Arc Flash Science and Regulation

Where the Industry is Going

Music City Power Quality Group and IEEE Nashville Chapter
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Schneider Electric

Outline

- Electrical Safety principles
- Where are the arc flash regulations and standards going?
  - OSHA
  - NFPA
    - 70E-2009
    - 70 (NEC)-2008
  - IEEE
    - 1584-2002
    - C2 (NESC) - 2007
- The Arc Flash Calculation Process
- The Arc Flash Mitigation Problem
- Principles of Arc Flash Mitigation Engineering
  - Reducing the arc flash energy
  - Separating the worker from arc

Section 1

Electrical Safety Principles

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Electrical Safety Principles

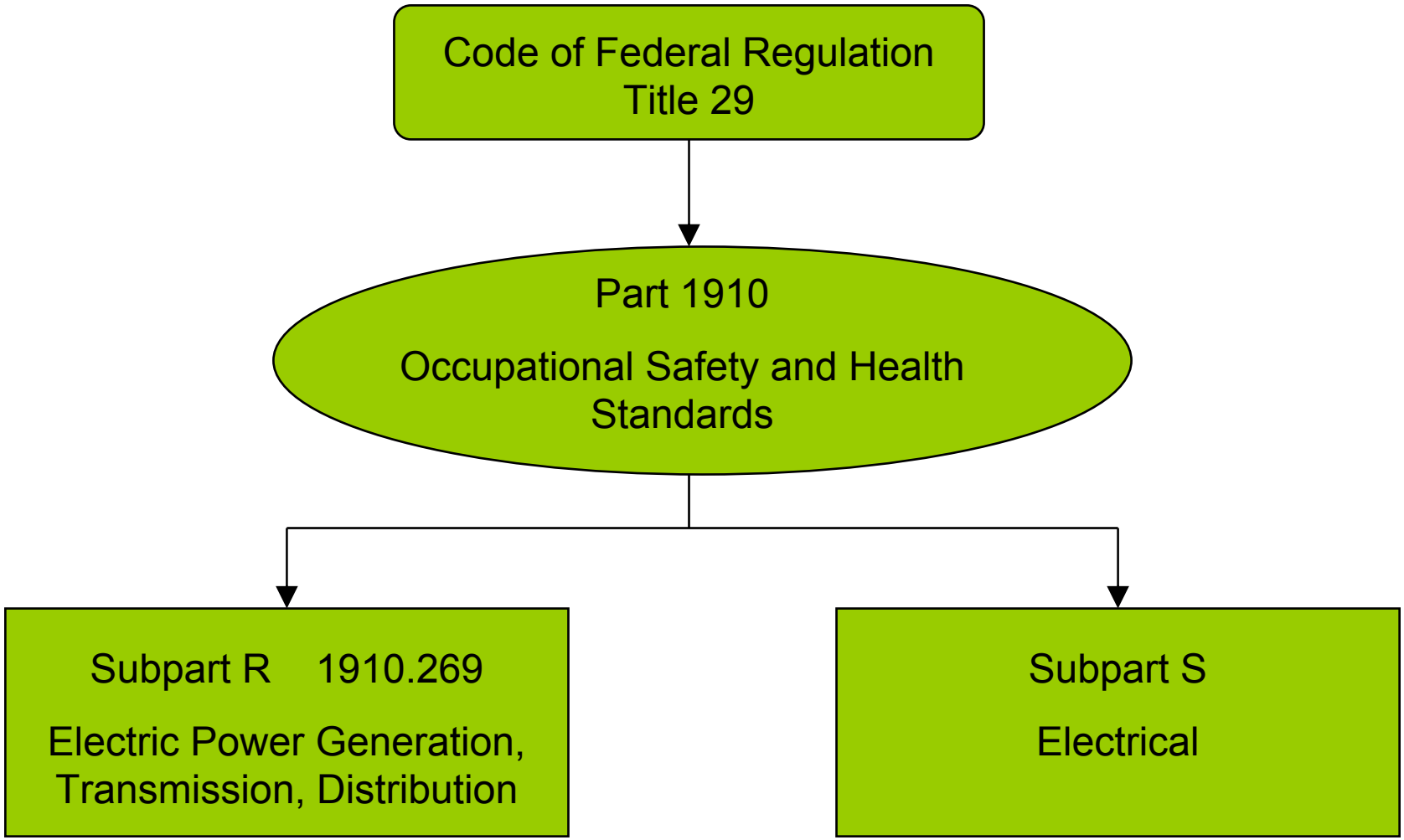
Goal:

Electrical installations that are free from electrical occurrences

Hazards:

- **Shock**
- **Electrocution**
- **Arc flash**
- **Arc blast**

OSHA Standard



OSHA, 29 CFR 1910.332(b)(1)

“Employees shall be trained in and familiar with the safety-related work practices required by 1910.331 through 1910.335 that pertain to their respective job assignments.”

NFPA 70E and the National Electrical Code (NEC) define a qualified person as “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.”

OSHA, 29 CFR 1910.333

“Live parts to which an employee may be exposed shall be de-energized before the employee works on or near them, unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is infeasible.”

The fundamental requirement is to de-energize!

When you allow work to be done energized, you take a risk.

OSHA, 29 CFR 1910.335

Personal Protective Equipment

"Employees working in areas where there are potential electrical hazards shall be provided with, and shall use, electrical protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed."

Citation Settlement

http://search.access.gpo.gov/oshrc/SearchRight.asp?ct=oshrc&q1=Electrical

OSHA is citing NFPA70E during injury investigation and fine assessment.

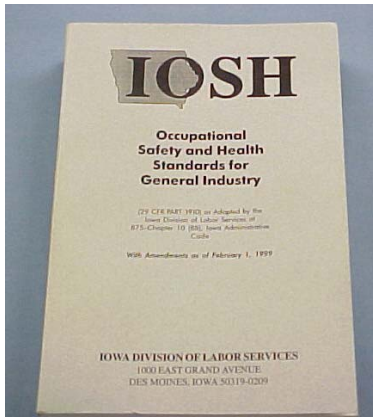
- **In light of the underlying concerns addressed in Items 6 and 7 of Citation I and Item I of Citation 2,** COMPANY agrees to develop, document, and implement hazard analyses evaluating plant-specific tasks that create the potential for exposure to electrical hazards when performed by one or more of the approximately 4,000 electricians employed by COMPANY at its 37 manufacturing facilities and parts distribution centers located in 13 states in the United States. COMPANY will develop the hazard analyses in accordance with the personal protective equipment provisions contained in Chapters 2 and 3 of Part II of the NFPA 70E (2000 Edition) *Standard for Electrical Safety Requirements for Employee Workplaces.* These hazard analyses will either designate the personal protective equipment to be used during the performance of the subject task, or they will refer to a label that designates the required personal protective equipment, which label shall be affixed to the relevant electrical equipment (e.g., electrical control enclosure, junction box, buss plug, transformer, substation).

Enforcement

- OSHA fine assessment based on:
  - 4000 electricians
  - X $7,000 per electrician
  - $2.8 M Fine
- However, if the COMPANY took the necessary steps to comply with NFPA70E,
  - Arc Flash Hazard Analysis
  - Electrical equipment labeling with PPE category
  - Worker Training
  - **Deploy products, solutions, or methods to limit arc flash whenever possible**

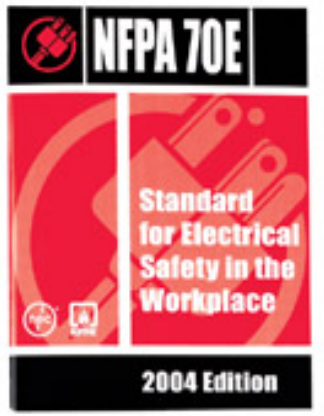
the fine would be reduced to $14,000

Requirement Documents



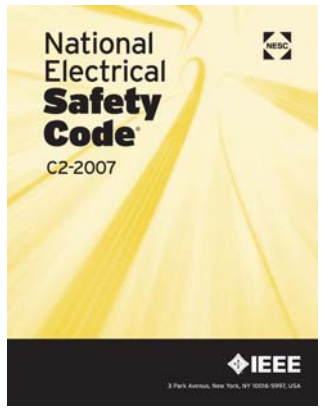
OSHA 29 CFR Part 1910

OSHA Standards (Iowa Shown)



NFPA70E-2009

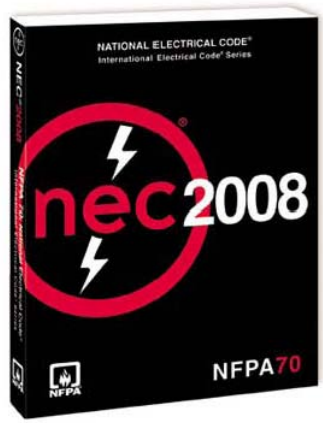
Governs Employee Workplace Safety



NESC

IEEE C2-2007

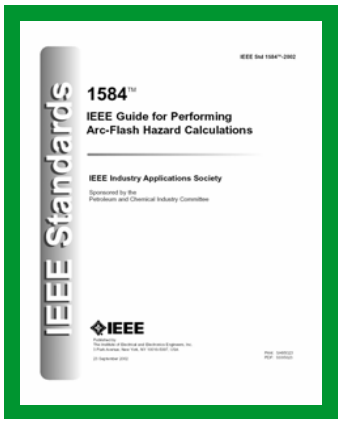
Applies to Utility Industry



NFPA70 (NEC)

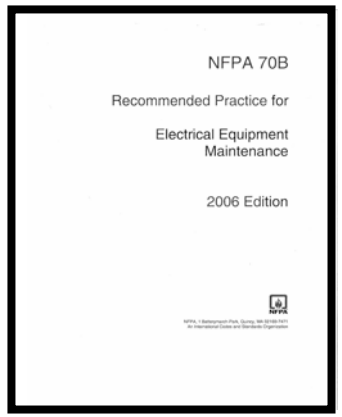
Governs Electrical Installations

Supporting Documents



IEEE 1584 -2002

Guide for Performing Arc Flash Hazard Calculations



NFPA 70B - 2006

Recommended Practice of Electrical Equipment Maintenance

ANSI Z535-2

Standard for Environmental and Facility Safety Signs

Electrical Safety Implementation

It is not just an arc flash study

- Develop / evaluate corporate Electrical Safety Policy
  - Must include (not a complete list)
    - Employee qualification and hazard recognition
    - Safe work practices – lockout tagout, etc
    - Flash hazard analysis
    - PPE selection and use
  - Employee training and qualification policy
- Arc flash study
- Arc flash labeling
- Employee training
- Review, reinforce and audit employees
- Procedure to update and revise the policy

Flash Hazard Analysis

Flash hazard analysis shall be done before a person approaches any exposed electrical conductor or circuit part that has not been placed in an electrically safe work condition. (NFPA 70E, Part II, 2-1.3.3)

Desired output for each equipment:

- Flash protection boundary distance
- Incident energy
- Hazard / risk category for PPE selection

Determine PPE Hazard Risk Category

Category	Cal/cm^2	Clothing
0	1.2	Untreated cotton
1	4	FR shirt & FR pants
2	8	Cotton underwear plus FR shirt & FR pants
3	25	Cotton underwear plus FR shirt & FR pants plus FR coverall
4	40	Cotton underwear plus FR shirt & FR pants plus double layer switching coat and pants

From incident energy value

Output category for Personal Protective Equipment

Source: NFPA 70E, Table 130.7(C)(11)

Protection is not 100%

- Rubber gloves can ignite
- Shoes are not tested for arc flash
- ATPV is level of incident energy that would just cause the onset of a 2nd degree burn under the clothing in question
  - Implies no fabric breakopen
- Use face shield with ATPV rating. Clear face shield will not protect your eyes

Optimal PPE Level

- Too little PPE: exposure to burn injury
- Too much PPE:
  - Heat stress
  - Loss of motion, visibility
  - Rush task at hand—carelessness
- Better too much than too little (don’t sacrifice safety for comfort), but best to select the “right” level for a given task in a given location. Provide breaks, drink a lot of water when working in a high category suit.

Frequently Asked Questions

Where is OSHA Citing NFPA 70E?

OSHA IS THE *SHALL* &
NFPA 70E IS THE *HOW*

Industry consensus standards, such as NFPA 70E, are used as guides to making the assessments and equipment selections required by the standard. Similarly, in OSHA enforcement actions, they can be used as evidence of whether the employer acted reasonably.

We Don’t Work on Stuff Hot. So, we Don’t need PPE. Right?

OSHA and NFPA 70E, Lockout Tagout Rules

- Identify sources (single-line diagram!)
- *De-energize source(s)
- *Visually verify
- Lockout/tagout
- **Test circuit
- **Apply grounds (if applicable)

*Task may need PPE

**Task will need PPE

Section 2

Where are the Arc Flash Regulations and Standards Going?

Note: This is not a complete list of the changes in standards. Only some key changes are listed.

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Where is OSHA Going?

- Hilda Solis (Secretary of Labor) and Jordan Barab (Acting Assistant Secretary of OSHA) spoke in late June 2009 to 3,300 members of the ASSE (American Society of Safety Engineers) in San Antonio…
  - Solis – “OSHA is back in the enforcement business”
  - Focus on voluntary (VPP) programs will be highly scrutinized
  - More than 150 new inspectors will be hired in 2009 (adding to the current staff of 2,500)
  - Enforcement budget will increase by10% to $22.5M
  - Number of annual inspections will increase from 38,000 nationwide to perhaps 44,000
  - More enforcement, less voluntary protection focus
  - Penalties will be higher for violations
  - OSHA will be more aggressive with standards and policing / enforcement than at any time in the last 20 years
  - Solis - “As long as I am Secretary of Labor the department will go after anyone who puts worker lives needlessly at risk.”
  - Barab - “Economic hardship is no excuse for taking short cuts with safety and health”

NFPA 70E – 2009 Changes

Article 130.3

- …The arc flash hazard analysis shall be updated when a major modification or renovation takes place. It shall be reviewed periodically, not to exceed five years, to account for changes in the electrical distribution system that could affect the results …
- The arc flash hazard analysis shall take into consideration the design of the overcurrent protective device and its operating time, including its condition of maintenance.
- Exception No.1: An arc flash hazard analysis shall not be required where all of the following conditions exist:
  - The circuit is rated <= 240V
  - Supplied by one transformer
  - The transformer supplying the circuit is <125KVA

NFPA 70E – 2009 Changes

Article 130.3 (C)

Equipment Labeling

- Equipment shall be field marked with a label containing the available incident energy or required level of PPE.

NFPA 70E – 2009 Changes

Table 130.7 (C)(10)

- Arc rated face shield required for category 1
- Hearing protection required on all categories 0-4

Article 130.7 (C)(14)(b) was in 2004 version is removed now

- Category 0 is limited to 1.2 Cal/Cm^2. The exception in 130.7 (C)(14)(b) which allowed 2.0 calories is removed.

Article 250.3 General Maintenance Requirements

- Overcurrent protective devices shall be maintained in accordance with the manufacturer's instructions or industry consensus standards.

IEEE 1584 - 2002

- Completed in less that 2 years
- Motivated by 1981 Lee paper, which work continued during 1990s by Doughty, and colleagues
- Applied design of experiments
- Provided empirical formulas
- Limited to 15KV
- For over 15KV, Lee equations were recommended

What's next?

IEEE 1584

Opportunities to fine tune present method

- Alternate box sizes
- Boxes of variable depths
- Exploration at 208 V
  - Conditions for arc to ignite, sustain
- More data on existing variables
  - Voltage, current, X/R ratio, electrode gap
- Copper versus aluminum?
- Horizontal versus vertical bus arrangement?
- Maximum arcing duration?
- Direct current?
- Single phase?

Arc Blast Pressure

What about this hazard?

- Standards do not cover protection for this hazard specifically
- Energy to pressure relationship
- Variables
  - Frequency, room size & configuration

IEEE C2-2007
National Electrical Safety Code

Article 410

- Effective January 1, 2009 the employer shall ensure that an assessment is performed to determine potential exposure to an electric arc…
- Introduced a new method of calculating arc flash energies for open switchyards and open conductor lines over 1000V using tables 410-1 and 410-2
- Article 410.A.3, Note 2: “It is recognized that arc energy levels can be excessive with secondary systems. Applicable work rules required by this part and engineering controls should be utilized.”

