Effective Workplace Electrical Safety

Arc Flash Hazard Control
Definitions

- **Hazard.** A source of possible injury or damage to health.

- **Risk.** A combination of the likelihood of occurrence of injury or damage to health and the severity of injury or damage to health that results from a hazard.
NFPA 70E - 110.1

• (G) **Risk Assessment Procedure.** An electrical safety program shall *include* a risk assessment procedure that *addresses* employee exposure to *electrical hazards*. The procedure shall identify the process to be used by the employee before work is started to *carry out* the following:
  
  • (1) Identify hazards
  • (2) Assess risks
  • (3) Implement risk control according to a hierarchy of methods
Hierarchy of Risk Controls Methods

- Informational Note No. 1: The hierarchy of risk control methods specified in ANSI/AIHA Z10, American National Standard for Occupational Health and Safety Management Systems, is as follows:
  - (1) Elimination
  - (2) Substitution
  - (3) Engineering controls
  - (4) Awareness
  - (5) Administrative controls
  - (6) PPE
First US consensus standard for a safety & health management system

Issued July 25, 2005
Updated 2012
Hazard Control Measures

Hierarchy of Hazard Control Measures
from ANSI Z10

**Elimination**
Eliminate the hazard during design

**Substitution**
Substitution of less hazardous equipment, system or energy

**Engineering Controls**
Design options that automatically reduces risk

**Warnings**
Automatic or manual, permanent or temporary, visible or audible warning systems, signs, barriers and labels

**Administrative Controls**
Planning processes, training, permits, safe work practices, maintenance systems, communications, and work management

**Personal Protective Equipment**
Available, effective, easy to use

Safety by Design

Control Effectiveness

Life Cycle Value
Hazard Control Measures outlined in ANSI Z10

- Elimination
- Substitution
- Engineering Controls
- Warnings
- Administrative Controls
- PPE

Addressed in 70E 2015 Annex O

ANSI Z10 provide the framework to enable decisions and actions in all hazard control measures

Addressed in OSHA and NFPA 70E
Hazard Control

Electrical injuries represent a serious workplace health and safety issue.

Regardless of the specifics of the Hazard there are always the same two concerns:

Concern #1  How likely is it to happen?
Concern #2  How bad will it be?
Hazard Control

Regardless of the specifics of the Hazard there are always the same two concerns:

| Concern #1 | How likely is it to happen? | What is the RISK? |

US Bureau of Labor Statistics indicate that there were nearly 6,000 fatal electrical injuries to workers in the US between 1992 and 2013.

BLS data also indicates there were 24,100 non-fatal electrical injuries from 2003 – 2012.

National Safety Council reported in its 2014 edition of Injury Facts that there were 961 fatal injuries from 2008 through 2010 due to exposure to electric current.

A study of electrical injuries over a 20 year period at a Texas burn center found that 40% of burns were electrical arc injuries.

Hazard Control

Regardless of the specifics of the Hazard there are always the same two concerns:

Concern #2  How bad will it be?  What will be the IMPACT?

Washington State Department of Labor and Industries “Burn Injuries Facts” reported that worker’s compensation costs for 30 serious arc flash or blast burn injuries that took place between September 2000 and December 2005 were in excess of $1.3 million.

OSHA in 2014 estimates a value of $62,500 per non-fatal injury for workers performing electric distribution work (direct costs only).

American Society of Safety Engineers estimates that indirect costs may be as much as 20 times higher than direct costs.

What is an Arc Flash?

According to NFPA 70E:

A dangerous condition associated with the release of energy caused by an electric arc.

A hazard beyond shock and electrocution.
What is an Arc Flash?

Electric arcing, commonly referred to as an arc flash, occurs when current passes through the air between two or more conducting surfaces or from conductors to ground.

(Workplace Safety Awareness Council) Electric arcing may produce temperatures as high as 35,000 degrees and may cause severe burns, hearing loss, eye injuries, skin damage from molten metal, lung damage and blast injuries.

Arc Flash

What does it do?

