Arc Flash Hazards

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Electrical Hazards

• Electrical Hazards
  • Shock
  • Arc Flash
  • Arc Blast
Arcing Fault Basics

- Copper Vapor: Solid to Vapor
  - Expands by 67,000 times

- Pressure Waves
- Sound Waves
- Shrapnel
  - 700 mph

- Intense Light
- Hot Air-Rapid Expansion
- Radiant Heat & UV
  - Speed of Light

Arc Flash Energy

- Arc flash Energy Is Dependent On:
  - Arcing fault duration or time to clear
    - Speed of the overcurrent protective device
  - Arcing fault current magnitude
    - Available fault current
    - Current-limitation can reduce
Arc Flash Testing - Test 4

- 480V, 22.6kA Short-Circuit Current
- 640A NCL OCPD: 6 cycle Clearing Time

Arc Flash Testing - Test 3

- 480V, 22.6kA Short-Circuit Current
- 601A CL Fuse: 1/2 Cycle Clearing Time
• 110.16 Arc-Flash Hazard Warning. Electrical equipment, such as switchboards, switchgear, panelboards, industrial control panels, meter socket enclosures, and motor control centers, that are in other than dwelling units, and are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field or factory marked to warn qualified persons of potential electric arc flash hazards. The marking shall meet the requirements in 110.21(B) and shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

• Informational Note No. 1: NFPA 70E-2012, Standard for Electrical Safety in the Workplace, provides guidance, such as determining severity of potential exposure, planning safe work practices, arc flash labeling, and selecting personal protective equipment.

• Informational Note No. 2: ANSI Z535.4-1998, Product Safety Signs and Labels, provides guidelines for the design of safety signs and labels for application to products.
Safety Standards & Regulations

- OSHA
  - 1910 – General industry
  - Regulations are law - the “Shall”
  - Performance Based

- NFPA 70E
  - Committee formed in 1976 at OSHA’s request
  - Consensus standard
  - Not law unless a state or government body adopts
  - Prescriptive - the “How”

OSHA and Workplace Safety

- General Duty Clause
  - Create a Workplace Free of Recognized Hazards

- Documentation
  - Workplace Hazard Analysis
    - 1910.132(d)
  - Training and Education
    - 1910.332 & 1910.333
  - Supply PPE and Tools
    - 1910.332, 1910.333, 1910.335
### Justification For Work – 2015 NFPA 70E

130.2 Electrically Safe Working Conditions. Energized electrical conductors and circuit **parts shall** be put into an electrically safe work condition before an employee performs work if any of the following conditions exist:

1. The employee is within the limited approach boundary.
2. The employee interacts with equipment where conductors or circuit parts are not exposed but an increased likelihood of injury from an exposure to an arc flash hazard exists.

(A) Energized Work

1. **Additional Hazards or Increased Risk.** Energized work shall be permitted where the employer can demonstrated that de-energizing introduces additional hazards or increased risk.

2. **Infeasibility.** Energized work shall be permitted where the employer can demonstrate that the task to be performed is infeasible in a de-energized state due to equipment design or operational limitations.

3. Less than 50 Volts.

### Justification For Work – Cont

4. **Normal Operation.** Normal operation of electric equipment shall be permitted where all of the following conditions are satisfied:
   1. The equipment is properly installed.
   2. The equipment is properly maintained.
   3. The equipment doors are closed and secured.
   4. All equipment covers are in place and secured.
   5. There is no evidence of impending failure.

Informational Note: The phrase properly installed means that the equipment is installed in accordance with applicable industry codes and standards and the manufacturer’s recommendations. The phrase properly maintained means that the equipment has been maintained in accordance with the manufacturer’s recommendations and applicable industry codes and standards...
(B) Energized Electrical Work Permit.

