Requirements For the Assessment of Electrical Hazards

Table of Contents

Introduction

Summary

This chapter provides the requirements and tools for assessing electrical hazards, and provides the recommended controls for mitigating those hazards. 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 to the exposed electrical hazard. Section 1 presents various types of electrical injury. Section 2 presents the 4 possible states or conditions of the electrical equipment and Section 3 presents the boundaries associated with the distance of the worker from the exposed electrical hazard. Section 4 presents the types of controls used to protect the worker from exposed electrical hazards. Finally, Section 5 classifies electrical hazards as determined by the possible injury and provides the recommended controls for mitigation of the hazard for the various Modes of Condition of the equipment.

Scope

An assessment of the electrical hazards, by a electrically qualified worker, must be performed for all work that requires employees to work on or near exposed electrical conductors or circuit parts that were, are, or could become energized in order to determine the required safety-related work practices. The electrical hazard assessment must include an identification of electrical hazards associated with each task or activity, along with specific mitigation, controls, or work rules for each hazard.

When an electrical hazard exists, the worker must, if feasible, place the exposed circuit parts into an electrically safe work condition. 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.

Purpose

The purpose of this chapter is to provide electrically qualified workers guidance to determine step 2 of ISM, Analyze the Hazard, and to give recommendations for the controls to be implemented in Step 3 of ISM, Develop the Controls.

Definitions

Unless expressly stated elsewhere, the following terms have the meanings indicated below.

Arc blast – A release of mechanical, acoustical, thermal, and optical energy from an electric arc.

Arc flash – A release of thermal energy from an electric arc, leading to burn or ignition of clothing.

Authorized work – Electrical work that a line manager has permitted electrically qualified workers to perform based on an approved safe work procedure and appropriate work practices.

Compelling reason – The reason for authorizing workers to perform work on or near hazardous energized electrical circuit parts. The reasons include two types:

- increased or additional hazards of de-energizing critical systems; and
- infeasibility due to equipment design or operational limitations (e.g., testing of electric circuits that can only be performed with the circuits energized).

Critical systems – Those systems that would result in increased or additional hazards if de-energized (e.g., life support equipment, emergency alarm systems, hazardous location ventilation equipment, area lighting, and systems maintaining national security).

De-energized – Free from any electrical connection to a source of potential difference and from electrical charge. Not having a potential different from that of earth. **Note:** *De-energized* **does not** describe a safe condition.

Electrical hazard – A dangerous condition such that inadvertent or unintentional contact or equipment failure can result in shock, arc flash burn, thermal burn, or blast.

Electrical work – (1) working on or near energized electrical parts; (2) design, assembly or fabrication of potentially hazardous electrical equipment; (3) working with unlisted or unapproved electrical equipment; and/or (4) using listed or approved equipment in a manner not consistent with the listing or approval.

Electrically qualified worker – One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved.

Electrically safe work condition – A state in which the conductor or circuit part to be worked on or near has been (1) disconnected from energized 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.

Energized – Electrically connected to a source of potential difference, or electrically charged to have a potential significantly different from that of earth in the vicinity. **Note:** *De-energized* parts that have **not** been verified and locked out and tagged (or equivalent) in accordance with established standards are considered energized.

Flash hazard – A dangerous condition associated with the release of energy caused by an arc that suddenly and violently changes material(s) into a vapor.

Flash protection boundary – An approach limit at a distance from exposed live parts within which a person could receive a second-degree burn if an electrical arc flash were to occur.

Hazardous electrical work – All electrical operations in which workers may be exposed to electrical hazards.

Limited approach boundary – An approach limit at a distance from an exposed live part within which a shock hazard exists.

Live parts – Electric conductors, busses, terminals, or components that are uninsulated or exposed and within which a shock hazard exists.

Prohibited approach boundary – An approach limit at a distance from an exposed live part within which work is considered the same as making contact with the live part.

Restricted approach boundary – An approach limit at a distance from an exposed live part within which there is an increased risk of shock, due to electrical arc over combined with inadvertent movement, for personnel working in close proximity to the live part.

Safety watch – A safety watch is a more stringent hazard control measure than the two-person rule and must be implemented when there are grave consequences from a failure to follow safe-work procedures. The safety watch must be an electrically qualified worker who must be responsible for monitoring qualified workers performing high-hazard electrical work.

Shock hazard – A dangerous condition associated with the release of electrical energy caused by contact or approach to exposed electrical conductors or circuit parts nearer than the minimum air insulation distance.

Two-person rule – The requirement for two electrically qualified workers to be present in the workplace and to be aware of the other worker's task while performing electrically hazardous work.

Working near – Any activity inside the limited approach boundary or the flash protection boundary (see NFPA 70E) of exposed energized electrical conductors or circuit parts that are not put into an electrically safe work condition.

Working on – Coming in contact with exposed energized electrical conductors or circuit parts with the hands, feet, or other body parts, with tools, probes, or with test equipment, regardless of the personal protective equipment a person is wearing. Also, any activity inside the prohibited approach boundary.

100% Rule – Work on or near energized parts must be performed only after all participating electrically qualified workers are in 100% agreement on the work to be completed, on the sequence in which it should be performed, and that the hazards are fully controlled or mitigated.

Section 1—Electrical Hazards

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

1.1 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 "live" (ungrounded) conductor while also in contact with a grounded object, he or she becomes part of the circuit, and 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, rf, impulse);
- current's pathway through the body (determined by contact location and internal body chemistry);
- duration of shock; and,
- energy deposited into the body.

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; and
- 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 (cessation of the heart's rhythmic pumping action) can be initiated by a current flow of as little as several tens of milliamperes. Without immediate emergency resuscitation electrical shock can cause nearly instantaneous fatality from direct paralysis of the respiratory system, failure 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 nerve center. 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; power frequencies, dc, radio frequencies, and impulse shock (such as a capacitor shock). Perhaps the most dangerous are power frequencies, 50 or 60 Hz. Exposure to current at these frequencies causes ventricular fibrillation at the lowest thresholds and causes clamping 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. Capacitor shocks above the skin breakdown threshold (400 to 500 V) result in immediate deposition of the high voltage capacitor energy into the body. Once above this skin breakdown threshold the actual voltage and current of the shock is not the determining factor in the body's response. The actual electrical energy deposited will determine the severity of the reflex action, the affect on the heart, and the neurological and other tissue injury.

Reflex action occurs when electric current causes a violent contraction of the muscles. Such contraction can result in violent recoil, resulting in falling off of heights, recoiling into a nearby hazard, or self injury 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.

1.2 Electrical Burn

Burns suffered in electrical accidents are of three basic types: electrical burns, arc burns, and thermal contact burns. In electrical burns, tissue damage (whether skin-deep or deeper) occurs because the body is unable to dissipate the heat from the current flow. Typically, electrical burns are slow to heal. Arc 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. Thermal contact burns are those that occur when skin comes into contact with the hot surfaces of overheated electric conductors.

1.3 Delayed Effects

Damage to the internal tissues may not be apparent immediately after contact with the current. Delayed swelling and irritation of internal tissues are possible. In addition, imperceptible heart arrhythmia can progress to total 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—this is the primary reason for reporting electrical shock immediately.**

1.4 Battery Hazards

During maintenance or other work on batteries and battery banks, there are electrical and physical hazards that must be considered. In addition, when working near or on flooded lead-acid storage batteries additional chemical and explosion hazards must 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; and
- Fire from overheated electrical components.

1.5 Other Hazards

Voltage sources that do not have dangerous current capabilities may not pose serious shock or burn hazards in themselves and, therefore, are often treated in a casual manner. However, low-voltage circuits are frequently used adjacent to lethal circuits, and even a minor shock can cause a worker to rebound into a lethal 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.

Electricity also poses other hazards. An arc can form when a short circuit occurs between two conductors of differing potential, or when two conductors carrying current are separated, attempting to interrupt the current. If the current involved is strong enough, the arc can cause injury or start a fire. Injury to personnel can result from the arc flash, or arc blast, resulting in severe burns to exposed skin, or ignition of clothing. Overheated equipment or conductors that carry too much current can also start fires. Extremely high-energy arcs can cause an explosion that sends fragmented metal flying in all directions. Even low-energy arcs can cause violent explosions in explosive or combustible atmospheres.

Because R&D equipment is often unique, the hazards it presents are sometimes peculiar. An uncommon or one-of-a-kind design scheme complicates analyzing and identifying such hazards. For this reason, special efforts are often necessary to identify all of the potential hazards that may be present in an R&D equipment design. In addition to shock, determining electrical hazards should include identifying potential arcs, blasts, and thermal burns. Once these hazards have been identified, a risk mitigation plan should be developed. Personnel working on unique R&D equipment should be specifically qualified through documented on-the-job training (OJT) to work on such equipment. The scope of such additional training depends on the unique safety problems inherent in the equipment.

