Tutorial B:
Conducting an Arc Flash Hazard Analysis to Determine the Maximum Likely Incident Energy in Plant Electrical Arcs; and Methods to Manage the Hazard

H Landis Floyd

Daniel R Doan

Craig M Wellman

Arc Flash Hazards Analysis

H. Landis Floyd

Tutorial Agenda

- **History, Research, Regulations - Lanny Floyd**
- **Incident Energy Assessment, Spreadsheet Use - Dan Doan**
- **Engineering and Administrative Controls, PPE - Craig Wellman**

Managing Arc Flash Hazards

- **How we got to where we are**
- **Impact of 2000 revision to NFPA70E**
- **Implementation tools**

DuPont
Arc Flash Injury Performance
1992 - 1999

- **148 Arc Flash Incidents**
- **21 Injuries**

- **1999**
  - **14 Incidents**
  - **4 Injuries**

Arc Flash Timeline

1968 Dow implements arc flash PPE program

1980 Published article on use of arc flash PPE

1981 Ralph Lee publishes theory for hazard calculations

1986 DuPont implements arc flash PPE program

1990 OSHA subpart S does not address arc flash details

Arc Flash Timeline

1994 OSHA 1910.269 addresses clothing hazards

1995 DuPont undertakes arc flash R&D

1995 ASTM Arc Test Method development

1995 NFPA70E defines arc flash boundary

1996 DuPont arc flash research published

Arc Flash Timeline

1997 DuPont protective clothing research published

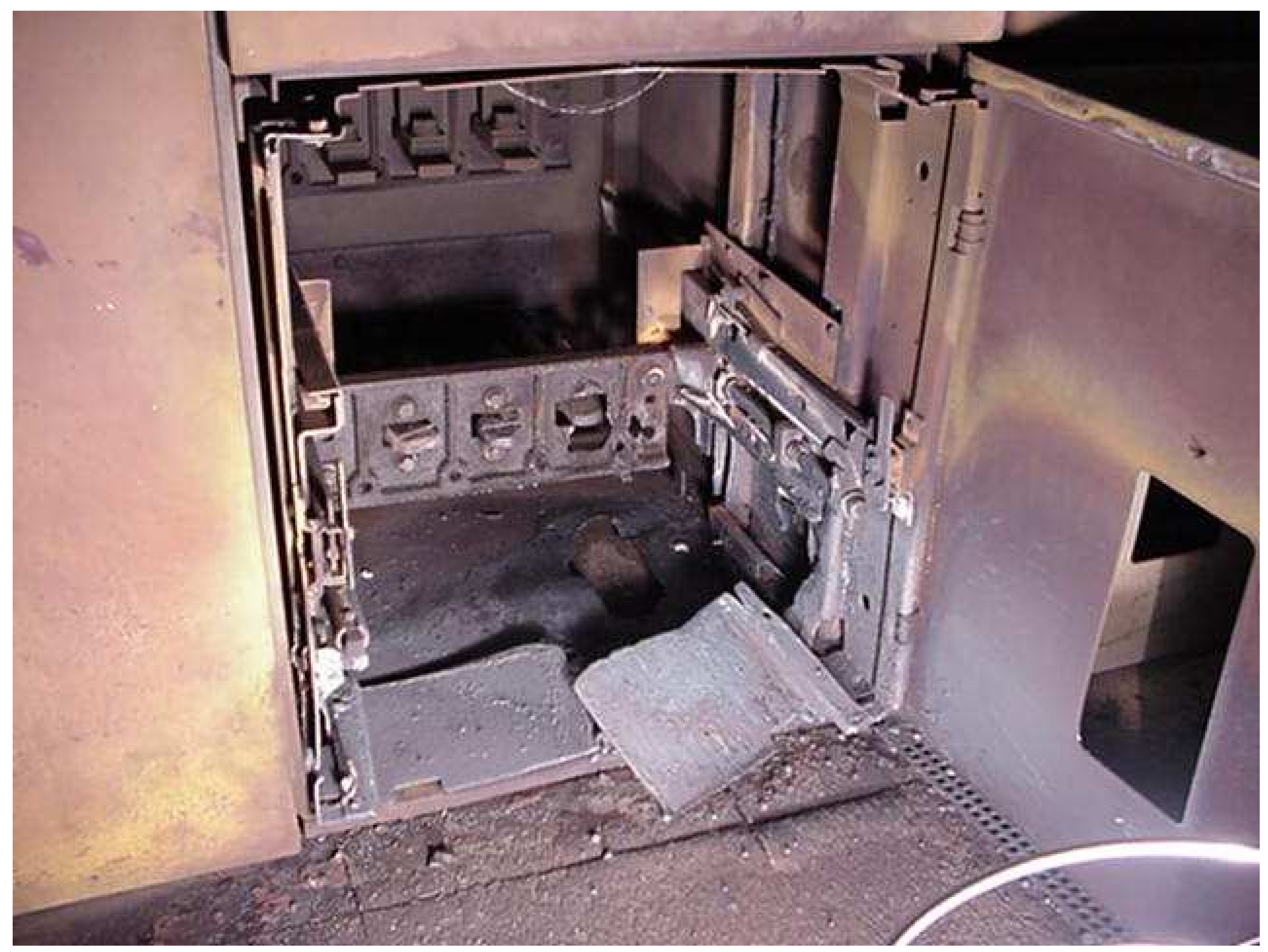
1998 ASTM standards for PPE testing

1999 Arc Flash rated PPE appears

2000 NFPA70E expands arc flash requirements

2002 NEC requires arc flash hazard warning

Bad things can happen.
An electric arc fault is a bad thing.



Why is Burn Injury a Major Concern?

- **The most severe burns are caused by ignited clothing, not by the original flash fire or electric arc exposure.**
- ***Clothed areas can be burned more severely than exposed skin.***

Clothed areas can be burned more severely than exposed skin

Injury Consequences

- ***Burn injuries can be fatal***
- Survival depends on age, health, exposure intensity and time, area of the body burned
- *Treatment of second degree burns requires weeks, for third degree burns it can be years*

Treating Burn Injury Is Very Expensive

- **The cost of treatment can exceed USD1,000,000 for a single case.**
- **Treatment can require years of skin grafting and rehabilitation.**
- **The victim may never be able to return to work.**

The Personal Cost Is Devastating

- **Due to disfigurement and intense pain the victim will often not want to live, depression is common.**
- **Children will likely not be able recognize the burn victim after the accident.**
- **The victim’s spouse will be traumatized, divorce is common.**

The Past:

- No standard methods to determine incident energy of a potential arc hazard
- No standard methods to rate PPE performance

Today:

Technology exists to determine incident energy and establish PPE ratings.