NESC Table 410-1

Table 410-1—Clothing and clothing systems—voltage, fault current, and maximum clearing time for voltages 1 to 46 kV ①

(See Rule 410A3.)

Phase-to-phase voltage (kV)	Fault current (kA)	4-cal system	8-cal system	12-cal system
		Maximum clearing time (cycles)	Maximum clearing time (cycles)	Maximum clearing time (cycles)
1 to 15	5	46.5	93.0	139.5
	10	18.0	36.1	54.1
	15	10.0	20.1	30.1
	20	6.5	13.0	19.5
15.1 to 25	5	27.6	55.2	82.8
	10	11.4	22.7	34.1
	15	6.6	13.2	19.8
	20	4.4	8.8	13.2
25.1 to 36	5	20.9	41.7	62.6
	10	8.8	17.6	26.5
	15	5.2	10.4	15.7
	20	3.5	7.1	10.6

NESC Versus IEEE 1584 / NFPA 70E

- The provided tables in NESC only cover over 1000V. Specific guidelines are not provided on low voltage system. IEEE 1584 is mainly focused on low voltage systems (but up to 15 KV is covered)

- NESC uses line to ground fault current for arc flash calculations. IEEE 1584 uses 3 phase fault.

- NESC basis for calculations is not defined in the standard – NESC does not provide the equations to calculate the arc flash energies. Rather it provides tables.

- NESC tables make no reference to the head and neck protection (flash hood). NFPA 70E mandates these.

- The arc flash energy calculated results come up quite lower using the NESC method compared to IEEE 1584 recommendations (Lee Method) for MV and HV systems.

NESC 2012, Where it is Going

Major changes proposed for 2012 version

- Low voltage systems will be covered
- Clothing categories may be expanded
- A new method proposed for arc flash energy calculation on HV systems (calculation formulas will be provided)

NEC-2011 Proposal 10-82

- **Add new text to read as follows:**

  240.87 Short-time Delay.

  Where short-time delay is utilized on a circuit breaker, one of the following shall be provided:

  (A) Zone-selective interlocking

  (B) Differential relaying

  (C) Energy-reducing maintenance switching

  FPN: An energy-reducing maintenance switch allows a worker to set a circuit breaker trip unit to instantaneous while the worker is working within an arc-flash boundary as defined in NFPA 70E, and then to set the trip unit back to a short-time delay setting after the potentially hazardous work is complete.

NEC 2011 - Proposal 10-82

- What is the real problem?
  - The problem is not with the presence of a short time delay function
  - The problem is with the absence of an instantaneous trip function

NEC 2011 - Proposal 10-82

- **CMP10 accepted in principle, revising the text to read as follows:**

  240.87 Non-instantaneous Trip. **Where a circuit breaker without an instantaneous trip is utilized, one of the following or approved equivalent means shall be provided:**

  (1) Zone-selective interlocking

  (2) Differential relaying

  (3) Energy-reducing maintenance switching with a local status indicator

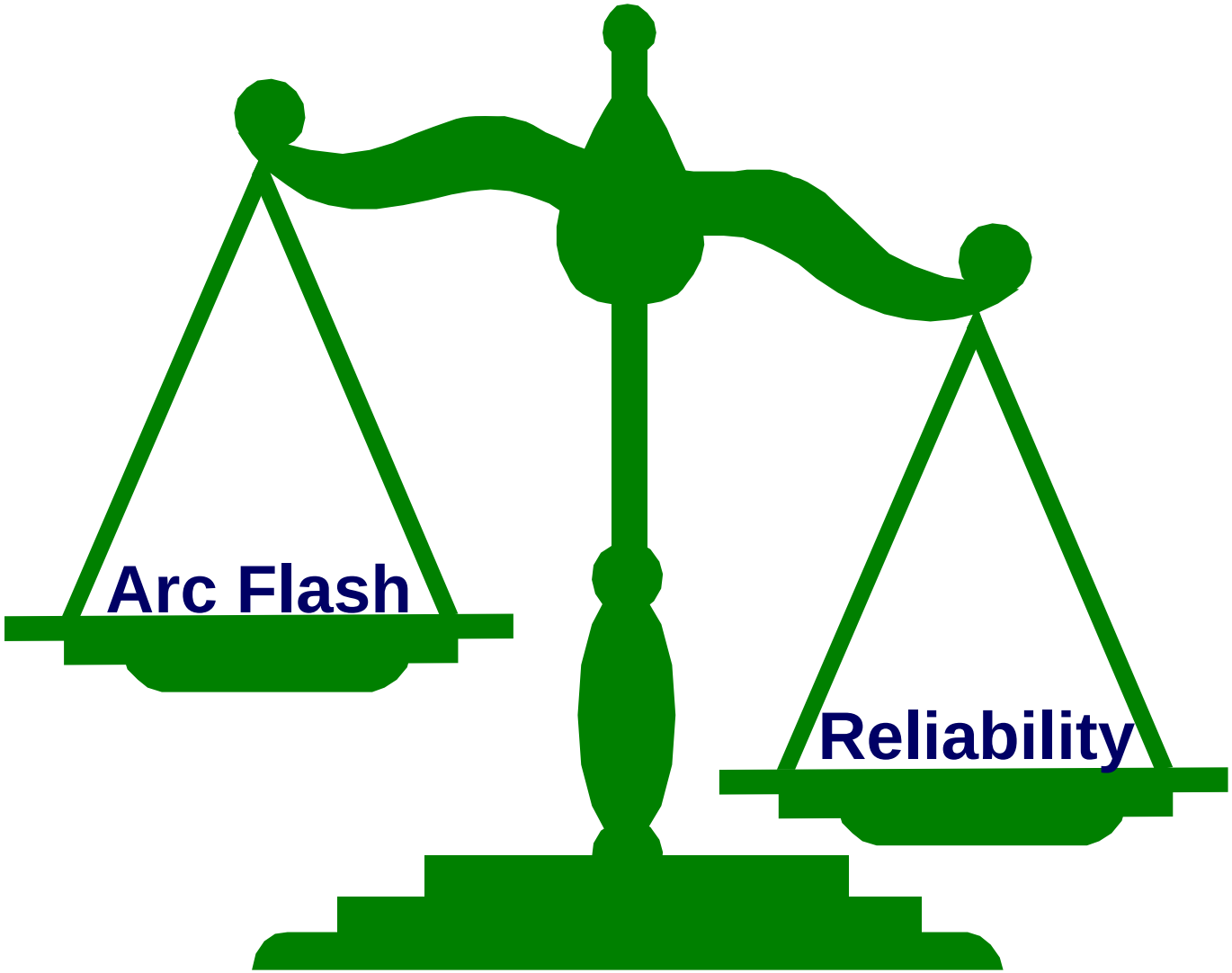
  FPN: An energy-reducing maintenance switch allows a worker to set a circuit breaker trip unit to instantaneous while the worker is working within an arcflash boundary as defined in NFPA 70E, and then to set the trip unit back to a normal setting after the potentially hazardous work is complete.

NEC 2011 - Proposals 10-26, 13-199, 13-236 and13-298

- **Revise text for 240.12(1), 700.27, 701.18 and 708.54**

  700.27 Selective Coordination.

  Emergency system(s) overcurrent devices shall be selectively coordinated with all supply side overcurrent protective devices. A means to intentionally defeat selectivity shall not be permitted.


Arc Flash
Reliability

Section 3

The Arc Flash Calculation Process

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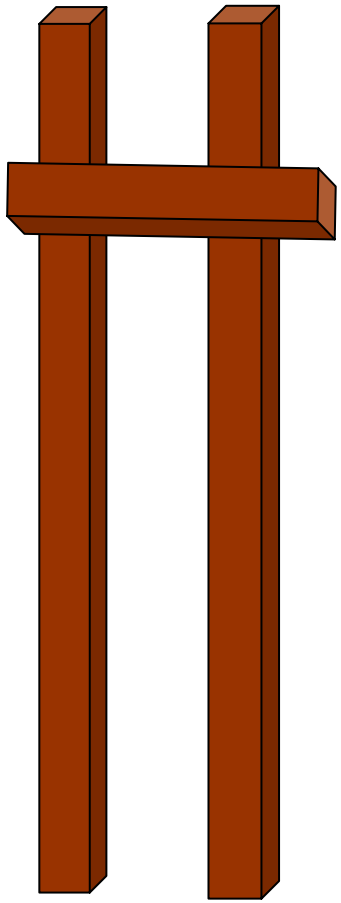
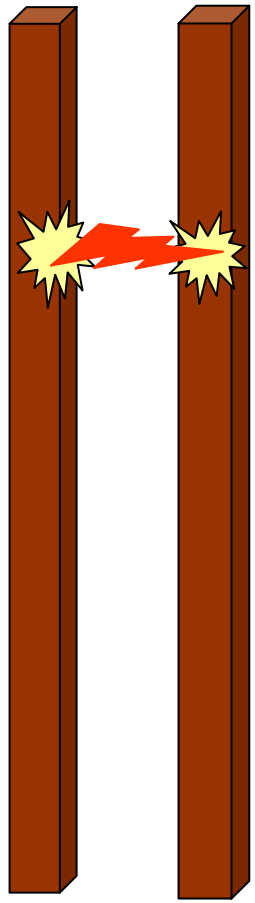
Two Types of Fault

Bolted



Arcing



IEEE 1584 Analysis Process Steps

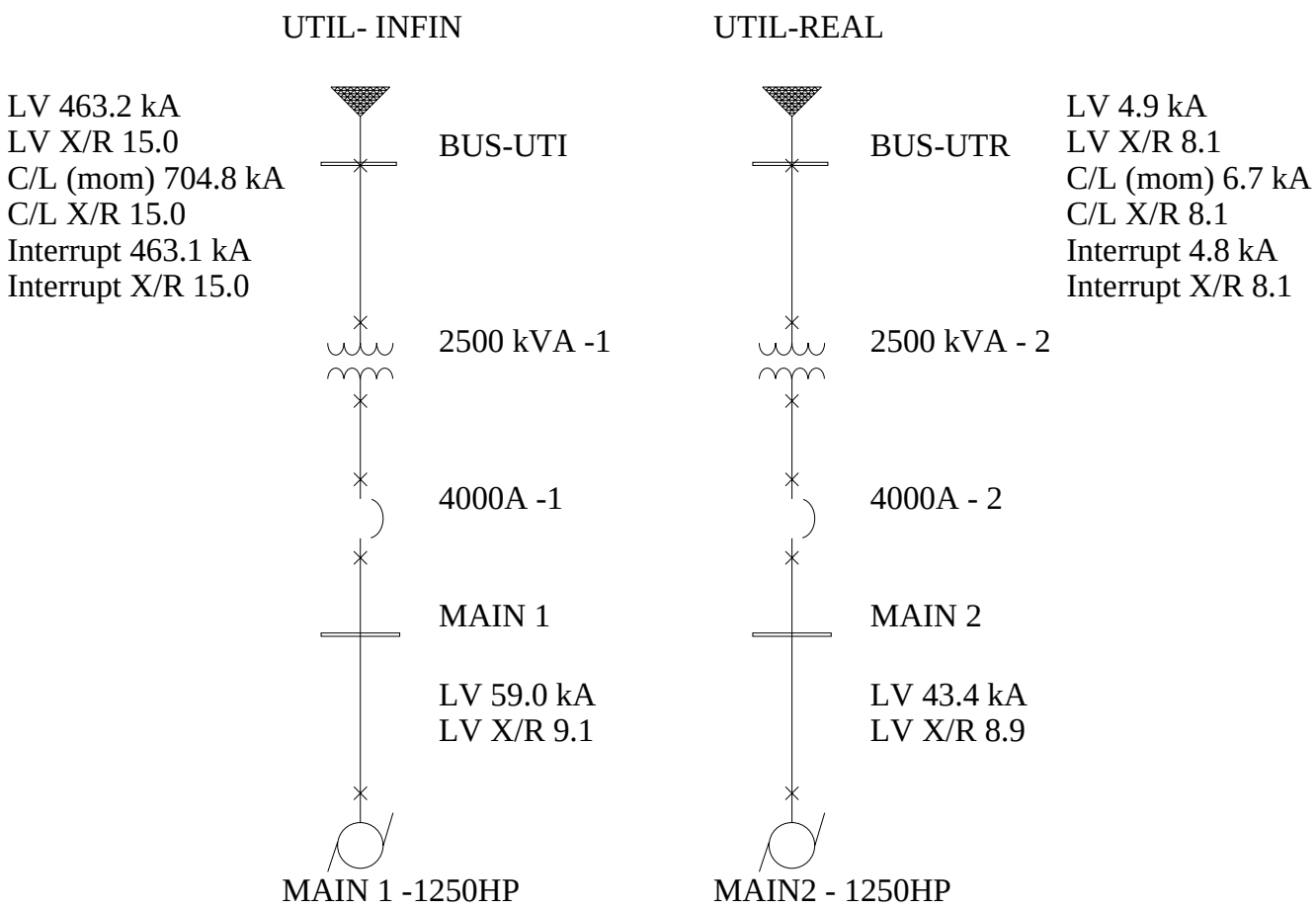
One Iteration

1 **Collect system and installation data**
2 **Determine system modes of operation**
2 **Determine bolted fault current**
3 **Determine arcing fault current**
4 **Find protective device characteristic and arc duration**
5 **Document system voltages and equipment class**
6 **Select working distances**
7 **Run the Calculations**