1.6 Unexpected Discovery of Electrical Hazards

When an unknown electrical hazard may exist (e.g., during penetrations into walls, ceilings, floors, or excavations into masonry surfaces, slabs, ground surfaces, or other structures), the hazard evaluation must include the following steps (appropriate to the job) to determine the presence of energized electrical conductors or circuits:

1. Review historical records, engineering plans, and as-built drawings.
2. Perform a walk-down of the job site, which must include visually identifying electrical installations and their locations.
3. Confer with the facility or building manager.
4. For excavations obtain a utility.
5. Penetrations into walls, floors, and ceilings require a branch circuit locate by the requestor if the location of the circuit is not known.
6. Integrate and validate these sources of information and locate, mark, and de-energize electrical circuits and conductors as accurately as possible.

The following controls must be applied:

Requirements for the Assessment of Electrical Hazards

1. Engineering controls (e.g., relocations, different work methods) must be applied if the presence and location of electrical conductors and circuits cannot be accurately identified and *de-energized.*
2. Workers doing blind penetration work must wear appropriate voltage class dielectric gloves with approved protective outer leather gloves, and dielectric mat, along with nonconductive safety glasses.

Section 2—Modes of Condition of 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, one of the following four conditions will exist.

2.1 Mode 1 – Electrically Safe Work Condition

An electrically safe work condition is a state in which the conductor or circuit part to be worked on or near has been (1) disconnected from energized 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 must be done de-energized unless there is a compelling reason as defined in this chapter. All operations must be conducted in a positively electrically safe work condition. All external sources of electrical energy must be disconnected by some positive action (e.g., with a locked and tagged-out circuit breaker) and all internal energy sources rendered safe.

2.2 Mode 1.5 – Establishing an Electrically Safe Work Condition

To establish an electrically safe work condition the following procedure is used:

1. Determine all sources of electrical supply to the specific equipment.
2. Check applicable drawings, diagrams, and identification tags.
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. 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.
7. Where 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.
8. Where the possibility of induced voltages exists, apply grounds to the normally energized conductors or circuit parts before touching them.
9. Where stored electrical energy exists (e.g., capacitors), discharge or remove the stored energy and apply grounds to the normally energized conductors.
10. 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.

2.3 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.

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). 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 the following:

- 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; and
- Working on experimental facilities that operate in this mode.

2.4 Mode 3 – Energized

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 must be treated as an electrical hazard that must be permitted only when justified by a compelling reason. Tasks performed in this mode must be conducted under close supervision and control. Work control with an approved EEWP is required, with exceptions as indicated in the hazard classification tables. Authorization by the worker's safety responsible line manager is required. The use of appropriate Personal Protective Equipment (PPE) is required.

Section 3—Approach Boundary Analysis

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 shock boundaries, (a) the Limited Approach Boundary, (b) the Restricted Approach Boundary, and (c) the Prohibited Approach Boundary. As shown in Figure 1, and as defined in the Definitions above, these three boundaries are encountered as a worker approaches an exposed electrical conductor.

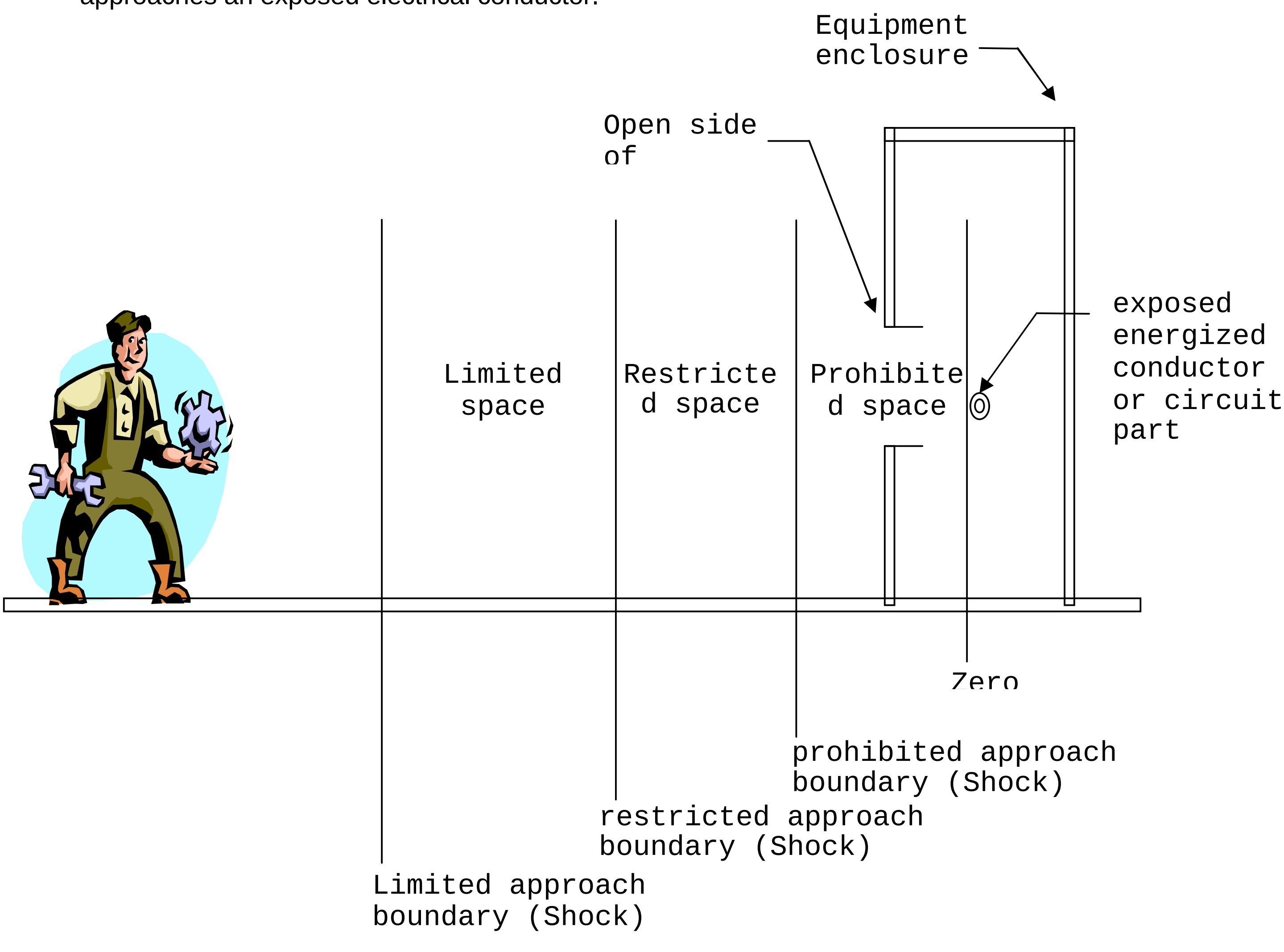


Fig. 1 – Shock Boundaries for an Exposed, Energized Conductor.

The arc flash boundary is the distance from an exposed, energized conductor that would 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 outside of, or within the shock boundaries. Figure 2 shows an arc flash boundary that is outside of the Limited Approach Boundary, as is typical with many facility circuits, and Fig. 3 shows an arc flash boundary that is within the shock boundaries, as is typical with many high voltage, low energy R&D circuits.