Standards

- **ASTM F1958-99** Standard Test Method for Determining the Ignitability of Non-flame-Resistance Materials for Clothing by Electric Arc Exposure Method Using Mannequins
- **ASTM F1959-99** Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing
- **ASTM F1506-01** Standard Performance Specification for Flame Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards
- **ASTM F1891-00a** Standard Specification for Arc and Flame Resistant Rainwear
- **NFPA70E-2000** Standard for Electrical Safety Requirements in Employee Workplaces

Incident Energy

- Energy Per Unit of Area Received On A Surface Located A Specific Distance Away From The Electric Arc, Both Radiant And Convective, in Units of cal/cm^2.

Cal/cm^2

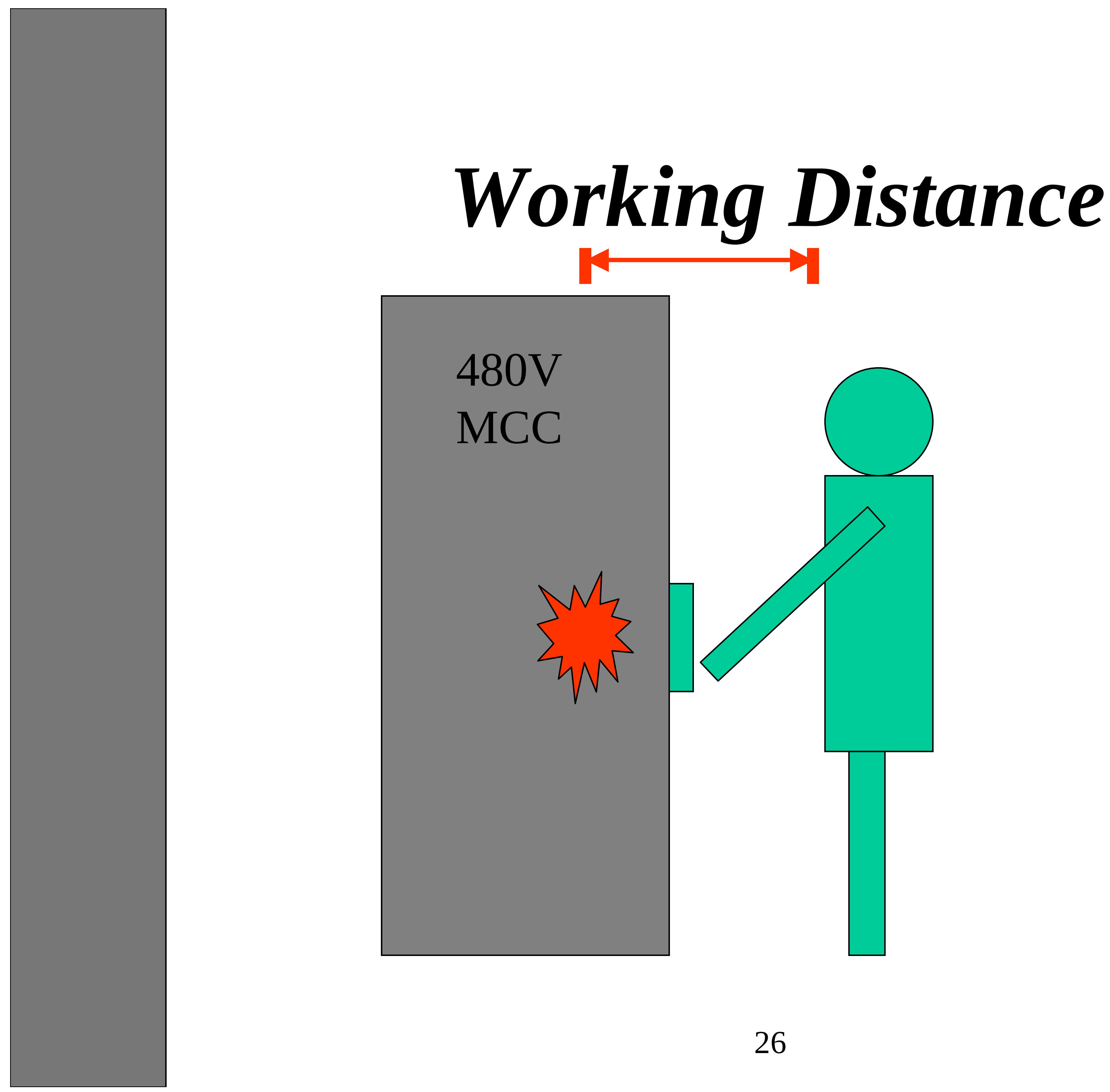
- **1.2 cal/cm^2 -** Second Degree Burn
- **3 cal/cm^2 -** 1% probability ignition of light weight cotton shirt.
- **6 cal/cm^2 -** Arc Rating of 1 layer 6 oz/yd^2 aramid.
- **32 cal/cm^2 -** Arc Rating of one layer 6 oz/yd^2 plus 4.5 oz/yd^2 aramid over a cotton T-shirt.

Highlights of changes impacting arc flash hazards PPE in the 2000 edition of NFPA70E

NFPA70E - 2000

Where it has been determined that work will be performed within the flash protection boundary, the flash hazard analysis shall determine, and the employer shall document, the incident energy exposure of the worker

This 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.


Working Distance
480V
MCC

Flame Resistant Clothing and Personal Protective Equipment shall be used by the employee based upon the incident energy exposure associated with the specific task.

Chapter 3
Protective Equipment

3-1 General.

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

3-3 Personal Protection Equipment.

3-3.1 General.

When an employee is working within the flash protection boundary, he/she shall wear clothing and other protective equipment in accordance with 2-1.3.3.3 of Part II.

3-3.2 Movement and Visibility

When flame resistant (or fire retardant treated) clothing is worn to protect an employee, it shall cover all ignitable clothing and shall allow for movement and visibility.

3-3.5 Body Protection

Employees shall wear clothing resistant to flash flame wherever there is possible exposure to an electric arc flash.

Such clothing can be provided as shirt and trousers, or as coveralls, or as a combination of jacket and trousers, or, for maximum protection, as coveralls and jacket. The higher degree of protection is provided by heavier fabrics or by layering combinations of natural fiber clothing resistant to electric arc flash (under layers of fire resistant clothing.)

Personal Protective Equipment

Flash Burn Protection

3-3.9.4.2 Outer Layers

Garments worn as outer layers over FR clothing, such as jackets or rainwear, shall also be made from FR material

3-3.9.4.3 Underlayers

Meltable synthetic fibers shall be avoided in fabric underlayers next to the skin. Garments worn as underlayers (underwear) that neither ignite nor melt and drip in the course of an exposure to the electric arc and related thermal hazard may provide additional thermal protection.

3-3.9.4.4 Coverage

Clothing shall cover potentially exposed areas as completely as possible.

3-3.9.4 Factors in Selection of Protective Clothing

Protective clothing includes shirts, pants, coveralls, jackets, and parkas worn routinely by workers who, under normal working conditions, are exposed to momentary electric arc and related thermal hazards. Arc and flame resistant rainwear worn in inclement weather are included in this category of clothing.

Clothing and equipment that maximize worker protection shall be utilized. Clothing and equipment required by the degree of exposure shall be permitted to be worn alone or be integrated with normal apparel. It shall cover associated parts of the body and all normal apparel that is not flame-flash resistant, while allowing movement and visibility.

