NFPA 70E Electrical Safety Presentation

(updated for 2012)

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OSHA and the IEC Alliance

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What is the best way to prevent the hazards of electricity?

- Stop - Before Action
- Think - Risks/Hazards
- Options - LOTO
- Protection - Proper PPE

Avoiding energized circuits is the safest way!

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Electrical Safety

Why Electrical Safety Practices and Procedures?

1. An estimated 30,000 non-fatal electrical shock accidents occur each year
2. Over 600 people die from electrocution each year
3. Electrocution remains the fourth (4^{th}) highest cause of industrial fatalities
4. Approximately 3000 flash burn incidents reported annually along with approximately 350 deaths

Electrical Safety

NFPA 70 E – Standard for Electrical Safety in the Workplace

- Formally "*Standard for Electrical Safety Requirements for Employee Workplaces*"
- Began in 1976 by NFPA to assist OSHA

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Electrical Hazards

- Shock
- Arc Flash & Arc Blast
- Fire Ignition

The Effects of Shock

Immediate

- Muscle contraction
- Vital organs (heart, lungs, etc.)
- Tingling
- Pain
- Breathing
- Disorientation
- Dizziness
- Death

Long Term

- Memory Loss
- Nervous disorders
- Chemical imbalances
- Damage to vital organs
- Sometimes fatal

Effects of Current on the Body

Men

- Perception Threshold
  - 0.0001 Amps (1 mA)
- Painful Shock
  - 0.009 Amps (9 mA)
- Cannot Let-Go Level
  - 0.010 Amps (10 mA)
- Ventricular Fibrillation
  - 0.100 Amps (100 mA) for 3 seconds
  - 0.200 Amps (200 mA) for 1 second
- Heart Failure
  - 0.5 Amps (500 mA)
- Organ Burn and Cell Breakdown
  - 1.5 Amps (1500 mA)

Women

- Perception Threshold
  - 0.0007 Amps (0.7 mA)
- Painful Shock
  - 0.006 Amps (6 mA)
- Cannot Let-Go Level
  - 0.010 Amps (10 mA)
- Ventricular Fibrillation
  - 0.100 Amps (100 mA) for 3 seconds
  - 0.200 Amps (200 mA) for 1 second
- Heart Failure
  - 0.5 Amps
- Organ Burn and Cell Breakdown
  - 1.5 Amps (1500 mA)

Resistance and the Body

- The body has a natural defense system to shock (skin)
- Why 50 v0lts?
  - As you can see from the calculation below, a 50 volt exposure would not cause muscles to lock and is insufficient to cause physical harm.
- The key to survival is to decrease our exposure to energized circuits.
- Ohm's Law for electric current (amps), voltage and body resistance
- The typical body has a contact resistance of approximately 500 ohms at the point of contact with the electrical source.
- The body has an internal resistance of approximately 100 ohms.
- There is another ac resistance or impedance to ground of approximately 5000 ohms.

  - 120v / (500Ω + 100Ω + 5000Ω) = 21mA
  - 50v / (500Ω + 100Ω + 5000Ω) = 8.9 mA
- It is around 10 mA that the "cannot let go" level is reached.

Two Types of Burns from Shock

- **Surface Burns**
  - Caused by entrance and exit of electrical currents through the body
  - Can be caused by a very small amount of current
  - 1st degree to 3rd degree

- **Internal Tissue Burns**
  - Caused by current flowing through organs of the body
  - Caused by currents in excess of 1.5 amps
  - 4th degree
  - Internal organs
  - Typically fatal

One Type of Burn from Arc Flash

- Surface Burns
  - Caused by exposure to the arc flash
  - Can cause more surface burns if the initial arc flash ignites other material such as clothing
  - 1st degree to 3rd degree
  - It has and may cause death!

Electrical Safety

How to prevent shock?

1. Place circuits in electrically safe working conditions by locking out and tagging out all sources
   Chapter 1, Section 120.2 of NFPA 70E-2012

2. Verifying that no electrical energy is present
   Chapter 1, Section 120.2 of NFPA 70E-2012

Fire Ignition from Arc Flash

- The original and primary mission of the NFPA
  - Primarily covered by installation standards contained in the National Electric Code – NFPA 70
  - The incidence of fire ignition has dropped dramatically since the advent of the NEC and the acceptance of installation requirements within the industry
- The NFPA 70 – NEC does not address the other hazards of electricity

Exposure to Danger

- The National Electric Code protects individuals from shock hazards under normal conditions.
- It is not designed to protect us from **abnormal** conditions.
- We need additional policies to protect from **abnormal** conditions.

Conditions

- **Normal Conditions**
  - Panel covers in place.
  - Equipment plugged in normally.
  - Normal, designed protection in place.
- **Abnormal Conditions**
  - Panel covers removed.
  - Equipment temporarily wired.
  - Normal, designed protection such as guards, limits switches, etc. not in place.
  - Faulty or Damaged Equipment.

