements (Section 12.2.3).
- The remaining units may be assumed to be built identically and approval granted after visual Field Evaluation of the outside of each unit has been complete to ensure it is the same make and model and has not been damaged or modified. This Field Evaluation must be performed by an EQUIPMENT INSPECTOR. Each identical unit approved must be recorded in the original approval documentation.
- For Systems, see Section 12.2.4.

12.3 EQUIPMENT FIELD EVALUATION NUMBERING

Approved electrical equipment must be assigned a Field Evaluation document file number. (e.g. an approving assignment number, bar code etc.)

12.3.1 Multiple Identical Model Units

Multiple units from a manufacturer with identical models may have the Field Evaluation document file number assigned as follows:

- The same approving assignment number, bar code etc. may be used for multiple identical make and model units/systems, or
- The serial number (if available) or other unique identifier of each identical model unit/system identified as approved is documented on the same approval form used to document the approval of the representative sample as specified in Section 1.4.

12.4 LABELING APPROVED ELECTRICAL EQUIPMENT

Approved electrical equipment must be labeled (See examples in Appendix F). The approval label must be green colored with black and/or white as optional additional colors. The label must be placed in a conspicuous (clearly visible) location. ***The Field Evaluation number must be on the equipment or the label.*** It is recommended that each site adopt use of a standard label for easy identification by employees and contractors. *(Note: Environmental conditions should be considered to prevent label deterioration)*.

12.4.1 NRTL-Listed Electrical Equipment Label (Recommended Practice)

A label that indicates the equipment is NRTL listed should be applied to NRTL-listed electrical equipment under the following conditions:

- The NRTL symbol (See http://www.osha.gov/dts/otpca/nrtl/nrtlmrk.html) is not in a conspicuous location (e.g., you cannot readily view it because the item is inaccessible in a rack or you need to open/disassemble the equipment enclosure to view the NRTL symbol, etc.), or
- The NRTL symbol(s) is difficult to read.

12.4.2 Multiple Identical Model Units

All multiple identical model units documented, tracked, and approved following the provisions of Section 12.2.5 must be labeled.

12.4.3 Systems

A system must be labeled or documented in such a manner that it is obvious to workers who use, work on, or work around the system that the system has been approved for use.

12.4.4 Low Hazard Equipment

Equipment that is Low Hazard Equipment (as defined in this document) may be labeled as such e.g. “Unlisted Approval Not Required”, “Low Hazard” or “Class X.0 X.1” to indicate it is equipment that does not require field evaluation and approval.

12.4.5 Equipment Rejected or Not Approved

It is acceptable to label equipment that has been field evaluated and not found acceptable as “Rejected” or “Not Approved”, etc. If a piece of equipment is found to have a serious defect resulting in it being taken out of service immediately, use of the key word “DANGER” on a label containing red color is recommended until the equipment is repaired, re-examined, and approved.

12.5 SPECIAL REQUIREMENTS FOR ELECTRICAL EQUIPMENT

12.5.1 Salvaging/Excess/Removal of Equipment Inspector Approved Electrical Equipment

The following applies to approved electrical equipment that is salvaged, excessed, or removed from site property:

- *For equipment that is salvaged* or *excessed*, the approval is no longer valid and is void. *Note: the label should be removed and the approval documentation updated to reflect removed equipment.*
- *For equipment going off site for use*, the approval is no longer valid and is void unless the site the equipment will be used at accepts the approval of the site the equipment came from. *Note: Acceptance of equipment that has been labeled by another site's AHJ without further examination is allowed provided that the receiving AHJ reviews and accepts the equipment approval procedures followed by the other site.*

12.5.2 Subcontractor Unlisted Electrical Equipment

Appropriate management must ensure that all subcontractor unlisted electrical equipment used at a DOE site is approved. Subcontractors working on site property are responsible for assuring that all unlisted electrical equipment they use is listed or approved by an Equipment Inspector.

12.5.3 Equipment Acquired From Excess/Salvage

Electrical equipment that is acquired from excess/salvage must be reviewed and approved following the Field Evaluation and documentation criteria for reputable manufacturer electrical equipment in Section 12.2.3, if applicable. Otherwise, follow the criteria listed in Section 12.2.1. If the equipment in storage is listed or previously approved, and is new and/or in good condition, requirements for Field Evaluation are at the discretion of the EQUIPMENT INSPECTOR.

12.5.4 Rental Equipment

All rental electrical equipment must be evaluated and accepted by an EQUIPMENT INSPECTOR prior to use according to the Field Evaluation and documentation criteria for reputable manufacturer electrical equipment listed in Section 12.2.3 regardless of its NRTL listing status.

12.6 EQUIPMENT APPROVAL FORMS

The following section contains sample forms for documenting the inspection and approval of the four types of electrical equipment discussed in Section 12.2 above, as well as the form for documenting multiple units.

12.6.1 In-House-Built/Other Than Reputable Manufacturer Non-NRTL/Modified NRTL-Listed Electrical Equipment Approval Form

SECTION 1 - Information		
Group:	Responsible Person: (optional)	employee#: (optional)
Equipment Name: ☐ Multiple ☐ Single		
Manufacturer:		
Model Number:		
Serial number of piece of equipment actually evaluated (see attached form for additional serial numbers of identical equipment):		
Property number of piece of equipment actually evaluated (see attached form for additional property numbers of identical equipment):		
Location Site: Bld: Room:		
Identify Equipment Status: ☐ New ☐ Modified ☐ Not Previously Approved ☐ In Use		
Equipment Type: ☐ Stand-alone custom built or other ☐ System ☐ Powered rack ☐ Appliance/electrical tools ☐ Powered workbench ☐ Extension cord/relocatable power taps ☐ Other		
Function and Use (duty cycle):		
Operating Environment: ☐ Indoor/dry ☐ Outdoor/wet/damp ☐ Flammable vapor/dust/flyings ☐ Explosives power/solid		

SECTION 2 – External Inspection	
Enclosure:	**Foreign Power Supplies and Equipment:**
Operator not exposed to any hazard: ☐	Connected to facility power with appropriate adapters: ☐ NA: ☐
Not damaged: ☐	Correct voltage, frequency, and phasing: ☐ NA: ☐
Appropriate Material: ☐	Correct wire ampacity for U.S. use: ☐ NA: ☐
Protects contents from operating environment: ☐	**Overcurrent Protection:**
Will contain any arcs, sparks, electrical explosions: ☐	Overcurrent protection: Equipment ☐ Branch Circuit: ☐ NA: ☐
Power Source – Cord and plugs:	**Marking Requirements:**
Proper voltage and ampacity rating for plug and cord: ☐ NA: ☐	Hazards, including stored energy: Yes ☐ NA: ☐
Grounding conductor included if required: ☐ NA: ☐	Power requirements (voltage, current, frequency)
Not frayed or damaged: ☐ NA: ☐	Restriction and limitations of use: Yes ☐ NA: ☐
Proper wiring of plug: ☐ NA: ☐	Make/Model/Drawing number:
Strain relief on cord: ☐ NA: ☐	**Other Requirements:**
Power Source – Direct wired into facility	Documentation adequate:
Proper voltage and ampacity rating for wiring method: ☐ NA: ☐	Procedures to use : Yes ☐ No ☐
Installation according to NEC: ☐ NA: ☐	Training and qualification to use: Yes ☐ No ☐
Proper loading and overcurrent protection in branch circuit: ☐ NA: ☐	**Secondary Hazards:**
Grounding:	rf hazards: Yes ☐ No ☐
Ground from cord or other is properly terminated: ☐ NA: ☐	dc electric or magnetic fields: Yes ☐ No ☐
All non-current carrying exposed metal is properly bonded: ☐ NA: ☐	IR, visible, or UV: Yes ☐ No ☐
All non-current carrying internal subsystems are properly bonded: ☐ NA: ☐	X-rays: Yes ☐ No ☐
Equipment ground is run with circuit conductors: ☐ NA: ☐	Fire, electrical explosion: Yes ☐ No ☐
Auxiliary ground permitted: Check Termination: ☐ NA: ☐	

PART 2 – Internal Inspection	
Internal Wiring	**Tests Performed**
Polarity correct: ☐ NA: ☐	Ground continuity (less than 1 ohm): ☐
Phasing correct: ☐ NA: ☐	Polarization of cord and plug: ☐
Landing of ground correct: ☐ NA: ☐	Auto discharge of high voltage capacitor: ☐ NA: ☐
Separated - line voltage and high voltage from low voltage: ☐ NA: ☐	Functional test (e.g., GFCI, emergency shut-off): ☐ NA: ☐
Wiring terminals and leads ok: ☐	Others:
Wire sizes adequate: ☐	
Proper dielectric: ☐	**Failure Analysis:**
Clearance/creepage distances for high voltage ok: ☐ NA: ☐	Effect of ground fault: ☐
Listed conductors, if applicable: ☐	Effect of short circuit: ☐
Other Internal Issues:	Effect of interlock failure: ☐ NA: ☐
Neat workmanship: ☐	Effect of overload: ☐
Listed components used, if applicable: ☐ NA: ☐	Effect of incorrect setting: ☐ NA: ☐
Proper management of conductors: ☐	Others:
Free of sharp edges: ☐	**Maintenance:**
Proper cooling: ☐	Any safety issues with access and maintenance: Yes ☐ No ☐ Explain
Automatic discharge of high voltage capacitor: ☐ NA: ☐	
Equipment Inspector Tracking Number of Piece of Equipment Actually Evaluated (See next page for additional Tracking numbers of identical equipment if individual numbers were assigned:	

NOTE: APPROVED EQUIPMENT WILL BE INSTALLED AND USED IN ACCORDANCE WITH THE INSTRUCTIONS PROVIDED BY THE DESIGNER/BUILDER AND EQUIPMENT INSPECTOR.
Condition of Usage/comments: (Include all designer/builder instructions, drawings, or information that is relevant to the safe installation and use of this equipment. Attach additional sheets as necessary.):

This equipment is **APPROVED** for installation and use at *YOUR INSTITUTION*. IF THIS EQUIPMENT IS MODIFIED, DAMAGED, OR UTILIZED FOR OTHER THAN THE INTENDED USE STATED ABOVE, THIS APPROVAL IS VOID, PENDING REEXAMINATION.

DATE:	Equipment Inspector Printed Name:	Equipment Inspector Signature

This equipment is **REJECTED** for use at *YOUR INSTITUTION* (see comments above).

DATE:	Equipment Inspector Printed Name:	Equipment Inspector Signature

12.6.2 Facility Unlisted Electrical Equipment Approval Form

SECTION 1 - Information		
Group:	Responsible Person: (optional)	Employee#: (optional)
Equipment Name: ☐ Multiple ☐ Single		
Manufacturer:		
Model Number:		
Serial number of piece of equipment actually evaluated (see attached form for additional serial numbers of identical equipment):		
Property number of piece of equipment actually evaluated (see attached form for additional property numbers of identical equipment):		
Location Site: Bld: Room:		
Identify Equipment Status: ☐ New ☐ Modified ☐ Not Previously Approved ☐ In Use		
Equipment Type: ☐ Stand-alone custom built or other ☐ System ☐ Powered rack ☐ Appliance/electrical tools ☐ Powered workbench ☐ Extension cord/relocatable power taps ☐ Other		
Function:		

SECTION 2 – Inspection (Refer to Appendix 5-3)	**APPROVE**	**REJECT**
1. Suitability for installation and use in conformity with 29 CFR 1910 Subpart S and/or NEC.	☐	☐
2. Mechanical strength and durability, including for parts designed to enclose and protect other equipment, the adequacy of the protection thus provided.	☐	☐
3. Wire bending and connection space.	☐	☐
4. Electrical insulation.	☐	☐
5. Heating effects under normal conditions of use and also under abnormal conditions likely to arise in service.	☐	☐
6. Arcing effects.	☐	☐
7. Classification by type, size, voltage, current capacity, and specific use.	☐	☐
8. Other factors that contribute to the practical safeguarding of persons using or likely to come in contact with the equipment.	☐	☐
Equipment Inspector Tracking Number of Piece of Equipment Actually Evaluated (See next page for additional Equipment Inspector Tracking numbers of identical equipment if individual numbers were assigned):		

NOTE: APPROVED EQUIPMENT WILL BE INSTALLED AND USED IN ACCORDANCE WITH THE INSTRUCTIONS PROVIDED BY THE DESIGNER/BUILDER AND EQUIPMENT INSPECTOR.
Condition of Usage/comments: (Include all designer/builder instructions, drawings, or information that is relevant to the safe installation and use of this equipment. Attach additional sheets as necessary.):

This equipment is **APPROVED** for installation and use at *YOUR INSTITUTION*. IF THIS EQUIPMENT IS MODIFIED, DAMAGED, OR UTILIZED FOR OTHER THAN THE INTENDED USE STATED ABOVE, THIS APPROVAL IS VOID, PENDING REEXAMINATION.