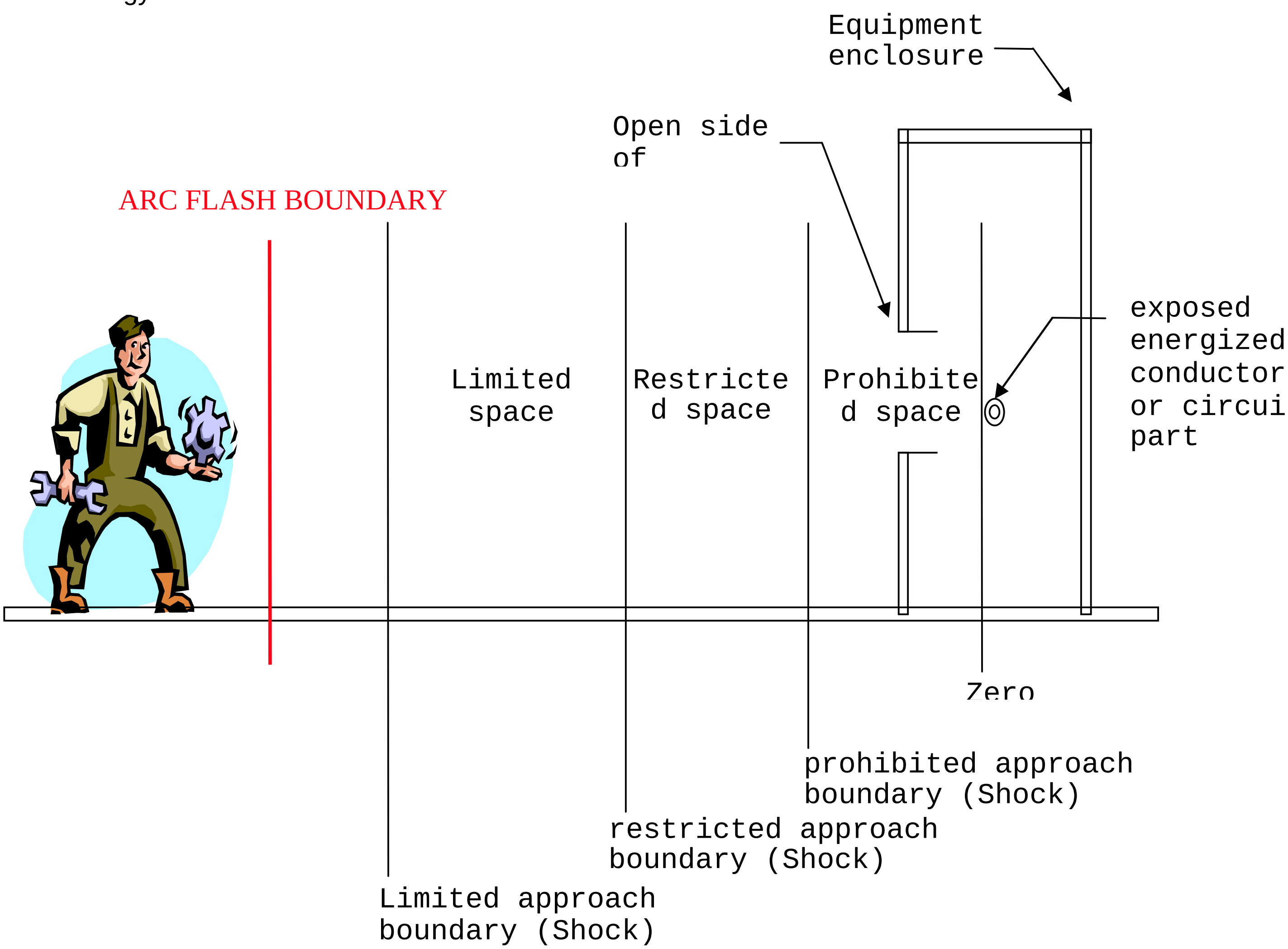


Fig. 2 – Arc Flash Boundary outside of the Limited Approach Boundary.

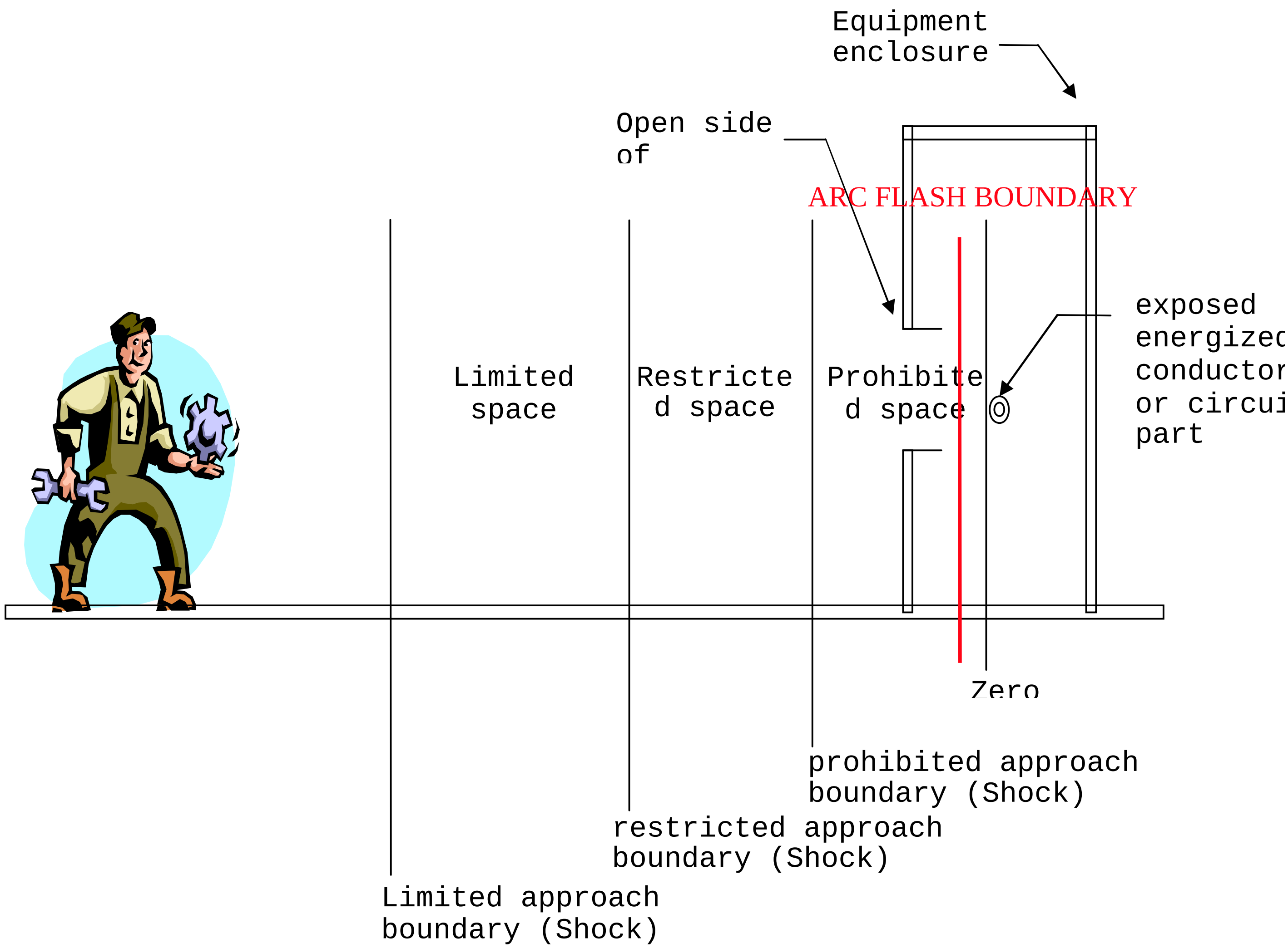


Fig. 3 – Arc Flash Boundary inside of the Limited Approach Boundary.

Section 4—Controls to Mitigate Electrical Hazards

Administrative controls to mitigate electrical hazards can be divided into four basic categories: (a) Working alone, two-person rule, or safety watch rule, (b) Qualification and Training, (c) Work Control (EEWP), and (d) Personal Protective Equipment (PPE). Each will be discussed briefly.

4.1 Working Alone, Two-Person Rule, or Safety Watch Rule

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 fibrillation, serious burn, a no-let-go threshold, or other injury, then the two-person rule shall be followed. The second person must be a qualified, energized electrical worker, and must understand the activities of the worker and the hazards present. The second person must know what to do in case of an electrical accident involving the worker.

A safety watch is a more stringent hazard control measure than the two-person rule and must be implemented when there are grave consequences from a failure to follow safe-work procedures. The safety watch must be a qualified energized electrical worker who must be responsible for monitoring qualified workers performing high-hazard electrical work.

Recommended working alone, two-person, and safety watch rules are provided for each of the four Modes of Condition for each of the 56 Electrical Hazard Classification Tables.

4.2 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) no training required, (2) non-Energized electrical worker, and (3) Energized electrical worker (which requires LOTO and CPR/AED). Recommended general training requirements are given for each of the four Modes of Condition for each of the 56 Electrical Hazard Classification Tables.

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.

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.

4.3 Work Control

An Energized Electrical Work Permit (EEWP) is required for certain high hazard electrical work. Recommended use of EEWPs are given for each of the four Modes of Condition for each of the 56 Electrical Hazard Classification Tables.

4.4 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 Condition for each of the 56 Electrical Hazard Classification Tables. 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.

4.5 Controls for Working On or Near Batteries

4.5.1 Overview of Controls

To limit the risks associated with shock, burn, chemical, and explosion hazards of batteries and battery banks, certain general precautions must be observed. As a rule, all work within the immediate vicinity of large storage battery systems must be done with the following attire:

- Long sleeves, long pants.
- Shoes or boots (no sandals).
- Safety glasses.
- Watches, rings, and other jewelry must be removed from the body and clothing.
- Badges, pens / pencils in pockets, etc, must be removed.
- Additional personal protective equipment must be considered for flooded lead acid batteries. This equipment includes:
    - Chemical-splash resistant goggles and face shield if work with electrolyte is planned.
    - Acid-tolerant gloves, boots, and aprons, depending on the type of work.

To further reduce the hazards outlined above, the following general procedures must be followed during maintenance:

- If the physical construction of the battery system permits, and the battery's terminal voltage is sufficiently high to present its own hazard, consideration should be given to "sectionalizing" the battery in order to reduce the voltage hazard presented.
- Ensure the battery charging system is not charging the battery at a rate sufficient to produce significant hydrogen.
  Note: This is not generally an issue, since a properly adjusted and functioning charger will not charge the battery at a high enough rate to evolve hydrogen in dangerous concentrations. For a flooded lead-acid battery, this figure is about 5% above the nominal float charge voltage.
- No smoking or open flames are permitted.
- Keep the flash arrestors installed on the cell jars at all times, unless the work actually involves the electrolyte (measurement of specific gravity, temperature, addition of water, addition / removal of electrolyte).
- Avoid any activities that increase the chance of arcing in the immediate vicinity of the battery.