Protection from Abnormal Conditions

- **The Company**
  - NFPA 70E
  - OSHA
  - Electrical Safety Procedures Manual
  - Electrical Safety Training
- **You**
  - The first line of defense
  - Only you can truly keep you safe
  - Implement safety procedures outlined in Safety Manual
  - Only you can implement the procedures that may save your life

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Old School

Electricians have always recognized the shock hazards of electricity. We are taught:

- To consider circuits to be energized
- To insulate and protect ourselves
- Stand to one side if an arc flash/blast is suspected

New School

- Arc Flash and Blast hazards were not formally studied until 1993 (IEEE 1584 began study).
- Electricians have not experienced arc flash and blasts to the same frequency as electrical shock.
- We have not been trained how to avoid and minimize arc flash and blasts in the past.
- The Electrical Energized Work Practices outlined in NFPA 70E incorporates measures to help avoid or minimize damage from arc flash.

Pictures from ESA Book

Practical Solution Guide to Arc Flash Hazards

Figure 1.1: (a) Arc blast in box[2] ; (b) Arcing fault in electrical panel board

- Electric arcs produce the highest temperatures on earth – up to 35,000 degrees Fahrenheit (4 x temp of the sun)!
- The intense heat from arc causes the sudden expansion of air that results in a blast with very strong air pressure (Lightning is a natural arc).
- All known materials are vaporized at this temperature. (Copper expands 67,000 times, Water 1,670 times).

- Arcs in enclosures, such as a Motor Control Centers (MCCs) or switchgear, magnify blast and energy transmitted as the blast is forced to the open side of the enclosure.
- Arcs spray droplets of molten metal at high-speed pressure. Blast shrapnel can penetrate the body.
- Blast pressure waves have thrown workers across rooms and knocked them off ladders. Pressure on the chest can be higher than 2000 lbs/sq. ft.

- Clothing can be ignited from several feet away. Clothed areas can be burned more severely than exposed skin.
- Hearing loss from sound blast. The sound can have a magnitude as high as 140dB at a distance of 2 feet from the arc.
- Energy released is a function of:
  - System voltage
  - Fault current magnitude
  - Fault duration

Notes are from *Practical Solution Guide to Arc Flash Hazards*, by Chet Davis, P.E.; Conrad St. Pierre; David Castor, P.E.; Robert Luo, PhD; and Satish Shrestha.

How to Protect Against Shock and Arc Flash/Blast?

Chapter 1, Section 130 of NFPA 70E-2012

1. Justification for Live Work
2. Work Permits Secured if Applicable
3. Approach Boundaries Established
    - A. Shock Protection
        1. Limited Boundary
        2. Restricted Boundary
        3. Prohibited Boundary
    - B. Flash Protection – ONE BOUNDARY

Pictures from ESA Book

Practical Solution Guide to Arc Flash Hazards

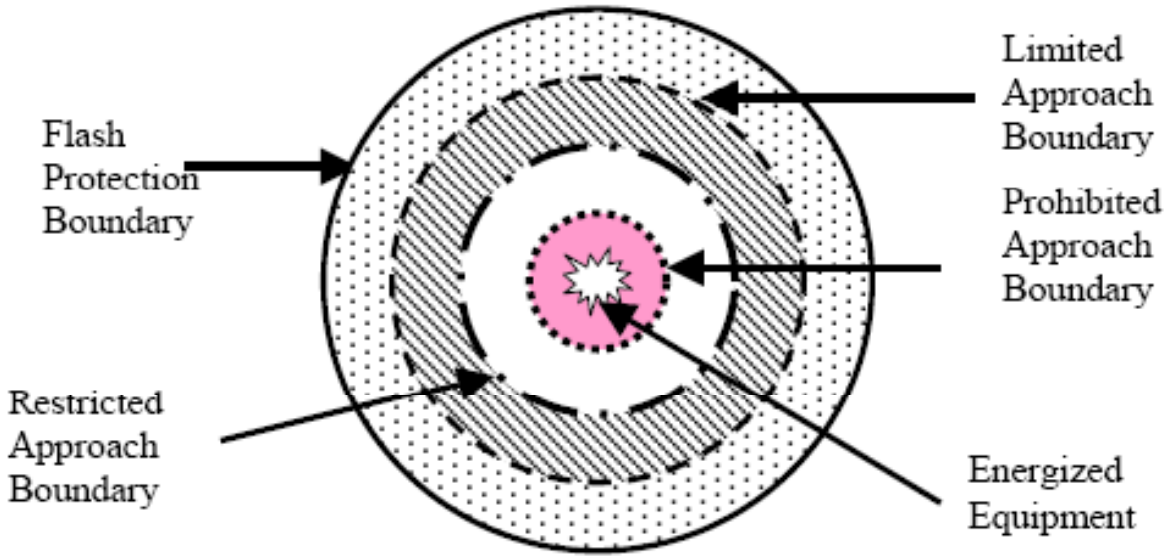

Figure 1.2: Protection boundaries

Approach Boundaries

NFPA 70E-2012 Ch. 1, Section 130

Limited Approach Boundary

Entered only by qualified persons or unqualified persons that have been advised and are escorted by a qualified person

Restricted Approach Boundary

Entered only by qualified persons required to use shock protection techniques and PPE

Prohibited Approach Boundary

Entered only by qualified persons requiring same protection as if direct contact with live part

Flash Protection Boundary

Linear distance to prevent any more than 2nd degree burns from a potential arc-flash (typically 4 feet)

SHOCK Hazard Analysis

Ch. 1, Sec. 130 Shock Hazard Analysis.