(1) When Required. When energized work is permitted in accordance with 130.2(A), an energized electrical work permit shall be required under the following conditions:
   (1) When work is performed within the restricted approach boundary
   (2) When the employee interacts with the equipment when conductors or circuit parts are not exposed but an increased likelihood of injury from an exposure to an arc flash hazard exists

(2) Elements of Work Permit. The energized electrical work permit shall include, but not be limited to, the following Items…

(3) Exemptions to Work Permit. An energized electrical work permit shall not be required if a qualified person is provided with and uses appropriate safe work practices and PPE in accordance with Chapter 1 under any of the following conditions:
   (1) Testing, troubleshooting, and voltage measuring
   (2) Thermography and visual inspections if the restricted approach boundary is not crossed
   (3) Access to and egress from an area with energized electrical equipment if no electrical work is performed and the restricted approach boundary is not crossed
   (4) General housekeeping and miscellaneous non-electrical tasks if the restricted approach boundary is not crossed
## Working While Exposed – 2015 NFPA 70E

130.3 Working While Exposed to Electrical Hazards. Safety-related work practices shall be used to safeguard employees from injury while they are exposed to electrical hazards from electrical conductors or circuit parts that are or can become energized. The specific safety-related work practices shall be consistent with the electrical hazards and the associated risk. Appropriate safety-related work practices shall be determined before any person is exposed to the electrical hazards involved by using both shock risk assessment and arc flash risk assessment. Only qualified persons shall be permitted to work on electrical conductors or circuit parts that have not been put into an electrically safe work condition.

## Shock Protection Boundaries – 2015 NFPA 70E

130.4 Approach Boundaries to Energized Electrical Conductors or Circuit Parts for Shock Protection.

(A) Shock Risk Assessment.
- Determine Voltage and PPE

(B) Shock Protection Boundaries.
- See Table 130.4(D)(b) for distances

(C) Limited Approach Boundary.
- An approach limit at a distance from an exposed energized electrical conductor or circuit part within which a shock hazard exists.
- Unqualified persons permitted near or in under specified conditions.

(D) Restricted Approach Boundary.
- An approach limit at a distance from an exposed energized electrical conductor or circuit part within which there is an increased likelihood of electric shock, due to electrical arc-over combined with inadvertent movement, for personnel working in close proximity to the energized electrical conductor or circuit part.
- Qualified persons only with PPE

Note: Deleted Prohibited Approach Boundary definition and requirements
Shock Protection Boundaries - AC

- Table for AC
- Table for DC

Arc Flash Risk Assessment - 2015 NFPA 70E

130.5 Arc Flash Risk Assessment. An arc flash risk assessment shall be performed and shall:

(1) Determine if an arc flash hazard exists. If an arc flash hazard exists, the risk assessment shall determine:
   a. Appropriate safety-related work practices
   b. The arc flash boundary
   c. The PPE to be used within the arc flash boundary

(2) Be updated when a major modification or renovation takes place. It shall be reviewed periodically, at intervals not to exceed 5 years, to account for changes in the electrical distribution system that could affect the results of the arc flash risk assessment.

(3) Take into consideration the design of the overcurrent protective device and its opening time, including its condition of maintenance.
Informational Note No. 1: Improper or inadequate maintenance can result in increased opening time of the overcurrent protective device, thus increasing the incident energy. Where equipment is not properly installed or maintained, PPE selection based on incident energy analysis or the PPE category method may not provide adequate protection from arc flash hazards.

Informational Note No. 2: Both larger and smaller available short-circuit currents could result in higher available arc flash energies...

Informational Note No. 3: The occurrence of an arcing fault inside an enclosure produces a variety of physical phenomena very different from a bolted fault. For example, the arc energy resulting from an arc developed in the air will cause a sudden pressure increase and localized overheating. Equipment and design practices are available to minimize the energy levels and the number of procedures that could expose an employee to high levels of incident energy. Proven designs such as arc-resistant switchgear, remote racking (insertion or removal), remote opening and closing of switching devices, high-resistance grounding of low-voltage and 5000 volts (nominal) systems, current limitation, and specification of covered bus or covered conductors within equipment are available to reduce the risk associated with an arc flash incident. See Informative Annex O for Safety-Related Design Requirements.

Informational Note No. 4: For additional direction for performing maintenance on overcurrent protective devices, see Chapter 2, Safety-Related Maintenance Requirements.