Source: IEEE 1584

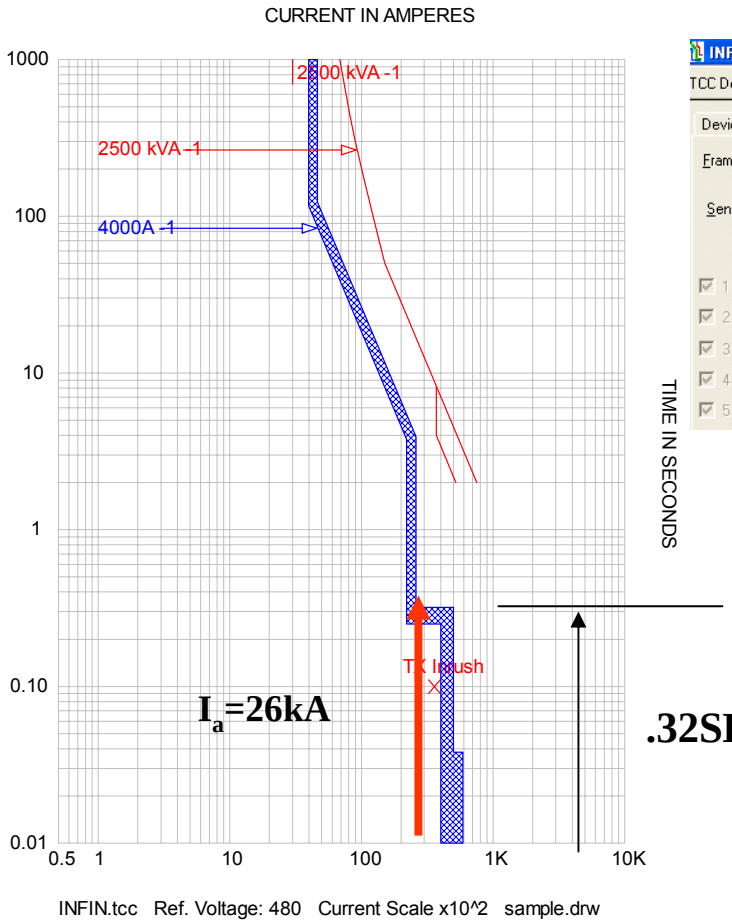
Case History #1

Infinite Bus versus Actual Available Fault Current

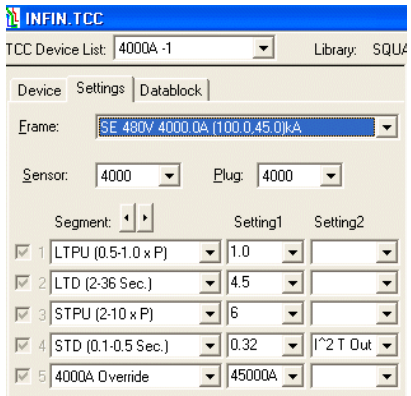


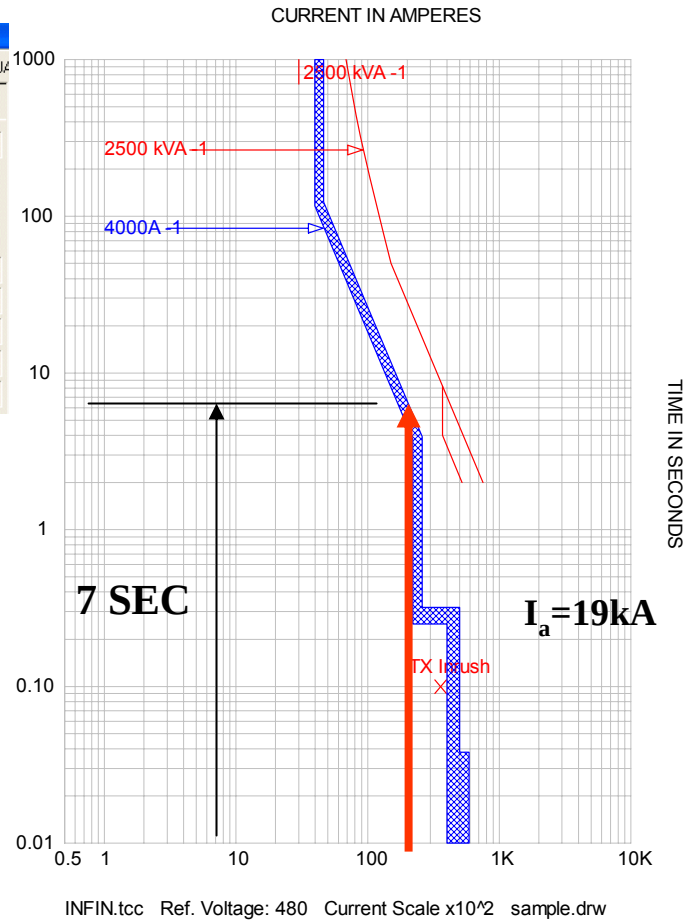
Case History #1

Infinite Bus versus Actual Available Fault Current



Infinite Bus

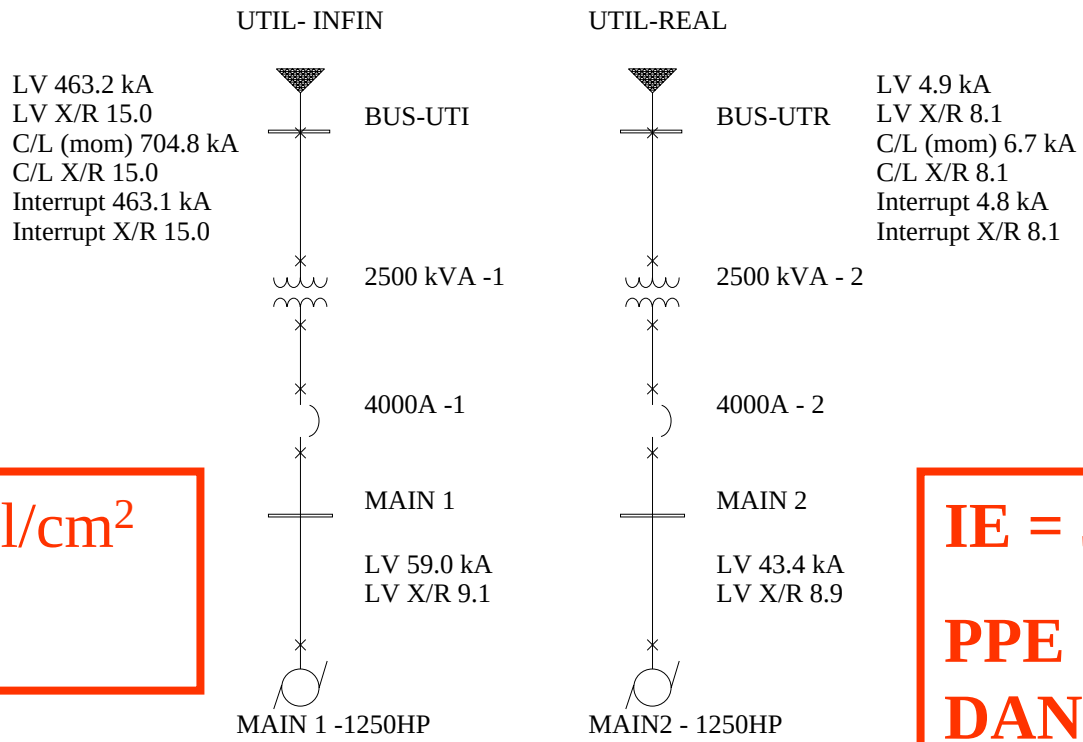




Real Values

Case History #1

Infinite Bus versus Actual Available Fault Current



IE = 33 cal/cm^2

PPE = 4

IE = 551 cal/cm^2

PPE = DANGEROUS

551/33 = 16.6

Practical Application

- Utility systems are dynamic
- Utility may change the parameters of power supply source at the distribution substation
- Customer may change the system arrangement in the plant

- Arc flash analysis is essentially a snap-shot of the system at the time of the study
- It will have to be repeated if the utility supply parameters change

- How do we resolve this problem?

Section 4

The Arc Flash Mitigation Problem

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A new Dimension in Protection

Traditional Method

- Preliminary short circuit analysis
- Design the system
- Goal is to maximize reliability

New Problem

- Arc flash exposure levels may be unacceptable to the end user

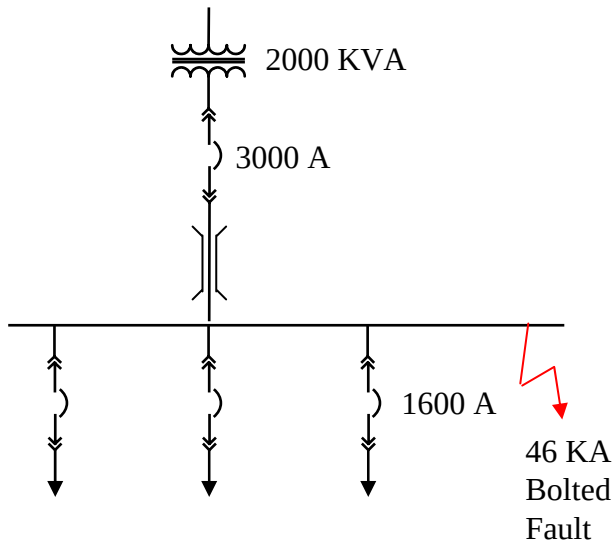
The Compromises

- Compromise between protection and reliability
- But the best protected system may have unacceptable Arc Flash Exposure

Case History #2

46 kA, 3ph. Bolted Fault on Unit Substation Bus

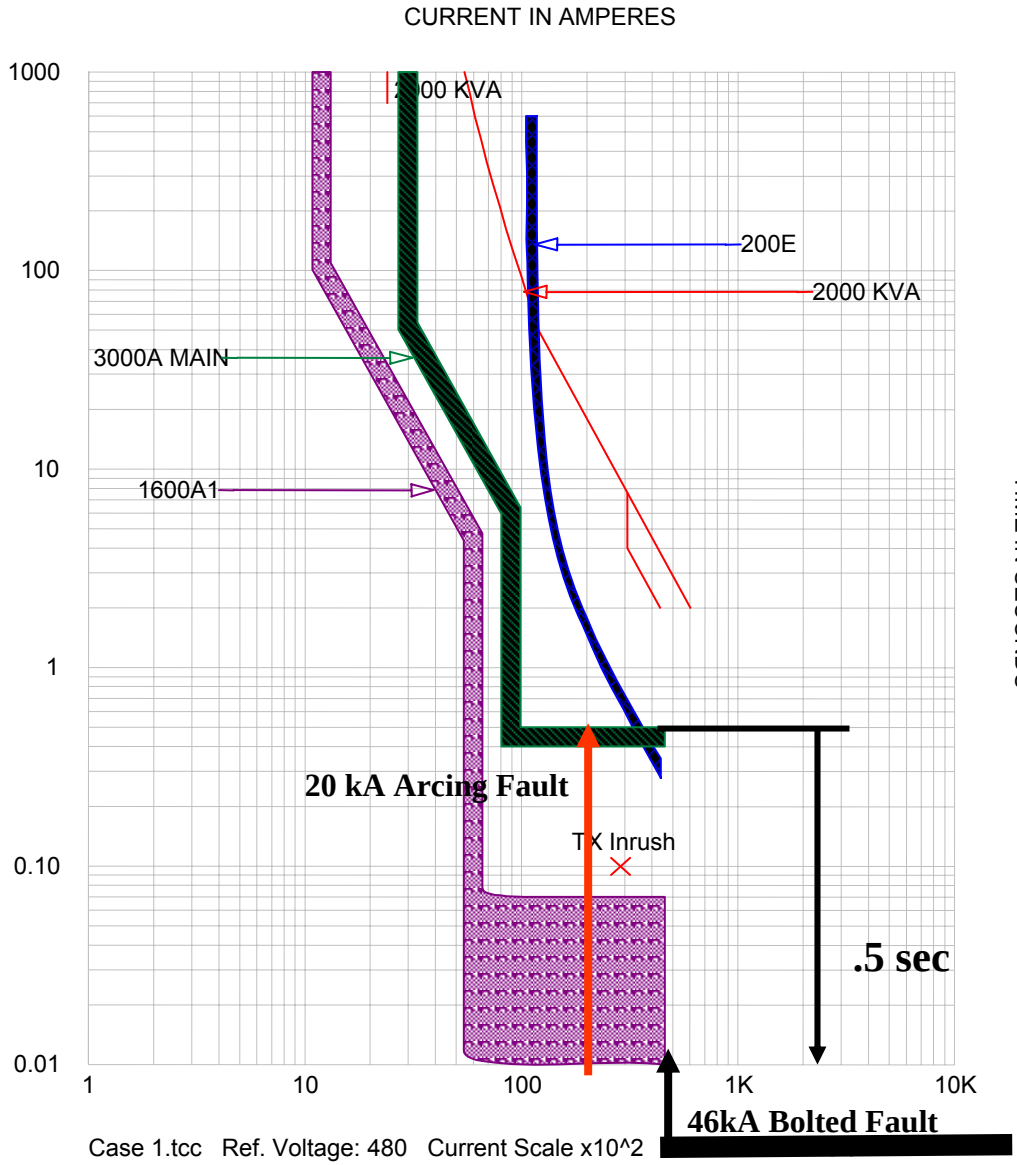
- Main Breaker does **not** have Instantaneous
- Primary Transformer Fuse is Available
- 2000kVA Transformer, 5.75% Z

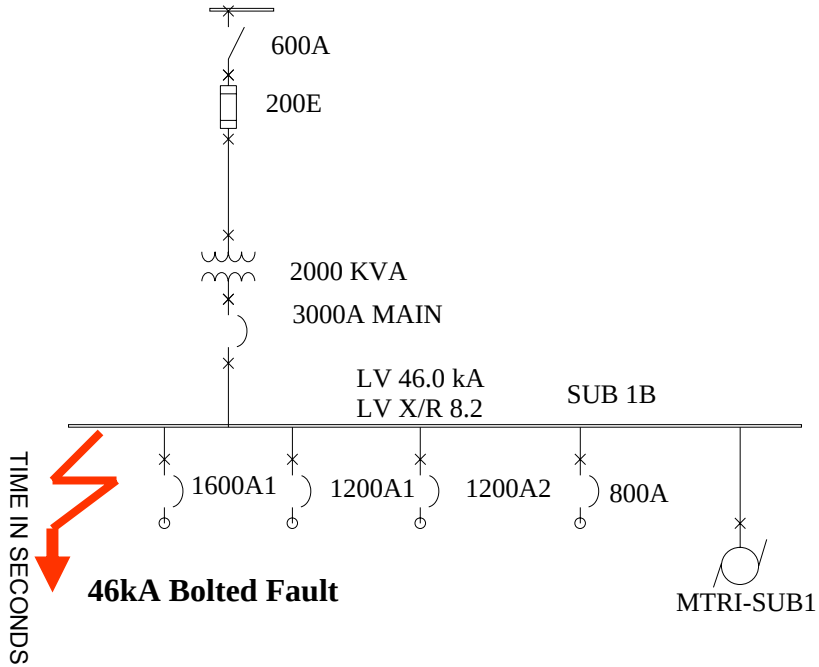


Questions:

1. How long does it take for Main breaker or Primary fuse to clear ?
2. What is Incident Energy ?
3. What is proper PPE ?

Case History #1

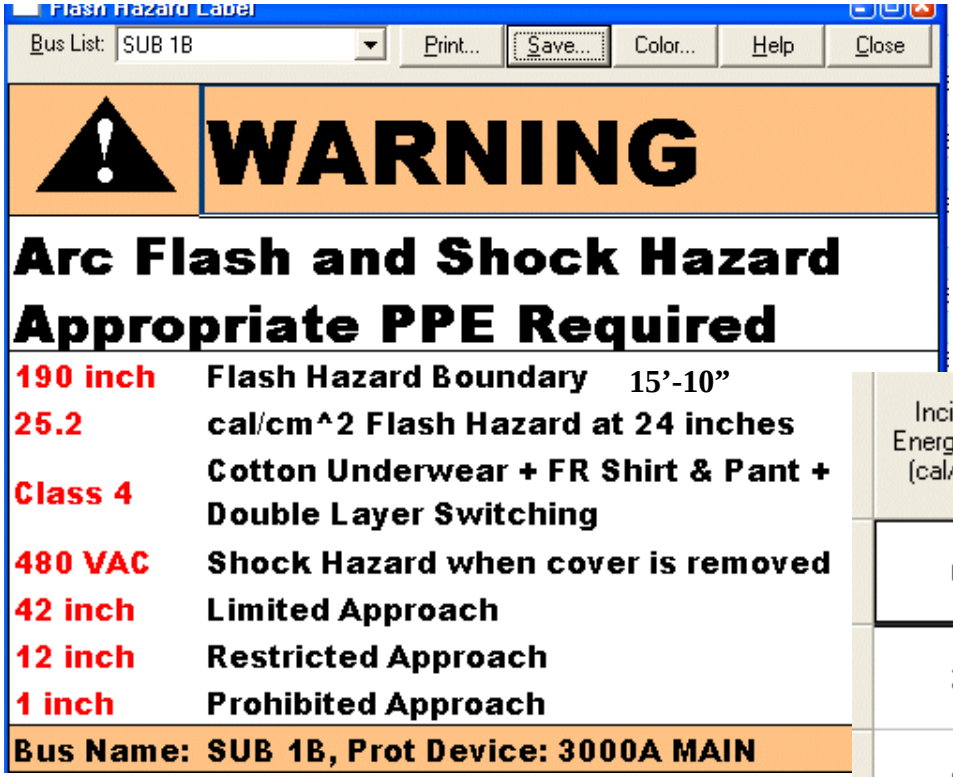




Arc Flash Data:

Time for breaker to clear 20kA Arcing fault = .5 sec (30 cycles)