- It hurts people!
- It destroys equipment!
- It Results in Penalties from OSHA
- It Causes outages!
- It Affects morale!
NFPA 70E Annex 0

General Design Requirements 0.2.1

Employers, facility owners, and managers who have responsibility for facilities and installations having electrical energy as a potential hazard to employees and other personnel should ensure that electrical hazards risk assessments are performed during the design of electrical systems and installations.”
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3. Enabling achievement of an electrically safe work condition

O.2.3 Incident Energy Reduction Methods. The following methods have proved to be effective in reducing incident energy:

1. Zone selective interlocking. A method that allows two or more circuit breakers to communicate with each other so that a short circuit or ground fault will be cleared by the breaker closest to the fault with no intentional delay. Clearing the fault in the shortest time aids in reducing the incident energy.

2. Differential relaying. The concept of this protection method is that current flowing into protected equipment must equal the current out of the equipment. If these two currents are not equal, a fault must exist within the equipment, and the relaying can be set to operate for a fast interruption. Differential relaying uses current transformers located on the line and load sides of the protected equipment and fast actuating relays.

3. Energy-reducing maintenance switching with a local status indicator. An energy-reducing maintenance switch allows a worker to set a circuit breaker trip unit to operate faster while the worker is working within an arc flash boundary, as defined in NFPA 70E, and then set the circuit breaker back to a normal setting after the work is complete.

O.2.4 Other Methods:

1. Energy-reducing active arc flash mitigation system. This system can reduce the arcing duration by creating a low impedance current path, located within a controlled compartment, to cause the arcing fault to transfer to the new current path, while the upstream breaker clears the circuit. The system works without compromising existing selective coordination in the electrical distribution system.

2. Arc flash relay. An arc flash relay typically uses light sensors to detect the light produced by an arc flash event. Once a certain level of light is detected the relay will issue a trip signal to an upstream overcurrent device.

3. High-resistance grounding. A great majority of electrical faults are of the phase-to-ground type. High-resistance grounding will insert an impedance in the ground return path and will typically limit the fault current to 10 amperes and below (at 5 kV nominal or below), leaving insufficient fault energy and thereby helping reduce the arc flash hazard level. High-resistance grounding will not affect arc flash energy for line-to-line or line-to-line-to-line arcs.

ANSI Z10 Hierarchy

Hierarchy of Hazard Control Measures
From ANSI Z10

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Personal Protective Equipment
Available, effective, easy to use
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### Control effectiveness

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*Life Cycle Value*
Typical Approach to Arc Flash Safety

Undertake an arc flash study

Determine magnitude of arc flash hazard

Purchase appropriate levels of PPE

Apply and post warning labels specifying risk.
Arc Flash Study is a Continuation of the Electrical Power System Study

1) Short Circuit Analysis
Determine the fault current available throughout the plant

2) Coordination Study
Design system so that nearest upstream clearing device opens the fault

3) Arc Flash Analysis
Calories determined by available fault current, opening time, and distance from the fault
Device Coordination
NFPA® has identified four FR hazardous risk category levels, which are numbered by severity from 1 to 4. Personal Protection Equipment is the level of arc flash protection clothing you must wear to protect against a minimum level of incident energy.

<table>
<thead>
<tr>
<th>RISK CATEGORY</th>
<th>CLOTHING DESCRIPTION (Typical number of clothing layers is given)</th>
<th>REQUIRED MINIMUM Arc Rating of PPE cal/cm²</th>
</tr>
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<tbody>
<tr>
<td>1 PPE</td>
<td>Arc-rated AR shirt and AR pants or Ar Coverall (1 layer)</td>
<td>4</td>
</tr>
<tr>
<td>2 PPE</td>
<td>Arc-rated AR shirt and AR pants or AR coverall (1 or 2 layers)</td>
<td>8</td>
</tr>
<tr>
<td>3 PPE</td>
<td>Arc-rated AR shirt and Ar pants or AR coverall, and arc flash suit selected so that the system arc rating meets the required minimum (2 or 3 layers)</td>
<td>25</td>
</tr>
<tr>
<td>4 PPE</td>
<td>Arc-rated AR shirt and Ar pants or AR coverall, and arc suit selected so that the system arc rating meets the required minimum (3 or more layers)</td>
<td>40</td>
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ARC Rating - A value of the energy necessary to pass through any given fabric to cause with 50% probability a second or third degree burn. **This would not make me feel safe!**
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Reducing the Likelihood of Exposure
High Resistance Grounding

How Does HRG reduce Arc Flash?

According to Industrial Power System Grounding Design Handbook - 95% of all electrical faults are phase to ground faults.