4.5.2 Chemical Hazards

Generally, chemicals associated with the battery systems include sulfuric acid (H_2SO_4) electrolyte and elemental lead (Pb) used in the internal structure of the battery and usually in the cell terminals and inter-cell connections. Additionally, sodium bicarbonate ($NaHCO_3$, or common baking soda) for neutralizing and cleaning cell jar tops may be available and in use.

Safety during electrolyte-handling operations (measurement of cell specific gravities, addition of distilled water, addition or removal of electrolyte) is enhanced by the use of certain personal protective equipment and other materials. Therefore, 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;
- Sodium bicarbonate solution (neutralizing agent for cleaning cell jars, acid spill neutralization);
- Class C fire extinguisher; and
- Adequately insulated or appropriate-length tools.

In the event of an acid spill, the first concern is to minimize contact with the acid by leaving the affected area (e.g., step out of the puddle of electrolyte).

- Rinse contaminated protective equipment with water and sodium bicarbonate.
- Remove contaminated clothing.
- If skin contact occurs, immediately flush with water followed by washing with soap and water. Do not attempt to neutralize with sodium bicarbonate any acid spilled on the skin.
- If eye contact occurs, flush eyes for a minimum of 15 minutes, then transport affected individual to HSR-2, Occupational Medicine, for further evaluation and treatment. This must be done regardless of the apparent severity of the injury.
- Electrolyte-contaminated material or equipment is considered hazardous material and is to be treated and disposed of as such in accordance with current guidance.

To minimize the hazard due to lead (Pb) exposure, appropriate gloves must be worn, and workers must wash their hands (soap and water) after completion of the work. Also, there should be no eating or drinking in the vicinity of the battery.

Additional guidance specific to the particular battery system can generally be found in the battery manufacturer’s Installation, Operating and Maintenance instructions.

4.5.3 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 very low internal resistance of the cells, such a short circuit could have disastrous and catastrophic results, including an explosion of the cells involved. Suitable clothing has been discussed above. In addition, personnel conducting electrical work on battery systems must observe the following guidelines:

- Tools must be the fully insulated type, or must be half-lap and double-wrapped with vinyl electrical tape prior to use on battery circuits. Also, only instruments having a non-conductive (e.g., the yellow rubber holster provided with Fluke multimeters) case should be permitted in the vicinity of the batteries.
- Large storage battery systems typically present terminal voltages of 48, 125, or 250 Vdc. Where practical by the physical construction of the battery system, to reduce this voltage during work, consider disconnecting inter-cell or inter-tier tie cables. See Figure 1 for more detail.
- Some battery systems may have one terminal bonded to ground. This introduces an additional hazard because now there is the possibility of a single-point contact between any exposed terminal on the battery and the surrounding structure. As a result, such a contact can cause very large short-circuit currents, possibly leading to fires.

4.5.4 Physical / Mechanical Hazards

Depending on the Amp-hour capacity of the battery system, individual cell jars may weigh in excess of 70 lbs. They are not typically provided with handles, and may be slippery and difficult to hold, particularly when wearing gloves. Removal and replacement of these jars subjects personnel to awkward, uncomfortable, and possibly unstable positions. This has the potential of causing muscle strains, falls, or dropped jars, possibly resulting in a ruptured jar and spill of electrolyte. Therefore, strong consideration should be given to appropriate handling of equipment, which is generally described in the battery manufacturer's installation, operating and maintenance instructions. Personnel attempting physical movement of such battery jars must be aware of these concerns, and plan their actions accordingly.

The cells have no arrangement to prevent spillage of electrolyte from the flash arrestor assembly if the jar is tipped on its side. Although the electrolyte will not "flood" out of the opening, but rather seep out, it is nonetheless highly desirable that this not be allowed to happen. Therefore, when lifting or moving electrolyte-filled jars, ensure they always remains in an upright position.

4.5.5 References

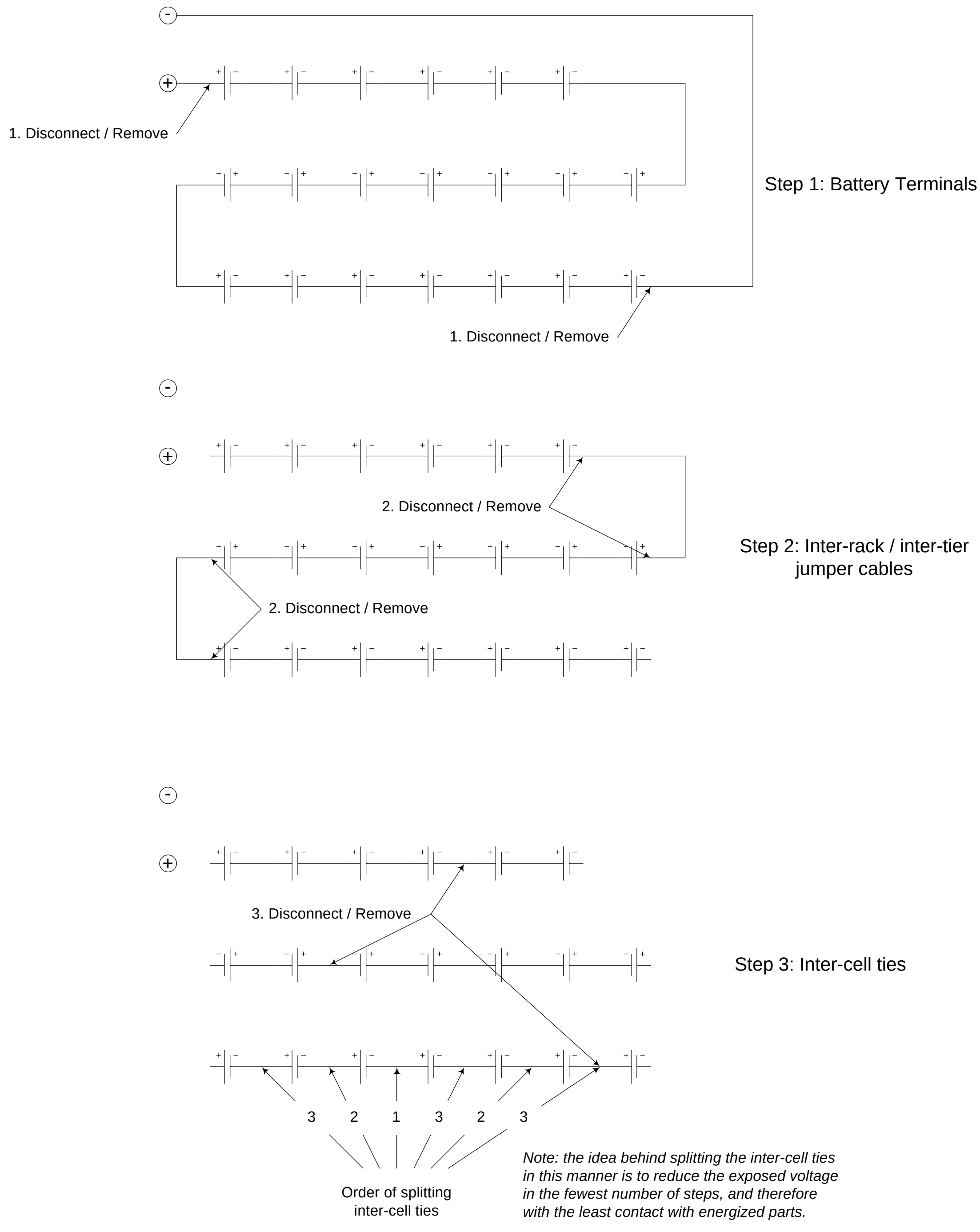
IEEE Std 484-1996: *"Recommended Practice for Installation Design and Installation of Vented Lead Acid Batteries for Stationary Applications."*

IEEE Std 485-1997: *"Recommended Practice for Sizing Large Lead Acid Storage Batteries for Generating Stations."*

IEEE Std 450-2002: *"Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead Acid Batteries for Stationary Applications."*