Case History #1



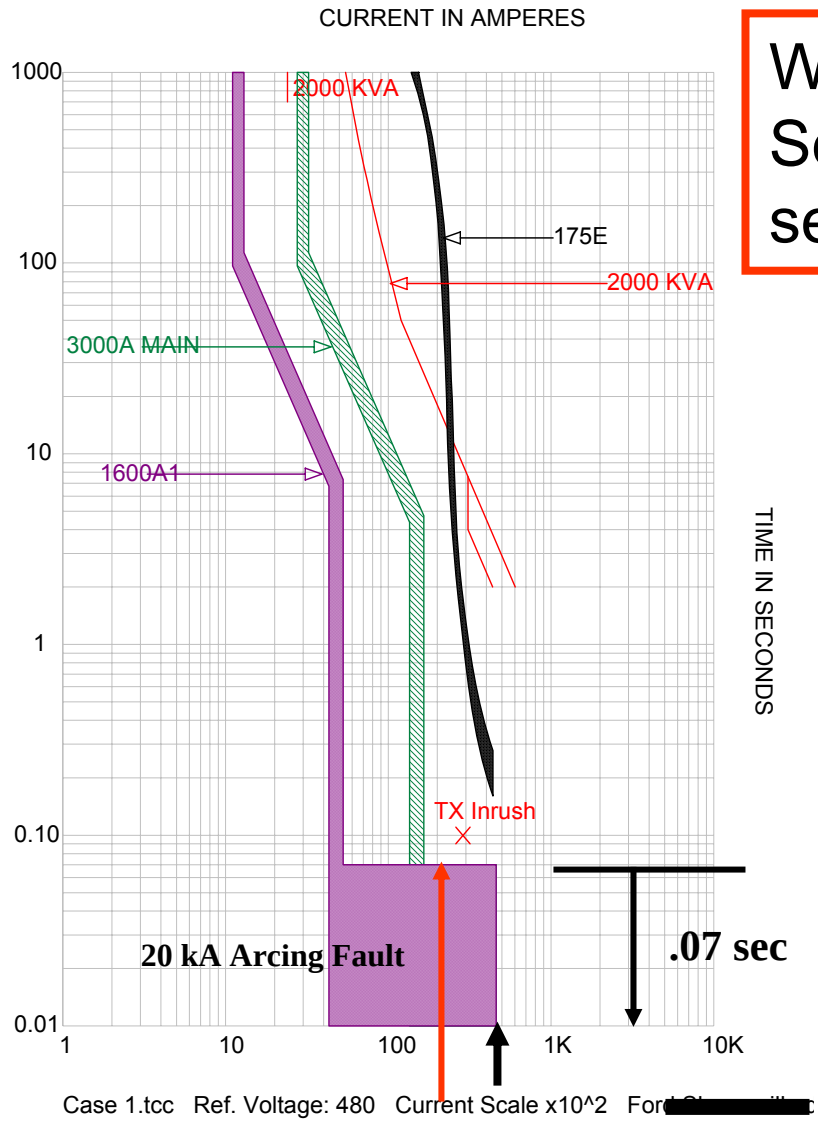
Arc Flash Label

Incident Energy Calculation Using IEEE 1584 Spreadsheets @ 24":

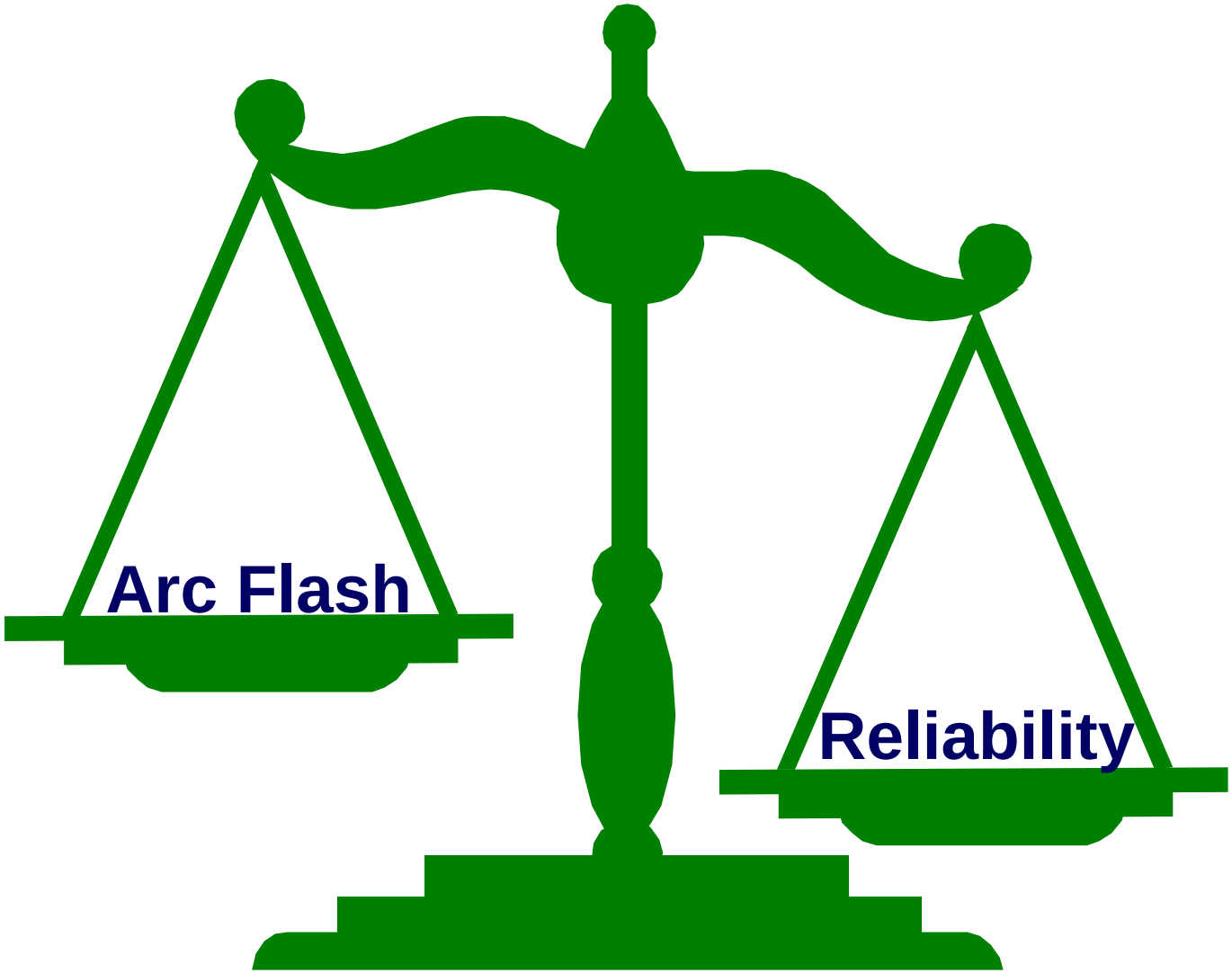
E = 25.2 cal/cm^2

Incident Energy From (cal/cm2)	Incident Energy To (cal/cm2)	FR Clothing Class No.	Clothing Description	Total Weight (oz/yd2)	Breakopen Threshold Energy (cal/cm2)
0	2	0	Untreated Cotton	4.5-7	N/A
2	5	1	FR Shirt & Pants	4.5-8	5
5	8	2	FR Underwear + FR Shirt & Pants	9-12	8
8	25	3	Cotton Underwear + FR Shirt & Pant + FR Coverall	16-20	25
25	40	4	Cotton Underwear + FR Shirt & Pant + Double Layer Switching Coat	24-30	40

Case History #1



What is PPE required if Main had Settings: STPU = 5X, STD = .1 sec, Inst = 5X ?


Arc Flash
Reliability

Section 5

Principles of Arc Flash Mitigation Engineering

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How Can you Reduce Arc Flash Energy?

You can not negate physical laws

- The Fundamentals
  - Review of PPE
  - Principles of mitigation
- Reducing Arc Flash Energy
  - Lowering device settings
  - Changing the device that controls arcing time
  - Specialized protective relaying
  - Active protection
- Separating the worker from the arc
  - IR window
  - Remote control of breakers
  - Active protection

Arc Flash Mitigation Misunderstanding

- Does not, repeat does not eliminate the need for arc flash PPE
- PPE also required for shock protection
- PPE required for arc flash may be reduced

Perception

Before

After

Reality?

Before

After

REVIEW: PPE

Category	Description	Minimum Rating (cal/cm^2)
0	Non-melting, natural fiber materials	1.2
1	FR shirt + FR pants	4
2	Cotton underwear + FR shirt + FR pants	8
3	(2) + FR Coverall	25
4	(2) + double-layer switching coat	40

Category 0

Category 2

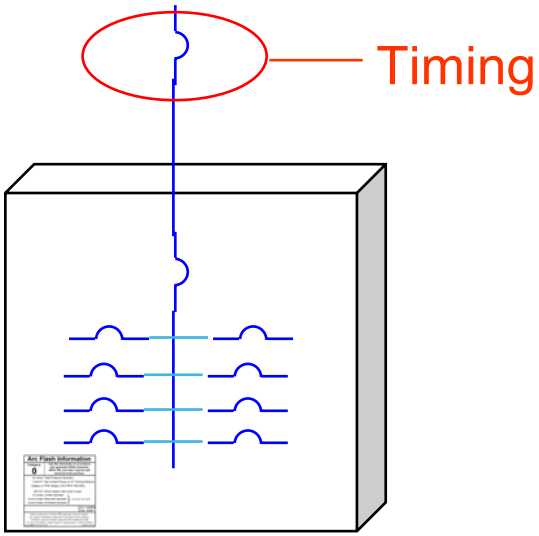
Category 4

NFPA 70E-2004

Mitigation Engineering- Step #1

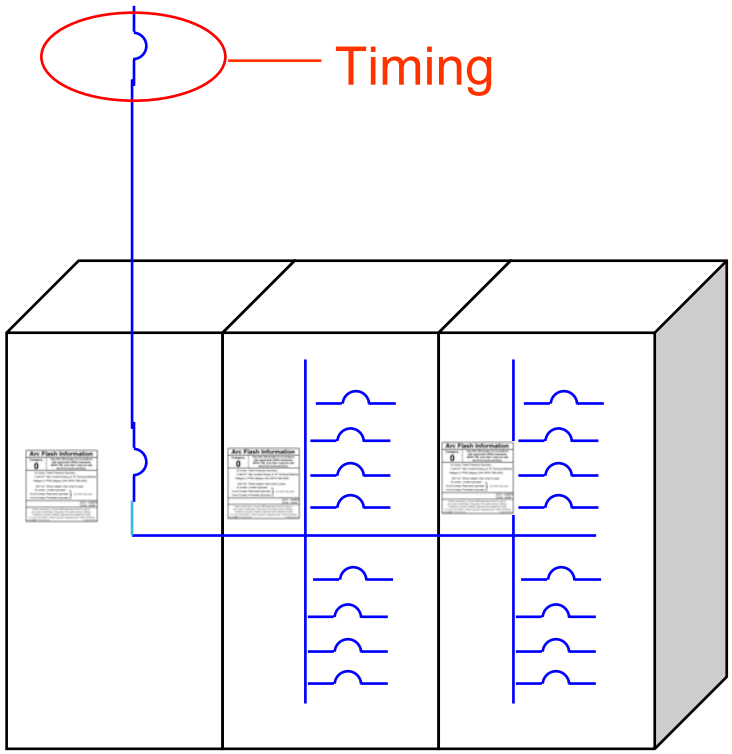
Determine which Device Controls the Arc

A Digression – Arc-Flash Labeling



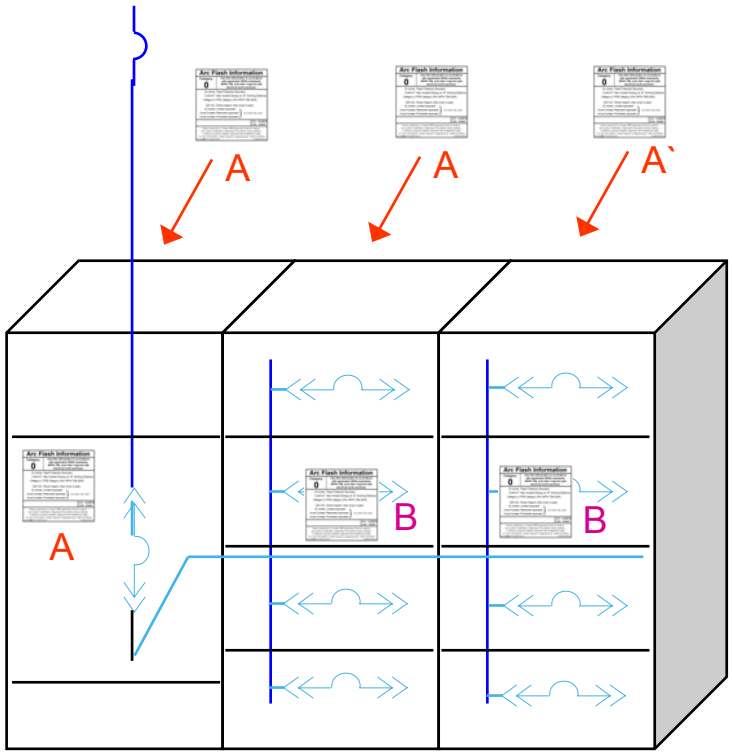
- Panelboard – open construction
  - Arc inside panelboard could propagate to line side of main breaker
- Timing characteristics of upstream breaker must be used for an arcing fault inside the panelboard
- One label is sufficient

A Digression – Arc-Flash Labeling



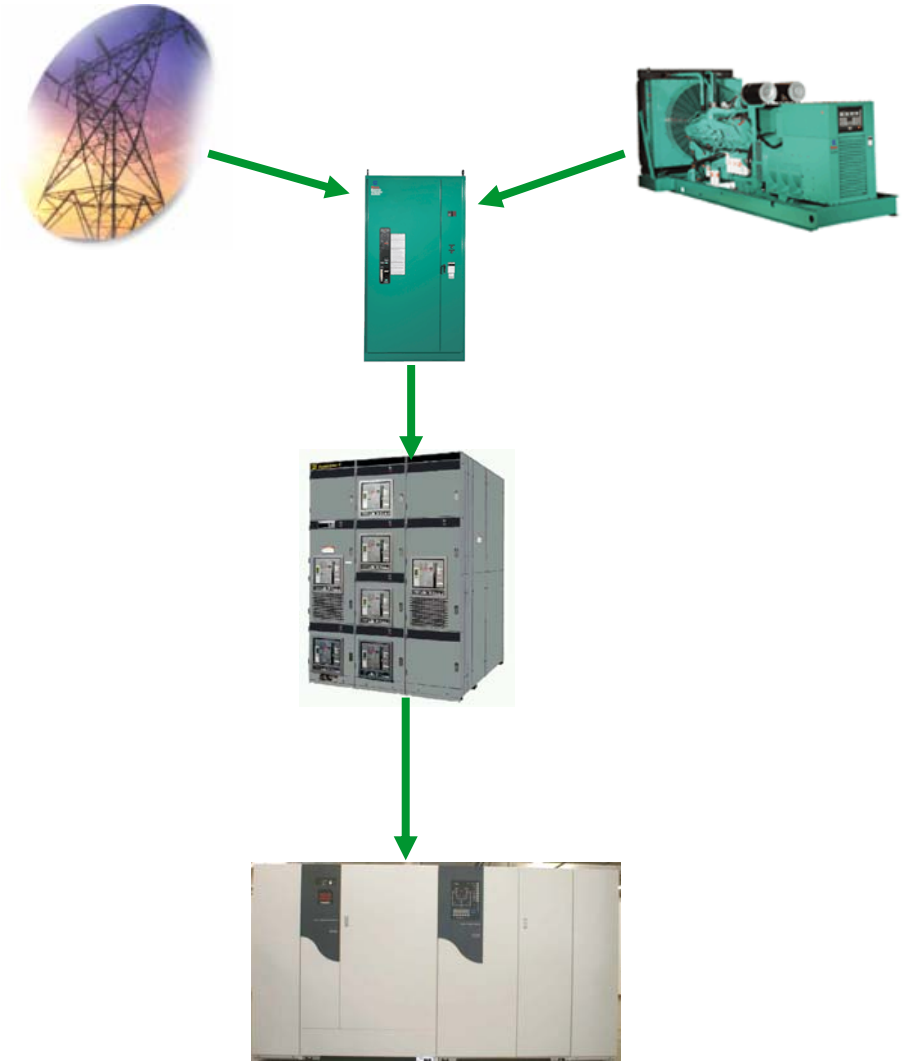
- Switchboard – Open Construction
- Timing characteristics of upstream breaker must be used for an arcing fault inside the switchboard
- One label is sufficient, typically with the same label applied to each section (possibly sides and rear also)