DATE:	Equip. Inspector Printed Name:	Equipment Inspector Signature

This equipment is **REJECTED** for use at *YOUR INSTITUTION* (see comments above).

DATE:	Equip. Inspector Printed Name:	Equipment Inspector Signature

12.6.3 Reputable Manufacturer Unlisted Electrical Equipment Approval Form

SECTION 1 - Information		
Group:	Responsible Person: (optional)	Employee#: (optional)
Equipment Name: ☐ Multiple ☐ Single		
Manufacturer:		
Model Number:		
Serial number of piece of equipment actually evaluated (see attached form for additional serial numbers of identical equipment):		
Property number of piece of equipment actually evaluated (see attached form for additional property numbers of identical equipment):		
Location Site: Bld: Room:		
Identify Equipment Status: ☐ New ☐ Modified ☐ Not Previously Approved ☐ In Use		
Function:		

SECTION 2 – Inspection	**APPROVE**	**REJECT**
1. The case is grounded through the power cord to the grounding pin on the plug.	☐	☐
2. The plug is polarized, if necessary.	☐	☐
3. The equipment input voltage and frequency match those of the building's electrical system.	☐	☐
4. The equipment construction is suitable for the intended operating environment.	☐	☐
5. The equipment is in its original, unmodified and undamaged condition.	☐	☐
6. The equipment has externally accessible supplementary over-current protection (e.g., fuses) that are properly sized. (Equipment not having this, needs evaluation to determine if the equipment is safe for use)	☐	☐
Equipment Inspector Tracking Number of Piece of Equipment Actually Evaluated (See next page for additional Equipment Inspector Tracking numbers of identical equipment if individual numbers were assigned):		

NOTE: APPROVED EQUIPMENT WILL BE INSTALLED AND USED IN ACCORDANCE WITH THE INSTRUCTIONS PROVIDED BY THE DESIGNER/BUILDER AND EQUIPMENT INSPECTOR.
Conditions of Usage: ☐ Indoor Only ☐ Damp/Wet Locations ☐ Hazardous Classified Locations (Flammable/Explosive) **Comments:** (Include all designer/builder instructions, drawings, or information that is relevant to the safe installation and use of this equipment. Attach additional sheets as necessary.):

This equipment is **APPROVED** for installation and use at *YOUR INSTITUTION*. IF THIS EQUIPMENT IS MODIFIED, DAMAGED, OR UTILIZED FOR OTHER THAN THE INTENDED USE STATED ABOVE, THIS APPROVAL IS VOID PENDING REEXAMINATION.

DATE:	Equip. Inspector Printed Name:	Equipment Inspector Signature

This equipment is **REJECTED** for use at *YOUR INSTITUTION* (see comments above).

DATE:	Equip. Inspector Printed Name:	Equipment Inspector Signature

12.6.4 Electrical Systems Approval Form

SECTION 1 – Information
Approval is for intended use within the approving organization only

Group:	Responsible Person: (optional)	Employee#: (optional)
System Name:		
System Description:		
Manufacturer, if any:	# of pieces of equipment in system:	
Model Number, if any:		
Serial Number of System Actually Evaluated (see attached for additional serial numbers of identical equipment):		
Date built:	Date Last Modified:	
Location Site:	Bld:	Room:
Identify Equipment Status: ☐ New ☐ Modified ☐ Not Previously Approved ☐ In Use		
Function and List of Subsystems:		

SECTION 2 – Hazard Assessment
Determine all electrical and non-electrical hazards that could injure an employee, including operation and maintenance workers.

1	Electrical hazard classifications	
2	Stored electrical energy in capacitors (E and V)	
3	Batteries, including UPSs	
4	Electromagnetic fields produced (dc to 300 GHz, pulsed)	
5	IR, optical, or UV produced	
6	X-rays (give voltage value in vacuum)	
7	Heat and sparks	
8	Acoustic energy	
9	Other (chemical, high pressure, cryogen, etc.)	

SECTION 3 – Evaluation for Operation: Determine that engineering controls adequately protect the operators and users during system operation.		**Approve**	**Reject**
1	Enclosure, isolation. No exposed hazardous energized conductors, no unused openings.	☐	☐
2	Grounding. All conductive enclosures exposed to personnel properly grounded.	☐	☐
3	Overcurrent protection. Provision for overload, ground fault, and short circuit	☐	☐
4	Failure analysis. Adequate electrical and fire protection systems for failure modes.	☐	☐
5	Operation safety analysis and controls documented where?	☐	☐
6	System is labeled as approved, how?	☐	☐
7	Other, explain.	☐	☐
SECTION 4 – Evaluation for Working on System: Determine that engineering controls are implemented, in conjunction with work control to safely enter into and work on the system.		**Approve**	**Reject**
1	Method(s) of energy isolation (e.g., plug control, LOTO, Kirk key)	☐	☐
2	Automatic methods of stored energy removal, if necessary	☐	☐
3	Proper design for the manual removal and/or verification of capacitively stored energy	☐	☐
4	Documentation for entry and work on system where?	☐	☐
Equipment Inspector Tracking Number:			

NOTE: System will be installed and used in accordance with the instructions provided by the designer/builder and/or Equipment Inspector

Comments/conditions of use: (Include all designer/builder instructions, restrictions on use, drawings or information that is relevant to the safe installation and use of this equipment. Attach additional sheets as necessary)

☐This system and its associated electrical equipment is **APPROVED** for installation and use at *YOUR INSTITUTION*. IF THIS SYSTEM IS MODIFIED, DAMAGED, OR REPAIRED IN A MANNER THAT AFFECTS SAFETY, THIS APPROVAL IS VOID, PENDING RE-EXAMINATION BY AN EQUIPMENT INSPECTOR.

☐ This system is **REJECTED** for use at *YOUR INSTITUTION* (See comments Above)

Note: the following signatures indicate that these Equipment Inspector(s) have reviewed some or all parts of this system for safety. In some cases an Equipment Inspector inspects only sections of the system for which their group is responsible. The Head Equipment Inspector (if any) ensures that all components have been reviewed by one or more group Equipment Inspectors.

System Approval Form (page 3/3)

SECTION 5 – Approval Signatures			
Division/Group	**Date:**	**Head Equipment Inspector Printed Name**	**Head Equipment Inspector Signature:**
Division/Group	**Date:**	**Equip. Insp Printed Name**	**Equip. Inspector Signature:**
Division/Group	**Date:**	**Equip. Insp Printed Name**	**Equip. Inspector Signature:**
Division/Group	**Date:**	**Equip. Insp Printed Name**	**Equip. Inspector Signature:**
Division/Group	**Date:**	**Equip. Insp Printed Name**	**Equip. Inspector Signature:**

SECTION 6 – Specific Tests Performed for Approval List tests performed relevant to safety.		**Date**	**Who**
1			
2			
3			
4			
5			
6			
7			
SECTION 7 – Immediate Improvements List required modifications (with a due date) and compensatory measures taken to ensure safety if system is operated before modifications.		**Date**	**Who**
1			
2			
3			
4			
5			
6			
7			

12.6.5 Form for Additional Identical Units

EQUIPMENT INSPECTOR Tracking Number:

Additional: Serial Numbers; Property Numbers (if applicable)

S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**
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S#: **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**	**S#:** **P#:**

12.7 INSTRUCTIONS FOR USING EQUIPMENT INSPECTION FORMS

The following guidance can help the Equipment Inspector to use the above Equipment Inspection and Approval Forms.

12.7.1 Instructions for the In-House Built/Other Than Reputable Manufacture Non-NRTL/Modified NRTL Listed Electrical Equipment Approval Form

These instructions provide assistance, clarification, and additional details to EQUIPMENT INSPECTORS while performing examinations using the In-House Built/Other Than Reputable Manufacture Non-NRTL/Modified NRTL Listed Electrical Equipment Approval Form.

1**. Enclosure**:

- Operator not exposed to any hazard
    - *Check to make sure the enclosure contains or covers all conductors and energized terminals, to prevent inadvertent contact with energized conductors*
    - *Make sure any knockouts are plugged.*
    - *Look for unusually sharp edges, or pinch hazards*
- Not Damaged
    - *Ensure that the enclosure is free from defects/dents, securely fastened, and that all components are intact.*
- Appropriate materials used
    - *Ensure that the enclosure material can withstand normal use and that it can protect the contents and user adequately.*
- Protects contents from operating environment
    - *Make sure that the enclosure is rated for the environment such as outdoor, corrosive, wet or humid environments, or classified locations (NEC Article 500 type locations.).*
- Adequate shock protection
    - *Ensure adequate enclosure, insulation, etc. to prevent incidental exposure to energized electrical conductors or parts.*
- Will contain any arcs, sparks, and electrical explosions
    - *Ensure that the enclosure is rated or suitable for the bolted fault energy of the input source.*
    - *Refer to NEMA Enclosure Types as appropriate*

2. **Power source – cord and plug:**

- Proper Voltage and ampacity rating for plug and cord
    - *See Ampacity Information in Section 11.14*
- Grounding conductor included (if required)

        - *Make sure the ground conductor has good continuity (< 1 Ohm) to the enclosure and any exposed metal surfaces.*
- Not frayed or damaged
    - *Inspect the cord and plug for cracks or cuts in the insulation.*
- Proper wiring of plug
    - *Refer to: NEMA Straight Blade Chart*
- Strain relief on cord
    - *If the power cord is hardwired to the enclosure a proper strain relief/insulator must be used to prevent damage to the cord.*

3. **Power source direct wired**:

- Proper voltage and ampacity rating for wiring method
    - *See <u>Ampacity Information</u> in Section 11.14*

4. **Foreign power supplies and equipment**:

- Connected to facility power with appropriate adapters
    - Adapter rating matches used voltages and is NRTL listed
- Correct voltage, frequency and phasing
    - *Insure the equipment will operate properly on 60 Hz line voltage*
    - *Make sure the line, neutral and ground connections are correct on the input and output of any transformers. This is especially important for autotransformers when stepping 120 VAC up to 220 VAC.*
- Correct wire ampacity for US use
    - *See <u>Ampacity Information</u> in Section 11.14*

5. **Grounding**

- Ground is properly terminated
    - *The green grounding conductor from the power source should be used as a single point ground inside the enclosure.*
- All non-current carrying exposed metal is properly bonded
    - *The exposed metal of the enclosure should be bonded to the ground conductor with clean unpainted connections.*
- All non-current carrying internal subsystems are properly bonded
    - *Internal components which require a ground should be bonded to the single point ground or through the enclosure using clean unpainted connections.*
- Equipment ground is run with circuit conductors

- Auxiliary ground is permitted
    - *An extra ground connection in addition to the power source ground is acceptable.*

6. **Internal wiring**:

- Polarity correct
    - *Make sure the neutral and line are properly connected internally*.
- Phasing correct
    - *For three phase power try and determine if the phasing is correctly connected. Some devices have phase detection LEDs, or other means to determine correct phase. Refer to the manual if available.*
- Landing of ground correct
    - *The green grounding conductor from the power source should be connected to the metal enclosure.*
- Separate line/high voltage from low voltage
    - *Make sure the low voltage (<50 volts) and high voltage (≥50 volts) conductors are not run in the same wire bundles.*
- Wiring terminals and leads ok (no tension on terminals)
    - *Inspect the terminals and wire to be sure the connectors are tight and that there is no physical stress on the conductors (such as wires pulled taut).*
- Proper wire size and color code
    - *Make sure the wire is rated for the correct operating voltage and current (see Ampacity Information in Section 11.14).*
    - *Wire insulation should conform to color code standards Refer to proper table or reference in Color Coding Guidelines at the end of this appendix.*
- No loose parts (mechanical bracing)
    - *All parts should be secured internally and not rely on gravity to maintain position.*
- Proper overcurrent protection
    - *Appropriate fuses and or circuit protectors should be used on the input source and on the input to any power components in the enclosure. These overcurrent devices should be labeled with the correct ratings. Overcurrent devices must be installed on the line (not neutral) side of the input power feed.*
- Proper dielectric
    - *Where insulation is required between components, make sure the dielectric can withstand the operating voltages.*
- Clearance/creepage distances for high voltage
    - *Ensure sufficient clearance for high voltage to prevent arcing or dielectric breakdown.*

7. **Marking requirements**:

- Power requirements (voltage, current, frequency)
    - *The source power (voltage, frequency, and either current or wattage) should be labeled on the enclosure at the point of entry for the power cable. Ex. 120VAC 2A 60 Hz, or 208 VAC 500 watt 60 Hz*
- Restrictions and limitations of use