All personal protective equipment shall be maintained in a sanitary and reliable condition. Individual protection items will normally be used in conjunction with one another as a system to provide appropriate protection.

3-3.9.4.1 Layering

FR and natural fiber garments shall be permitted to be used for a layered system for added protection. A typical layering system may include an undershirt, a shirt and trouser and coverall. Specific tasks may call for specific protection systems.

Table 3-3.9.3 Protective Clothing Characteristics

Typical Protective Clothing Systems			
Hazard Risk Category	Clothing Description (Number of clothing layers is given in parentheses)	Total Weight oz./yd^2	Minimum Arc Thermal Performance Exposure Value (ATPV)* or Breakopen Threshold Energy (E_{BT})* Rating of PPE cal/cm^2
0	Untreated Cotton (1)	4.5-7	N/A
1	FR Shirt and FR Pants (1)	4.5-8	5
2	Cotton Underwear plus FR Shirt and FR Pants (2)	9-12	8
3	Cotton Underwear plus FR Shirt and FR Pants plus FR Coverall (3)	16-20	25
4	Cotton Underwear plus FR Shirt and FR Pants plus Double Layer Switching Coat and Pants (4)	24-30	40

The 2002 Edition of the National Electrical Code will have this new requirement in Article 110.16

110.16 Flash Protection. Switchboards, panelboards, and motor control centers in other than dwelling occupancies, that 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.

FPN No. 1: NFPA 70E-2000, Electrical Safety Requirements for Employee Workplaces, provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment.

FPN 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.

Summary so far...

- **Arc Flash Hazard just recognized in last decades of the 20th century.**
- **Regulations and standards developed in the last decade.**
- **We have the tools to assess the hazard.**

Questions?

Arc Flash Hazard Analysis

Daniel R. Doan

Methods of Analysis

- 70E equations
- Arc Pro
- Use of C. L. Fuses to
  Reduce Arc Flash Energy
- Worksheet
- All rigorous methods require the same steps

Arc Flash Hazard Analysis

- **Review the steps for analysis**
- **Example**
- **Document Control**

Arc Flash Hazard Analysis

Step 1 Determine plant conditions

Step 2 Find short circuit fault values

Step 3 Find arcing fault currents in protection

Step 4 Find arc clearing times

Step 5 Determine working distance

Step 6 Calculate the incident energy

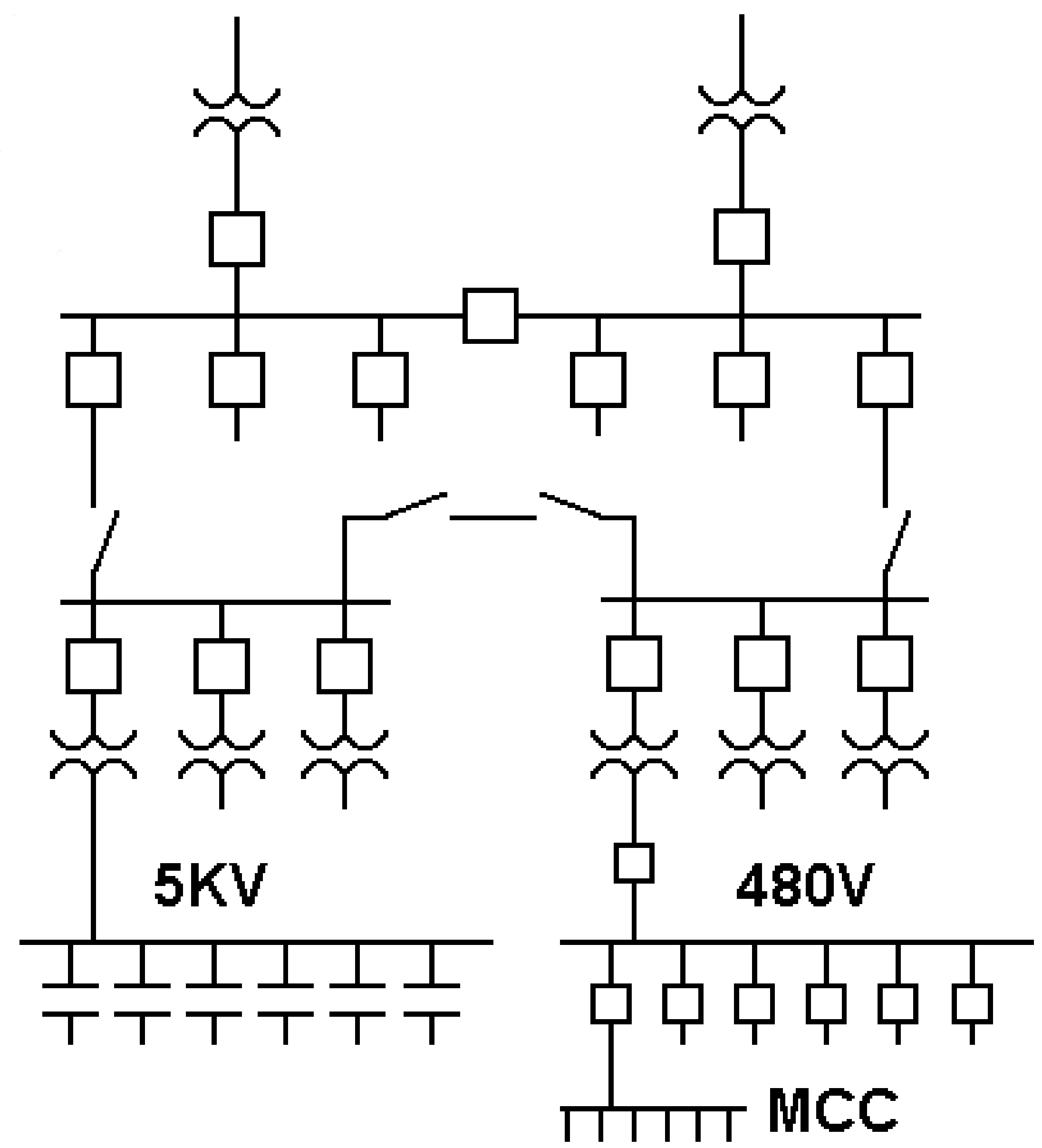
Arc Flash Hazard Analysis

Step 1 Determine plant conditions

Step 1. Determine plant conditions

- Review system single line and operation.
- List conditions, such as:
  - Normal operation
  - Loops closed
  - Transformers in parallel
  - Dual Feeds
- Do analysis for each condition that applies

Example System



Step 1 - Example conditions

- **Two main transformers, Loop open (Normal condition)**
- **Two main transformers, Loop closed**
- **One main transformer, Loop open**
- **One main transformer, Loop closed**