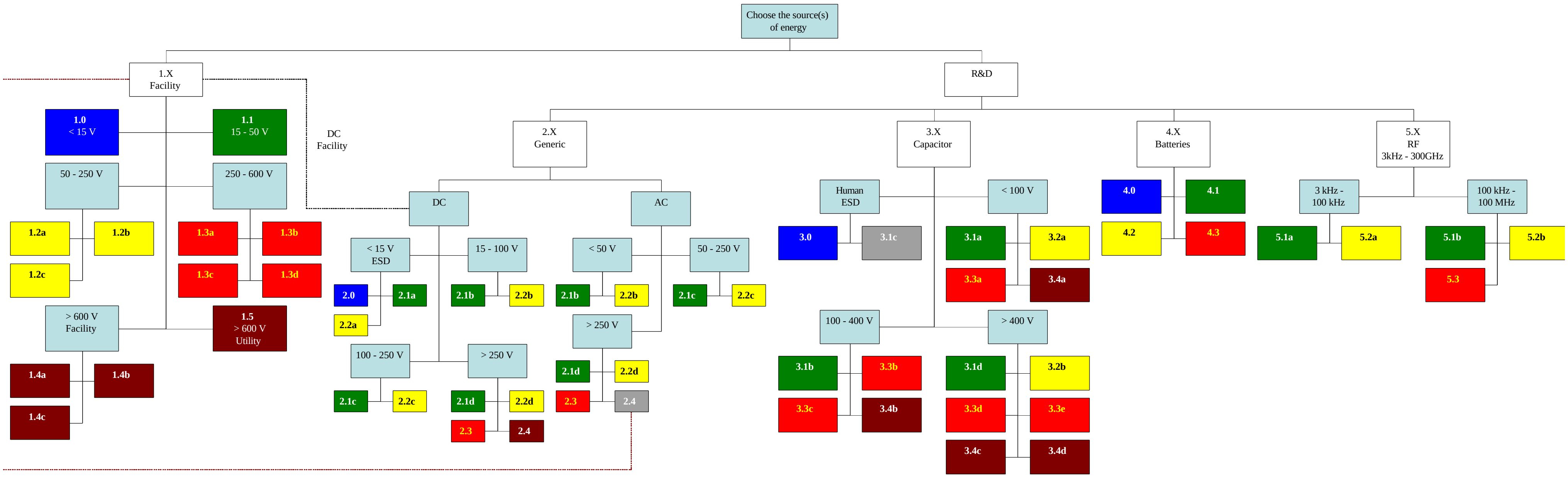
IEEE Std 1375-1998: *"Guide for Protection of Stationary Battery Systems."*

Figure 4: Example of Sectionalizing a Large, Multi-Tier Rack Mounted Battery System



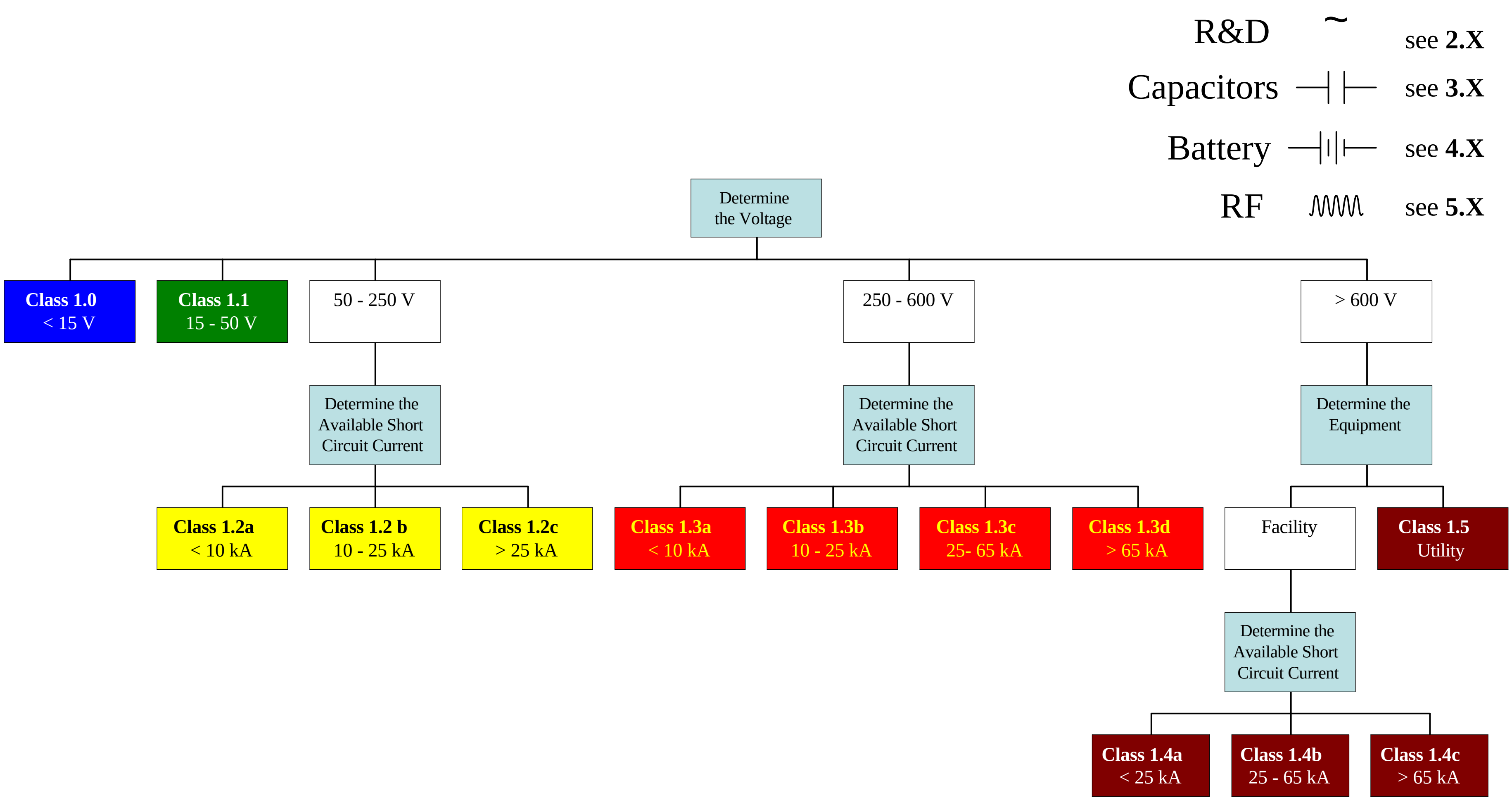
Section 5—Hazard Assessment Tables and Recommended Controls

The hazard tables cover five broad areas, ranging from R&D, to capacitors, to batteries. These tables, taken collectively, represent most of the electrical hazards found in electrical equipment. Consequently, all tables 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 group and division Electrical Safety Officers are ways to ensure that all of the hazards are fully understood and that all the pertinent tables are taken into account.



Class 1.X: Requirements for Facility and Utility Sources

Classification Table 1.X: Facility



Note: for DC Facility Power refer to Table 2.X: R&D

Controls Table 1.X: Facility

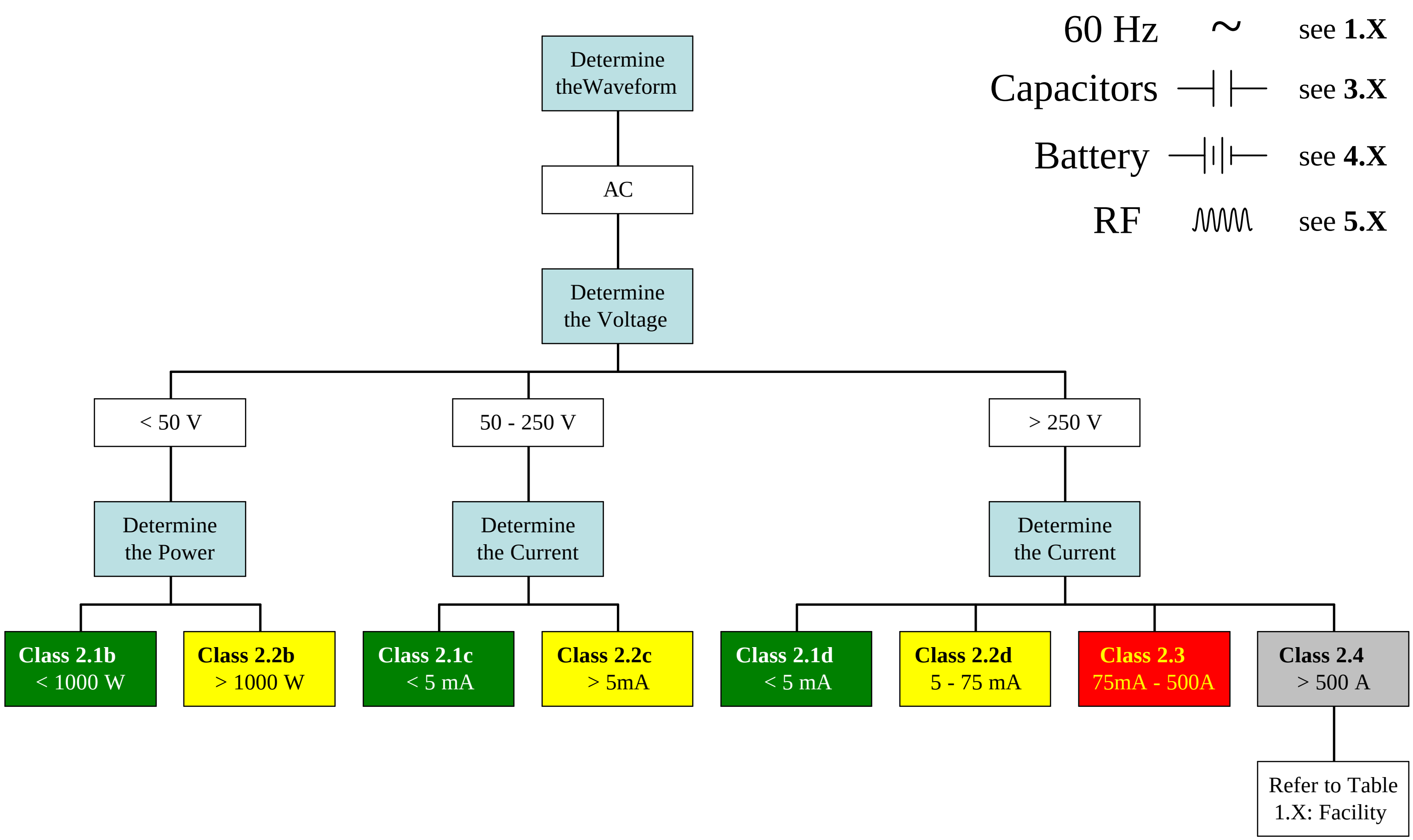
CLASS	MODE	QUALIFIED WORKER(S)	TRAINING	WORK CONTROL	PPE
1.0	ALL	Alone	None	None	None
1.1	ALL	Alone	Non-Energized	None	None
1.2a	1	Alone	Non-Energized and LOTO	None	None
	1.5	Alone	Energized	suggested	Shock and arc flash boundary analysis[1]
	2	Alone	Energized	suggested	Shock and arc flash boundary analysis[1]
	3	2nd	Energized	suggested	Shock and arc flash boundary analysis[1]
1.2b	1	Alone	Non-Energized and LOTO	None	None
	1.5	Alone	Energized	suggested	Shock and arc flash boundary analysis[1]
	2	Alone	Energized	suggested	Shock and arc flash boundary analysis[1]
	3	2nd	Energized	EEWP	Shock and arc flash boundary analysis[1]
1.2c	1	Alone	Non-Energized and LOTO	None	None
	1.5	Alone	Energized	suggested	Shock and arc flash boundary analysis[1]
	2	Alone	Energized	suggested	Shock and arc flash boundary analysis[1]
	3	2nd	Energized	EEWP	Shock and arc flash boundary analysis[1]
1.3a	1	Alone	Non-Energized and LOTO	None	None
	1.5	2nd	Energized	suggested	Shock and arc flash boundary analysis[1]
	2	2nd	Energized	suggested	Shock and arc flash boundary analysis[1]
	3	2nd	Energized	suggested	Shock and arc flash boundary analysis[1]
1.3b	1	Alone	Non-Energized and LOTO	None	None
	1.5	2nd	Energized	suggested	Shock and arc flash boundary analysis[1]
	2	2nd	Energized	suggested	Shock and arc flash boundary analysis[1]
	3	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]