Informational Note No. 5: See IEEE 1584, Guide for Performing Arc Flash Calculations, for more information regarding arc flash hazards for three-phase systems.

Incident Energy Analysis

- Informational Note No. 2: Both larger and smaller available short-circuit currents could result in higher available arc flash energies. If the available short-circuit current increases without a decrease in the opening time of the overcurrent protective device, the arc flash energy will increase. If the available short-circuit current decreases, resulting in a longer opening time for the overcurrent protective device, arc flash energies could also increase.
When fault is between CB2 and CB3, CB3 does not send a restraint to CB2, CB2 sends a restraint to CB1, and CB2 opens as fast as it can (instantaneous trip) rather holding to its short-time delay setting.

Arc Flash Reduction Switch

- Clearing times are much faster than ZSI
- Clearing times are faster than standard INST

<table>
<thead>
<tr>
<th>Bolted Fault (kA)</th>
<th>Arcing Fault (kA)</th>
<th>Fault Duration (Seconds)</th>
<th>Incident Energy (cal/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>20</td>
<td>2</td>
<td>89</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>0.5</td>
<td>22</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>0.3</td>
<td>13</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>0.1</td>
<td>4.4</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>0.05</td>
<td>2.2</td>
</tr>
<tr>
<td>40</td>
<td>20</td>
<td>0.04</td>
<td>1.8</td>
</tr>
</tbody>
</table>

Ref: Incident energy calculated using IEEE STD 1584TM-2002 method for a 480 Vac system, working distance of 24 inches, Grounding type = solid grounded and Equipment type = Switchgear.
Incident Energy Analysis

- Informational Note No. 2: Both larger and smaller available short-circuit currents could result in higher available arc flash energies. If the available short-circuit current increases without a decrease in the opening time of the overcurrent protective device, the arc flash energy will increase. If the available short-circuit current decreases, resulting in a longer opening time for the overcurrent protective device, arc flash energies could also increase.

Arc Flash Risk Assessment - Cont

(A) Documentation. The results of the arc flash risk assessment shall be documented.

(B) Arc Flash Boundary.

(1) The arc flash boundary shall be the distance at which the incident energy equals 5 J/cm² (1.2 cal/cm²).

   Informational Note: For information on estimating the arc flash boundary, see Informative Annex D.

(2) The arc flash boundary shall be permitted to be determined by Table 130.7(C)(15)(A)(b) or Table 130.7(C)(15)(B), when the requirements of these tables apply.
Arc Flash Protection Boundary

- NFPA 70E Article 100 – Definitions
  - Boundary, Arc Flash. When an arc flash hazard exists, an approach limit at a distance from a prospective arc source within which a person could receive a second degree burn if an electrical arc flash were to occur.
  - Informational Note: A second degree burn is possible by an exposure of unprotected skin to an electric arc flash above the incident energy level of 5 J/cm² (1.2 cal/cm²).

Arc Flash Risk Assessment - Cont

(C) Arc Flash PPE. One of the following methods shall be used for the selection of PPE. Either, but not both, methods shall be permitted to be used on the same piece of equipment. The results of an incident energy analysis to specify an arc flash PPE Category in Table 130.7(C)(16) shall not be permitted.

(1) Incident Energy Analysis Method. The incident energy exposure level shall be based on the working distance of the employee’s face and chest areas from a prospective arc source for the specific task to be performed. Arc-rated clothing and other PPE shall be used by the employee based on the incident energy exposure associated with the specific task. Recognizing that incident energy increases as the distance from the arc flash decreases, additional PPE shall be used for any parts of the body that are closer than the distance at which the incident energy was determined.

Informational Note: For information on estimating the incident energy, see Informative Annex D. For information on selection of arc-rated clothing and other PPE, see Table H.3(b) in Informative Annex H.

(2) Arc Flash PPE Categories Method. The requirements of 130.7(C)(15) and 130.7(C)(16) shall apply when the arc flash PPE category method is used for the selection of arc flash PPE.
Incident Energy Analysis

- Specific to the actual installation
- Based on IEEE1584
  - Most state of the art calculations
- Represents ALL tasks
- Both high and low values of fault current can result in worst case incident energy
- Manufacturer tools available.