    - *Any limitations of use should be clearly labeled to prevent the device from being used inappropriately.*
- Make, model and drawing number
    - *For a manufactured device the manufacturer, model number, serial number should be listed on the enclosure. An in-house built device usually will not have a model or serial number. In this case the approval sticker can become the serial number.*
- Hazards, including stored energy
    - *Hazards such as hazardous stored energy, high voltage, high current, RF etc. should be labeled on the enclosure.*
- Requirements for access (LOTO, stored energy, PPE)
    - *If the equipment requires LOTO, or special procedures for access during maintenance or troubleshooting, labeling should be used to direct personnel to the appropriate documents for servicing the equipment. The documentation should have a work procedure and should list the PPE requirements.*

8. **Tests performed**:

- Ground continuity less than 1 ohm
    - *This test ensures that the ground wire from the source is securely connected to the equipment ground point. Use a quality DVM with a resolution of 0.1 ohm or better to make this measurement. Short the leads to determine the lead resistance and subtract this reading from the ground test reading.*
- Polarization of cord and plug
    - *Use a DVM to confirm that the neutral and line are properly connected to the plug and to the internal circuitry.*
- Functional test (GFCI, Emergency Shut OFF)
    - *If the equipment has a Ground Fault Circuit Interrupter or Emergency Shut OFF, test that these devices are operational.*
- Automatic discharge of high voltage capacitor
    - *For equipment with high voltage capacitors or large capacitor banks, make sure a method is used to automatically discharge the capacitors. Bleeder resistors are typically used to discharge capacitors. For large energy capacitor banks there must be engineered controls and procedures in place to make sure the capacitors have fully discharged before access can be made to the terminals.*

9. **Other Issues**:

- Neat Workmanship
- Proper management of conductors
    - *This refers to proper lead dress and keeping high voltage leads separated from low voltage leads. Use of barrier strips and terminals should be used rather that wire nuts and tape. Wire bundles should be secured to prevent them from moving.*
- Free from sharp edges
    - *The enclosure feedthroughs should be deburred and have appropriate grommets or strain reliefs for and wires or cables. The enclosure should also be free from sharp edges which could cause the user to be cut or which could pierce any conductor insulation.*
- Proper cooling
    - *Equipment which dissipates enough power to cause excessive heat buildup in the enclosure should have a fan or proper ventilation to keep the temperature*

below the rating of the wire or internal devices. A rule of thumb is to keep the temperature below 50ºC

- Switches and controls readily accessible
  - o *The controls should be conveniently located for the user to operate without difficulty. Good design practices will ensure a logical placement for the equipment controls.*

10. **Maintenance**

- Any safety issues with access and maintenance
  - o *Equipment which requires maintenance by personnel should have appropriate engineered controls to prevent exposing the workers to hazardous conditions.*
  - o *Examples of engineered controls include: interlocks, bleeder resistors across capacitors, covers over exposed terminals, and LOTO capability.*
  - o *Look for controls and or procedures which are used for maintenance operations.*

11. **Failure analysis**:

- Effect of ground fault
  - o *Analyze the effects of a ground fault and the resulting condition. Does the equipment pose a hazard should a ground fault occur?*
- Effect of short circuit
  - o *Ensure that the circuit protection devices i.e. fuses, circuit breakers etc. are adequate to protect the equipment and personnel in the event of a short circuit in the device or load.*
- Effect of interlock failure
  - o *Would an interlock failure create a hazardous condition? What controls are in place to prevent injury?*
- Effect of overload
  - o *Ensure that the circuit protection devices i.e. fuses, circuit breakers etc. are adequate to protect the equipment and personnel in the event of an overload. An overload could occur from the user applying too much power to the load, or using an inappropriate load.*
- Effect of incorrect setting
  - o *This basically refers to the consequences of the operator inadvertently placing the controls in a wrong position or using the controls inappropriately. The system should be designed to minimize hazards due to accidental inputs or controls. These include interlock; fail-safe systems and inability to allow the system to be operated in a hazardous manner.*

12. **Secondary hazards**

Note: For all non-ionizing radiation safety refer to the appropriate site's ESH manual chapter.

- RF hazards
  - o *Does this equipment produce harmful RF? If so proper RF shielding should be in place and leakage fields should be measured.*
- DC electric or magnetic fields
  - o *If the equipment produces strong magnetic fields safeguards should be in place to prevent injury by accidental contact with ferromagnetic material such as tools. Placards should be in place to warn people of the presence of high magnetic fields. This is very important for people with pacemakers.*
- IR, visible or UV

    - *Safeguards should be in place to prevent exposure to high levels of electromagnetic radiation. Laser systems are especially dangerous for IR or UV radiation. Refer to site's ESH manual chapter on laser safety.*
- X-Rays
    - *Refer to site's ESH manual chapter pertaining to X-ray safety. To ensure all interlocks and safety measures are covered in the system design.*
- Fire or electrical explosion
    - *The system should be designed to minimize the risk from an explosion or fire due to a system fault. The enclosure should be robust enough to contain the available energy due to a fault.*

13. **Documentation**

- Documentation adequate
    - *The user should have the owner's manual for purchased equipment. "Homebrew" equipment should have at least a schematic diagram.*
- Operating procedures
    - *The operating procedures should be readily available to the users*.
- Training and qualifications to use
    - *If use of the equipment warrants training, sufficient instructions or training are provided prior to use.*

12.7.2 Instructions for the Facility Electrical Equipment Approval Form

PART 1 – Equipment Identification

- Enter as much information as necessary to be able to track adequately.
- Equipment Status refers to equipment operation. If equipment is new or modified, it must be examined and approved using Section 2 of this document checklist. If equipment has not been previously approved, the equipment must be examined and approved before use.
- The function should be stated to give a short description of the use of the equipment.

PART 2 – Example Guidelines for Equipment Approval

I. Some potential considerations of suitability for installation and use are as follows:

- Operation, considering environmental conditions
- Temperature, humidity, air pressure, non-ionizing radiation (RF and EMI), ionizing radiation, outdoor/indoor, etc.
- Normal and abnormal use, considering duty cycle, average and peak power, etc.
- Properly sized and installed equipment grounding (chassis grounding)
- Equipment design that includes consideration of the available short circuit and ground fault current
- Properly sized and installed over-current protection (fuses or circuit breakers)
- Separation of high- and low-voltage components, especially where high voltage could escape along a hidden fault path

(See 2005 NEC 250.110 & 110.9.)

II. Mechanical strength and durability considerations include the following:

- Enclosure of parts to:

    - Prevent damage to internal components during use and transportation
    - Contain arcing, heating, and explosion
    - Prevent injury to personnel from hazardous energized parts
    - Prevent damage to internal components from environmental conditions
- Workmanship—unused openings effectively closed
- Integrity of electrical equipment and connections
- Any item that would adversely affect the safe operation or mechanical strength of the equipment, such as damaged, corroded, or overheated parts

(See 2005 NEC 110.12.)

III. Wire bending and connection space includes the consideration of assembly and potential repair based on the following:

- The protection of conductors and their insulation against damage by over-bending, over crowding, location near moving parts in equipment, and at termination points.

(See 2005 NEC 312.6 and Tables 312.6(a) & (b).)

IV. The integrity of insulation ensures that the system or component does the following:

- Prevents the escape/transfer of electrical energy to other conductors and to personnel;
- Is free from short circuits or potential short circuits;
- Uses listed conductors where possible; and
- Is free from grounds other than those required or permitted by Article 250 of the National Electrical Code.

(See 2005 NEC 110.7.)

V. Verify that conductors are installed and used in such a manner that normal listed or approved temperature ratings are not exceeded. If the condition of use in the R&D environment is substantially different from that anticipated in the product listing, have a subject matter expert determine that an appropriate level of safety is maintained. Also determine that exposed parts will not burn personnel or initiate fires.

(See 2005 NEC 310.10, including the Fine Print Note.)

VI. Appropriate requirements for arcing effects include the following:

- If the equipment's ordinary operation produces arcs, sparks, flames, or molten metal, verify that it is enclosed or separated and isolated from all combustible material.
- Verify that potential arc blast/electrical explosions are prevented from injuring personnel and damaging other equipment

(See 2005 NEC 110.18.)

VII. Require that a permanent label be attached to the equipment that includes the following:

- The manufacturer's (or local builder's) name or other descriptive marking by which the organization responsible for the equipment can be identified
- Other markings will include the equipment voltage, current, wattage, and any additional wording that the EQUIPMENT INSPECTOR deems necessary for the safe operation of

the equipment (e.g., type, size, power, stored energy, secondary hazards, specific use, and specific users)

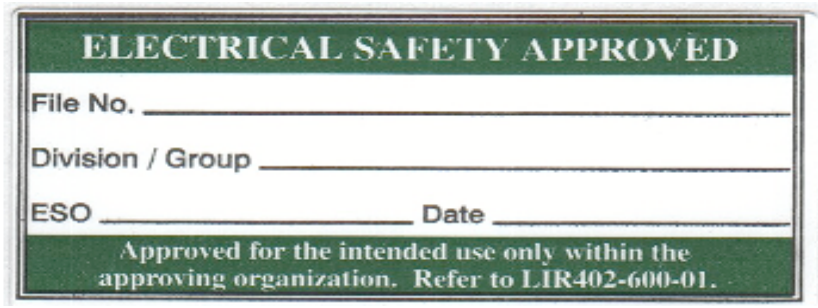
(See 2005 NEC 110.21.)

VIII. Other factors contributing to the practical safeguarding of personnel include the following:

- Reviewing non-electrical hazards by appropriate subject matter experts.
- Preventing electric shock, burn, or reflex hazards by eliminating personnel contact,
- Ensuring that energized parts of equipment operating at 50 volts or more are protected against accidental contact by approved enclosures or by any of the following means:
    - By location in a box, enclosure, room, or vault that is accessible only to Equipment Inspectors
    - By suitable permanent, substantial partitions or screens arranged so that only Equipment Inspectors will have access to the space within reach of the energized parts
    - By location on a suitable balcony, gallery, or platform elevated and arranged so as to exclude unqualified people from entering the limited approach boundary
    - By elevation of 8 ft or more above the floor or other working surface
- A procedure of safeing and energy removal, e.g., disconnection, LOTO, removal of stored energy, for both normal/emergency shutdown has been established
- Damage to eyes, skin or other equipment from UV and IR
- Personnel injury or equipment interference from RF fields
- Preventing personnel exposure to excessive noise
- Preventing personnel exposure to X-rays for equipment >15 kV operating, especially in a vacuum
- Standard designs, including fail-safe design:
    - Use listed or recognized components where possible
    - Use accepted color coding of wires, especially grounded (white or gray) and grounding conductors (bare or green)
- Consider the loss of electrical power, pneumatic, etc.
- Consider the automatic removal of stored energy
- Consider the use of interlocks on enclosures and other systems

(See 2005 NEC 110.27 and 110.31.)

12.8 EXAMPLE EQUIPMENT APPROVAL LABELS



Los Alamos National Laboratory (LANL) Label

Sandia National Laboratory (SNL) Label

Argonne National Laboratory (ANL) Label

13.0 RESEARCH & DEVELOPMENT

The DOE complex engages in a variety of research & development (R&D) activities that often incorporate the design and use of special or unusual apparatus and equipment in its facilities.

13.1 PURPOSE

Requirements of existing electrical codes, recognized industry standards, and DOE Orders do not specifically address these types of apparatus. Even with these specialized R&D needs, the workplace must be maintained free of known hazards that cause, or are likely to cause, death or serious injury. Special efforts must therefore be made to ensure adequate electrical safety beginning with design and continuing through development, fabrication and construction, modification, installation, inspection, testing, operation, and maintenance of R&D electrical apparatus and facilities. This section provides guidelines to complement existing electrical codes and recognized industry standards in conformance with DOE Orders and OSHA requirements.

Because of the differences in R&D program requirements in the DOE complex and the unpredictability of R&D activities, it is impractical to establish a single set of electrical safety requirements to be applied uniformly. General electrical safety guidelines, however, apply across the DOE complex.

This section contains safety criteria for the DOE complex in the design, development, fabrication and construction, modification, installation, inspection, testing, operation, and maintenance of R&D electrical apparatus and facilities. Personnel safety shall be the primary consideration. When conflicts between electrical codes, recognized industry standards, DOE Orders, or regulations arise, the requirement that addresses the particular hazard and provides the greater personnel safety protection shall govern.

13.2 SCOPE

This section addresses R&D electrical systems which are not specifically addressed elsewhere in the Electrical Safety Handbook. The electrical environment of the DOE complex is extremely varied, ranging from low-voltage electronic circuits to common office and industrial electrical systems to large, high-voltage power distribution systems to high-voltage/low-current and low-voltage/high current systems associated with R&D programs. Electrical systems of all types are an integral part of R&D operations and associated support work.

13.3 COMPLIANCE WITH OSHA

It is important to note that special types of work on R&D electrical systems (e.g., electronic circuits) are considered electrical work, and therefore the work shall follow electrical safety requirements.