1.3c	1	Alone	Non-Energized and LOTO	None	None
	1.5	2nd	Energized	suggested	Shock and arc flash boundary analysis[1]
	2	Safety Watch	Energized	suggested	Shock and arc flash boundary analysis[1]
	3	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
1.3d	1	Alone	Non-Energized and LOTO	None	None
	1.5	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
	2	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
	3	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
1.4a	1	Alone	Non-Energized and LOTO	None	None
	1.5	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
	2	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
	3	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
1.4b	1	Alone	Non-Energized and LOTO	None	None
	1.5	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
	2	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
	3	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
1.4c	1	Alone	Non-Energized and LOTO	None	None
	1.5	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
	2	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
	3	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis[1]
1.5	1	Alone	Non-Energized	suggested	Refer to 29CFR1910.269
	1.5	Safety Watch	Lineman	suggested	Refer to 29CFR1910.269
	2	Safety Watch	Lineman	suggested	Refer to 29CFR1910.269
	3	Safety Watch	Lineman	suggested	Refer to 29CFR1910.269

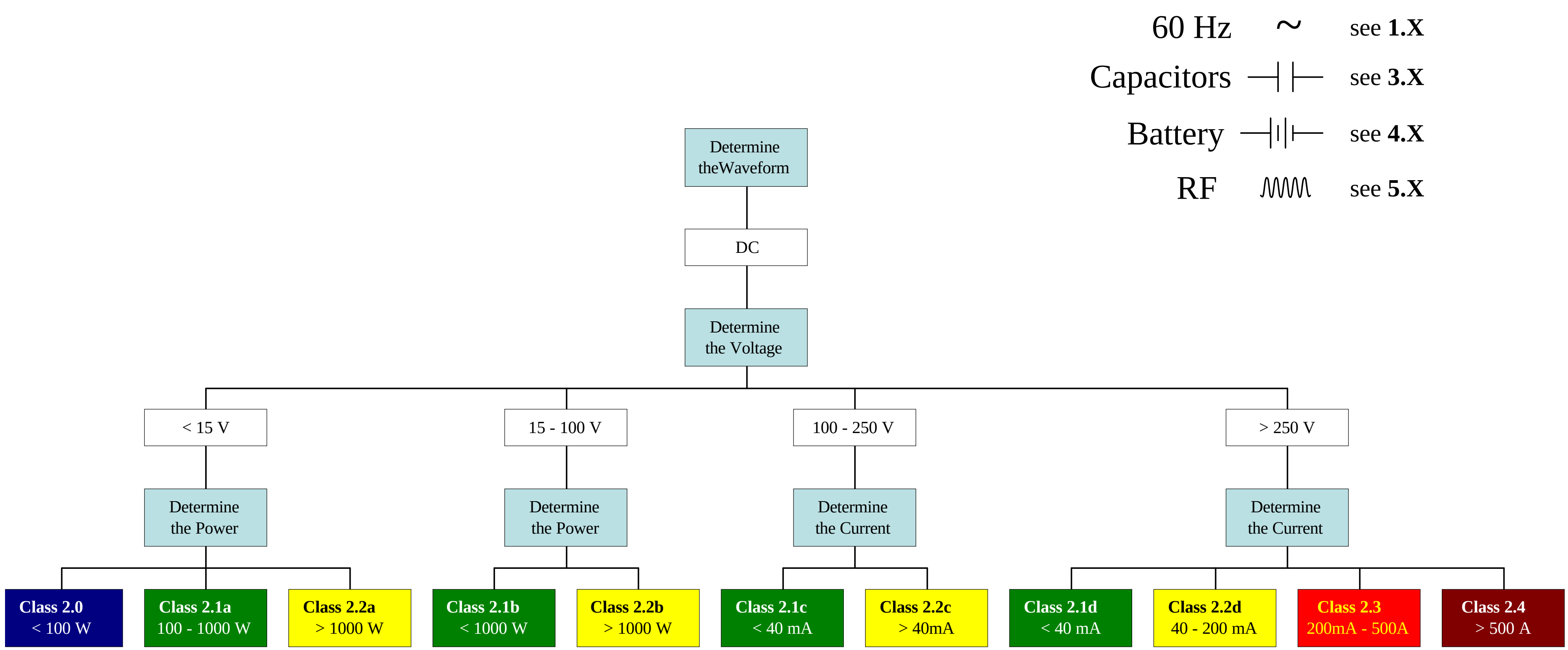
[1] see NFPA 70E tables (pp 29 – 34) or perform a shock and arc flash boundary analysis.