"Shock hazard analysis shall determine the voltage to which personnel will be exposed, boundary requirements, and the PPE necessary in order to minimize the possibility of electric shock to personnel."

What is required?

1. Determine the Operating Voltage of the System
2. Determine Shock Protection Boundaries
3. Determine the Personnel Protective Equipment

SHOCK Hazard Analysis

How to comply with NFPA 70E?

1. *Determine the Operating Voltage.*
2. *Determine the Three Shock Protection Boundaries by using Table 130.4(c)(a) of NFPA 70E-2012*
    - *A. Limited Approach Boundary*
        - *10 ft for 480 V for movable energized object*
        - *3 ft 6 in. for fixed energized object*
    - *B. Restricted Approach Boundary*
        - *12 in. for 480 V*
    - *C. Prohibited Approach Boundary*
        - *1 in. for 480 V*

SHOCK Hazard

How to comply with NFPA 70E?

3. *Determine the Personnel Protective Equipment:*

   NOTE: Short-Circuit Current and Clearing Time Limitations Apply for use of tables!

   a. *Determine risk category from Table 130.7 (c)(15)(a) on NFPA 70E-2012*
   b. *Determine specific PPE & clothing from Table 130.7(c)(16) of NFPA 70E-2012*

Flash Hazard

Ch. 1, Sec. 130.5 Arc Flash Hazard Analysis.

"An arc flash hazard analysis shall determine the arc flash boundary, the incident energy at the working distance, and the personal protective equipment that people within the arc flash boundary shall use."

How to comply with NFPA 70E for Flash Protection?

1. Determine the flash protection boundary
2. Determine the incident energy exposure level
3. Determine the protective clothing and PPE

Flash Hazard

How to Comply with NFPA 70E for FLASH Protection?

1. Determine Flash Protection Boundary:

Calculate using the $I_{Short\text{-}Circuit\ Amperes}$ & the clearing time for the overcurrent protection

(see Formula below & Annex D of NFPA 70E-2012 <u>or</u> default to the distances listed in the Table 130.7(C)(15)(a) if the $I_{Short\text{-}Circuit\ Amperes}$ & the clearing time are not exceeded!

Flash Protection Boundary Formula (600 V or less)

$$D_C = [53 \times MVA \times t]^{1/2}$$

where Dc = Arc Flash Boundary (AFB) in Feet

MVA = Transformer capacity in MVA

t = clearing time in seconds

Second Degree Burn Threshold

1.2 cal/cm²

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Flash Hazard Analysis

2. Determine the Incident Energy Level:

   Calculate incident energy exposure level for the distance between worker's face & chest from the potential arc source (18" typical) ***OR*** *use 130.7(C)(15)(a) and 130.7(C)(16)*

Incident energy formula for Arc in a Cubic Box:

$$E_{MB} = 1038.7 D_A^{-1.4738} t_A [0.0093F^2 - 0.3453F + 5.9675]$$

Where
- E_{MB} = cal/cm^2 in 20 inch Cubic Box
- D_A = distance from electrode in inches (typically this value would be 18")
- t_A = clearing time
- F = $I_{short\text{-}Circuit}$ Amperes available (range of 16 kA to 50 kA)

Flash Hazard Analysis

3. *Determine the Proper PPE:*

Once the incident energy is determined, the PPE has to have a rating equal to or greater than the incident energy available. Or, if the alternate method of using 130.7(C)(15)(a), then the proper PPE is selected from 130.7(C)(16) of NFPA 70E-2012 if the $I_{\text{Short-Circuit Amperes}}$ & the clearing time limitations are not exceeded.

Flash Hazard Analysis

Example 1 – An electrician is to remove the covers to measure the voltage on a panelboard operating at 480 V with no arc flash analysis labels to indicate the incident energy and the $I_{\text{Short-Circuit Amperes}}$ & the clearing time exceeds the limitations in the Table 130.7(C)(15)(a).

Table 130.7(C)(15)(a) > Hazard Risk Category (HRC) = 2 cannot be used because the $I_{\text{Short-Circuit Amperes}}$ & the clearing time limitations have been exceeded!

In this situation Table 130.7(C)(15)(a) could not be used to determine the HRC and would require an incident energy analysis to be performed in accordance with Article 130.5 of the 2012 NFPA 70E prior to starting any work.

Flash Hazard Analysis

Example 2 - An electrician is to operate a circuit breaker in the main switchgear (with all of the covers on the switchgear) to de-energize a circuit that is operating at 480 V for lock-out tagout and the $I_{\text{Short-Circuit Amperes}}$ & the clearing time limitations are not exceeded.

Table 130.7(C)(15)(a) > Hazard Risk Category (HRC) = 0
(No V-Rated Gloves & No V-Rated Tools Required)

Table 130.7(C)(16) specifies the following required:

- Untreated Natural Fiber long-sleeve shirt & pants
- Safety Glasses & Hearing Protection

NEXT STEP IS TO VERIFY VOLTAGE IS OFF!
Electrician goes to machine disconnect to open and test for presence of voltage – What is the HRC level? (Ans: 2)

ELECTRICAL HOT WORK PERMIT REQUIRED? (Ans: NO)

Flash Hazard Analysis

Example 3 - An electrician is to operate a circuit breaker in the main switchgear (with some of the covers removed from the switchgear) to de-energize a circuit that is operating at 480 V for lock-out tagout and the $I_{\text{Short-Circuit Amperes}}$ & the clearing time limitations are not exceeded.