Consistent with other sections of this document, electrical systems and equipment and all design, development, fabrication and construction, modification, installation, inspection, testing, operation, and maintenance shall be in accordance with applicable electrical requirements. Specific attention shall be focused on the electrical regulations of OSHA, including:

1 29 CFR 1910.137

2 29 CFR 1910.147

3 29 CFR 1910.269

4 29 CFR 1910.301-399

5 29 CFR 1926.401-449.

13.4 STANDARDIZED SAFETY PRACTICES AND PROCEDURES

Standardized safety practices shall be developed for performing electrical work (refer 10 CFR 851). These practices should be consistent with the other electrical safety-related work practices noted elsewhere in this document.

13.5 OPERATION AND MAINTENANCE

Maintenance procedures and schedules should be developed for R&D equipment. Electrical equipment shall be checked, cleaned, and maintained on a schedule and in a manner based on its application and use. Additional information is referenced in Chapter 4, Electrical Preventive Maintenance.

13.6 EMPLOYEE QUALIFICATIONS

This section provides guidance for determining the qualification process for persons involved with specialized electrical equipment, configurations or work tasks associated with experiments. The guidance provided in this section is in addition to the minimum qualifications described in Section 2.8, Training and Qualifications of Qualified Workers.

13.6.1 Hazards

The hazards associated with R&D equipment are sometimes unique because the equipment itself is unique. These hazards are sometimes made worse because of an uncommon design or the fact that it may be one of a kind. Special efforts are thus necessary to identify all the potential hazards that may be present in a specific unique design. These hazards should be identified and a plan developed to mitigate the associated risk. Personnel working on R&D equipment shall be qualified to work on this equipment, depending on its unique safety problems. See Chapter 3 for more information on the identification and control of R&D electrical hazards.

13.6.2 Additional Qualifications

Personnel assigned to tasks involving R&D equipment shall be apprised of the hazards identified in Chapter 3. It is suggested that they participate in developing mitigation plans to reduce the risks associated with the hazards.

A list of additional experience qualifications should be developed by the appropriate personnel including the workers. This list should identify specific training requirements necessary for unusual equipment or tasks.

13.7 GENERIC R&D EQUIPMENT

There are many possible types of electrical AC and DC power source hazards in complex R&D systems and the various design philosophies preclude establishing hazard classifications based on voltage alone.

13.7.1 Power Sources

13.7.1.1 Hazards

1. Internal component failure can cause excessive voltages. Internal component open-circuit failure in capacitor banks and Marx generators can result in full voltages across components that may not be appropriately discharged in the usual manner.
2. Internal component shorts in capacitor banks and Marx generators can result in excessive fault current, causing extreme heat, over pressurization of capacitor enclosures, and rupture.
3. Overloading or improper cooling of power supplies can cause excessive temperature rise.
4. Output circuits and components can remain energized after input power is interrupted.
5. Auxiliary and control power circuits can remain energized after the main power circuit is interrupted.
6. When power supplies serve more than one experiment, errors made when switching between experiments may create hazards to personnel.
7. R&D electrical apparatus may contain large amounts of stored energy, requiring fault analysis.
8. Liquid coolant leaking from R&D electrical equipment may pose an electrical hazard to personnel.

13.7.1.2 Design and Construction

In design and construction of R&D equipment, it is important to remember the following cautions:

1. Install only components essential to the power supply within the power-supply enclosure.
2. Provide appropriate separation between high-voltage components and low-voltage supply and/or control circuits.
3. Provide to personnel a visible indicator that the power supply is energized.
4. Minimize the number of control stations and provide an emergency shutdown switch where needed.
5. Where possible, avoid multiple-input power sources.
6. Apply a label containing emergency shutdown instructions to equipment that is remotely controlled or unattended while energized.

13.7.1.3 Operation and Maintenance

Before working in a power-supply enclosure or an associated equipment enclosure, see Sections 2.8 and 13.6 for qualification requirements. Personnel should take the following precautions:

1. Implement lockout/tagout.
2. Check for auxiliary power circuits that could still be energized.
3. Inspect automatic shorting devices to verify proper operation.
4. Short the power supply from terminal to terminal and terminal to ground with grounding hooks.

13.7.2 Conditions of Low Voltage and High Current

13.7.2.1 Hazards

It is usual for R&D facilities to have equipment that operates at less than 50 V AC or less than 100 V DC. Although this equipment is generally regarded as nonhazardous, it is considered hazardous when high currents are involved. Examples of such equipment are a power supply rated 3 kA at 25 V, a magnet power supply with rated output of 200 A at 40 V, and a bus bar carrying 1 kA at 5 V.

Though there is a low probability of electric shock at voltages less than 50 V AC or 100 V DC (see Chapter 3, Table 3-1), there is a hazard due to arcing and heating in case of an accidental fault. For example, a tool could drop onto the terminals and initiate an arc, causing severe burns (see Section 3.2.2.4).

13.7.2.2 Design and Construction

A circuit operating at 50 V or less AC and 100 V or less DC shall be treated as a hazardous circuit if the power in it can create electrical shocks, burns, or an explosion due to electric arcs. Observe all of the following rules for such circuits:

1. Provide protective covers and/or barriers over terminals and other energized parts to protect personnel.
2. Apply suitable marking to identify the hazard at the power source and at appropriate places.
3. Consider magnetic forces in both normal-operation and short-circuit conditions. Use conductors that have appropriate physical strength and are adequately braced and supported to prevent hazardous movement.
4. Inductive circuits may create high-voltage hazards when interrupted. Careful circuit design will include a method to bleed off power safely should an interruption occur.

13.7.2.3 Operation and Maintenance

Follow these guidelines for working on circuits operating at 50 V AC or less or at 100 V DC or less that are treated as hazardous:

1. Work on such circuits when they are de-energized.
2. If it is essential to work on or near energized low-voltage, high-current circuits, observe the safety rules as if the circuits were operating at higher voltages. Refer to Section 2.1.2, "Considerations for Working on Energized Systems and Equipment" and 2.13.4, "Safe Energized Work (Hot Work)."

13.7.3 Conditions of High Voltage and Low Current

13.7.3.1 Hazards

When the output current of high-voltage supplies is below 5 mA, the shock hazard to personnel is low. Where combustible atmospheres or mixtures exists, the hazard of ignition from a spark may exist. High-voltage supplies (ac or dc) can present the following hazards:

1. Faults, lightning, or switching transients can cause voltage surges in excess of the normal ratings.
2. Internal component failure can cause excessive voltages on external metering circuits and low-voltage auxiliary control circuits.
3. Overcurrent protective devices such as fuses and circuit breakers for conventional applications may not adequately limit or interrupt the total inductive energy and fault currents in highly inductive dc systems.
4. Stored energy in long cable runs can be an unexpected hazard. Safety instructions should be in place to ensure proper discharge of this energy.
5. Secondary hazards such as startle or involuntary reactions from contact with high-voltage low-current systems may result in a fall or entanglement with equipment.

13.7.3.2 Design Considerations

Personnel in R&D labs may encounter energized parts in a variety of configurations, locations, and under environmental conditions that are not usual for most electrical power personnel. Sometimes the equipment can be designed to incorporate mitigation of the hazards associated with working on such equipment. If not, then safe operating procedures must be developed and used.

13.7.3.3 Safety Practices

An analysis of high-voltage circuits should be performed by a qualified person before work begins unless all exposed energized parts are guarded as required for high-voltage work. The analysis must include fault conditions where circuit current could rise above the nominal rated value. Depending on the results of the analysis, any of the following may apply:

1. If the analysis concludes that the current is above 5 mA or stored high-voltage capacitive energy is above 1 joule for voltages between 100 and 400 V DC, or above 0.25 joule for voltages equal to or greater than 400 V, then the work is considered to be energized work and should be performed in accordance with Chapter 2, "General Requirements" and/or Chapter 3, "Hazard Analysis." See Chapter 3 for details on electrical hazard classification.
2. If the analysis concludes that the current is between 0.5 mA and 5 mA and between 0.25 and 1 joules, then the worker may be exposed to a secondary hazard (e.g., startle reaction) that must be mitigated.
3. If the analysis concludes that the current is below 0.5 mA and below 0.25 joules, then the worker exposure is minimal and no special precautions are required, even for high voltage circuits.

High-voltage supplies that use rated connectors and cables where there are no exposed energized parts are not considered hazards. Connections shall not be made or broken with the power supply energized unless they are designed and rated for this type of duty (e.g., load-break elbows). Inspect cables and connectors for damage and do not use if they are damaged. Exposed high-voltage parts must be guarded to avoid accidental contact.

13.7.4 Radio-Frequency/ Microwave Radiation and Fields

The DOE complex conducts R&D programs that involve sources of radio-frequency/microwave (RFMW) nonionizing electromagnetic radiation. Devices that may produce RFMW radiation include telecommunications and radar equipment, industrial equipment such as radio-frequency heaters, and scientific and medical equipment such as magnetic resonance imagers and klystron tubes. The nationally recognized consensus standard for personnel exposure to radio-frequency radiation is ANSI/IEEE C95.1(2005), *Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz*.

13.7.4.1 Hazards

1. RF amplifiers frequently use DC high-voltage power sources.
2. There may be x-ray hazards (when supply voltage exceeds 10 kV and there are evacuated components). Currents maybe induced in conductive objects or metal structures that are not part of the RF structure.
3. RF currents can cause severe burns.
4. Falls from towers may result from RF burns from antennas.
5. Electromagnetic interference may cause equipment to malfunction.
6. Electromagnetic fields may cause unintended ignition of explosives, fuel, and ordnance.
7. Grounding and bonding conductors that are adequate for dc and power frequencies may develop substantial voltage when fast pulses and radio frequency currents are present, due to inductance and skin effect.

13.7.4.2 Design and Construction

Engineering control in accordance with ANSI/IEEE C95.1 (2005) should be the primary method used to restrict exposure whenever practical. If engineering controls are not practical, work-time limits, based on the averaging intervals and other work-practice and administrative controls, must be used.

1. Warning Signs - Signs commensurate with the RFMW level must be used to warn personnel of RFMW hazards. These signs must be posted on access panels of RFMW enclosures and at entrances to and inside regulated areas.
2. Access Limitation - Access can be limited by controls such as barriers, interlocks, administrative controls or other means. The operation supervisor controls access to regulated areas and must approve non routine entry of personnel into these places. When practical, sources of RFMW radiation should be switched off when not in use.
3. Shielding - Shielding that encloses the radiating equipment or provides a barrier between the equipment and the worker may be used to protect personnel; the shielding design must account for the frequency and strength of the field.
4. Interlocks - Chamber or oven-type equipment that uses microwave radiation must have interlocks designed to (1) prevent generation of the radiation unless the chamber is sealed and (2) shut off such equipment if the door is opened.

5. Lockout/Tagout - The design shall incorporate features that allow the equipment to be locked out and tagged out for servicing.
6. PPE - PPE such as eyewear is not readily available and is generally not a useful option as protection against RFMW radiation and fields. Protection must therefore be achieved by other means.

13.7.4.3 Exemptions from RFMW Exposure Limits

The following items are exempt from the RFMW exposure limits; however, their manufacture is subject to Federal RFMW emission standards:

1. Cellular phones and two-way pagers and PDAs
2. Two-way, hand-held radios and walkie-talkies that broadcast between 10 kHz and 1 GHz and emit less than 7 W
3. Microwave ovens used for heating food.
4. Video display terminals.

13.7.4.4 Exposure Criteria for Pulsed RFMW Radiation

The basic considerations for peak-power exposure limits are consistent with ANSI/IEEE C95.1 (2005) as follows:

1. For more than five pulses in the averaging time and for pulse durations exceeding 100 milliseconds, normal time averaging applies and the time-averaged power densities should not exceed the Maximum Permissible Exposure (MPE) found in IEEE/ANSI C95.1 (2005).

2. For intermittent pulse sources with no more than five pulses during the averaging time, the peak power density for any of the pulses should not exceed the limit given by the following equation.

$$MPE_p = \frac{MPE_\alpha (t_\alpha)}{5(t_p)}$$

where:

MPE_p – Peak (power density)
MPE_α = Time-Average (power density)
t_α = Averaging time (seconds)
t_p = Pulse width (seconds)

This limits the specific absorption (SA) of each pulse to SA=28.8 joules/kg (whole-body or spatial average), or SA=144 joules/kg for 5 pulses.

For intermittent pulse sources with no more than five pulses during the averaging time, the single-pulse SA of < 28.8 joules/kg, though higher than the threshold for auditory effect (clicking), is three orders of magnitude lower than the SAs that produce RF-induced unconsciousness.