Class 2.X: Requirements for R&D and Electronic Work

Classification Table 2.X: R&D AC



Classification Table 2.X: R&D DC



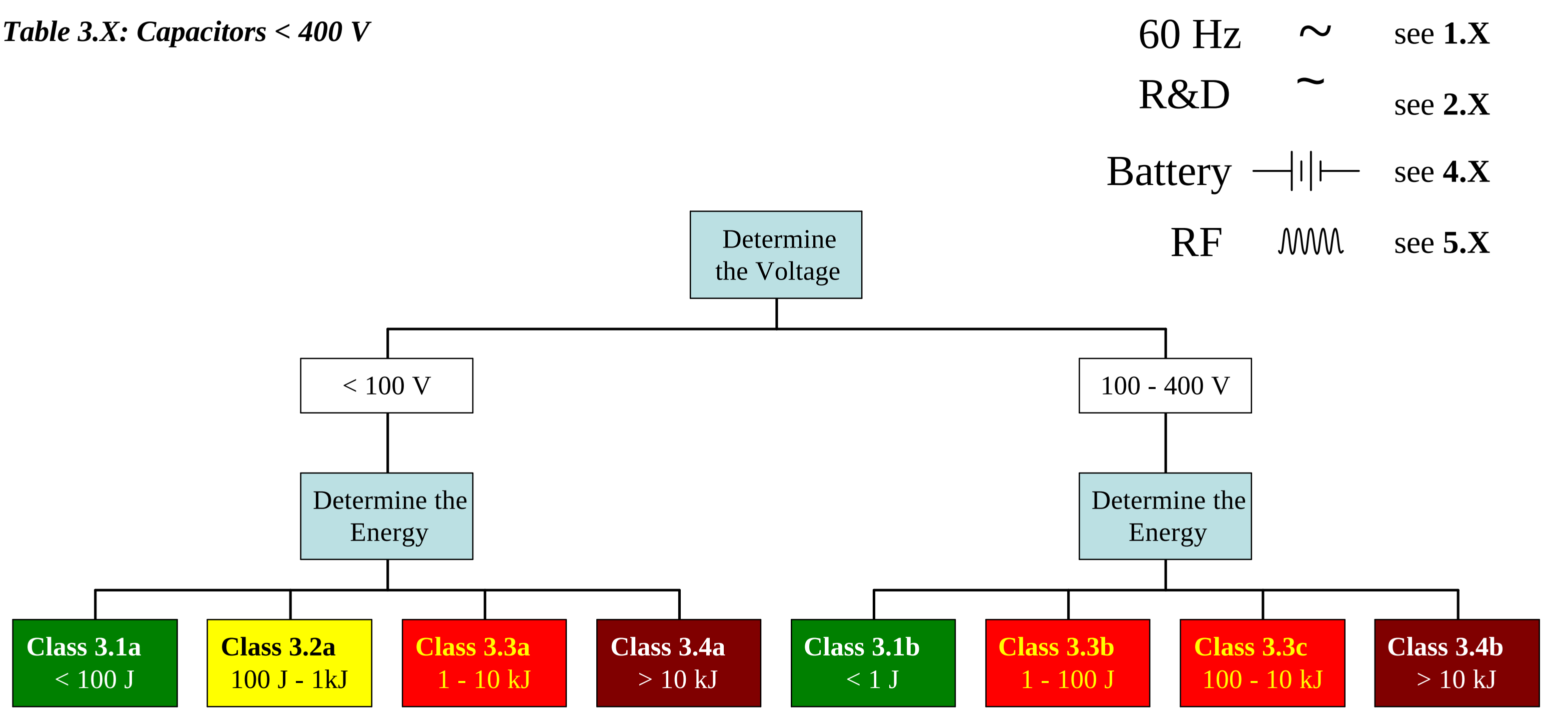
Controls Table 2.X: R&D Generic

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	1	Alone	Non-Energized and LOTO	None	None
	1.5	Alone	Energized	suggested	Shock boundary analysis
	2	2nd	Energized	suggested	Shock boundary analysis
	3[2]	Safety Watch	Energized	EEWP	Shock boundary analysis
2.2b	1	Alone	Non-Energized and LOTO	None	None
	1.5	Alone	Energized	suggested	Shock boundary analysis
	2	2nd	Energized	suggested	Shock boundary analysis
	3[2]	Safety Watch	Energized	EEWP	Shock boundary analysis
2.2c	1	Alone	Non-Energized and LOTO	None	None
	1.5	Alone	Energized	suggested	Shock boundary analysis
	2	2nd	Energized	suggested	Shock boundary analysis
	3[2]	Safety Watch	Energized	EEWP	Shock boundary analysis
2.2d	1	Alone	Non-Energized and LOTO	None	None
	1.5	Alone	Energized	suggested	Shock boundary analysis
	2	2nd	Energized	suggested	Shock boundary analysis
	3[2]	Safety Watch	Energized	EEWP	Shock boundary analysis
2.3[3]	1	Alone	Non-Energized and LOTO	None	None
	1.5	2nd	Energized	suggested	Shock boundary analysis
	2	Safety Watch	Energized	EEWP	Shock boundary analysis
	3[2]	Safety Watch	Energized	EEWP	Shock boundary analysis
2.4[3,4]	1	Alone	Non-Energized and LOTO	None	None
	1.5	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis
	2[2]	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis
	3[2]	Safety Watch	Energized	EEWP	Shock and arc flash boundary analysis

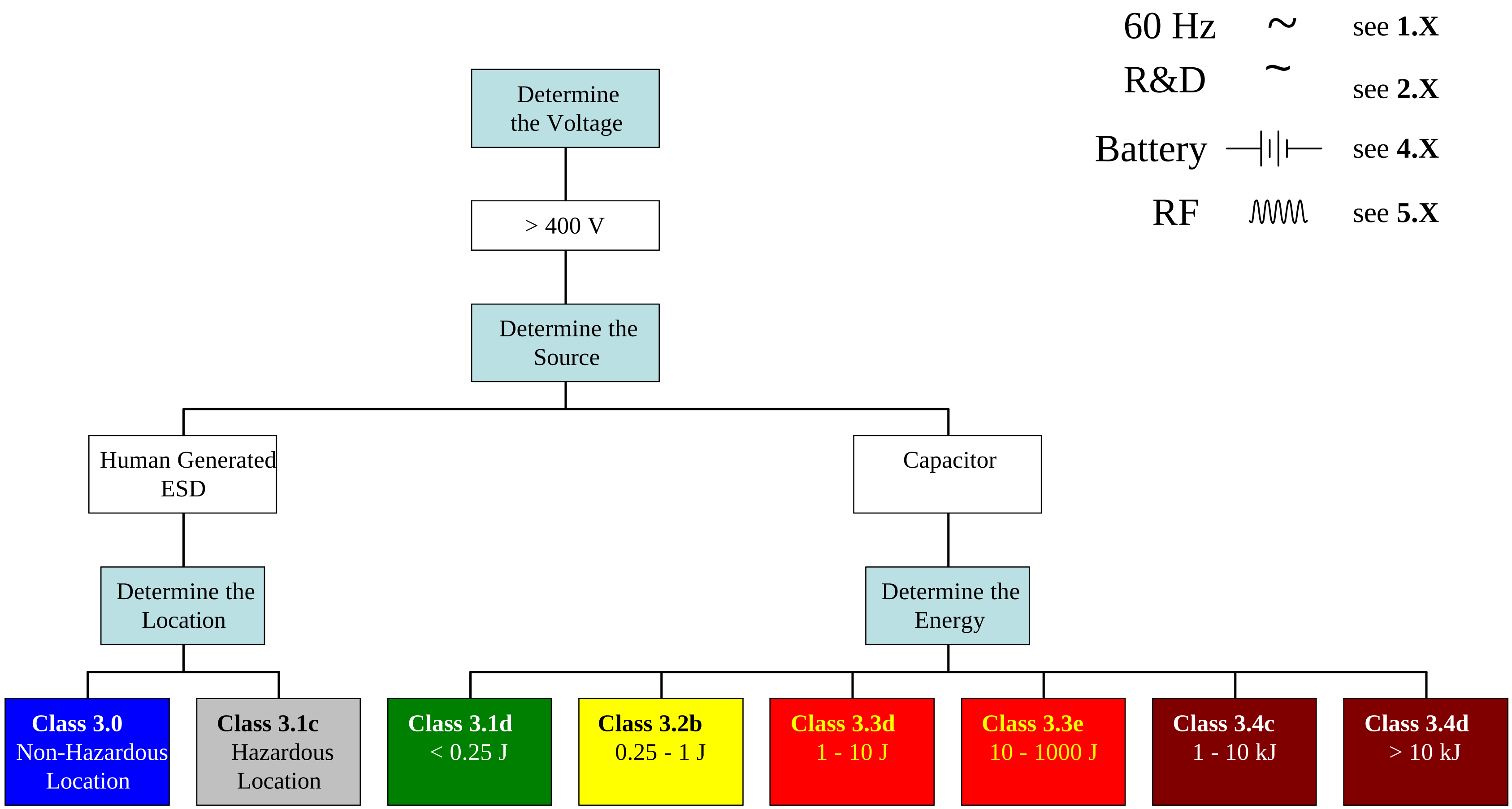
[1] determined by a shock boundary analysis
[2] this mode of work should be avoided
[3] DO NOT move probes while energized
[4] for AC refer to Table 1.X: Facility