Table 130.7(C)(15)(a) > Hazard Risk Category (HRC) = 1
(No V-Rated Gloves & No V-Rated Tools Required)

Table 130.7(C)(16) specifies the following required:

- AR Pants & Shirt or Coveralls of at least 4 cal/cm^2
- Hard Hat
- Arc Rated Face Shield
- Safety Glasses or Goggles
- Hearing Protection
- Leather Shoes
- Leather Gloves

NEXT STEP IS TO VERIFY VOLTAGE IS OFF!

Electrician goes to machine disconnect to open and test for presence of voltage – What is the HRC level? (Ans: 2)

Flash Hazard Analysis

Example 4 - An electrician is to remove the covers on a panelboard to troubleshoot a 20 A lighting circuit that is not working . The circuit is operating at 208/120 V and the $I_{\text{Short-Circuit Amperes}}$ & the clearing time limitations are not exceeded.

Table 130.7(C)(15)(a) > Hazard Risk Category (HRC) = 1
(V-Rated Gloves & V-Rated Tools Required)

Table 130.7(C)(10) specifies the following required:

- AR Pants & Shirt or Coveralls of at least 4 cal/cm^2
- Hard Hat
- Arc Rated Face Shield
- Safety Glasses or Goggles
- Hearing Protection
- Leather Shoes
- Leather Gloves

ELECTRICAL HOT WORK PERMIT REQUIRED? (Ans: NO)

Flash Hazard Analysis

Example 5 - An electrician is to install a 100 A, 480 V I-Line circuit breaker on a panelboard for a new bailer machine. If the panel is shutdown, all the lines will stop and the warehouse will be without lighting and the $I_{\text{Short-Circuit Amperes}}$ & the clearing time limitations are not exceeded.

Table 130.7(C)(9) > Hazard Risk Category (HRC) = 2
(V-Rated Gloves & V-Rated Tools Required)

Table 130.7(C)(10) specifies the following required:

- AR (8 cal/cm2) Long Sleeve Shirt & Pants or AR Coveralls
- Hard Hat
- Safety Glasses or Safety Goggles
- Arc-Rated Face Shield w/ Flash Hood or AR Balaclava
- Hearing Protection
- Leather Gloves
- Leather Work Shoes

ELECTRICAL HOT WORK PERMIT REQUIRED? (Ans: YES)