Arc Flash Hazard Analysis

Step 1 Determine plant conditions

Step 2 Find bolted short circuit fault values

Step 2. Find Short Circuit Values

- If available, look at previous studies or design calculations

- Use a vendor's on-line program

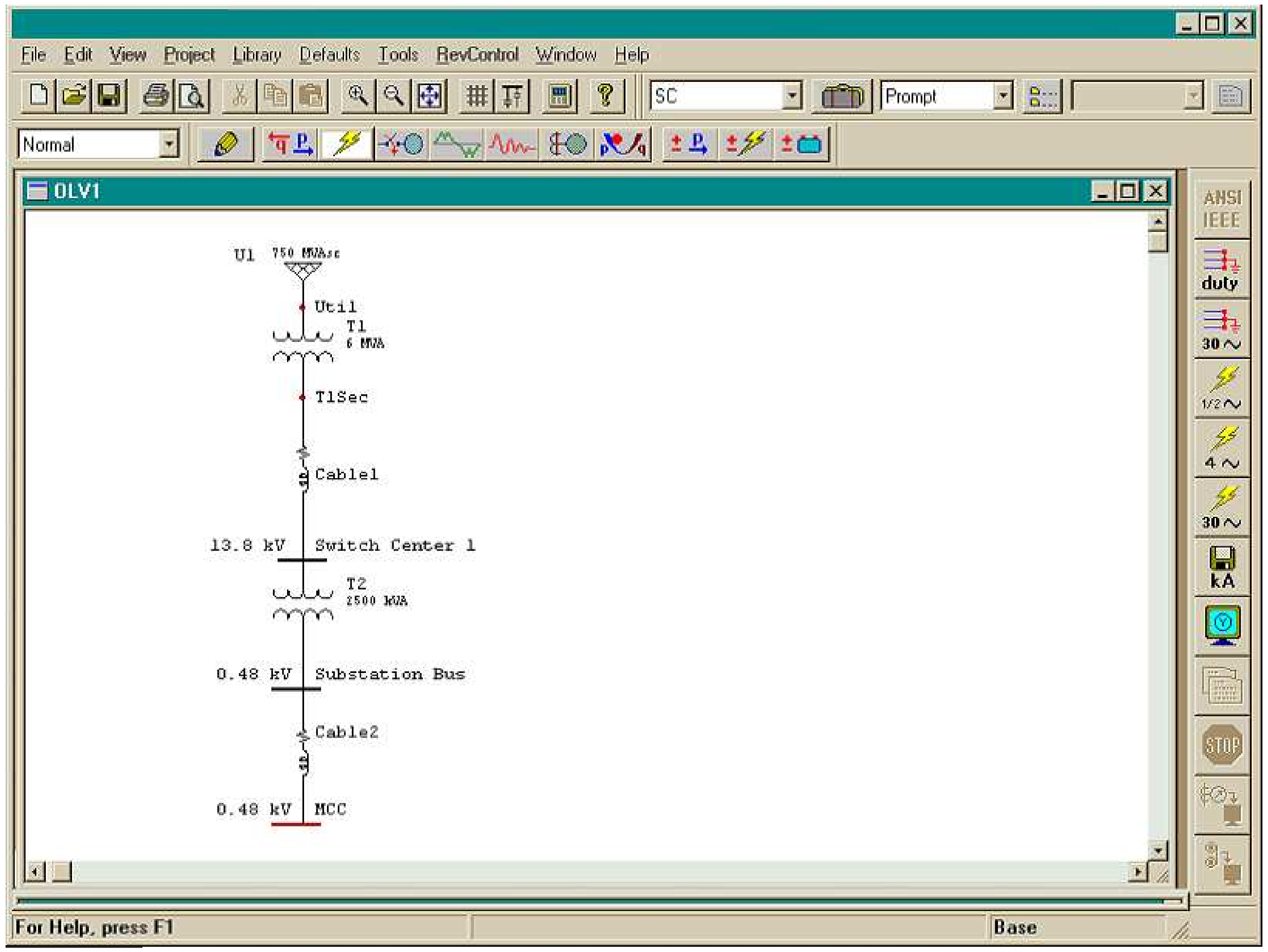
- Use a short circuit study program for large or complicated systems

Step 2. Find Short Circuit Values

- Determine symmetrical three phase fault values for the 1.5 to 4 cycle case.

- Don’t add a safety factor. Higher current can give shorter arc fault duration and the wrong energy value.

- Example of a system entered into a commercial program



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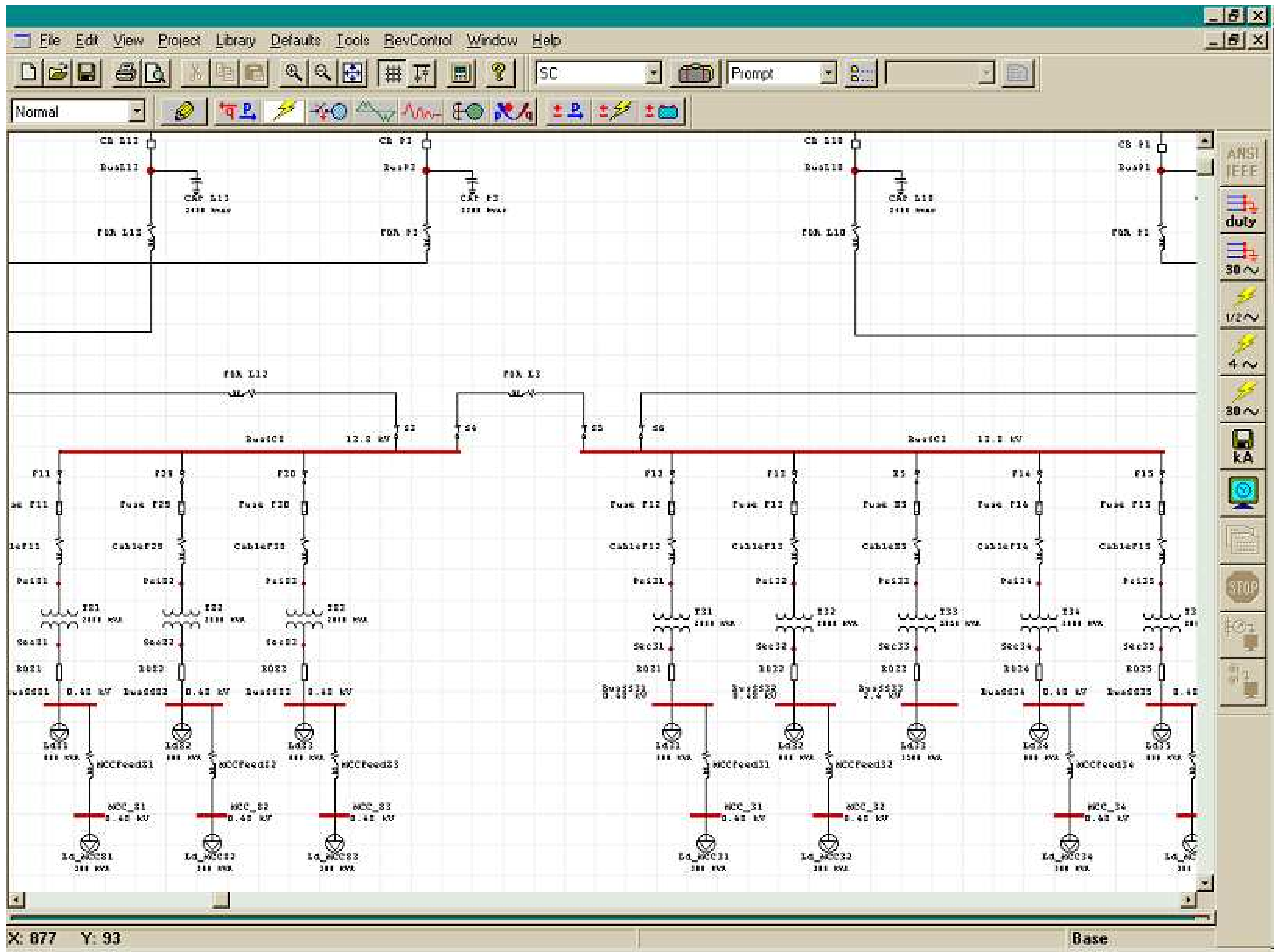
T2 2500 kVA
0.48 kV Substation Bus
Cable2
0.48 kV MCC
ANSI IEEE
duty
kA
STOP
For Help, press F1
Base