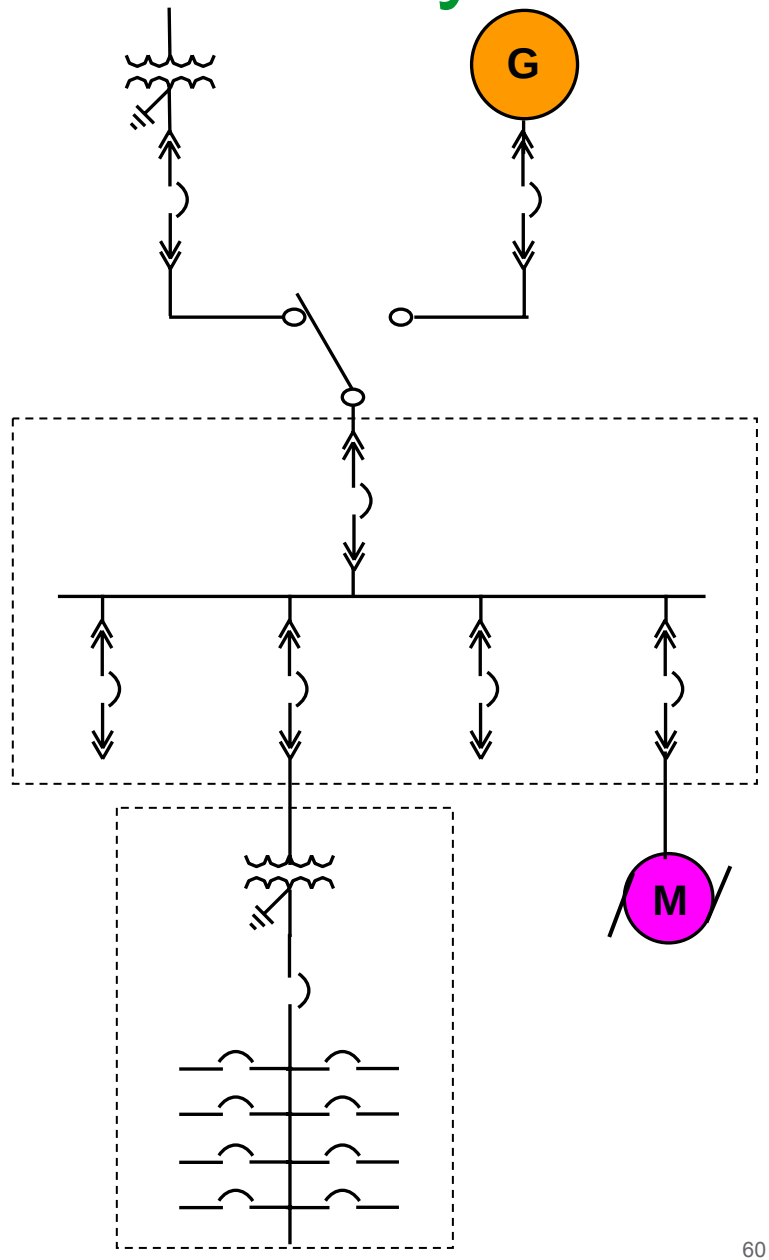
A Digression – Arc-Flash Labeling



- LV Switchgear – Circuit breakers are compartmentalized
- Timing characteristics of upstream breaker must be used for an arcing fault inside the main breaker compartment, incoming line terminals, load terminals
- But, for fault in a feeder breaker compartment, timing characteristics of main breaker in the switchgear may be used
- Two labels A and B

Example – Data Center Power System

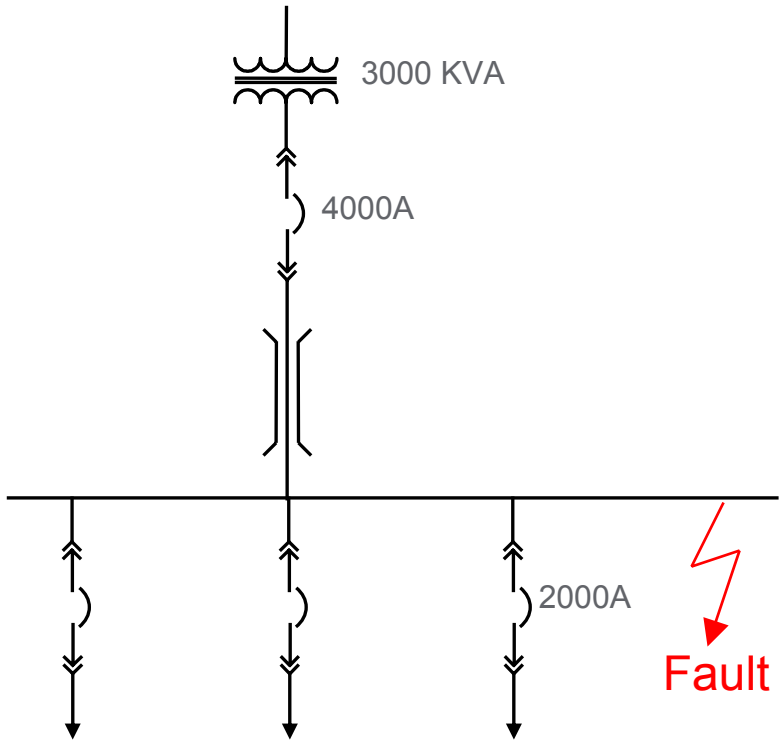




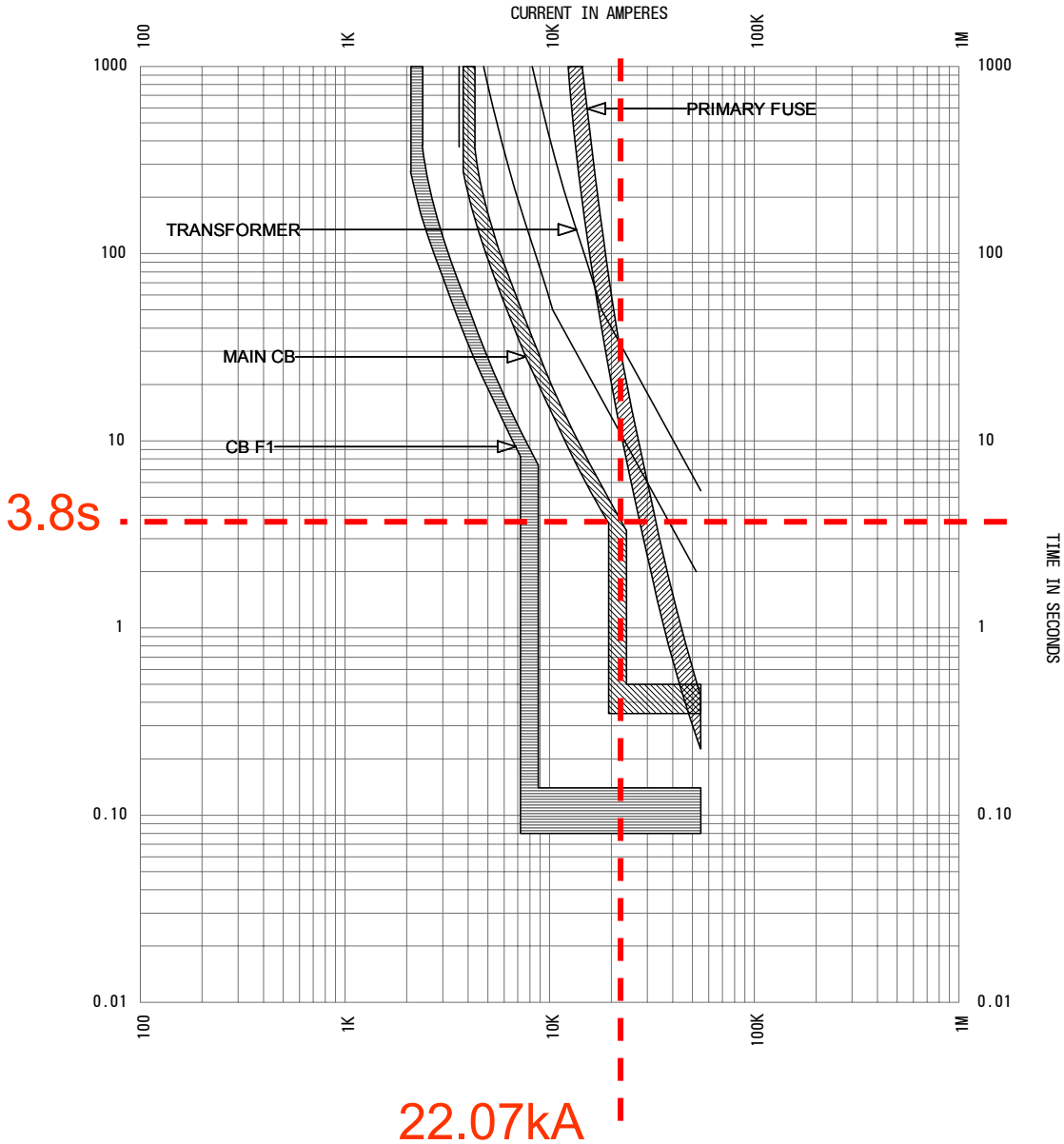
Axiom #1

- ARC-FLASH INCIDENT ENERGY (AND FLASH PROTECTION BOUNDARY) MAY BE REDUCED BY LOWERING ARCING TIME
  - LOWERING DEVICE SETTINGS – there is a limit to how much reduction can be made and still achieve “adequate” selective coordination.
  - CHANGING THE DEVICE THAT CONTROLS ARCING TIME – for example, using remote main.
  - SPECIALIZED PROTECTIVE RELAYING such as zone-selective interlocking or differential relaying – these operate independently of selective coordination, so selectivity is not reduced.
  - ACTIVE PROTECTION – detects an arc and acts upon it to minimize arcing time or nature of the arc.

Lowering Device Setting

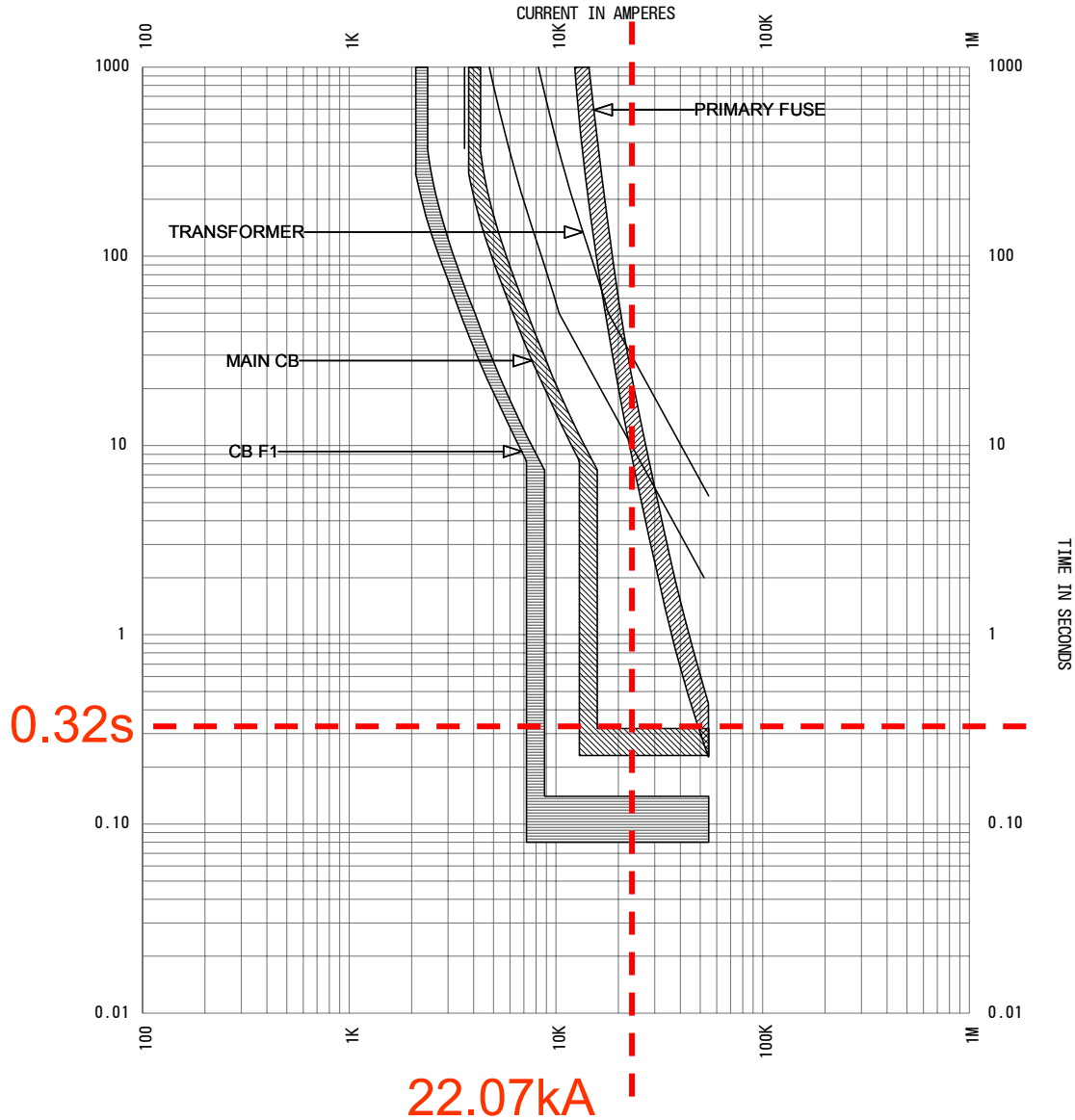


Lowering Device Setting



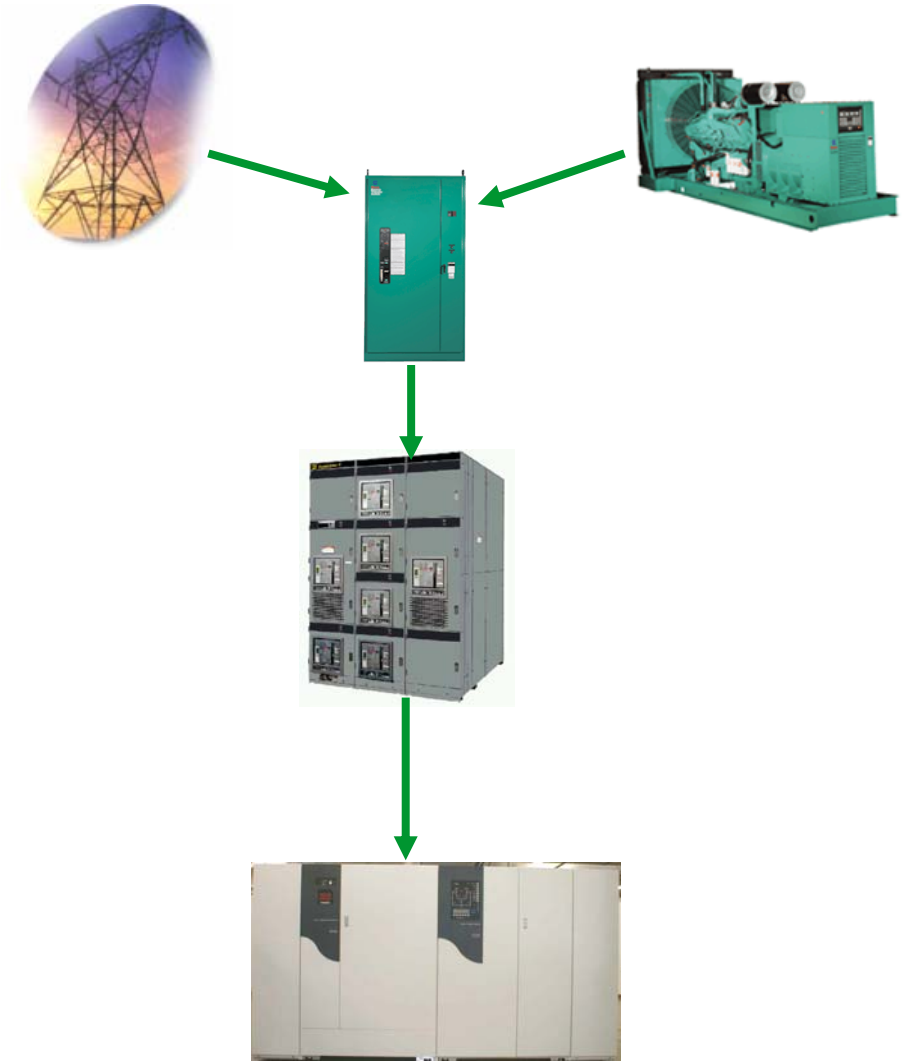
- System is selectively coordinated
- Calculated AFIE at switchgear main bus: 291 cal/cm^2 – not suitable for live work
- The reason: Calculated arcing current of 22.07kA yields an arcing time of ~3.8s