3. Maximum E field for any of the pulses should be no more than 100 kV/m. This peak E-field limit is prescribed to eliminate the possibility of air breakdown or spark

discharges, which occur at 2,900 V/m. A large safety factor is applied to account for local field enhancements where nominally lower fields may result in arcing discharges.

a. The exposure values in terms of electric and magnetic field strength are the values obtained by spatially averaging values over an area equivalent to the vertical cross section of the human body (projected area).

b. These plane-wave equivalent power density values, although not appropriate for near-field conditions, are commonly used as a convenient comparison with MPEs at higher frequencies and are displayed on some instruments in use.

c. The f = frequency in MHz.

d. It should be noted that the current limits given in this table may not adequately protect against startle reactions and burns caused by transient discharges when contacting an energized object.

13.8 METHODS

13.8.1 Wiring Methods

13.8.1.1 Hazards

Unsafe wiring methods can cause electrical injury or fire hazards.

R&D work may require the use of wiring methods that are not anticipated in the NEC. These methods may not be consistent with normal commercial and industrial wiring methods, and should be reviewed by the AHJ for approval.

13.8.1.2 Design and Construction

13.8.1.2.1 Design and Construction as an Integral Part of Equipment

If the AHJ determines that wiring is an integral part of an apparatus (e.g., instrumentation interconnections), then the wiring methods used should be evaluated by the AHJ as providing safe operating conditions. This evaluation may be based on a combination of standards and engineering documentation where appropriate. Such an evaluation should consist of an analysis of all stresses imposed on any electrical conductive elements, including, but not limited to electrical, magnetic, heating, and physical damage potential. The wiring methods selected must mitigate to the greatest practical extent any undesired effects of a failure sequence.

If cable trays are used as mechanical support for experimental circuits, they should be solely dedicated to this use and appropriately labeled. Any such use must be analyzed for detrimental heating effects of the proposed configuration.

13.8.1.2.2 Power Supply Interface Between Utility Systems and R&D Equipment

Utility supply voltages should be brought as near to the utilization equipment as possible using NEC-compliant wiring methods.

Any temporary wiring methods used (e.g., extension cords) should be approved by the AHJ for a specified limited time.

Flexible cords and cables should be routed in a manner to minimize tripping hazards.

The conventional use of cable trays is defined in NEC Article 392. If power cables are placed in a cable tray used for control and signal cables, separation is advised but not always required. According to NEC Article 392.6(E), multiconductor cables rated at 600 volts or less are permitted to be installed in the same cable tray. This presumes the cables are listed, having a minimum rating of 300 volts. However, cables rated over 600 volts require separation from those rated at 600 volts or less, per Article 392.6(F). Communications cables are required to be separated from light or power conductors by at least 2 inches, in accordance with NEC Article 800.52(A)(2).

Certain experimental configurations or physical constraints may require the unconventional application of cable trays. Only the AHJ may approve these unconventional applications. If deemed necessary, enhanced fire protection or other safety measures shall be used to ensure safety to personnel and equipment.

For coaxial, heliax, and specialty cables used for experimental R&D equipment, where NEC tray-rated cable types are not available which meet the technical requirements of the installation, the non-tray-rated cables shall be permitted with the approval of the AHJ. If deemed necessary, enhanced fire protection or other safety measures shall be used to ensure safety to personnel and equipment.

When metallic cable tray is being used, it shall be bonded to the equipment grounding system, but should not be relied upon to provide the equipment ground. The experimental equipment must be appropriately grounded by some other method.

13.8.1.3 Operation and Maintenance

The operation and maintenance of R&D systems which use wiring methods that are not anticipated by the NEC require special considerations from all personnel. The AHJ evaluation for safe operating conditions must include a review of unique features in the engineering documentation.

13.8.2 Unconventional Practices

R&D performed by DOE contractors often incorporates the design of specialized equipment resulting in the need for specialized grounding and the use of materials and components in an unconventional manner. Even with these experimental needs and special design considerations, the maximum safety of personnel and equipment still needs to be ensured. The practice of using materials or components for purposes other than originally designed needs special consideration in their use, identification, personnel protection, and equipment protection.

13.8.2.1 Grounding

13.8.2.1.1 Hazards

The lack of proper grounding can cause electrical shock and/or burns to personnel. The NEC and NESC define legally-required grounding. To mitigate potential hazards, grounding shall be provided in accordance with the NEC and NESC.

13.8.2.1.2 Design and Construction

NEC, Article 250, "Grounding" notes that grounds also provide:

1. Voltage limitation in case of lightning, line surges, or unintentional contact with higher voltage lines
2. Stability of voltage to ground under normal operation
3. Facilitated overcurrent device operation in case of ground faults
4. A path to conductive objects that will limit the voltage to ground.

In R&D work there is one additional function for grounds: a common reference plane or system ground return for electronic devices, circuits, and systems. (See Section 11.3) It is recognized that such grounds are essential in some cases to control:

1. Noise associated with the primary power system:
   a. Incoming on the line
   b. Outgoing from local equipment
2. Ground wire noise
3. Circuit coupling
   a. Ground loop (shared circuit return)
   b. Magnetic, capacitive, or electro-magnetic.

If system return impedances are low enough, then simple radio-frequency chokes can be used to limit this noise with no effect on the safety function.

A 50-microhenry choke will add 1/50 of an ohm impedance at 60 Hz, 2 ohms impedance at 7.5 kHz and 30 ohms impedance at 100 kHz. Such an RF choke will serve to discriminate against noise on the ground circuit.

An inexpensive RF choke may be installed in the safety ground by:

1. Pulling the green ground wire 20 feet longer than required.
2. Coiling the extra length into a 6-inch diameter coil (about 12 turns).
3. Securing it tightly wound with cable ties.
4. Connecting it into the circuit.

These actions satisfy the NEC requirement for a continuous ground and noise isolation is also enhanced.

Whatever scheme is used, the ground of experimental equipment shall be connected to the same ground as the facilities' electrical system to ensure equal potential.

For practices involving hazardous materials, such as explosives, the grounding shall also comply with the requirements of Chapter 6, Special Occupancies.

13.8.2.1.3 Noise Coupling Mechanisms.

Grounding can reduce the interference in the five types of coupling mechanisms listed here.

1. Conductive Coupling. (Source and load wired together) - It is sometimes practical to provide a separate return path for both the source and the load. If the system layout allows this, then conductive coupling cannot occur between these two, as is shown in Figures 13-1 and 13-2.
2. Capacitive Coupling. (High-impedance proximity coupling) - The technique for increasing resistance to capacitive coupling among cables is to ground one end of the shield to produce the shortest, most direct shunt path back to the source of the coupled current as is shown in Fig. 13-3.

   Caution: It is possible to inadvertently increase coupling between source and load if the shield ground does not properly shunt the current coupled onto the shield.

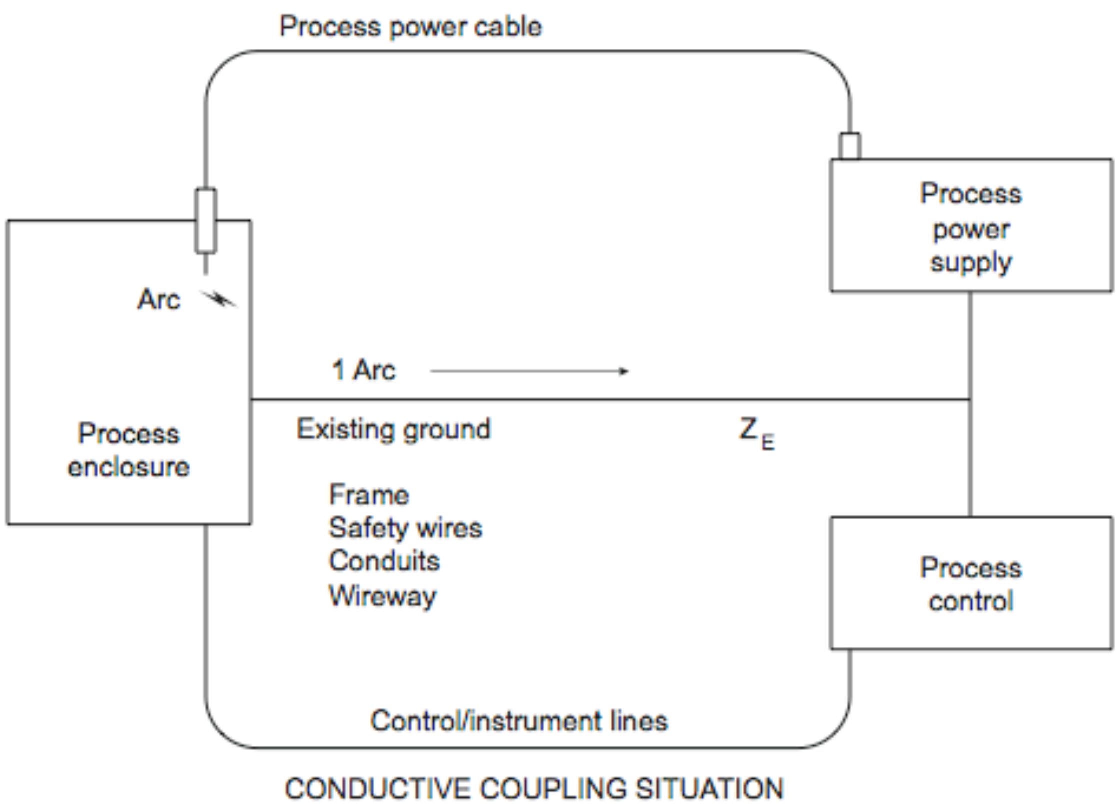


Fig. 13-1. Conductive coupling through a common ground.

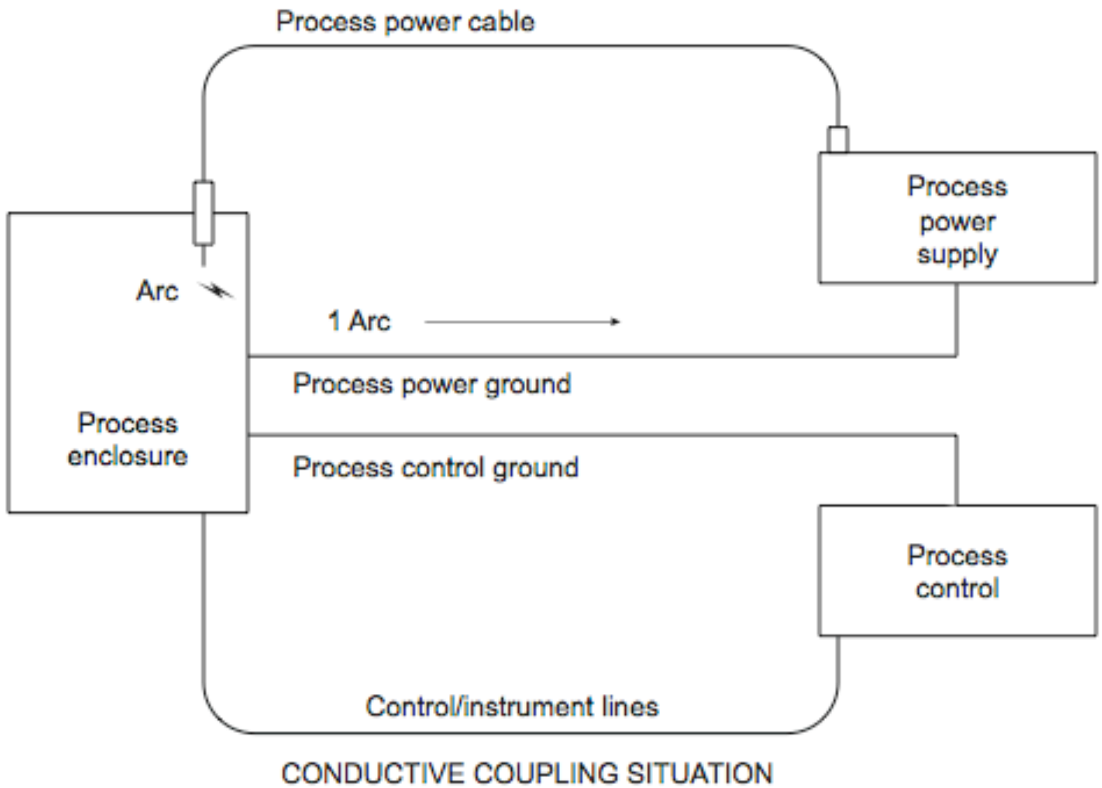


Fig. 13-2. Solution to common ground conductive coupling.