Example

- Create Single Line - layout, bus names
- Enter details on transformers, buses, substations, and feeders
- Enter large motors
- At MCC Level, enter single motors if above 100 HP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Base

Example

Bus Name	Voltage	Bolted Fault kA
Switch Center 1	12kV	9
Substation Bus	480V	52
MCC	480V	41

Arc Flash Hazard Analysis

Step 1 Determine plant conditions

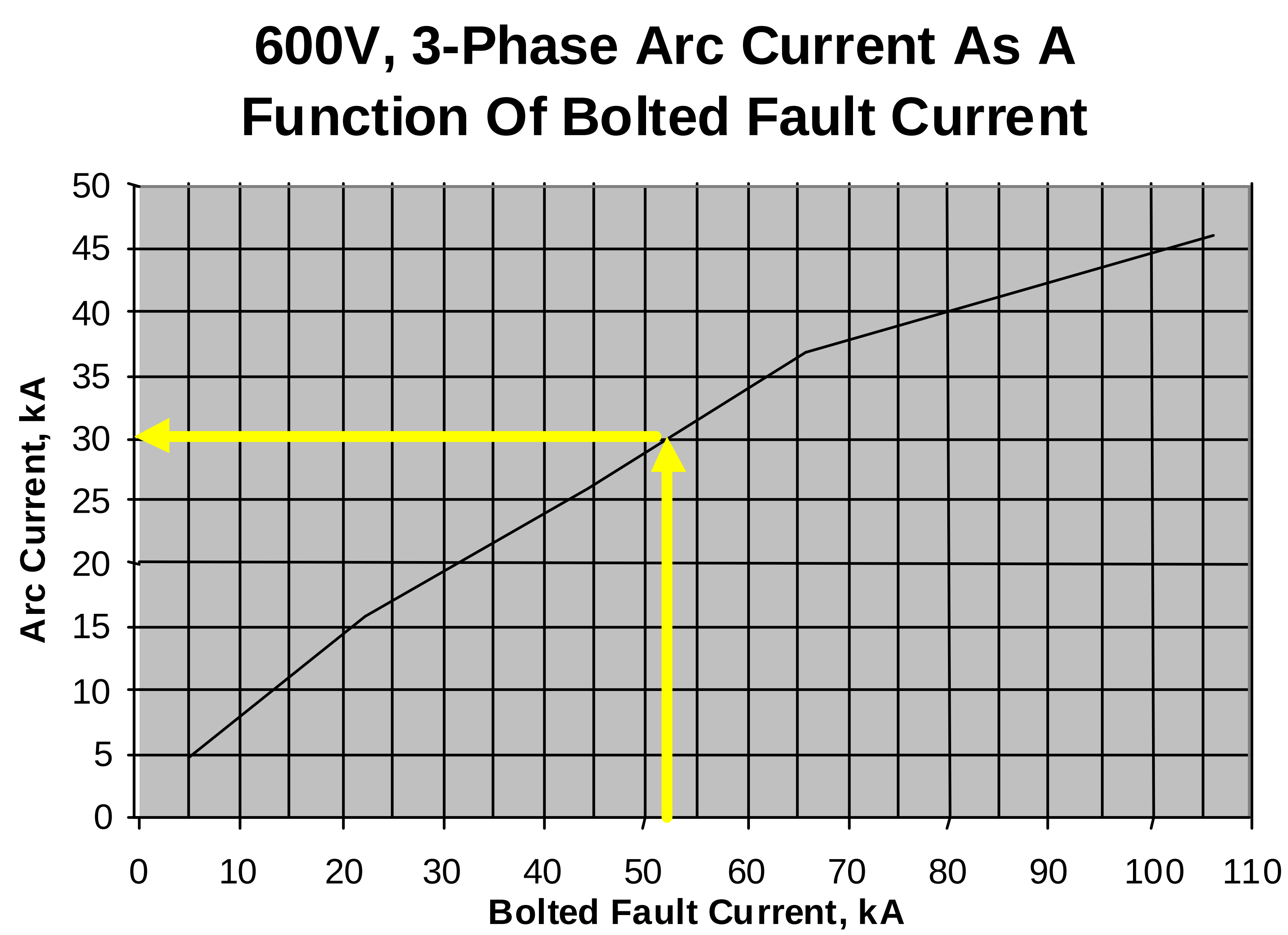
Step 2 Find short circuit fault values

Step 3 Find arcing fault current in protection

Step 3. Find Arcing Current

- Arcing fault current is less than bolted fault (systems no higher than 690 Volts) .

-- Arcing Fault Current is the same as the bolted fault current in systems over 690 V.