By limiting the fault current to a low level, 10 amps or less, there is insufficient current for the arc to re-strike and it self-extinguishes.
Reducing the Likelihood of Exposure
High Resistance Grounding

IEEE Std 141-1993 (Red Book)
7.2.2. High-resistance grounding provides the same advantages as ungrounded systems yet limits the steady state and severe transient over-voltages associated with ungrounded systems.

IEEE Std 242-1986 Recommended Practice for the Protection and Coordination of Industrial and Commercial Power Systems
7.2.5. Ungrounded systems offer no advantage over high-resistance grounded systems in terms of continuity of service and have the disadvantages of transient over-voltages, locating the first fault and burn-downs from a second ground fault. For these reasons, they are being used less frequently today than high-resistance grounded systems.”
Reducing the Likelihood of Exposure
High Resistance Grounding

FM Global 5-18 Protection of Electrical Equipment Single Phase
and Other Related Faults

- In ungrounded systems a phase to ground fault often produces
dangerous overvoltage…
- Sustained arcing faults in low voltage apparatus are often initiated
by a single-phase fault to ground which results in extensive
damage to switchgear and motor control centers.

FM Global 5-10 Protective Grounding for Electric Power Systems
and Equipment

- 2.3.3.1 Unlike the ungrounded system the high resistance
grounded system prevents transient overvoltage which can cause
potential failure of insulation.
- 2.3.4.1 Convert ungrounded systems to high resistance grounded
systems.
IEEE Standard 242-2001 (Buff Book)
Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

8.2.5 If this ground fault is intermittent or allowed to continue, the system could be subjected to possible severe over-voltages to ground, which can be as high as six to eight times phase voltage. Such over-voltages can puncture insulation and result in additional ground faults. These over-voltages are caused by repetitive charging of the system capacitance or by resonance between the system capacitance and the inductance of equipment in the system.
Case Study

Automotive Facility

- Phase to Ground voltage monitored for 4 weeks ungrounded and 4 weeks high resistance grounded.
- 485 events with peak voltage above 700 volts due to intermittent ground faults.
- Peak voltage 1050 volts
- Transients lead to insulation degradation.
Impact of Transient Over-voltages

Insulation failure resulting in phase to phase fault and equipment damage in excess of $200k.
Case Study

Automotive Facility

Phase voltage ungrounded

High level of transients
485 peak events over 700 volts
Peak voltage 1050 volts

Troy Michigan

Phase voltage HRG

Transients controlled
0 peak events over 700 volts
Peak voltage 660 volts
Elimination of Hazard Arc Faults on Solidly Grounded Systems

IEEE Std 142-1991 (Green Book)
Recommended Practice for Grounding of Industrial and Commercial Power Systems

1.4.3 The reasons for limiting the current by resistance grounding may be one or more of the following.

*To reduce the arc blast or flash hazard to personnel who may have accidentally caused or who happen to be in close proximity to the ground fault.*

IEEE Std 141-1993 (Red Book)
Recommended Practice for Electric Power Distribution for Industrial Plants

7.2.2 There is no arc flash hazard, as there is with solidly grounded systems, since the fault current is limited to approximately 5A.

Another benefit of high-resistance grounded systems is the limitation of ground fault current to prevent damage to equipment.
Solidly Grounded Systems

IEEE Std 242-2001 (Buff Book)
• 8.2.2. One disadvantage of the solidly grounded system involves the high magnitude of destructive, arcing ground-fault currents that can occur.

IEEE Std 141-1993 (Red Book)
• 7.2.4. The solidly grounded system has the high probability of escalating into a phase-to-phase or three-phase arcing fault, particularly for the 480V and 600V systems. The danger of sustained arcing for phase-to-ground fault...is also high for the 480V and 600V systems, and low or near zero for the 208V system.
## Hierarchy of Hazard Control Measures from ANSI Z10

### Control effectiveness

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| High Resistance Grounding |

### Life Cycle Value

[www.i-gard.com](http://www.i-gard.com)
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- Current-limiting devices: Current-limiting protective devices reduce incident energy by clearing the fault faster and by reducing the current seen at the arc source. The energy reduction becomes effective for currents above the current-limiting threshold of the current-limiting fuse or current limiting circuit breaker.
Arc Damage versus Arc Duration

An arc is developed within milli-seconds and leads to the discharge of enormous amounts of destructive energy. The energy in the arc is directly proportional to the square of the short-circuit current and the time the arc takes to develop.