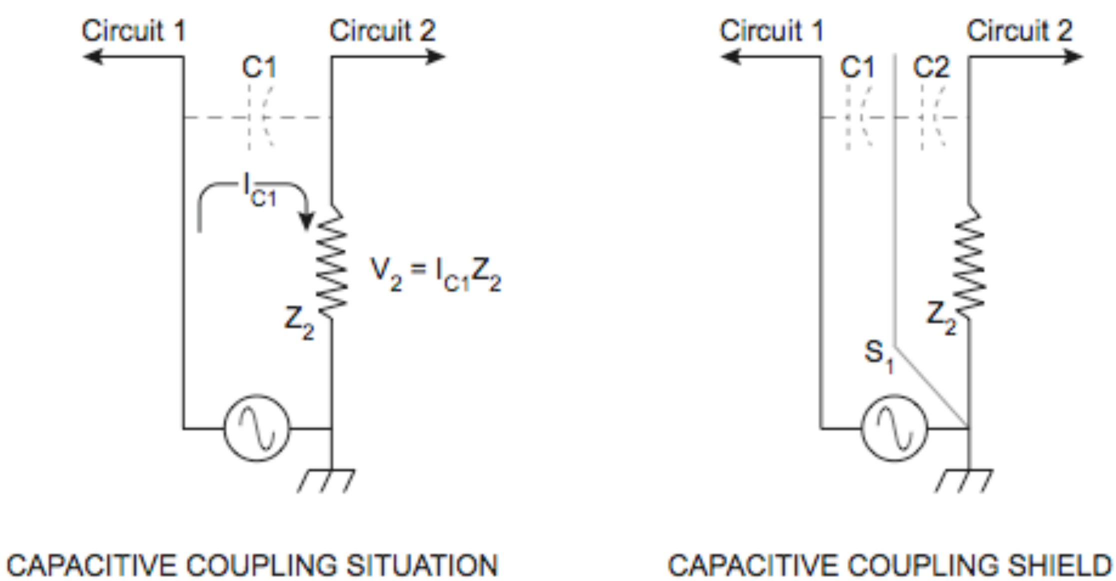


Fig. 13-3. Capacitive coupling between two circuits

3. Inductive Coupling. (Near-field, low-impedance loop-to-loop coupling) - The technique for increasing resistance to magnetic coupling in shielded cables is to ground both ends of the shield to an effective signal return ground as is shown in Figures 13-4.

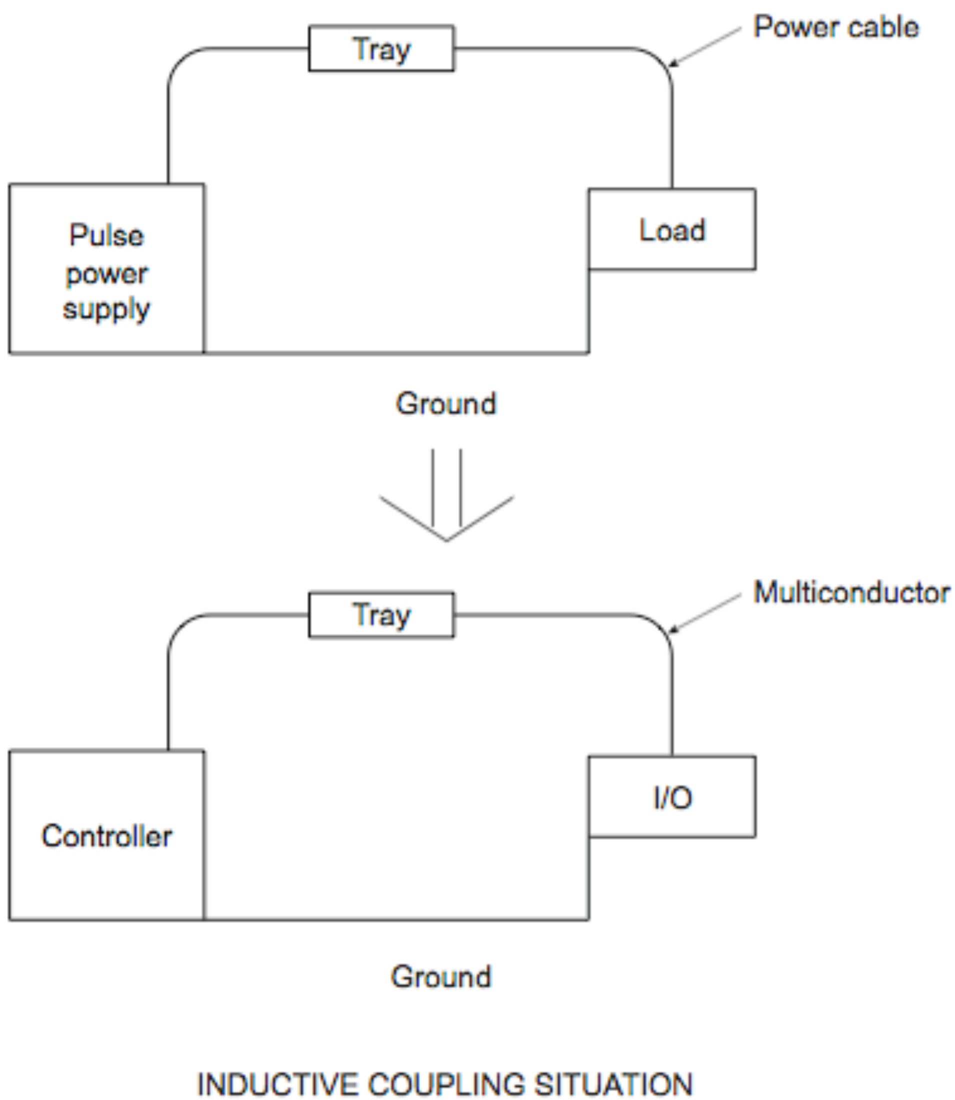


Fig. 13-4. Inductive coupling between two circuits.

4. System Signal Returns. Each installation will require individual analysis and treatment. A single ground poses no problem, but multiple grounds can result in a ground loop. These can upset the proper functioning of instruments. A signal isolator offers a way of overcoming the problem.

5. Instrumentation Grounding[2]. - Equipment that is used to implement a control instrumentation strategy (see Fig. 13-5) makes use of a common signal ground as a reference for analog signals. Any additional grounds that are introduced into the control circuit will almost certainly cause ground loops to occur.

A typical process instrumentation loop is shown in Figure 13-5. It is a DC system that operates at a specific voltage (24 volts in this case) to a master ground reference called a signal ground. The instrumentation signal varies within the range of 4-20 mA, depending upon the value of the variable (pressure, temperature, etc.) seen by the sensor. A precisely calibrated circuit takes this mA signal and converts it into a form that can be used by a process-control computer, PLC, dedicated instrument, or whatever controller that supervises the system. In this example, the mA signal is converted to a 1-5 V signal for a chart recorder. At 4 mA, the voltage measured by the recorder is 250 x.004 = 1 V. At 20 mA, the measured voltage is 5 V. Normally, the recorder scale is calibrated so the voltage reads directly in °F, psi, etc.

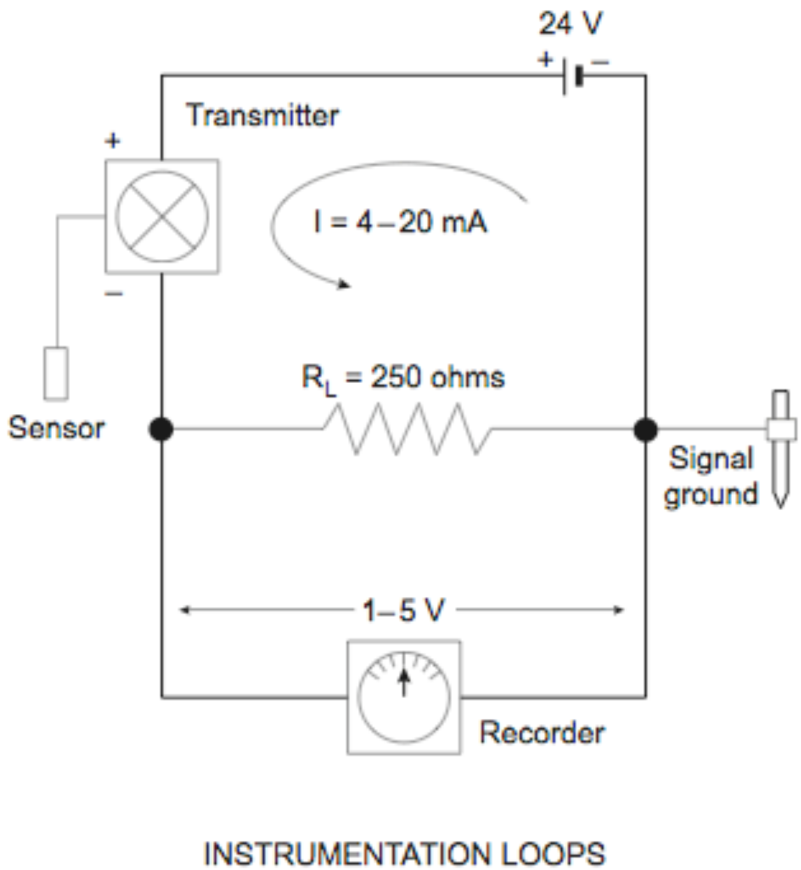


Fig. 13-5. Noise in an instrumentation loop.

In order to minimize the danger of introducing ground loops into this complicated network of sensitive equipment, a dedicated instrumentation system ground bus is usually employed. This bus ultimately receives grounds from the signal common, the dc power supply common, the cabinet ground, and the instrumentation ac power ground. The bus is tied to earth via the building ground and the plant ground grid. Figure 10-9 shows the typical way in which interconnection of these various grounds is accomplished.

The cabinet ground is a safety ground that protects equipment and personnel from accidental shock hazards while providing a direct drain line for any static charges or electromagnetic interference (EMI) that may affect the cabinets. The cabinet ground remains separate from the dc signal ground until it terminates at the master ground bus.

Eliminating grounds is not feasible for some instruments, such as thermocouples and some analyzers, because they require a ground to obtain accurate measurements. Also, some instruments must be grounded to ensure personnel safety.

When grounds cannot be eliminated, the solution to instrumentation ground loops lies in signal isolators. These devices break the galvanic path (dc continuity) between all grounds while allowing the analog signal to continue throughout the loop. An isolator also eliminates the noise of ac continuity (common-mode voltage)[3].

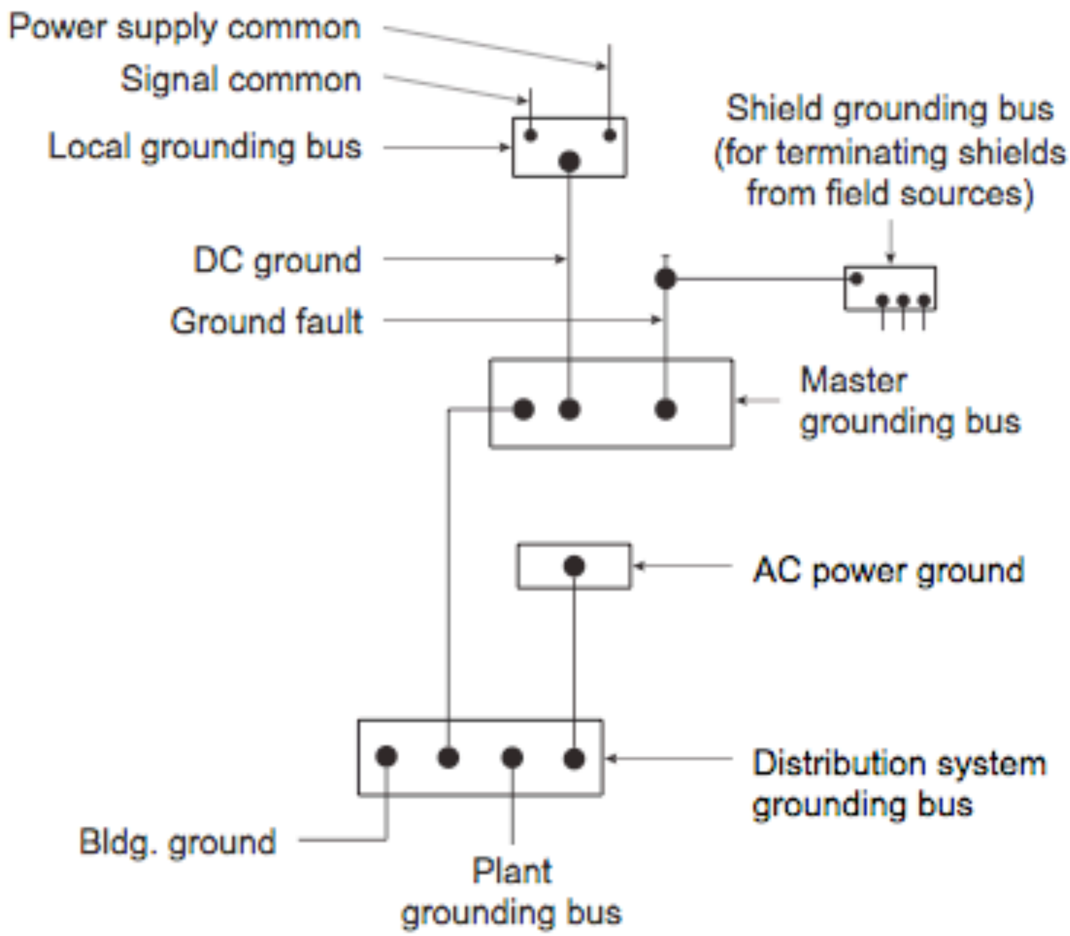


Fig. 13-6. Typical control instrumentation ground system.