600V, 3-Phase Arc Current As A
Function Of Bolted Fault Current
Arc Current, kA
0
5
10
15
20
25
30
35
40
45
50
0 10 20 30 40 50 60 70 80 90 100 110
Bolted Fault Current, kA

Find arcing fault current using equations

For < 1 kV,

$F_A = -0.003\ F_B^{\ 2} + 0.734\ F_B + 1.356$

where:

F_A = Arcing fault current in kA

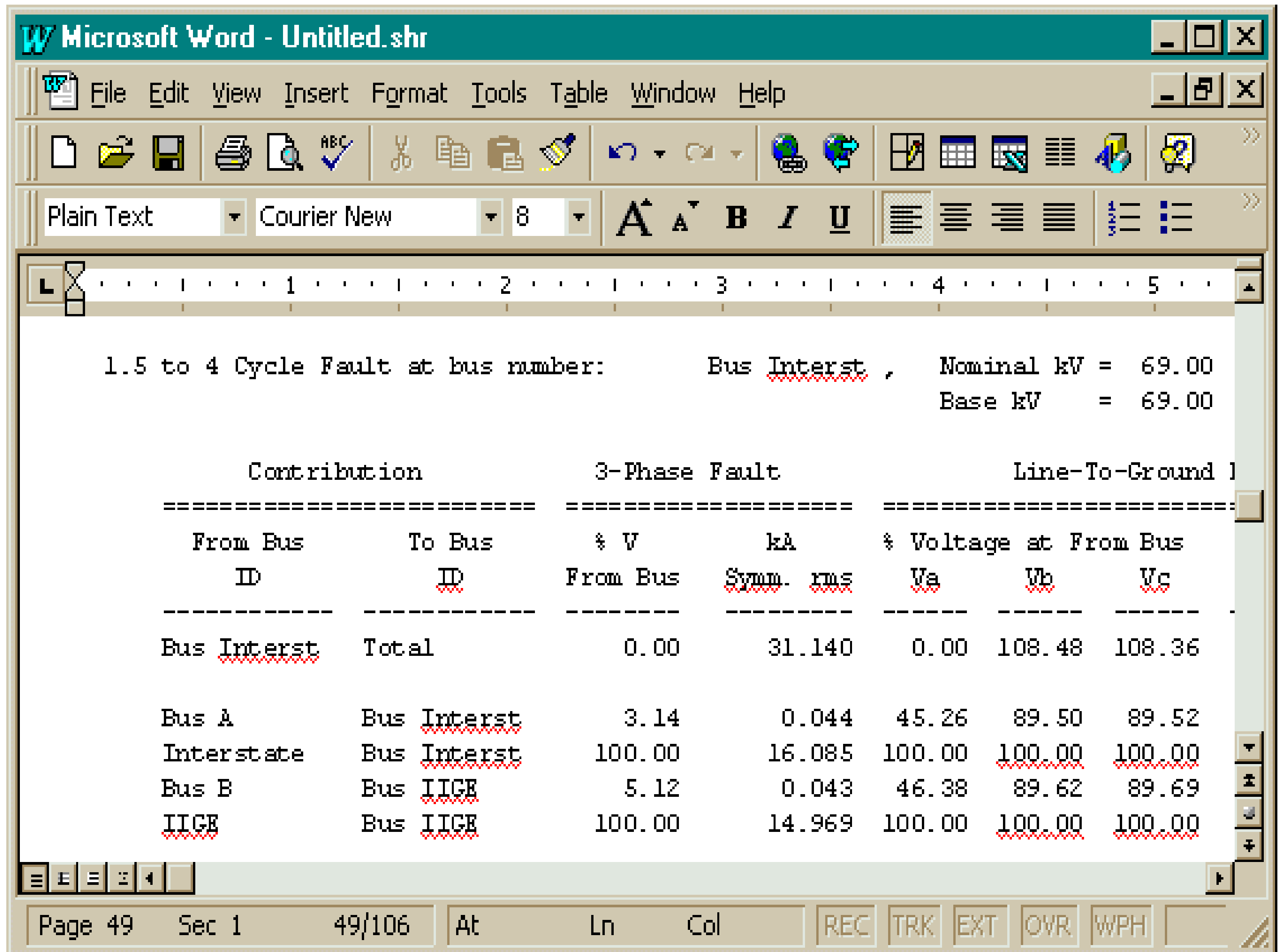
F_B = Bolted fault current in kA (5-106 kA)

For > 1 kV,

$F_A = F_B$

Step 3. Find Arcing Current in Protection

- Arcing current divides between multiple sources
- Motor contribution from the faulted bus doesn’t go through the fuse or breaker.
- Study report will show contributions from motors and different buses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Line-To-Ground I
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kA Symm. rms
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Va
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Vc
Bus Interst Total 0.00 31.140 0.00 108.48 108.36
Bus A Bus Interst 3.14 0.044 45.26 89.50 89.52
Interstate Bus Interst 100.00 16.085 100.00 100.00 100.00
Bus B Bus IIGE 5.12 0.043 46.38 89.62 89.69
IIGE Bus IIGE 100.00 14.969 100.00 100.00 100.00
Page 49 Sec 1 49/106 At Ln Col REC TRK EXT OVR WPH

Step 3. Find Arcing Current in Protection

	Bolted		Arcing
Total	52,000	100.0%	31,400
From:			
Bus A	26,000	50.0%	15,700
Bus B	24,000	46.2%	14,492
Motors	2,000	3.8%	1,208

Example

Bus Name	Voltage	Bolted Fault kA	Arcing Fault kA
Switch Center 1	12kV	9	8.7
Substation Bus	480V	52	30.5
MCC	480V	41	25.6

Arc Flash Hazard Analysis

Step 1 Determine plant conditions

Step 2 Find short circuit fault values

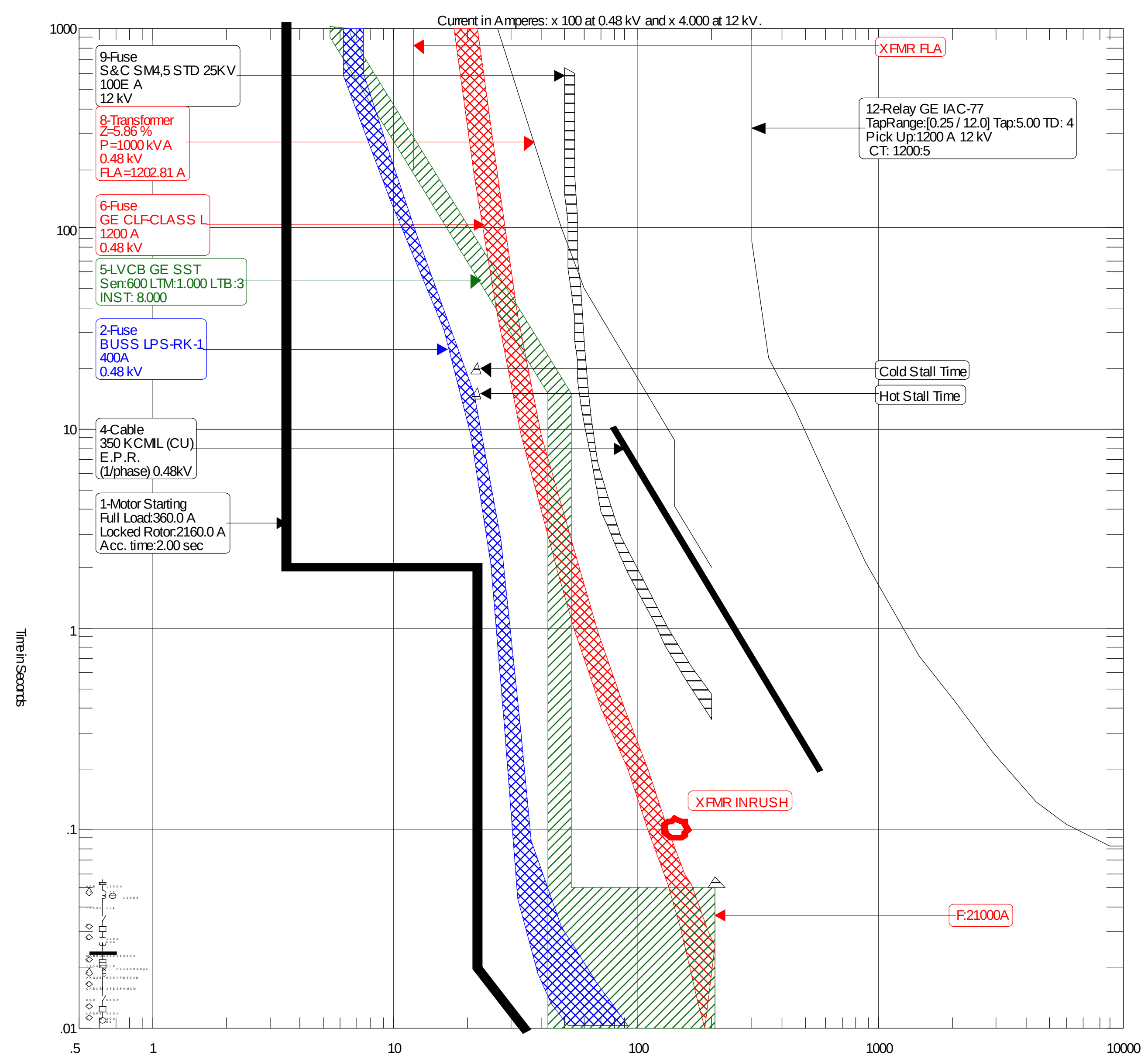
Step 3 Find arcing fault currents in protection