Flash Hazard Analysis

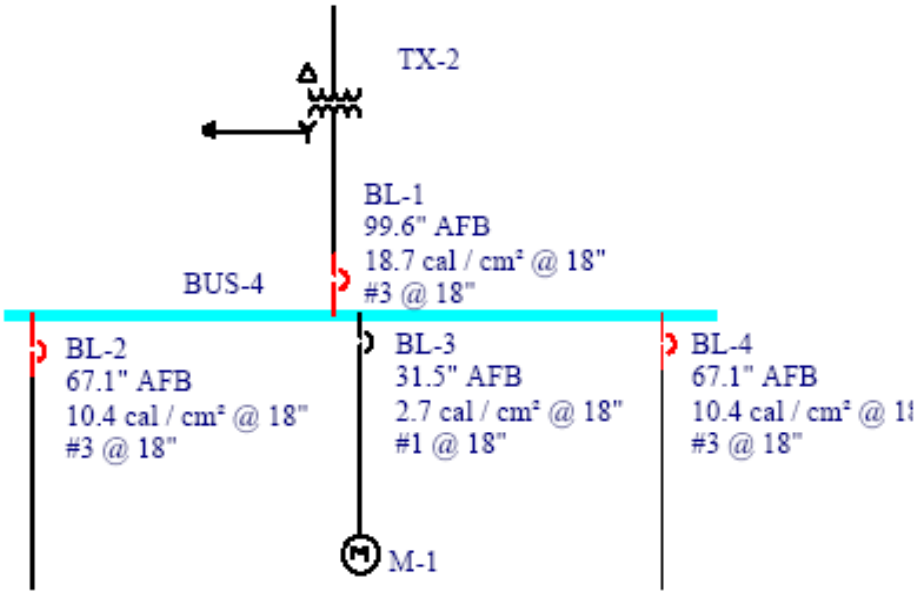


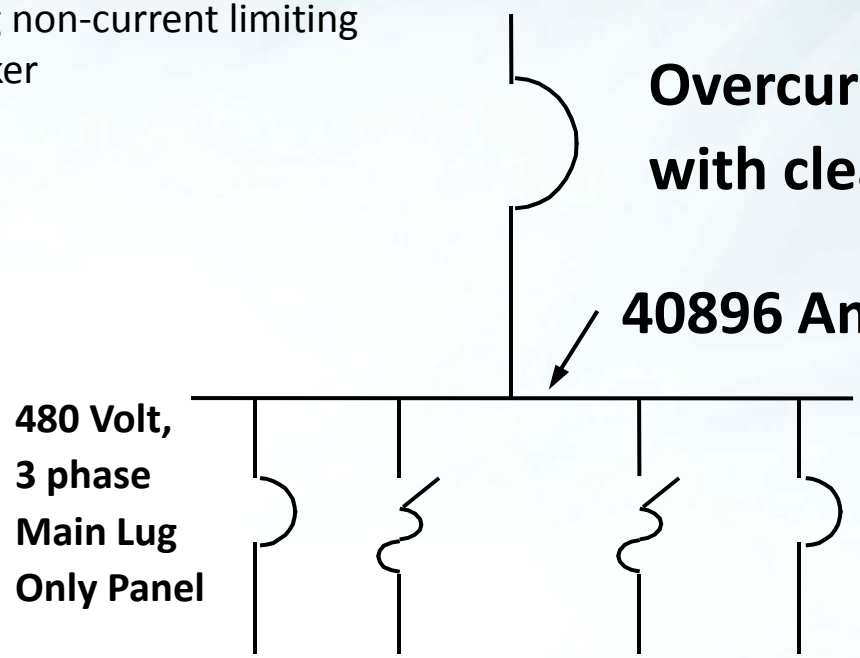
Figure 1.3: Example of arc flash hazard calculation results on one-line diagram in the integrated software EasyPower®.

Notes are from *Practical Solution Guide to Arc Flash Hazards*, by Chet Davis, P.E.; Conrad St. Pierre; David Castor, P.E.; Robert Luo, PhD; and Satish Shrestha.

Flash Hazard Analysis – Example 2

Flash Protection Boundary Calculation

Circuit using non-current limiting circuit breaker



Answer

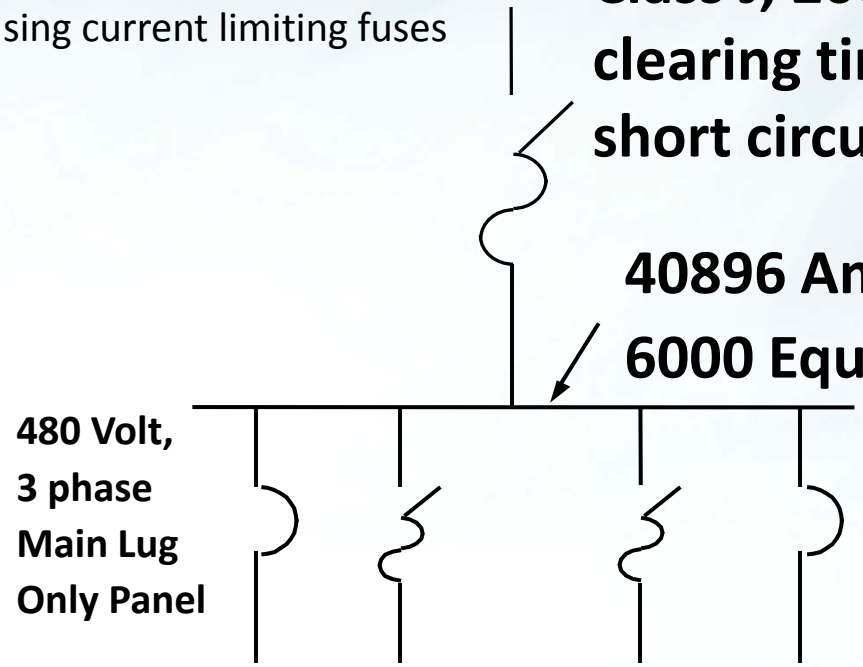
D_C = 10 ft

This example provided by Bussmann®

Flash Hazard Analysis – Example 2

Flash Protection Boundary Calculation

Circuit using current limiting fuses



Class J, 200 A fuse clearing time of 1/4 cycle under short circuit conditions.

40896 Amperes Available

6000 Equivalent RMS Let-Through

Answer

D_C = .23 ft

Flash Hazard Analysis

Incident Energy Calculation

‘Formula: Based on CUBIC BOX

$$E_{MB} = 1038.7\, D_B^{-1.4738}\, t_A[0.0093F^2-.3453F+5.9675]\ cal/cm^2$$

E_{MB} = Incident Energy (cal/cm^2)

D_B = Distance, (in.) *[for Distances $\geq$ 18 inches]*

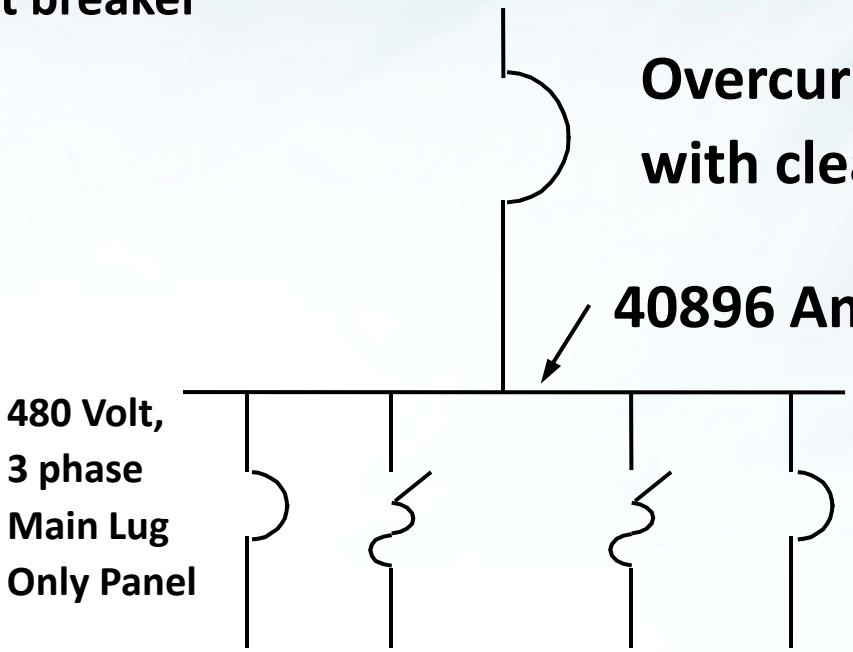
t_A = Arc Duration, (sec.)