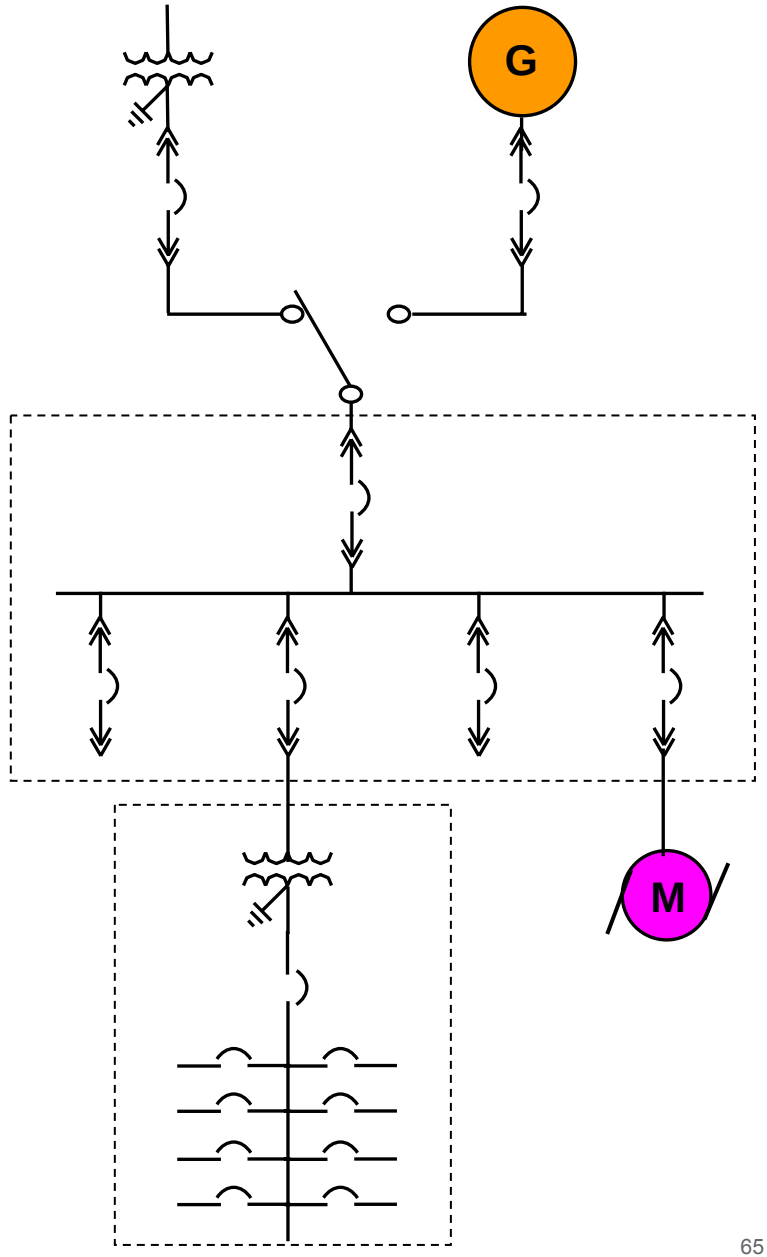
Optimal Settings Selection Technique



- Without sacrificing coordination, attempt to reduce short-time or instantaneous setting of circuit breaker so that short-time or instantaneous tripping occurs at calculated arcing fault current level
- In this case, AFIE is reduced to 28.9 cal/cm^2, hazard/risk category 4
- Drawback is that amount of AFIE reduction is limited by selectivity requirements

Data Center Example

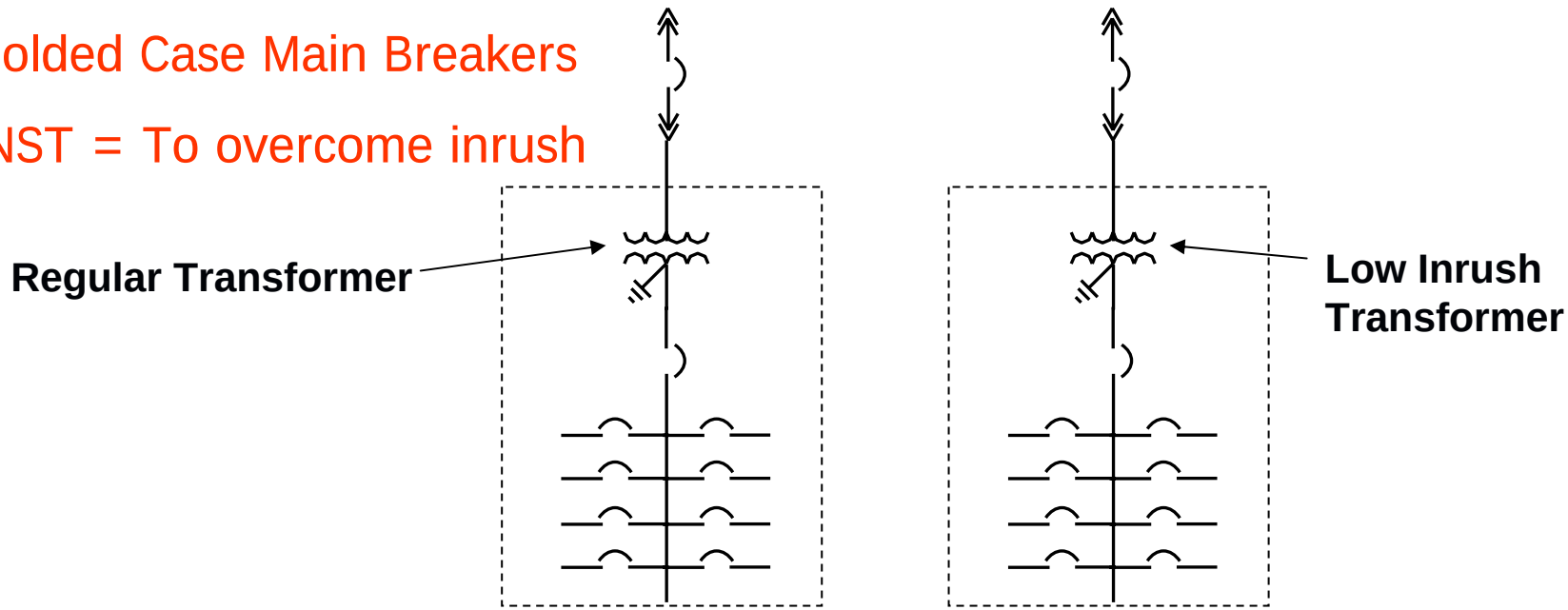




Data Center Example

What is PPE required for 208V Panels?

- 45 kA Available at 480V from substation
- Standard transformers 300 KVA
- Molded Case Main Breakers
- INST = To overcome inrush



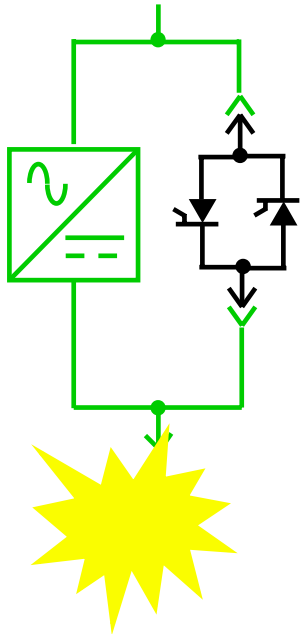
IE = 1591 cal/cm^2

PPE = DANGEROUS

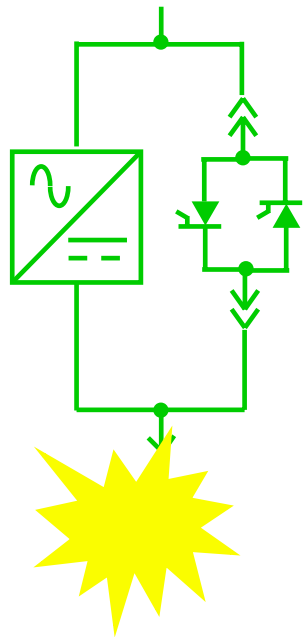
IE = 2.87 cal/cm^2

PPE = 1

Data Center Application
Issues with UPS Equipment



UPS can only produce
~3x its rating for bolted fault.
Arcing current will be less than bolted fault.
May burn longer due to CB inverse-time characteristics → more arc-flash energy



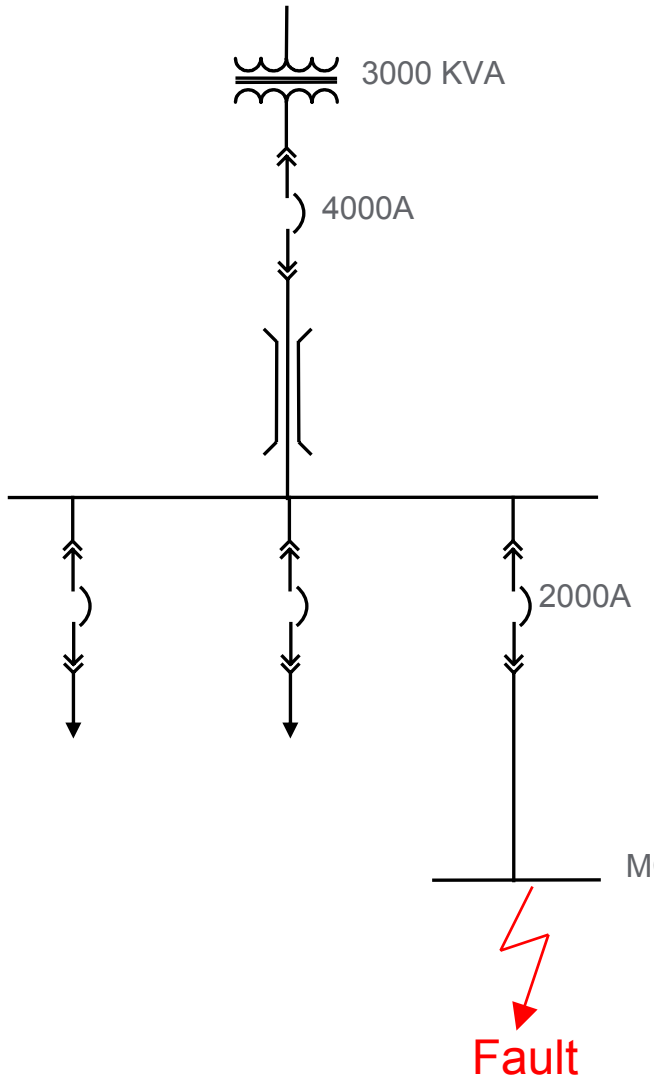
If arcing current exceeds UPS time-current threshold, it will pulse the static bypass switch – this will allow utility/generator to source fault current in parallel w/UPS
Larger arcing fault → shorter clearing time

Axiom #1

- ARC-FLASH INCIDENT ENERGY (AND FLASH PROTECTION BOUNDARY) MAY BE REDUCED BY LOWERING ARCING TIME

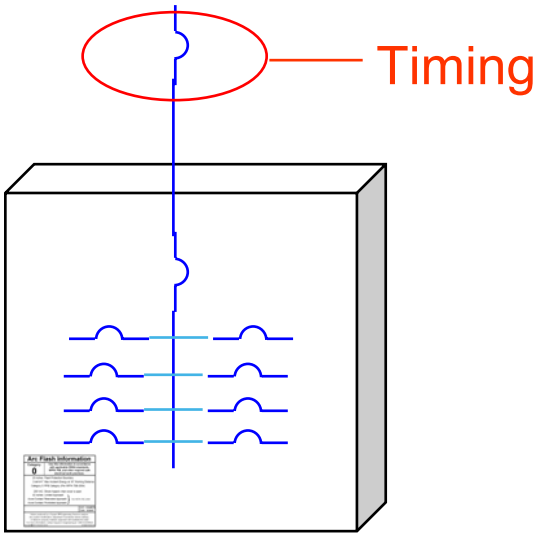
✓
- LOWERING DEVICE SETTINGS – there is a limit to how much reduction can be made and still achieve “adequate” selective coordination.
- CHANGING THE DEVICE THAT CONTROLS ARCING TIME – for example, using remote main.
- SPECIALIZED PROTECTIVE RELAYING such as zone-selective interlocking or differential relaying – these operate independently of selective coordination, so selectivity is not reduced.
- ACTIVE PROTECTION – detects an arc and acts upon it to minimize arcing time or nature of the arc.

Upstream Device is Key



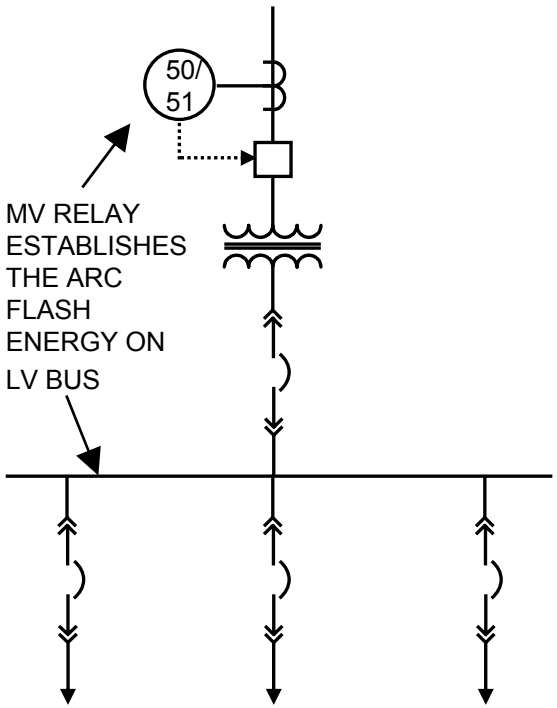
- The arc flash energy on the MCC is controlled by the branch breaker in the upstream switchboard