Step 4 Find arc clearing times

Step 4. Arc Clearing Times

- Get system coordination drawings.
- Update as required.
- Get protective device Time-Current Curves for simple case
- Use arcing fault current in protective device.
- Arc clearing time = Trip time + Operating time

  = Melting time + Arcing time



Substation 80J - N. AIR COMPRESSOR

TIME CURRENT CHARACTERISTIC CURVES
GE SST Trip Unit - Existing Settings

CURVES ARE PLOTTED TO 0.48 kV

NO: TCC-1A
DATE: 1-26-1999

Step 4. Arc Clearing Times - CLF

- Use maximum melting time from fuse curve if fault current is not in limiting range
- Limit point is the 0.01 sec point on the fuse curve.
- For 1-2 times limit point in amps, use 0.008 seconds (1/2 cycle)
- Over 2 times limit point, use 0.004 seconds (1/4 cycle)

Step 4. Arc Clearing - Relays, Bkrs

- Get relay trip times from curves

    Instantaneous: use 0.01 sec

- Use typical breaker operating times

LV Power Breakers	.05 sec
MV Breakers	.08 sec
HV Breakers	.13 sec

- Clearing Time = Trip time + Operating Time

Example

Bus Name	Trip Time	Operating Time	Clearing Time
Switch Center 1	0	0.4	0.4
Substation Bus	0.15	0.05	0.20
MCC	0.25	0.05	0.30

Arc Flash Hazard Analysis

Step 1 Determine plant conditions

Step 2 Find short circuit fault values

Step 3 Find arcing fault currents in protection

Step 4 Find arc clearing times

Step 5 Determine working distance

Step 5. Working Distance

- Depends on task and equipment

- Small distance increase makes a big difference in incident energy

- General work: 18 inches (50 cm)

- MV: consider tasks with 36 inches (100 cm) distance

- HV: may be remote air switches, use larger distances like 72 inches (2 meters)

Example

Bus Name	Working Distance (in)
Switch Center 1	36
Substation Bus	18
MCC	18

Arc Flash Hazard Analysis

Step 1 Determine plant conditions

Step 2 Find short circuit fault values

Step 3 Find arcing fault currents in protection

Step 4 Find arc clearing times

Step 5 Determine working distance

Step 6 Calculate the incident energy and arc flash boundary

Step 6. Calculate Incident Energy

- Now you have all the data you need
- Insert data in Worksheet
- Use equations
- Example

380-1000V, 3-Phase "Arc-In-Box" Maximum Incident Energy Algorithm

$$E_{MB} = 1038.7\ D^{-1.474}\ t\ [.0093F_B^2\ - 0.3453\ F_B + 5.9675]$$

where:

E_{MB} = Maximum Box Incident Energy, cal/cm^2

D = Distance From Electrodes, inches ($D_B \geq 18$)

F_B = Bolted Fault Current, kA (16-52 kA Range)

t = Duration of Arc, seconds

380-1000V, 3-Phase
"Arc-In-Box" Algorithm Solved For Boundary Distance

$$D = [\ (t/E_{MB})\ (9.66\ F_B^2 - 358.7\ F + 6198)\ ]^{0.6785}$$

Equation can define boundary distance
For specific incident energy levels such as:

- 2nd Degree Burn Boundary of Bare Skin
- FR Clothing Protection Boundary

> 1 KV, 3-Phase, Incident Energy Algorithm - Lee Theory

$$\mathbf{E_{MB} = 793\ F_B\ V\ t\ /\ D^2}$$

where:

E_{MB} = Maximum Box Incident Energy, cal/cm^2

D = Distance From Electrodes, inches ($D_B \geq 18$)

F_B = Bolted Fault Current, kA

V = System Ph-Ph Voltage, kV

t = Duration of Arc, seconds

Example

Bus Name	Incident Energy(cal/cm^2)
Switch Center 1	22.1
Substation Bus	28.2
MCC	30.0

Final Results

- Run calculations for all conditions
- Put together in summary
- Group by voltages or by area

Equation Limitations

- LV Equations per current published research are limited to Bolted Fault currents between 16 kA and 52 kA.
- Theoretical equations have no limit, but are incorrect when compared to actual tests.
- Developed a method to use theoretical equations to extend the range of useful equations...