F = Bolted Fault Short Circuit Current [16KA to 50kA]

Flash Hazard Analysis – Example 2

Incident Energy **Calculation @ 18”**

Circuit using non-current limiting circuit breaker



Overcurrent protective device with clearing time of 6 cycles

40896 Amperes Available

Answer

E_{MB} = 10.92 cal/cm²

This example provided by Bussmann®

Flash Hazard Analysis

Incident Energy Calculation @ 18”

Example 2: **40896 amps** of available fault current, 480 volt 3 phase system, **Non-current limiting** overcurrent device **6 cycle (0.1 sec) opening time**.

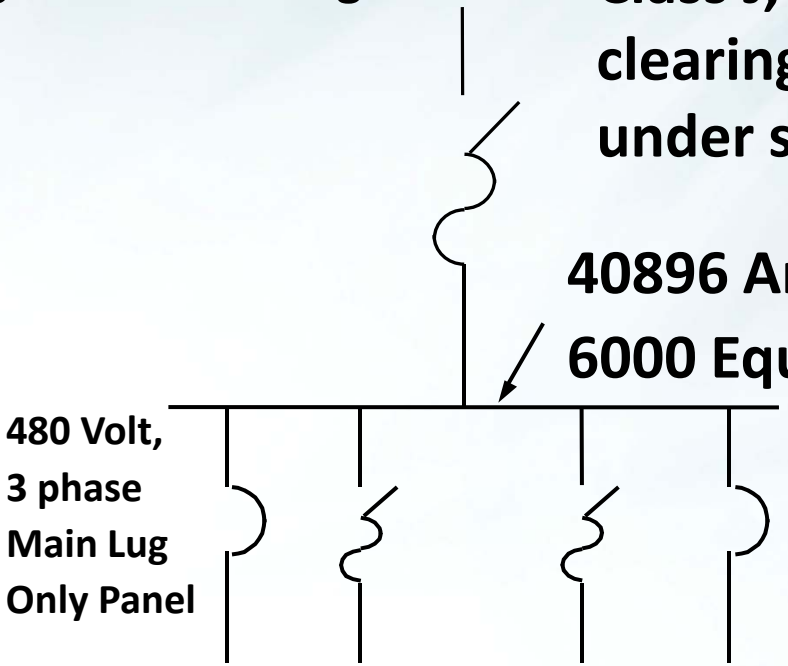
$$E_{MB} = 1038.7\ D_B^{-1.4738}\ t_A[0.0093F^2-.3453F+5.9675]$$
$$E_{MB} = 1038.7\ (18)^{-1.4738}(.1)\ [0.0093(41)^2-.3453(41)+5.9675]$$
$$E_{MB} = 10.92\ cal/cm^2$$

This example provided by Bussmann®

Flash Hazard Analysis – Example 2

Incident Energy **Calculation @ 18”**

Circuit using current limiting fuses



Class J, 200 A fuse clearing time of 1/4 cycle under short circuit conditions.

40896 Amperes Available

6000 Equivalent RMS Let-Through

Answer

E_{MB} < .17 cal/cm^2

Section 110.16 of the 2011 NEC® Requires Arc Flash Hazards Labels

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Arc Flash Labeling Required by NEC

• **110.16 Arc-Flash Hazard Warning**. Electrical equipment, such as switchboards, 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 marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

• Also see Informational Notes 1 and 2 for additional information.
• Reprinted from NEC® 2011

Arc Flash Labeling by NEC & NFPA 70E Minimum Requirement

Generic labels prior to September 30, 2011 are acceptable if they at least have the incident energy or required PPE/HRC level.