Class 3.X: Requirements for Capacitor Sources

Classification Table 3.X: Capacitors < 400 V



Classification Table 3.X: Capacitors > 400 V



Controls Table 3.X: Capacitors

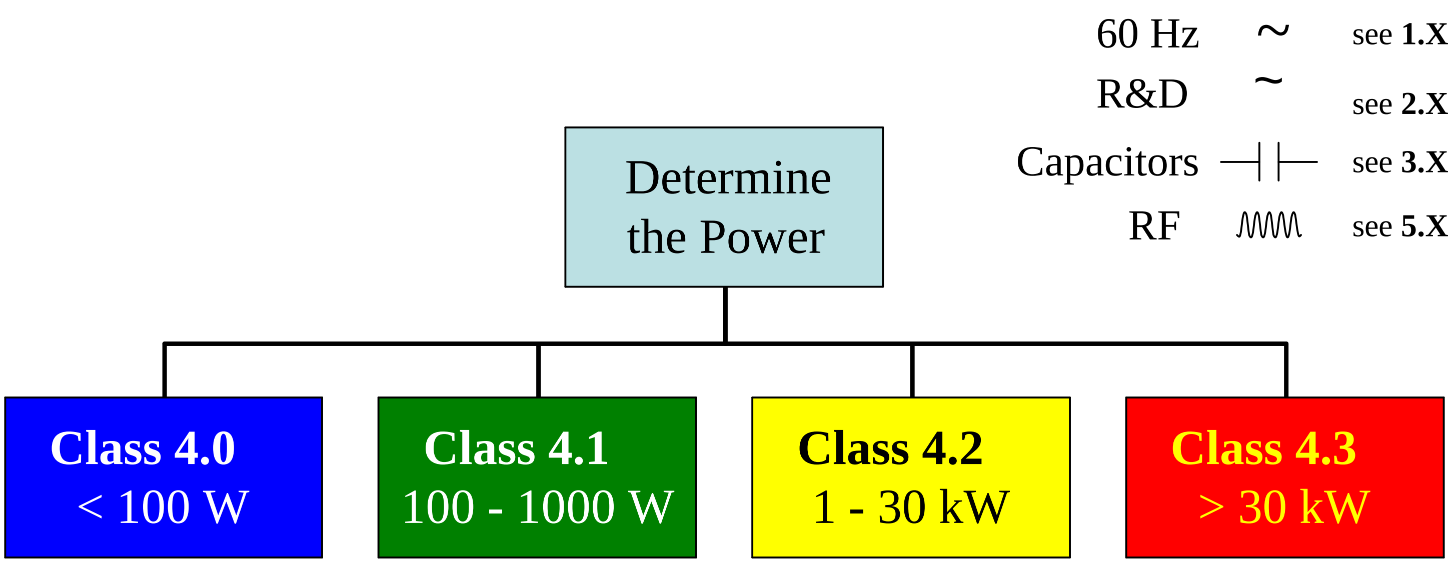
CLASS	MODE	QUALIFIED WORKER(S)	TRAINING	WORK CONTROL	PPE	ENERGY REMOVAL
3.0	ALL	Alone	None	None	None	
3.1a,b,d	ALL	Alone	Non-Energized	None	None	
3.1c[3]	ALL					
3.2a	1	Alone	Non-Energized	None	None	
	1.5	Alone	Energized	suggested	Eye, No Jewelry	Hard ground hook
	2	2nd	Energized	suggested	Eye, No Jewelry	
	3	2nd	Energized	suggested	Eye, No Jewelry	
3.2b	1	Alone	Non-Energized	None	None	
	1.5	Alone	Energized	suggested	[1]	Hard ground hook
	2	2nd	Energized	suggested	[1]	
	3	2nd	Energized	suggested	[1]	
3.3a	1	Alone	Non-Energized	None	None	
	1.5	2nd	Energized	suggested	Eye, No Jewelry	Soft ground hook
	2	2nd	Energized	EEWP	Eye, No Jewelry	
	3	Safety Watch	Energized	EEWP	Eye, No Jewelry	
3.3b	1	Alone	Non-Energized	None	None	
	1.5	2nd	Energized	suggested	Eye,[1]	Hard ground hook
	2	2nd	Energized	suggested	Eye,[1]	
	3[4]	Safety Watch	Energized	EEWP	Eye,[1]	
3.3c	1	Alone	Non-Energized	None	None	
	1.5	Safety Watch	Energized	suggested	Eye, Ear,[1],[2]	Soft ground hook
	2[5]	Safety Watch	Energized	EEWP	Eye, Ear,[1],[2]	
	3[4]	Safety Watch	Energized	EEWP	Eye, Ear,[1],[2]	
3.3d	1	Alone	Non-Energized	None	None	
	1.5	2nd	Energized	suggested	Eye,[1]	Hard ground hook
	2	2nd	Energized	suggested	Eye,[1]	
	3[4]	2nd	Energized	EEWP	Eye,[1]	
3.3e	1	Alone	Non-Energized	None	None	
	1.5	Safety Watch	Energized	suggested	Eye, Ear,[1]	Hard or Soft[1] ground hook
	2[5]	Safety Watch	Energized	EEWP	Eye, Ear,[1]	
	3[7]					

3.4a	1	Alone	Non-Energized	None	None	
	1.5	Safety Watch	Energized	suggested	Eye, No Jewelry	Remotely
	2[5]	Safety Watch	Energized	EEWP	Eye, No Jewelry	
	3[4]	Safety Watch	Energized	EEWP	Eye, No Jewelry	
3.4b	1	Alone	Non-Energized	None	None	
	1.5	Safety Watch	Energized	suggested	Eye, Ear,[1],[2]	Remotely
	2[5]	Safety Watch	Energized	EEWP	Eye, Ear,[1],[2]	
	3[4]	Safety Watch	Energized	EEWP	Eye, Ear,[1],[2]	
3.4c	1	Alone	Non-Energized	None	None	
	1.5	Safety Watch	Energized	suggested	Eye, Ear,[1],[2]	Soft ground hook
	2[6]	Safety Watch	Energized	EEWP	Eye, Ear,[1],[2]	
	3[7]					
3.4d	1	Alone	Non-Energized	None	None	
	1.5	Safety Watch	Energized	suggested	Eye, Ear,[1],[2]	Remotely
	2[6]	Safety Watch	Energized	EEWP	Eye, Ear,[1],[2]	
	3[7]					

[1] determined by a shock boundary analysis
[2] determined by an arc flash boundary 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

Class 4.X: Requirements for Battery Sources

Classification Table 4.X: Batteries



Note: > 50 V also refer to Table 2.X: Generic to classify the shock hazard.

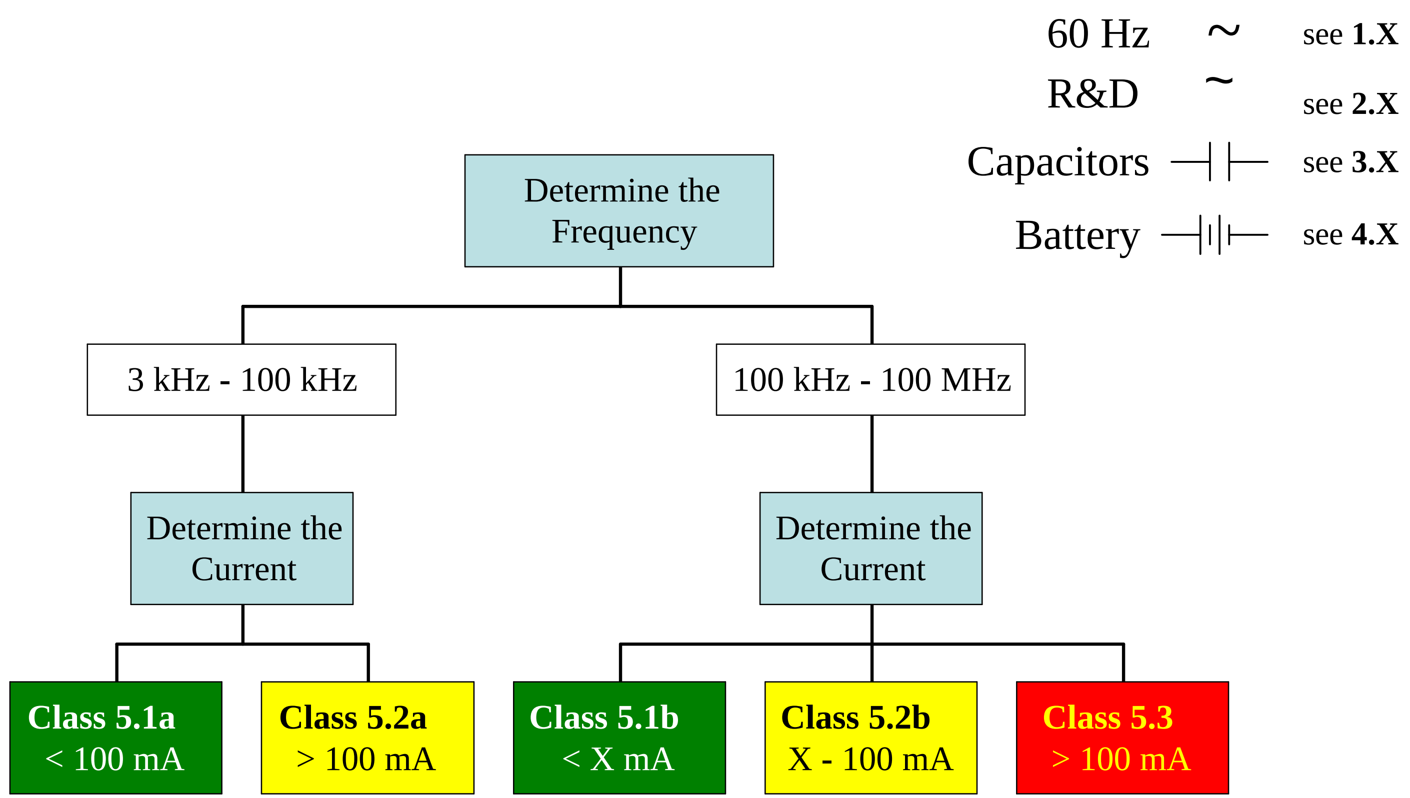
Controls Table 4.X: Batteries

CLASS	MODE	QUALIFIED WORKER(S)	TRAINING	WORK CONTROL	PPE
4.0	ALL	Alone	None	None	None
4.1[1]	ALL	Alone	Non-Energized	suggested	No Jewelry
4.2	2	2nd	Energized	suggested	No Jewelry
	3	2nd	Energized	suggested	No Jewelry
4.3	2	Safety Watch	Energized	EEWP	No Jewelry
	3[2]	Safety Watch	Energized	EEWP	No Jewelry, Tools

[1] if the terminals are exposed
[2] break up bank for work

Class 5.X: Requirements for Radio Frequency

Classification Table 5.X: RF



Controls Table 5.X: RF 3kHz – 100 MHz **(WORK IN PROGRESS)**

CLASS	MODE	QUALIFIED WORKER(S)	TRAINING	WORK CONTROL	PPE
5.0					
5.1 a					
5.1b					
5.2a					
5.2b					
5.3					