[3] Much of the information above came from the article entitled Causes and Cures of Instrumentation Ground Loops, by Pat Power, Moore Industries, Houston, TX.

13.8.2.1.4 Operation and Maintenance

Before starting each operation (experiment, test, etc.) the exposed portions of the grounding system should be visually checked for any damage and to determine that all necessary connections have been made. If more than one operation is conducted every day visual checks should be performed only at the beginning of each shift during which the grounding system will be needed. The adequacy of the grounding system should be verified annually. It is recommended that the grounding impedance within the equipment be maintained at 0.25 ohms or less. (See IEEE 1100).

13.8.2.2 Materials Used in an Unconventional Manner

The practice of using materials or components for purposes other than originally designed needs special safety considerations in use, identification, personnel protection, and equipment protection.

13.8.2.2.1 Hazards

The use of materials for something other than their original design criteria has the potential for providing an additional hazard, especially to personnel unfamiliar with the research apparatus. Personnel may assume that the material is used as originally designed and can unknowingly expose themselves to hazards unless special precautions are followed.

Some examples of items used in an unconventional manner are:

1. Copper pipe used as an electrical conductor
2. Insulated flexible copper pipe used as an electrical conductor
3. Specially designed high-voltage or high-current connectors
4. Specially designed high-voltage or high-current switches
5. Water column used as a high-voltage resistor
6. Standard coax cable used in special high-voltage pulsed circuits
7. Water column used as a charged-particle beam attenuator
8. Commercial cable tray used as a mechanical support for experimental apparatus.

13.8.2.2.2 Design and Construction

During design, special consideration should be given to installing interlocks and protective barriers. Signs warning of the hazards should be posted to help prevent unsuspecting personnel from being injured.

13.8.2.2.3 Operation and Maintenance

Appropriate safety procedures and training should be part of the process to qualify personnel. The procedures should describe the methods used to promote safe work practices relating to work on energized circuits in accordance with Section 2.1.2, Considerations for Working on Energized Systems and Equipment, Section 2.13, Work Practices, and 29 CFR 1910.331-335.

13.8.3 Work on Energized or De-Energized Electrical Equipment

Unless explicitly stated otherwise in this section, all work on energized/de-energized equipment will conform to Section 2.0, "General Requirements."

13.9 REQUIREMENTS FOR SPECIFIC R&D EQUIPMENT

Electrical equipment and components used in research may pose hazards not commonly found in industrial or commercial facilities. Special precautions are required to design, operate, repair, and maintain such equipment. Electrical safety and personnel safety circuits (e.g., interlocks) are covered in this section as a guide to reduce or eliminate associated hazards. Training and experience in the specialized equipment are necessary to maintain a safe workplace.

All personnel involved with research electrical equipment should be trained and be familiar with the hazards they may encounter in the workplace. Only qualified electrical personnel should design, install, repair, or maintain electrical research equipment or components. Safety-related design, operation, and maintenance techniques should be incorporated into all new or modified equipment. Existing equipment should be modified when necessary to ensure safety. Equipment for which specific standards are not available should be constructed according to the principles of established standards, as determined by the AHJ.

Capacitors and inductors are used in research apparatus in special configurations as well as in their standard configurations. The design, operation, and maintenance of research apparatus using capacitors and inductors in these special configurations require that special consideration be given to the safety of both personnel and equipment.

13.9.1 Capacitors

This section covers capacitors that are used in the following typical R&D applications:

1. Energy storage
2. Voltage multipliers
3. Filters
4. Isolators

13.9.1.1 Hazards

Examples of capacitor hazards include:

1. Capacitors may store and accumulate a dangerous residual charge after the equipment has been de-energized. Grounding capacitors in series may transfer rather than discharge the stored energy.
2. A hazard exists when a capacitor is subjected to high currents that may cause heating and explosion.
3. When capacitors are used to store large amounts of energy, internal failure of one capacitor in a bank frequently results in explosion when all other capacitors in the bank discharge into the fault. Approximately 10^4 joules is the threshold energy for explosive failure of metal cans.

4. High-voltage cables should be treated as capacitors since they have the capability to store energy.
5. The liquid dielectric and combustion products of liquid dielectric in capacitors may be toxic.
6. Because of the phenomenon of "dielectric absorption," not all the charge in a capacitor is dissipated when it is short-circuited for a short time.
7. A dangerously high voltage can exist across the impedance of a few feet of grounding cable at the moment of contact with a charged capacitor.
8. Discharging a capacitor by means of a grounding hook can cause an electric arc at the point of contact. (See 11.19.1.2.3).
9. Internal faults may rupture capacitor containers. Rupture of a capacitor can create a fire hazard. Dielectric fluids may release toxic gases when decomposed by fire or the heat of an electric arc.
10. Fuses are generally used to preclude the discharge of energy from a capacitor bank into a faulted individual capacitor. Improperly sized fuses for this application may explode.

13.9.1.2 Design and Construction

The following cautions in design and construction should be considered:

1. Isolate capacitor banks by elevation, barriers, or enclosures to preclude accidental contact with charged terminals, conductors, cases, or support structures.
2. Interlock the circuit breakers or switches used to connect power to capacitors.
3. Provide capacitors with current-limiting devices.
4. Design safety devices to withstand the mechanical forces caused by the large currents.
5. Provide bleeder resistors on all capacitors not having discharge devices.
6. Design the discharge-time-constant of current-limited shorting and grounding devices to be as small as practicable.
7. Provide suitable grounding.

13.9.1.2.1 Automatic Discharge Devices

1. Use permanently connected bleeder resistors when practical.
2. Have separate bleeders when capacitors are in series.
3. Use automatic shorting devices that operate when the equipment is de-energized or when the enclosure is opened, which discharges the capacitor to safe voltage (50 V or less) in less time than is needed for personnel to gain access to the voltage terminals. It must never be longer than 5 minutes.
4. For equipment with stored energy greater than 10 J, provide an automatic, mechanical discharging device that functions when normal access ports are opened.
5. Ensure that discharge devices are contained locally within protective barriers to ensure wiring integrity. They should be in plain view of the person entering the protective barrier so that the individual can verify proper functioning of the devices.
6. Provide protection against the hazard of the discharge itself.

13.9.1.2.2 Safety Grounding

1. Fully visible, manual grounding devices should be provided to render capacitors safe while work is being performed.
2. Grounding points must be clearly marked.
3. Prevent transferring charges to other capacitors.

13.9.1.2.3 Ground Hooks

1. Conductor terminations should be soldered or terminated in an approved crimped lug. All conductor terminations must be strain-relieved within 15 cm.
2. Ground hooks must be grounded and impedance should be less than 0.1 ohms to ground.
3. The cable conductor must be clearly visible through its insulation.
4. A cable conductor size of at least #2 AWG should be used, and the conductor shall be capable of carrying the available fault current of the system.
5. Ground hooks shall be used in sufficient number to adequately ground all designated points.
6. Permanently installed ground hooks must be permanently grounded and stored in a manner to ensure that they are used.

13.9.1.2.4 Discharge Equipment with Stored Energy in Excess of 10 Joules

1. A discharge point with an impedance capable of limiting the current to 500A or less should be provided.
2. The discharge point must be identified with a unique marker (example: yellow circular marker with a red slash), and should be labeled "HI Z PT" in large legible letters.
3. A properly installed grounding hook should first be connected to the current-limiting discharge point and then to a low-impedance discharge point (< 0.1 ohm) that is identified by a unique marker (example: yellow circular marker).
4. The grounding hooks should be left on all of these low-impedance points during the time of safe access.
5. The low-impedance points shall be provided whether or not the HI-Z current-limiting points are needed.
6. Voltage indicators that are visible from all normal entry points should be provided.

13.9.1.2.5 Fusing

1. Capacitors connected in parallel should be individually fused, when possible.
2. Caution must be used in the placement of automatic discharge safety devices with respect to fuses. If the discharge will flow through the fuses, a prominent warning sign should be placed at each entry indicating that each capacitor must be manually grounded before work can begin.
3. Special knowledge is required for high-voltage and high-energy fusing.

13.9.1.3 Operation and Maintenance

1. The protective devices (interlocks) shall not be bypassed unless by qualified electrical personnel when inspecting, adjusting, or working on the equipment. Proper procedures need to be followed when bypassing interlocks.

2. Procedures should be established for tagging the interlock and logging its location and the time when bypassed and restored. Written approval shall be obtained from an appropriate authority before bypassing an interlock.
3. Only qualified electrical personnel (those trained in the proper handling and storage of power capacitors and hazard recognition) shall be assigned the task of servicing/installing such units.
4. Proper PPE shall be used when working with capacitors.
5. Access to capacitor areas shall be restricted until all capacitors have been discharged, shorted, and grounded.
6. Any residual charge from capacitors shall be removed by grounding the terminals before servicing or removal.
7. Automatic discharge and grounding devices should not be relied upon.
8. Grounding hooks shall be inspected before each use.
9. Capacitor cases should be considered "charged."
10. Protective devices should be tested periodically.
11. All uninstalled capacitors capable of storing 5 joules or greater shall be short-circuited with a conductor no smaller than #14 AWG.
12. A capacitor that develops an internal open circuit may retain substantial charge internally even though the terminals are short-circuited. Such a capacitor can be hazardous to transport, because the damaged internal wiring may reconnect and discharge the capacitor through the short-circuiting wires. Any capacitor that shows a significant change in capacitance after a fault may have this problem. Action should be taken to minimize this hazard when it is discovered.

13.9.2 Inductors

This section covers inductors as well as electromagnets and coils that are used in the following typical applications:

1. Energy storage
2. Inductors used as impedance devices in a pulsed system with capacitors
3. Electromagnets and coils that produce magnetic fields to guide or confine charged particles
4. Inductors used in dc power supplies
5. Nuclear Magnetic Resonance (NMR), Electron Paramagnetic Resonance (EPR), and Magnetic Susceptibility Systems.

13.9.2.1 Hazards

Examples of Inductor hazards include:

1. Overheating due to overloads, insufficient cooling, or failure of the cooling system could cause damage to the inductor and possible rupture of the cooling system.
2. Electromagnets and superconductive magnets may produce large external force fields that may affect the proper operation of the protective instrumentation and controls.

3. Magnetic fields could attract nearby magnetic material, including tools and surgical implants, causing injury or damage by impact.
4. Whenever a magnet is suddenly de-energized, production of large eddy currents in adjacent conductive material can cause excessive heating and hazardous voltages. This state may cause the release or ejection of magnetic objects.
5. The worker should be cognizant of potential health hazards.
6. Interruption of current in a magnet can cause uncontrolled release of stored energy. Engineered safety systems may be required to safely dissipate stored energy. Large amounts of stored energy can be released in the event of a "quench" in a superconducting magnet.

13.9.2.2 Design and Construction

The following should be considered:

1. Provide sensing devices (temperature, coolant-flow) that are interlocked with the power source.
2. Fabricate protective enclosures from materials not adversely affected by external electromagnetic fields. Researchers should consider building a nonferrous barrier designed to prevent accidental attraction of iron objects and prevent damage to the cryostat. This is especially important for superconducting magnet systems.
3. Provide equipment supports and bracing adequate to withstand the forces generated during fault conditions.
4. Appropriately ground electrical supply circuits and magnetic cores and provide adequate fault protection.
5. Provide means for safely dissipating stored energy when excitation is interrupted or a fault occurs.
6. Provide appropriate warning signs to prevent persons with pacemakers or similar devices from entering areas with fields of greater than 0.001 Tesla.
7. Personnel exposure to magnetic fields of greater than 0.1 Tesla should be restricted.
8. When a magnet circuit includes switching devices that may not be able to interrupt the magnet current and safely dissipate the stored energy, provide a dump resistor connected directly across the magnet terminals that is sized to limit the voltage to a safe level during the discharge and safely dissipate the stored energy.

13.9.2.3 Operation and Maintenance

Verify that any inductor is de-energized before disconnecting the leads or checking continuity or resistance.

13.9.3 Electrical Conductors and Connectors

The conductors and connectors covered here are only those used in unconventional applications.

13.9.3.1 Hazards

Examples of hazards are as follows:

1. Metallic cooling-water pipes that are also used as electrical conductors present shock hazards (i.e., they may not be readily recognizable as electrical conductors).
2. Improper application or installation of connectors can result in overheating, arcing, and shock hazards.
3. Hazardous induced voltages and arcing can result from inadequate separation between high- and low-voltage cables.
4. Use of an improper cable for a given type of installation (routing) can result in a fire hazard.