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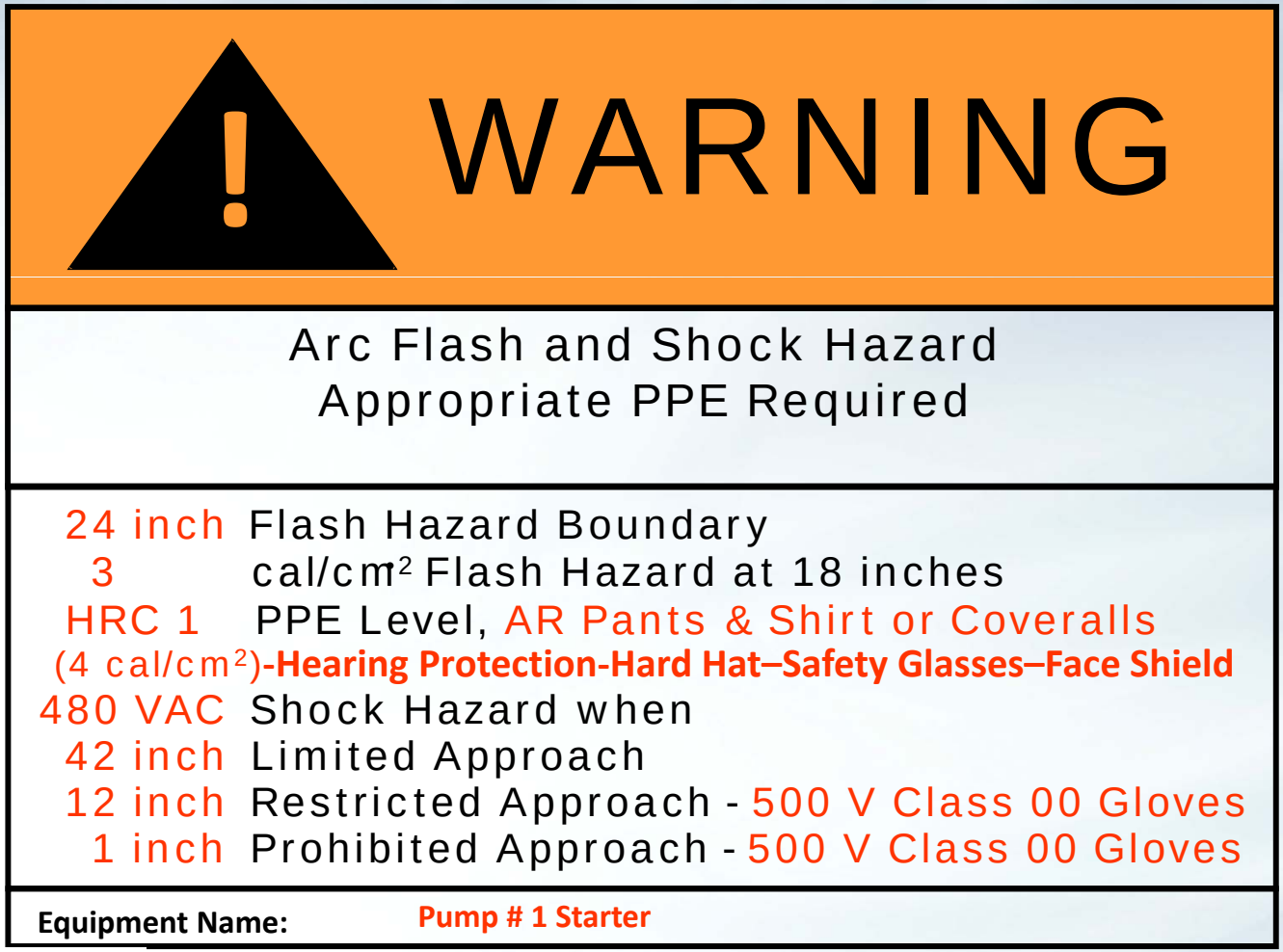
Arc Flash Labeling Required by NEC & NFPA 70E



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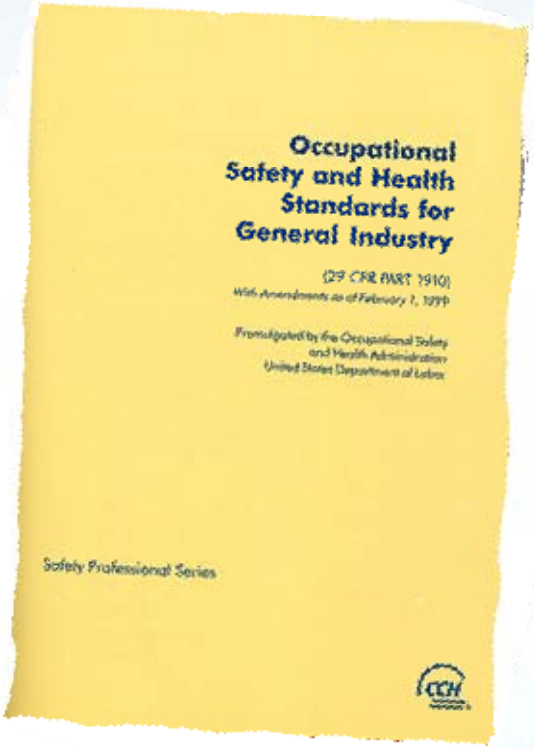
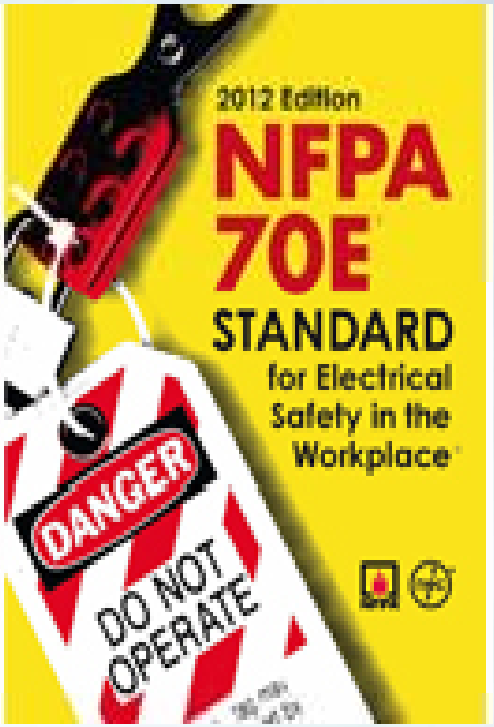
What are the OSHA Regulations and NFPA 70E Requirements for Working on "Live" Equipment?