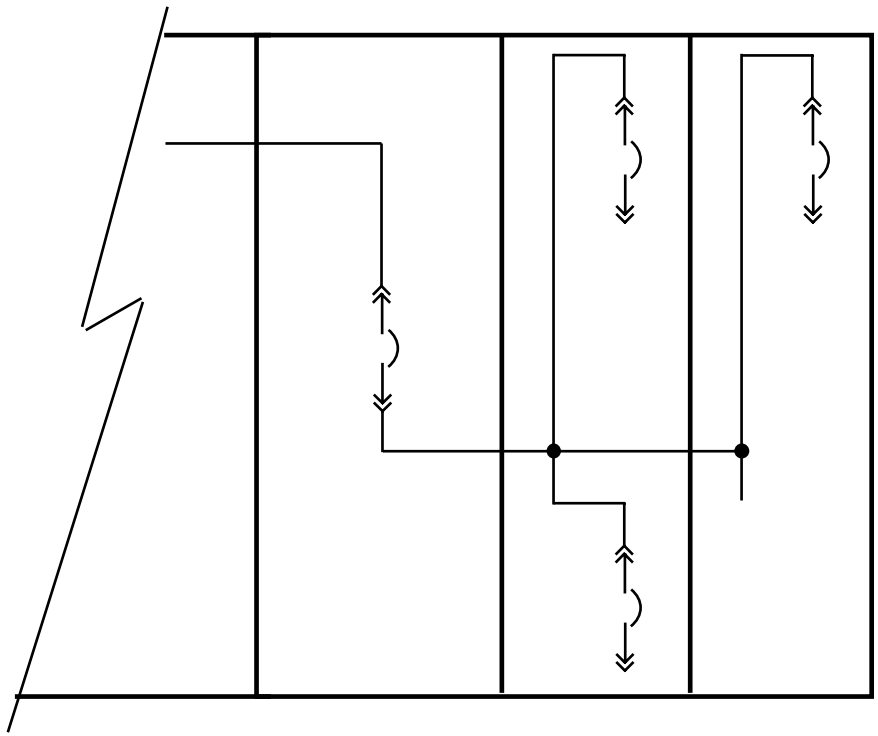
Refresher – Upstream Device is Key



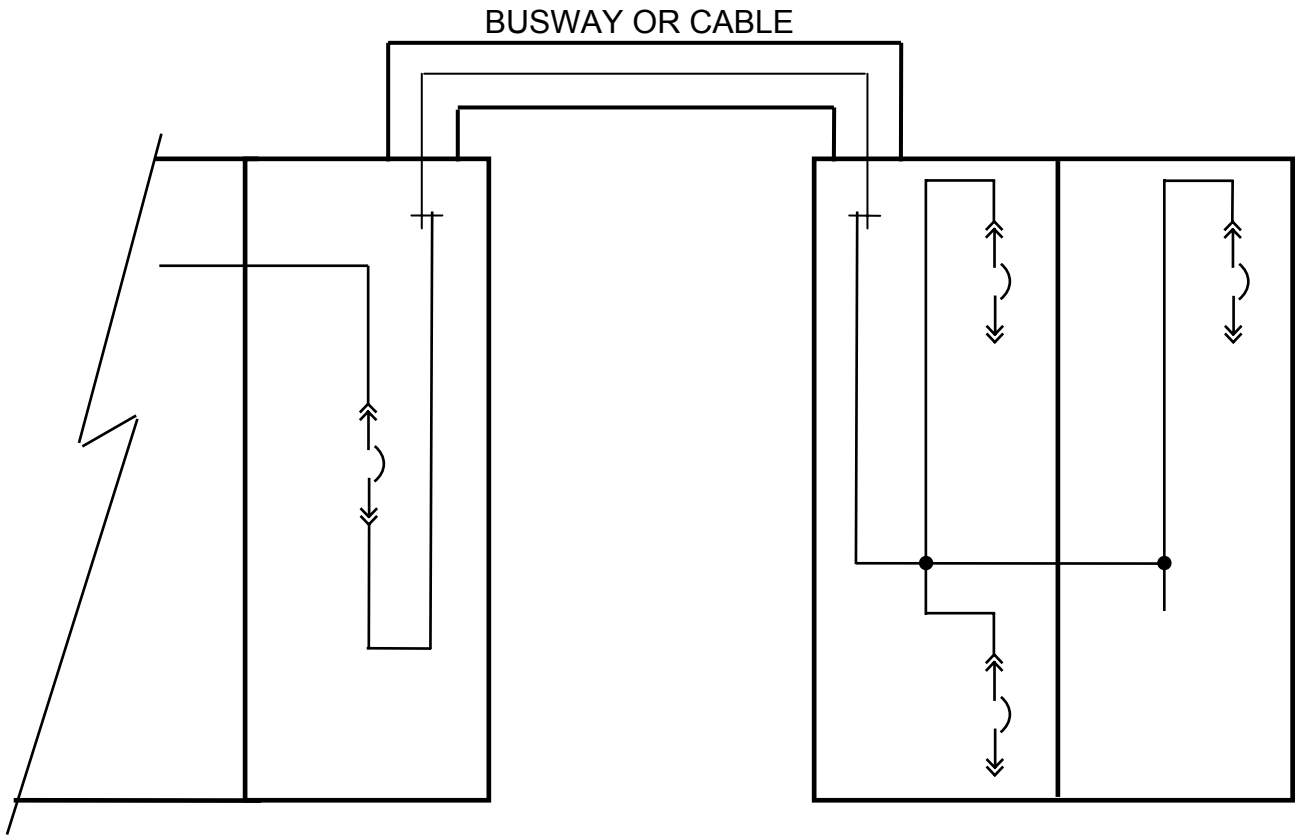
- Upstream device controls the arc flash energy
- At first glance this seems like a disadvantage
- Could we use the upstream device to our advantage?

The Upstream Device Controls the Energy

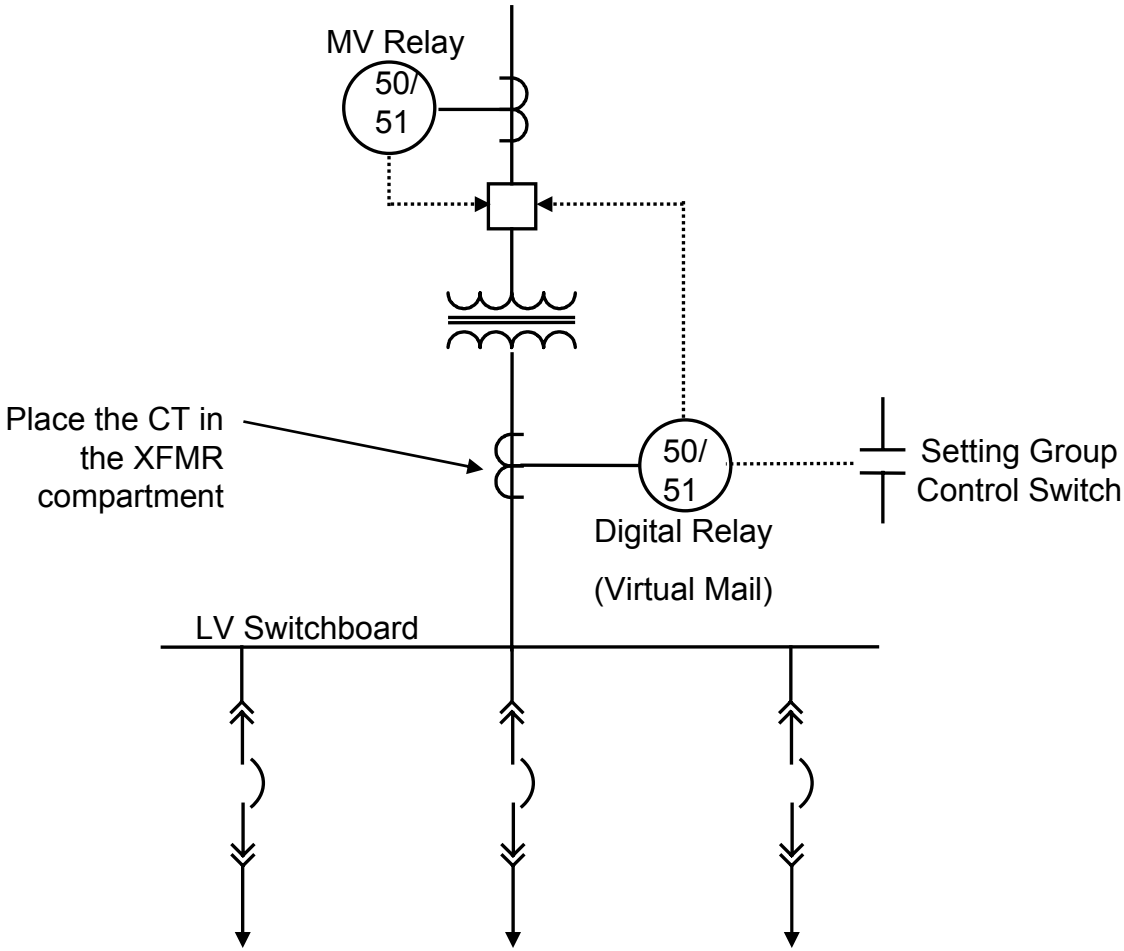




Separating The Upstream Device



The Virtual Main
Leveraging the Upstream Device



Virtual Main Setting Group A:

- Transformer overload protection
- To coordinate with branch breakers
- To coordinate with upstream device

Virtual Main Setting Group B:

- Fast trip at the arcing current level

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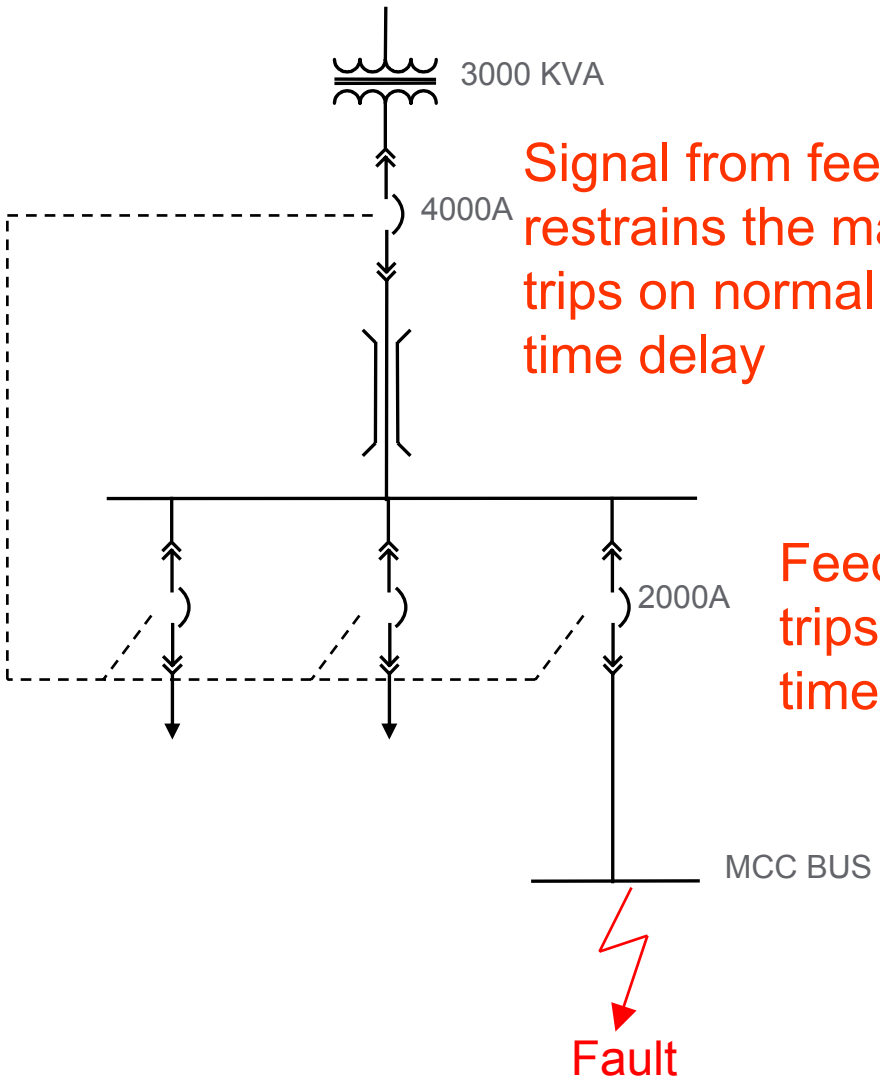
Zone Selective Interlocking (ZSI)

How does it work?

- Originally developed to limit fault damage
- Requires circuit breakers on at least two different levels (main/feeder, for example) to have ZSI-capable trip units
- Whenever a trip unit sees a fault, it sends a restraint signal upstream

Fast-Tripping Scheme (ZSI)

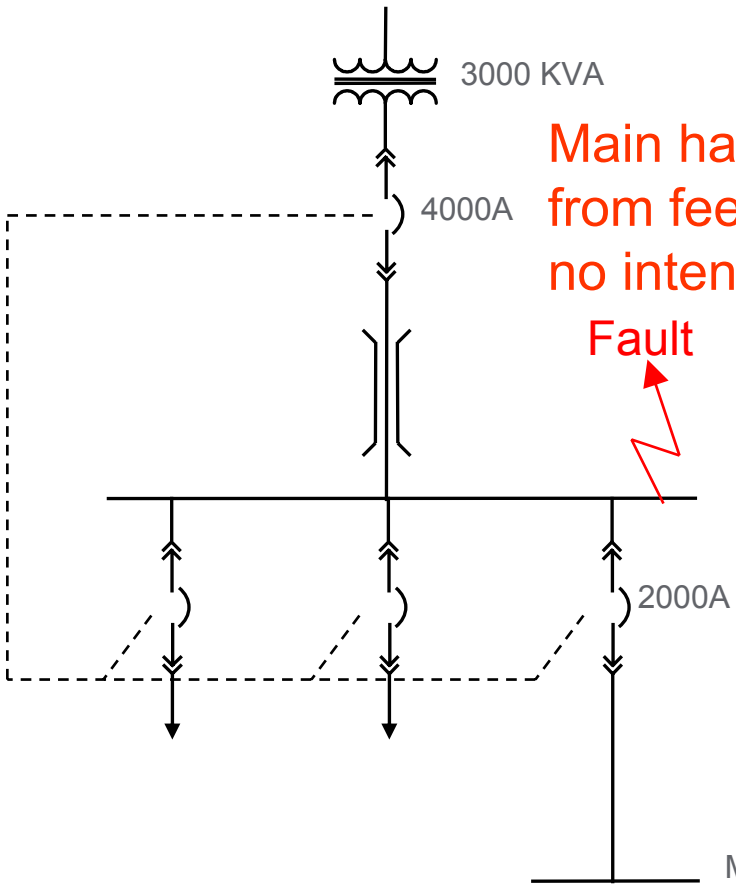


Signal from feeder restrains the main. Main trips on normal short-time delay

Feeder restrains itself, trips on normal short-time delay

Fault shown is assumed to exceed short-time pickup of main and feeder circuit breakers

Fast-Tripping Scheme (ZSI)