13.9.3.2 Design and Construction

When working with special conductors and connectors for R&D applications, the following guidelines shall be implemented for design and construction:

1. Select cables that are listed by an NRTL for a given type of installation (such as in conduits, trays, underground, or in an enclosure) whenever possible. Since cables used for R&D are sometimes unique (such as some coaxial cables), they may not be available as NRTL listed. In that case, obtain AHJ approval in accordance with Chapter 12.
2. Where liquid- or gas-cooled conductors are used, sensing devices (temperature or coolant-flow) shall be provided for alarm purposes or equipment shutdown if the cooling system malfunctions.
3. Provide adequate labeling, insulation, or other protection for metallic cooling-water piping used as electrical conductors.
4. Provide engineering calculations to support overrating of conductors for any application.
5. Avoid conductor loops (wide spacing) between high-current supply and return conductors to prevent voltage and current induction in adjacent circuits or structural members.
6. Ground coaxial cable shielding when possible. If test conditions require an ungrounded shield, provide barriers and warning signs to notify personnel that the shield is ungrounded and should be assumed to be energized.
7. Provide suitable routing and additional protection for coaxial cables used in pulsed-power applications where the braid of the coaxial cable rises to high voltage levels.

13.9.3.3 Operation and Maintenance

Cable connectors and connections should be checked after installation, periodically, and should be tightened as necessary. Special attention should be given to aluminum cable connections.

Ensure that charges are not built up on equipment that has been disconnected, such as vacuum feed through systems.

13.9.4 Induction and Dielectric Heating Equipment

This section describes electrical hazards associated with induction heating, RF equipment, and microwave equipment used in research. The hazards are mainly associated with high-power/high-frequency RF generators, waveguides and conductors, and the working coils producing high temperatures.

13.9.4.1 Hazards

1. RF power as high as 50 kW and frequency in the tens of kHz range to hundreds of MHz is supplied from the RF and microwave generators. Being close to or making contact with an unprotected coil, conductors or waveguide opening may result in severe body burns.
2. Dangerous voltages are present inside the power generators.
3. Dangerous levels of RF energy may be present in the laboratory.

13.9.4.2 Design and Construction

1. The heating coils, sources of high-frequency energy, and other energized parts outside the generator cabinet must be shielded or guarded to prevent access or contact.
2. The heating coil should have its cold (outside) lead properly grounded.
3. A coaxial cable of correct impedance and adequate construction may be desirable to deliver the RF power to the coil in order to prevent the leakage of the RF energy in the laboratory.

13.9.4.3 Operation and Maintenance

1. Shielding must be maintained to minimize RFMW radiation.
2. Wearing metallic objects when operating or maintaining the induction heating system is prohibited
3. Posting suitable warnings to indicate equipment hazards.

13.9.5 Batteries

Batteries are used in multiple applications. Specialized types exist that are suitable for different applications.

Lead-acid storage battery types are the lead-antimony and the lead-calcium. The lead-antimony battery is low cost, high efficiency, small size and long life. The lead-calcium is typically chosen for use in UPS systems due to the similar characteristics of lead-antimony coupled with lower maintenance requirements. Both types use dilute sulfuric acid as the electrolyte.

Alkali storage battery types are the nickel cadmium and the nickel metal hydride. These batteries use compounds of nickel peroxide and iron oxide for the plate materials, and potassium hydroxide as the electrolyte. Storage batteries of this type perform well in extremes of temperature.

Other Batteries

Specialized batteries for applications include silver zinc, silver cadmium and mercury. Manufacturers' data sheets will provide guidelines for safety for these and other battery types.

13.9.5.1 Hazards

13.9.5.1.1 Chemical Hazards

For each battery type considered for use, obtain MSDS information and understand the specific hazards involved before use.

Chemicals associated with battery systems may include:

1. cadmium (Cd)
2. lead (Pb)
3. lead peroxide (PbO_2)
4. lithium hydroxide (LiOH)
5. potassium hydroxide (KOH)
6. sodium bicarbonate $NaHCO_3$
7. sodium hydroxide (NaOH)
8. sulfuric acid (H_2SO_4)

Many of these chemicals (and other battery components not listed here) are corrosive, poisonous and/or flammable. Possible consequences of a ruptured container or spilled electrolyte include:

- fire
- explosion
- chemical burns
- reactions to toxic fumes, solids or liquids

13.9.5.1.2 Electrical Hazards

Electrical safety during battery operations is primarily concerned with prevention of a direct short circuit across one or more cells. Due to the large amount of stored energy in the battery cells and the low internal resistance of the cells, a short circuit could have catastrophic results including an explosion of the cells involved. Suitable clothing has been discussed above. Personnel conducting electrical work on battery systems must follow the following guidelines:

1. tools must be fully insulated or must be half-lap and double-wrapped with vinyl electrical tape
2. only instruments having a non-conductive case (e.g., the yellow rubber holster provided with Fluke multimeters) are permitted in the vicinity of battery systems
3. storage battery systems may present terminal voltages of 48, 125 or 250 Vdc. If the physical construction of the battery system permits, inter-cell or inter-tier cables should be disconnected when performing work on the battery system
4. if one terminal of the battery system is bonded to ground, an additional hazard exists. Single-point contact between an exposed battery terminal and surrounding structures could result in very large short-circuit currents and possibly lead to fires or personal injury.

13.9.5.1.3 Physical / Mechanical Hazards

individual cell containers:

- may weigh in excess of 70 lbs
- are not typically provided with handles
- may be slippery and difficult to hold, especially when wearing gloves

Removal and replacement of these containers requires work in positions which are:

- awkward
- uncomfortable
- possibly unstable.

Possible consequences include:

- muscle strains, falls, or dropped containers
- dropped containers which rupture and spill electrolyte.

13.9.5.2 Design and Construction

1. isolate battery systems by elevation, barriers, or enclosures to preclude accidental contact with energized terminals, conductors, cases, or support structures
2. provide battery systems with overcurrent protection devices
3. provide means of partitioning or 'sectionalizing' battery systems to allow multiple or single batteries to be disconnected (refer to Figure 13-7)
4. design safety devices to withstand the mechanical forces caused by the large currents
5. provide suitable grounding
6. provision should be made to contain possible spills of electrolyte.

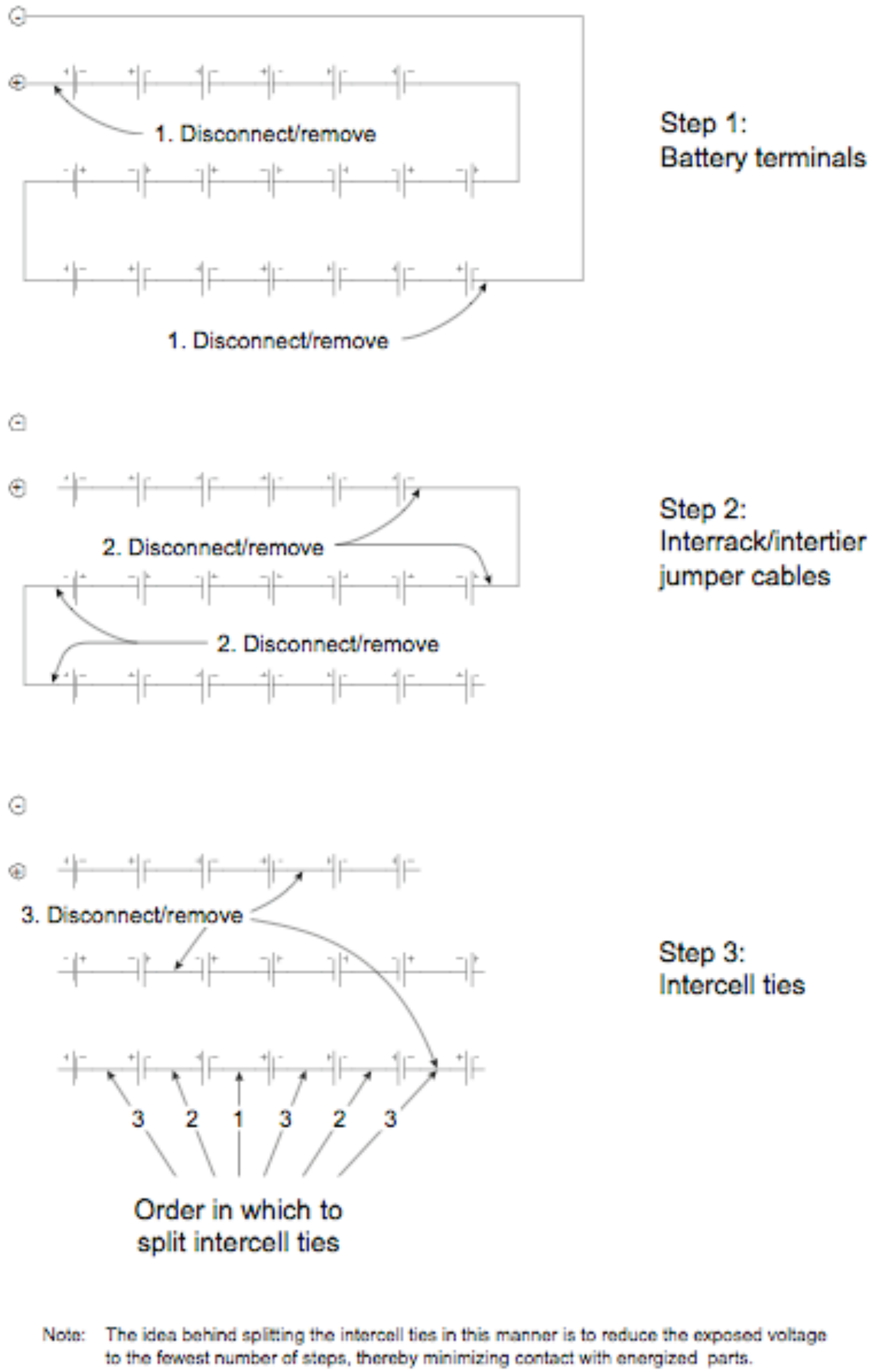


Figure 13-7. Example of sectionalizing a large, multi-tier battery system

13.9.5.3 Operation and Maintenance

Workers must handle the equipment carefully. The battery manufacturer's installation, operating and maintenance instructions give guidance about appropriate handling. Personnel attempting physical movement of battery containers must plan their work accordingly.

Safety during electrolyte-handling operations (measurement of cell specific gravities, addition of distilled water, addition or removal of electrolyte) requires the use of certain personal protective equipment and other materials. The following protective equipment must be available to personnel performing battery maintenance tasks:

- face shield and chemical splash goggles
- acid-tolerant gloves and apron, and shoe covers if the work warrants
- emergency shower / eye wash equipment capable of delivering 450 gallons of water within a 15-minute interval
- sodium bicarbonate solution (neutralizing agent for cleaning cell containers and neutralizing acid spills)
- Class C fire extinguisher
- adequately insulated tools of appropriate-length.

If the cell container is tipped over, electrolyte may spill from the flash arrestor assembly. The flow of electrolyte will not be rapid, but is still a safety hazard. When lifting or moving electrolyte-filled containers, ensure they always remain in an upright position.

In the event of an electrolyte spill:

(a) minimize contact with the electrolyte by leaving the spill area
(b) rinse contaminated protective equipment with water and sodium bicarbonate
(c) remove contaminated clothing
(d) in case of skin contact, immediately flush with water followed by washing with soap and water
(e) do not attempt to neutralize with sodium bicarbonate any acid spilled on the skin
(f) in case of eye contact, flush eyes for a minimum of 15 minutes, then provide transport for the individual to medical facilities. This must be done regardless of the apparent severity of the injury
(g) electrolyte-contaminated material or equipment is considered hazardous material and is to be treated and disposed of as such in accordance with current guidance

Appropriate gloves and other PPE must be worn to minimize the hazard due to toxic material exposure. Workers must wash their hands with soap and water after completion of the work. There must be no eating or drinking in the vicinity of the battery system.

13.9.6 Lasers and X-Ray Equipment

This section is applicable to laser systems and x-ray equipment used in research. Both fixed and portable equipment are covered regardless of input voltage. Only electrical hazards are addressed in this subsection. Refer to ANSI Z136.1 for laser hazards and 29 CFR 1910.306 (f) for x-ray hazards.

13.9.6.1 Hazards

1. Dangerous voltages are present inside the equipment.
2. Implosion hazards may exist with the covers removed.

3. Energy storage devices may present a hazard due to a residual charge even when the system is de-energized
4. Dangerous voltages can exist across the impedance of the grounding conductor during operation.
5. Failure of interlocks and safety devices may allow access to energized parts.

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