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NFPA 70 E: Safety in Workplace

OSHA 29CFR 1910.333 & 29CFR 1926.416

These two paragraphs are very similar, but apply differently. It is important that you realize that Electrical Safety applies wherever you are working. 29CFR 1910 applies to the General Industry and 29CFR 1926 applies to the Construction Industry. We may quote an article from 29CFR 1910 but due to the parallel article in 29CFR 1926 the information presented still applies to the Construction Industry.

NFPA 70E: Safety in Workplace

OSHA 29CFR 1910 Subpart S & 29CFR 1926 Subpart K

- Before we go any further, it is important for you to understand a few important definitions:

  - *Qualified Worker – One who has received training in and has demonstrated skills and knowledge in the construction and operation of electric equipment and installations and the hazards involved.* (Qualification is dependent on several factors, such as different equipment, systems and/or voltages qualified to work on. A qualified worker could be qualified at a certain level or on a certain voltage, etc. While working under the direct supervision of a qualified worker, and would be considered qualified).

  -- ***Unqualified Worker – One who is not qualified, has not had training, or does not possess the experience with the equipment, systems, and/or voltage to be worked on.***

NFPA 70E: Safety in Workplace

OSHA 29CFR 1910 Subpart S & 29CFR 1926 Subpart K

- Before we go any further, it is important for you to understand a few important definitions:

  - *Guarded – Covered, fenced, enclosed, or otherwise protected by means of suitable covers or casings, barrier rails or screens, mates or platforms designed to minimize the possibility, under normal conditions, of dangerous approach or accidental contact by persons or objects.*

Note: Wires which are insulated, but not otherwise protected are not considered as guarded.

NFPA 70 E: Safety in Workplace

OSHA 29CFR 1910.333 & NFPA 70E 130.2

Qualified electrical workers shall not be asked to work on equipment that is “hot” or “live” except for these demonstrable reasons:

1. Deenergizing introduces additional or increased hazards
    - Interruption of life support equipment
    - Deactivation of emergency alarm systems
    - Cutting ventilation to a hazardous location

Or

2. Infeasible due to equipment design or operational limitations
    - Voltage testing for diagnostics
    - Start up testing

Or

3. Live parts that operate at less than 50 volts to ground need not be deenergized if there will be no increased exposure to electrical burns or to explosion due to electric arcs.

NFPA 70 E: Safety in Workplace

OSHA 29 CFR 1926.416(a)(1) & NFPA 70E 130.2

This article disallows work in such close proximity to any part of an energized electrical power circuit that the employee could contact in the course of their work, unless the employee is protected against electric shock by deenergizing and grounding the circuit, or guarding it effectively by insulation or other means.

Safety-Related Work Practices

1910.333 Selection & use of work practices

(a) General. Safety-related work practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contact, when work is performed near or on equipment or circuits which are or may be energized. The specific safety-related work practices shall be consistent with the nature and extent of the associated electrical hazards.

Safety-Related Work Practices

1910.335 Safe guards for personnel protection

(a) (2) (ii) Protective shields, protective barriers, or insulating materials shall be used to protect each employee from shock, burns, or other electrically related injuries while that employee is working near exposed energized parts which might be accidentally contacted or where dangerous electric heating or arcing might occur. When normally enclosed live parts are exposed for maintenance or repair, they shall be guarded to protect unqualified persons from contact with live parts.

Who is Responsible for Safety?

The "Employer" is responsible for

- OSHA requirements
- Electrical Safety Program
- Safety Policies and Procedures
- Safety Training and Retraining

The "Employee" is responsible for

- Implementing employer's safety procedures

The "Owner" and Contractors are both responsible to coordinate and document hazards and safety procedures

- Contractors on site with Owner

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Response to an Electrical Accident

Personnel that are trained in CPR & AEDs should be identified and available when work near or on energized parts is being performed and they shall be trained annually.

Responses to an Electrical Accident

The FIRST step must be to: “TURN OFF THE POWER and/or attempt to remove the victim from the power with dry wood or other insulating type of materials” to remove the hazard!

SECOND step: CALL 911 or the local emergency number

THIRD step: Administer CPR & First Aid if needed

Note: 29CFR 1926.50(c) requires that in the absence of a reasonably accessible medical professional, that someone with valid CPR/First-aid training be on site.

What is the best way to prevent the hazards of electricity?

- Stop - Before Action
- Think - Risks/Hazards
- Options - LOTO
- Protection - Proper PPE

Avoiding energized circuits is the safest way!

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