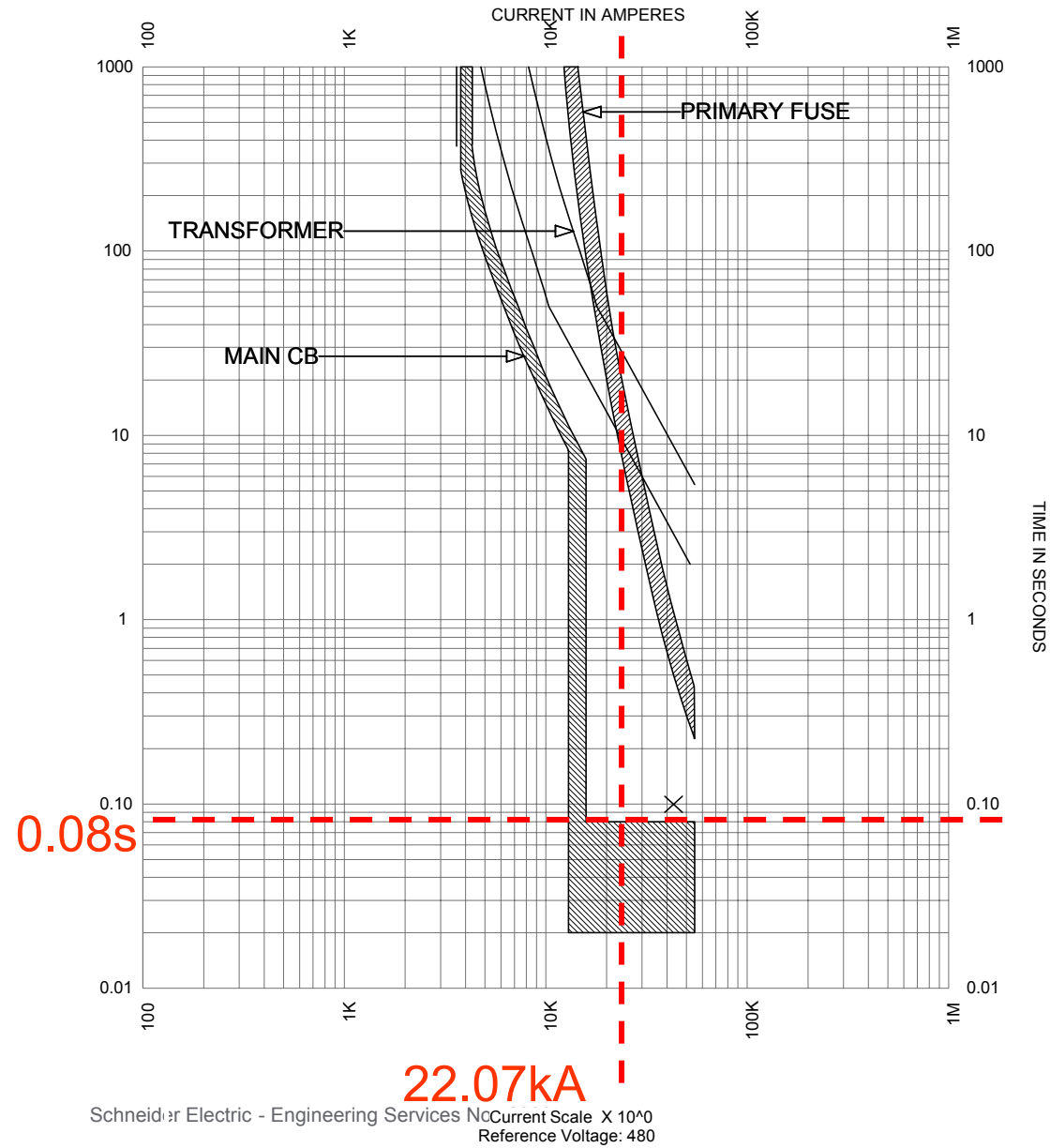


Main has no restraint from feeder, trips with no intentional delay

Fault

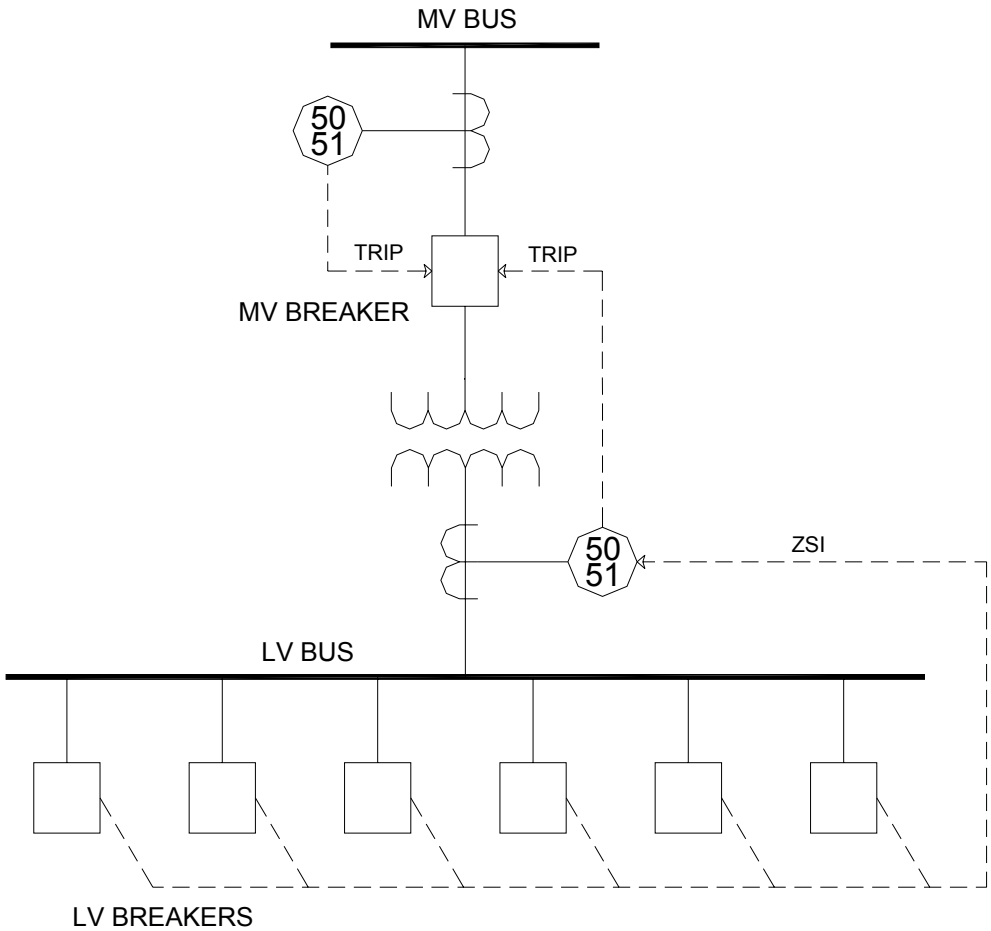
Fault shown is assumed to exceed short-time pickup of main circuit breakers

Fast-Tripping Scheme (ZSI)



- Set short-time delay for mains and feeders below calculated arcing fault level on main bus
- In this case, AFIE is reduced to 7.22 cal/cm2, hazard/risk category 2, without sacrificing coordination
- Some considerations:
  - Must have trip units with ZSI on at least two levels
  - Distance limitations for ZSI
  - Requires field testing

Virtual Main with ZSI



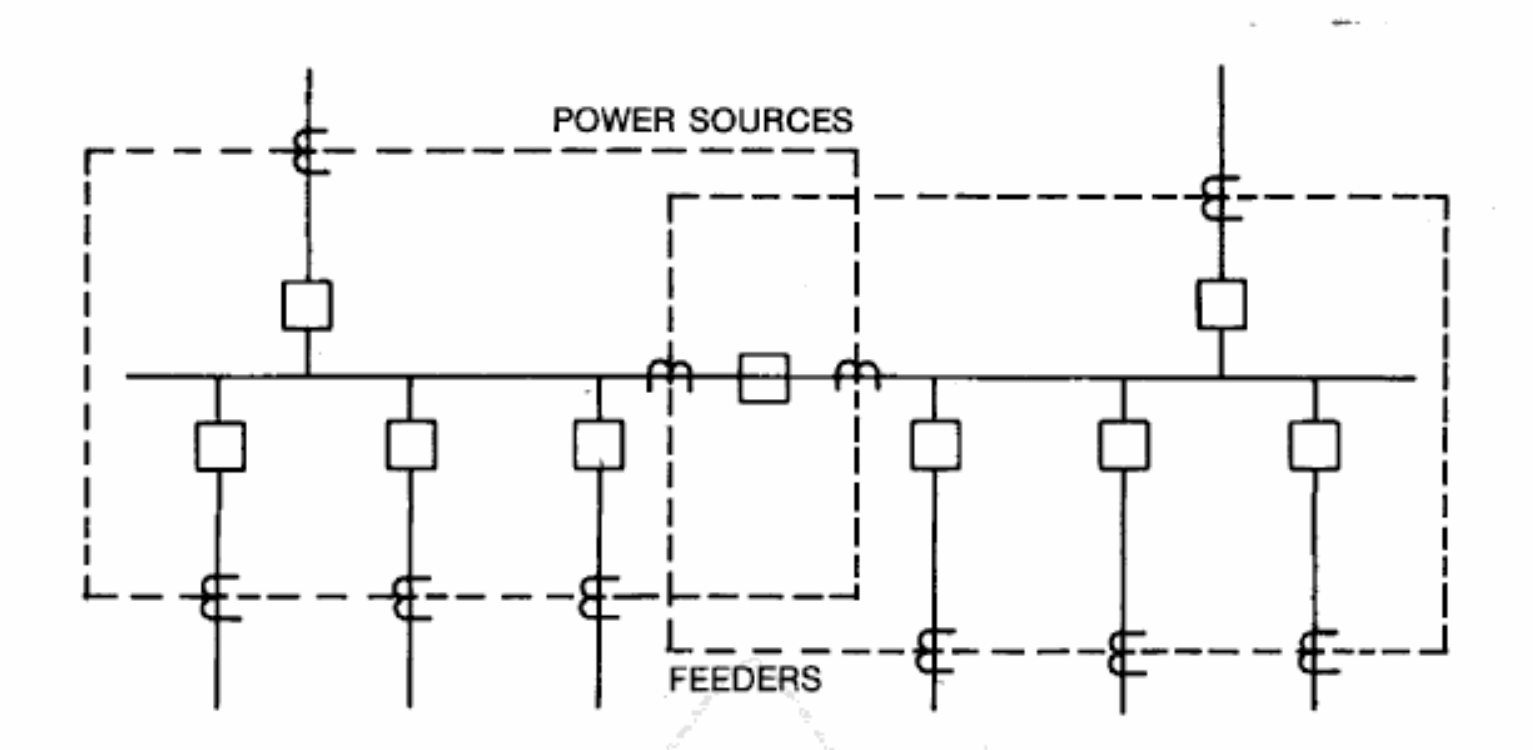
ZSI Considerations

- Must interlock all devices at same level in system
  - Otherwise, nuisance trip of feeder or main is possible
    - For example, not interlocking one feeder on switchboard where main and other feeders have ZSI
- Upstream instantaneous settings can interfere with operation of downstream ZSI
  - The trip curves on the upstream and downstream devices must be coordinated. ZSI does not eliminate the need for a coordination study
  - Just as any coordination study, the instantaneous setting on the upstream device makes coordination difficult

Bus Differential Protection

- Provides protection for buses and/or switchgear
- Favorable characteristics for arc-flash:
  - High-speed
  - Sensitive
  - Compatible with other types of relaying
- Sum currents into & out of “zone of protection”
  - Normally at or near zero (KCL)
  - Non-zero value indicates presence of fault

Sample Schematic



From IEEE Std. 242-1986 (Buff Book)

Bus Differential Protection

- Frequently used at 15kV, less so at 5kV, uncommon at 480V
- May be warranted in situations having:
  - High exposure to faults (outdoor or contaminated environment)
  - Need to prevent damage (extensive downtime)
  - High incident energy (relay coordination requirements lead to high arcing energy levels)
- Trips all relays connected to the bus

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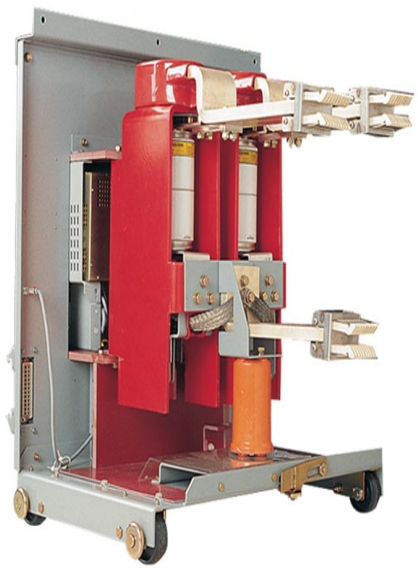
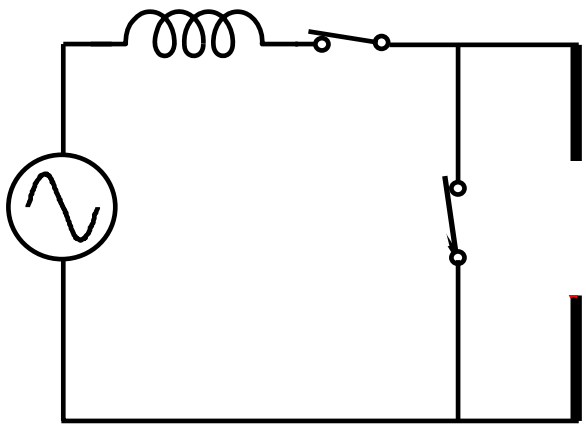
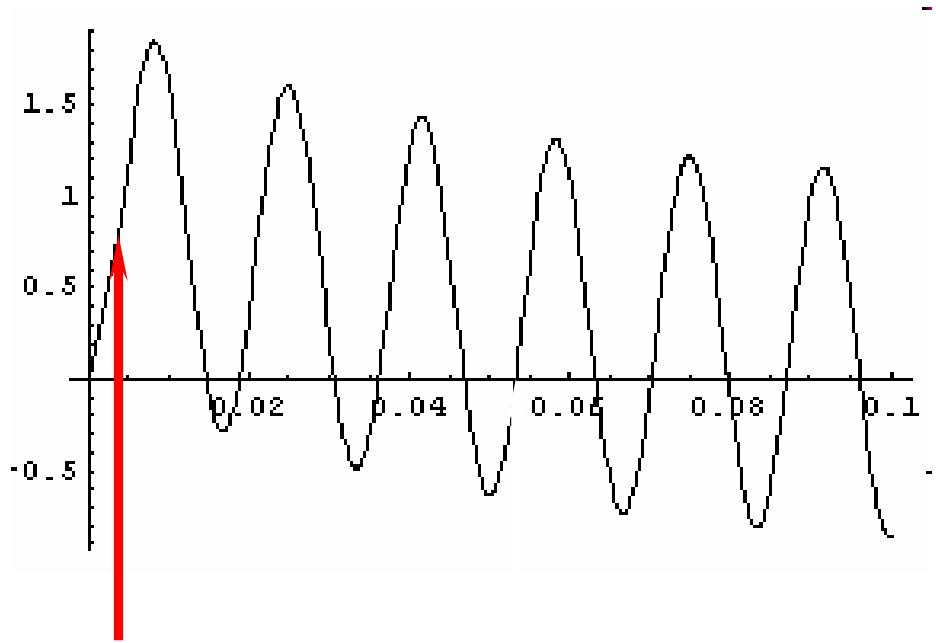
Axiom #1 - Active Protection

- Current sensor senses change in current using current transformers
- Optical sensors in each compartment look for light as evidence of arcing
- Both sensors give positive: close switch



Active Protection
How it Works



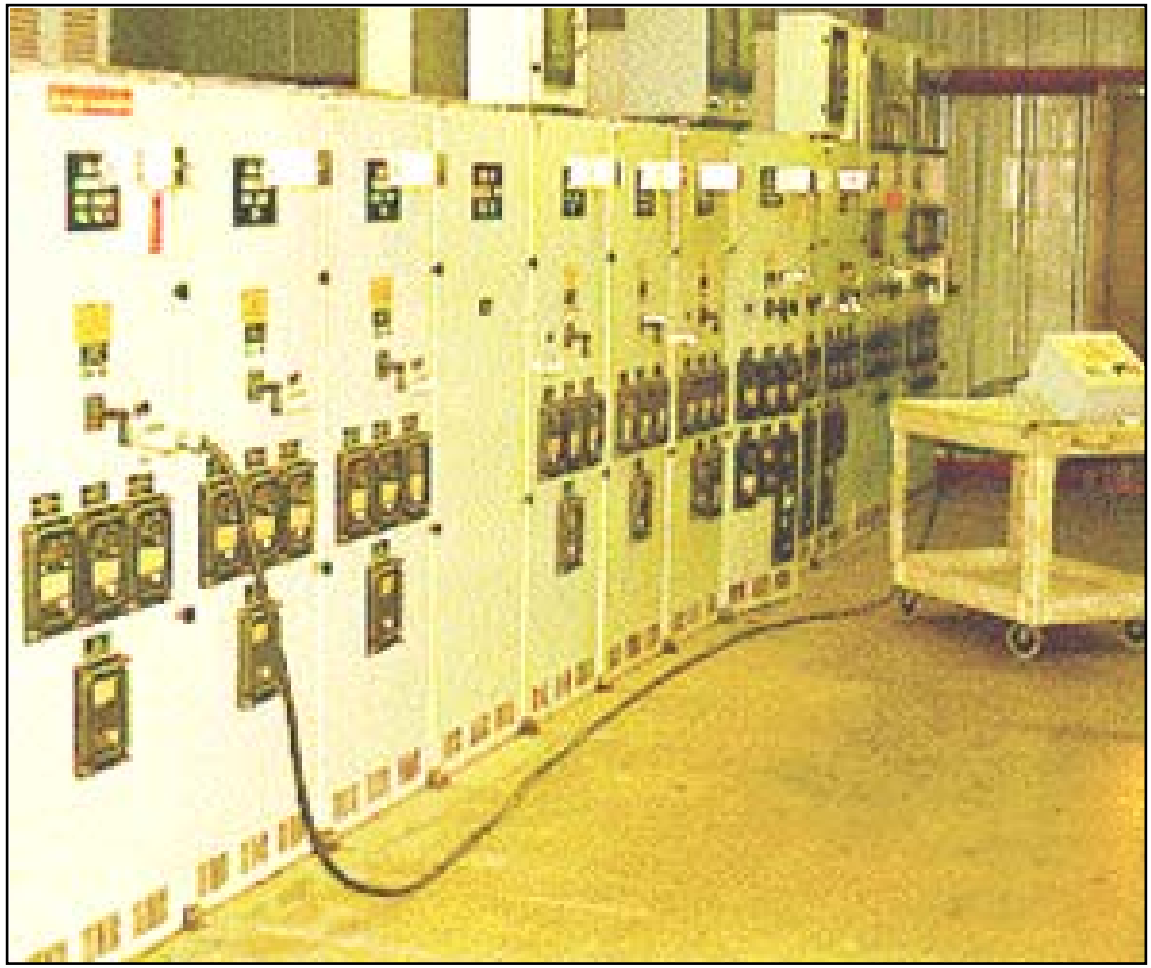


Axiom #2

- PROTECTION OF WORKERS CAN ALSO BE ACHIEVED BY SEPARATING THEM FROM THE SOURCE OF ARC – THE SEPARATION CAN BE BY INTERPOSING DISTANCE OR A PHYSICAL BARRIER
  - IR window
  - Remote control of breakers
  - Arc-resistant equipment

Axiom #2 - IR Window

Axiom #2 – Remote Control



Axiom #2 – Arc-Resistant