Reduce the Time,
Reduce the Damage,
Reduce the Incident Energy.
Total Clearing Time is Critical

<table>
<thead>
<tr>
<th>Reduce the Time</th>
<th>Reduce the Damage</th>
<th>Reduce the Incident Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>-35 ms:</td>
<td>no significant damage to persons or Switchgear, which can often be returned to use</td>
<td>2.9 Cal/cm²</td>
</tr>
<tr>
<td></td>
<td>after checking the insulation resistances</td>
<td></td>
</tr>
<tr>
<td>- 100ms:</td>
<td>small damage, requires cleaning and possibly some minor repair likely</td>
<td>8.31 Cal/cm²</td>
</tr>
<tr>
<td>- 500ms:</td>
<td>large damage both for persons and the switchgear, which must be partly replaced.</td>
<td>41.58 Cal/cm²</td>
</tr>
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The arc burning time is the sum of the time to detect the arc and the time to open the correct breaker.

*Based on 50kA maximum bolted fault current on a 480 volt solidly grounded system @ 18 “ Working distance.*
Optical Arc Detection Relays

An arc is accompanied by radiation in the form of light, sound, and heat.

Therefore, the presence of an arc can be detected by analyzing visible light, sound waves, and temperature change.

To avoid erroneous trips, it is normal to use a short-circuit current detector along with one of the aforementioned arc indicators.

The most common pairing in North America is current and light and in Europe it is common to employ light and pressure.
Arc Flash Relay
Optical Arc Detection Relays

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<th>Protection Type</th>
<th>Clearance Time</th>
<th>Incident Energy</th>
</tr>
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<tr>
<td>MCGG Over-Current</td>
<td>2.0 seconds</td>
<td>211 Cal / cm²</td>
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<td>MCGG Instantaneous</td>
<td>0.45 seconds</td>
<td>47 Cal / cm²</td>
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<td>0.084 seconds</td>
<td>9.0 Cal / cm²</td>
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- Assumes circuit breaker interrupting time of 5 cycles
- Assumes 480V and 65kA bolted fault current, 18 inches
# Hierarchy of Hazard Control Measures from ANSI Z10

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**High Resistance Grounding**

- Arc Flash Detection Relay

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Active Arc Mitigation

Arcing starts. The sensors detect the arc.

The tripsignal is sent.

All the phases connected to ground. The arc is extinguished.

The shortcircuit current is disconnected within less than 3-5 cycles.
Incident Energy without Arc Mitigation

Without ArcEliminator

After 100-1000 ms:
Cubicles, apparatus and sometimes the building are damaged and have to be repaired.

After 100-1000 ms:
The fault is cleared by the upstream breaker. During the arcing period the hot gases and melted material is a threat to operator’s life. Inspection, repair and replacement might require several weeks.
Incident Energy with Active Arc Mitigation

Fault clearing time: 3.1 ms ~ 1.17 cal/cm²

Introduction of an impedance controls the fault energy eliminating concern over mechanical stresses
Reducing the Magnitude of Exposure
Active Arc Mitigation

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</table>

- Assumes circuit breaker interrupting time of 5 cycles
- Assumes 480V and 65kA bolted fault current, 18 inches
## Hierarchy of Hazard Control Measures from ANSI Z10

### Control effectiveness

<table>
<thead>
<tr>
<th>ELIMINATION</th>
<th>SUBSTITUTION</th>
<th>ENGINEERING CONTROLS</th>
<th>WARNINGS</th>
<th>ADMINISTRATIVE CONTROLS</th>
<th>PERSONAL PROTECTIVE EQUIPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliminate the hazard during the design phase</td>
<td>Substitute for a lower energy level.</td>
<td>Design options that automatically reduce risk.</td>
<td>Automatic or manual, permanent or temporary, visible or audible warning systems, signs, barriers and labels.</td>
<td>Planning processes, training permits, safe work practices, maintenance systems, communications and work management</td>
<td>Available, effective, easy to use.</td>
</tr>
<tr>
<td>High Resistance Grounding</td>
<td>Arc Flash Detection Relays and/or Active Arc Mitigation System</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Life Cycle Value
0.2.2 Design option decisions should facilitate the ability to eliminate hazards or reduce risk by doing the following:

(1) Reducing the likelihood of exposure = High Resistance Grounding

(2) Reducing the magnitude or severity of exposure = arc flash relays or active arc mitigation.
A great majority of electrical faults are of the phase-to-ground type. High resistance grounding will insert an impedance in the ground return path and will limit the fault current, leaving insufficient fault energy and thereby helping reduce the arc flash hazard.
Engineering Controls: Remote Switching

Permanently installed – remote mounted switches, mimic panels, SCADA systems

Advantages:
• Permanently mounted
• May already exist through SCADA systems

Disadvantages:
• Expensive to install
• Increased chance of operating the wrong breaker
• Requires cabinet or wall space located outside of the arc-flash hazard boundary of every breaker
Engineering Controls: Remote Switching

Portable – “Chicken Switch®” motor operated actuator with remote hand-held controller.

Advantages:

- No modification to switchgear – held in place with magnets
- One “Chicken Switch®” can be used on many breakers
- No additional space required in substation
- Most cost effective solution in most all cases
- Reduced chance of operating the wrong breaker
- Models are available for pistol-grip control switches, pushbuttons, and low voltage power circuit breakers

Disadvantages:

- Not permanently installed
# Hierarchy of Hazard Control Measures from ANSI Z10

## Control effectiveness

<table>
<thead>
<tr>
<th>ELIMINATION #1.</th>
<th>SUBSTITUTION #2.</th>
<th>ENGINEERING CONTROLS #3.</th>
<th>WARNINGS #4</th>
<th>ADMINISTRATIVE CONTROLS #5</th>
<th>PERSONAL PROTECTIVE EQUIPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eliminate the hazard during the design phase</td>
<td>Substitute for a lower energy level. Reduce the impact of the hazard.</td>
<td>Design options that automatically reduce risk. Increase distance away from the hazard.</td>
<td>Automatic or manual, permanent or temporary, visible or audible warning systems, signs, barriers and labels.</td>
<td>Planning processes, training permits, safe work practices, maintenance systems, communications and work management</td>
<td>Available, effective, easy to use.</td>
</tr>
</tbody>
</table>

- **High Resistance Grounding**
- **Arc Flash Detection Relays and/or Active Arc Mitigation System**
- **Remote racking and remote switching**
- **Arc flash warning labels**
- **PPE clothing**
<table>
<thead>
<tr>
<th>Technology</th>
<th>Reduces the Likelihood of Exposure</th>
<th>Reduces the Severity of the Arc Flash Hazard</th>
<th>Protects Personnel in the event of an Arc Flash</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone Selective</td>
<td>❑</td>
<td>☑</td>
<td></td>
<td>COMMENT</td>
</tr>
<tr>
<td>Differential Relay</td>
<td>❑</td>
<td>☑</td>
<td></td>
<td>COMMENT</td>
</tr>
<tr>
<td>Maintenance Switch</td>
<td>❑</td>
<td>☑</td>
<td></td>
<td>Manual operation required</td>
</tr>
<tr>
<td>Active Arc Mitigation</td>
<td>❑</td>
<td>☑</td>
<td></td>
<td>COMMENT</td>
</tr>
<tr>
<td>Arc Flash Relay</td>
<td>❑</td>
<td>☑</td>
<td></td>
<td>Fast automatic operation</td>
</tr>
<tr>
<td>High Resistance Grounding</td>
<td>❑</td>
<td>☑</td>
<td></td>
<td>Risk reduction by design, eliminate up to 95% of occurrences</td>
</tr>
<tr>
<td>Current Limiting Fuse</td>
<td>❑</td>
<td>☑</td>
<td></td>
<td>Under specific operating conditions</td>
</tr>
<tr>
<td>Remote Switching</td>
<td></td>
<td>☑</td>
<td></td>
<td>Removes personnel from danger zone</td>
</tr>
<tr>
<td>Remote Racking</td>
<td></td>
<td>☑</td>
<td></td>
<td>Removes personnel from danger zone</td>
</tr>
<tr>
<td>Arc Resistant Switchgear</td>
<td></td>
<td>☑</td>
<td></td>
<td>Redirects blast away from personnel, although equipment is damaged.</td>
</tr>
</tbody>
</table>
Thank You

Questions?

For comments or product information, please contact: marketing@i-gard.com