Table Method – 130.7(C)(15)(A)(a)

- Parameters
  - AC and DC
- Task
- Equipment Condition
- PPE Required
**Table Method – 130.7(C)(15)(A)(b)**

- **Parameters**
  - AC or DC
  - Equipment Type and Parameters
  - PPE Category
  - Arc Flash Boundary

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Arc Flash PPE Category</th>
<th>Arc Flash Boundary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flashboards or other equipment rated 240 V and below</td>
<td>1</td>
<td>855 mm (10 ft)</td>
</tr>
<tr>
<td>Parameters: Maximum of 25 ka short-circuit current available; maximum of 0.05 sec (2 cycles) fault clearing time; working distance 855 mm (10 ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flashboards or other equipment rated &gt;240 V and up to 690 V</td>
<td>2</td>
<td>900 mm (10 ft)</td>
</tr>
<tr>
<td>Parameters: Maximum of 25 ka short-circuit current available; maximum of 0.05 sec (2 cycles) fault clearing time; working distance 900 mm (10 ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.690-V class motor control center (MCC)</td>
<td>2</td>
<td>1.5 m (5 ft)</td>
</tr>
<tr>
<td>Parameters: Maximum of 45 ka short-circuit current available; maximum of 0.05 sec (2 cycles) fault clearing time; working distance 1.5 m (5 ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.690-V class motor control center (MCC)</td>
<td>4</td>
<td>4.3 m (14 ft)</td>
</tr>
<tr>
<td>Parameters: Maximum of 45 ka short-circuit current available; equipment of 0.690-V cyclic fault clearing time; working distance 4.3 m (14 ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.690-V class switchgear with power circuit breakers or hand operated and 690 V class switchboards</td>
<td>4</td>
<td>6 m (20 ft)</td>
</tr>
<tr>
<td>Parameters: Maximum of 45 ka short-circuit current available; maximum of 0.05 sec (2 cycles) fault clearing time; working distance 6 m (20 ft)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other 690-V class 77 V through 480 V nominal equipment</td>
<td>2</td>
<td>1.5 m (5 ft)</td>
</tr>
<tr>
<td>Parameters: Minimum of 20 ka short-circuit current available; equipment of 0.690-V cyclic fault clearing time; working distance 1.5 m (5 ft)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table Method – 130.7(C)(16)**

<table>
<thead>
<tr>
<th>PPE Category</th>
<th>Protective Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Arc-Rated Clothing, Minimum Arc Rating of 4 cal/cm² (see Note 3)</td>
</tr>
<tr>
<td></td>
<td>Arc-rated long-sleeve shirt and pants or arc-rated coverall</td>
</tr>
<tr>
<td></td>
<td>Arc-rated face shield (see Note 2) or arc-Flash suit hood</td>
</tr>
<tr>
<td></td>
<td>Arc-rated jacket, pants, raincoat, or hard hat liner (AN)</td>
</tr>
<tr>
<td></td>
<td>Protective Equipment</td>
</tr>
<tr>
<td></td>
<td>Hard hat</td>
</tr>
<tr>
<td></td>
<td>Safety glasses or safety goggles (SR)</td>
</tr>
<tr>
<td></td>
<td>Hearing protection (not canal plugs)</td>
</tr>
<tr>
<td></td>
<td>Leather footwear</td>
</tr>
</tbody>
</table>

| 2            | Arc-Rated Clothing, Minimum Arc Rating of 8 cal/cm² (see Note 3) |
|              | Arc-rated long-sleeve shirt and pants or arc-rated coverall |
|              | Arc-Flash suit hood or arc-rated face shield (see Note 2) and arc-rated raincoat |
|              | Arc-rated jacket, pants, raincoat, or hard hat liner (AN) |
|              | Protective Equipment |
|              | Hard hat |
|              | Safety glasses or safety goggles (SR) |
|              | Hearing protection (not canal plugs) |
|              | Leather footwear |

3. **Arc-Rated Clothing Selected so That the System Arc Rating Meets the Required Minimum Arc Rating of 25 cal/cm² (see Note 3)**
   - Arc-rated long-sleeve shirt (AN)
   - Arc-rated pants (AN)
   - Arc-rated coverall (AN)
   - Arc-rated arc flash suit jacket (AR)
   - Arc-rated arc Flash suit pants (AN)
   - Protective Equipment
   - Hard hat
   - Safety glasses or safety goggles (SR)
   - Hearing protection (not canal plugs)
   - Leather footwear

4. **Arc-Rated Clothing Selected so That the System Arc Rating Meets the Required Minimum Arc Rating of 40 cal/cm² (see Note 3)**
   - Arc-rated long-sleeve shirt (AN)
   - Arc-rated pants (AN)
   - Arc-rated coverall (AN)
   - Arc-rated arc flash suit jacket (AR)
   - Arc-rated arc Flash suit pants (AN)
   - Arc-rated arc Flash suit hood
   - Arc-rated gloves (see Note 1)
   - Arc-rated jacket, pants, raincoat, or hard hat liner (AN)
   - Protective Equipment
   - Hard hat
   - Safety glasses or safety goggles (SR)
   - Hearing protection (not canal plugs)
   - Leather footwear
Arc Flash Hazard Analysis - Labeling

(D) Equipment Labeling. Electrical equipment such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers that are in other than dwelling units and that are likely to require examination, adjustment, servicing, or maintenance while energized shall be field-marked with a label containing all the following information:

1. Nominal system voltage
2. Arc flash boundary
3. At least one of the following:
   a. Available incident energy and the corresponding working distance, or the arc flash PPE category in Table 130.7(C)(15)(A)(b) or Table 130.7(C)(15)(B) for the equipment, but not both
   b. Minimum arc rating of clothing
   c. Site-specific level of PPE

Exception: Labels applied prior to September 30, 2011 are acceptable if they contain the available incident energy or required level of PPE.

The method of calculating and the data to support the information for the label shall be documented. Where the review of the arc flash hazard risk assessment identifies a change that renders the label inaccurate, the label shall be updated.

The owner of the electrical equipment shall be responsible for the documentation, installation, and maintenance of the field-marked label.

Arc Flash Labels – NFPA 70E

- Must identify incident energy or HRC

**WARNING**

Arc Flash and Shock Hazards
Appropriate PPE Required
Failure to Comply Can Result in Death or Injury

| 34 inch | Arc Flash Boundary |
| 3 cal/cm² | Flash Hazard at 18 inches |
| 1 cal/cm² | Hazard Risk Category 4 |
| 480 VAC | Shock Hazard |
| 42 inch | Limited Approach |
| 12 inch | Restricted Approach |
| 1 inch | Prohibited Approach |

Equipment Name: XYZ Motor Starter
Maintenance Requirements

• 205.3 General Maintenance Requirements. Electrical equipment shall be maintained in accordance with manufacturers’ instructions or industry consensus standards to reduce the risk of failure and the subsequent exposure of employees to electrical hazards.

• 205.4 Overcurrent Protective Devices. Overcurrent protective devices shall be maintained in accordance with the manufacturers’ instructions or industry consensus standards. Maintenance, tests, and inspections shall be documented.

• 210.5 Protective Devices.
Protective devices shall be maintained to adequately withstand or interrupt available fault current.

IN: Failure to properly maintain protective devices can have an adverse effect on the arc flash hazard analysis incident energy values.

Maintenance Requirements

• 225.1 Fuses. Fuses shall be maintained free of breaks or cracks in fuse cases, ferrules, and insulators. Fuse clips shall be maintained to provide adequate contact with fuses. Fuseholders for current-limiting fuses shall not be modified to allow the insertion of fuses that are not current-limiting.

• 225.2 Molded-Case Circuit Breakers. Molded-case circuit breakers shall be maintained free of cracks in cases and cracked or broken operating handles.

• 225.3 Circuit Breaker Testing After Electrical Faults. Circuit breakers that interrupt faults approaching their interrupting ratings shall be inspected and tested in accordance with the manufacturer’s instructions.
Questions?