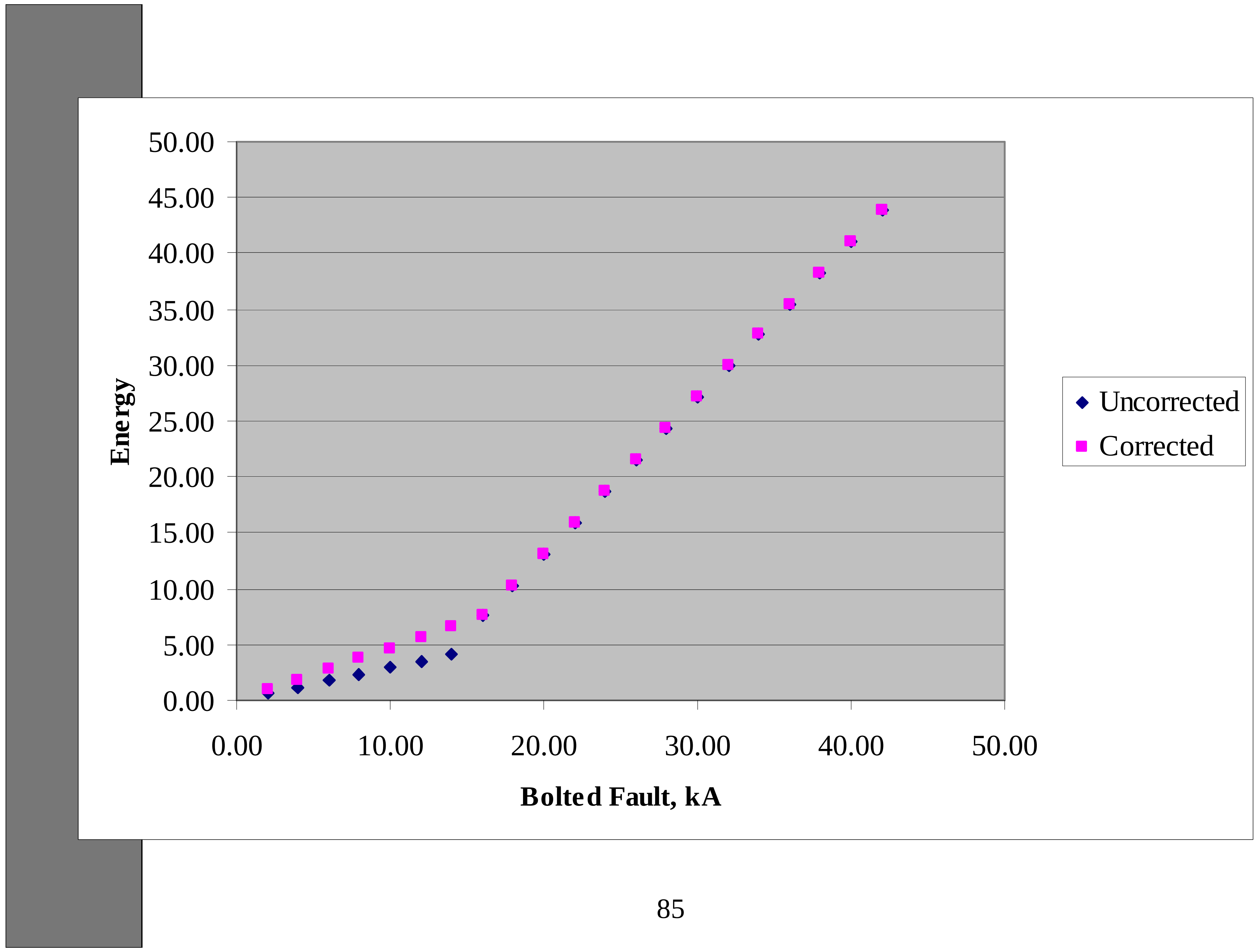
Compare Equations

At 480V, Fault of 16kA, and Distance of 36 inches,

Equation 1 (Research) returns 7.5 cal/cm^2
Equation 2 (Theoretical) returns 4.7 cal/cm^2
Scale factor k = 7.5 / 4.7 = 1.61

Now use Equation 2 multiplied by k when Fault is less than 16 kA.

Similar method applied for over 52 kA



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15.00
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Energy
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Bolted Fault, kA
Uncorrected
Corrected

Common Mistakes

1. Use the wrong current.

Remedy: The arcing fault current should be used to determine T_A. The bolted fault current should be used in the incident energy equation.

2. Forget to consider multiple sources of fault current.

Remedy: In loop systems the fault current will probably be divided between two protective devices - making the arcing time much longer.

Learnings

1. Found MCCs and buses with much higher energy levels than expected

2. Current Limiting fuses don't always keep the energy below 1.2 cal/cm^2.

3. Non-fused LV Breakers can give very high energy levels, depending on settings.

Spreadsheet available at PCIC Website

At the Safety Subcommittee web page,

http://www.ieee-pcic.org/safety/safety.htm

Arc Flash Hazard Analysis

Step 1 Determine plant conditions

Step 2 Find short circuit fault values

Step 3 Find arcing fault currents in protection

Step 4 Find arc clearing times

Step 5 Determine working distance

Step 6 Calculate the incident energy

Final Results and Document Control

Questions?

Arc Flash Hazard
Managing the Hazard

Craig M. Wellman

Managing the Hazard

- PPE Program
  - Apply PPE to protect people
- Administrative controls
  - Operate/maintain so as to minimize the hazard
- Engineering controls
  - Design to minimize the hazard

PPE program

- Assess functional needs
- Plan for garment management
- Train users
- Institutionalize program

PPE program

- Assess functional needs
  - Determine incident energy (E) levels for equipment
  - Determine tasks in equipment requiring PPE
  - Job factors - duration, weather, dexterity, vision

Classes of equipment

Panelboards, drives, starters, controllers, transformers, 240V to 690V, fed by breaker
600 V class motor control center (MCCs) fed by fused switch or breaker with limiter
600 V class MCCs and plug- in- bus duct fed by breaker without limiter
600 V/ 1000 V class switchgear
Other 600 V/ 1000 V class equipment
Fused contactor type motor starters, 1kV to 5kV
Metal- clad switchgear, 1 kV to 5 kV
Metal- enclosed switchgear, 1 kV to 5 kV
Metal- clad switchgear, > 5 kV
Metal- enclosed switchgear, > 5 kV

Example site task list

Reading a panel meter while operating a meter switch
CB or fused switch operation with enclosure doors closed
CB or fused switch operation with enclosure doors open
Work on energized parts, including voltage testing
Work on control circuits with energized parts I20 V or below exposed
Work on control circuits with energized parts >120 V exposed
Insertion / removal / racking / of CBs / units from cubicles, doors open
Insertion / removal / racking of CBs / units from cubicles, doors closed
Application of safety grounds, after voltage test
Removal of bolted covers (to expose bare, energized parts)
Opening hinged covers (to expose bare, energized parts)
Opening voltage transformer or control power transformer compartments

Task list guidance

- One level of PPE per class of equipment may not be reasonable
- One or two feeds
- Doors
- Medium voltage applications where resistance grounding is used, in either modern metal clad switchgear (includes sleeves over stabs) or shielded cable

PPE Program

- Garment management plan
  - Assignment plan - People/group/location? Number?
  - Maintenance plan - Contract vs. individual
  - Select PPE for E levels, tasks, job conditions,
    - Everyday wear

FR garments rated by fabric weight

- Men's and women's lines

– Shirts	4.5 oz and 6 oz
– Lab coats	6 oz
– Pants	6 oz, 7.5 oz, 8.5 oz
– Bib overalls	6 oz
– Coveralls	4.5 oz, 6 oz, and 7.5 oz
– Knit shirts	6.5 oz and 9.5 oz
– Hooded sweatshirts	9.5 oz
– Switching coats	7.5 oz, 10 oz

Flame resistant shirt

(Pants also needed)

Face shield

- Green face shield with extenders provides 8 cal/cm2 protection to front
- Clear face shield provides very limited protection
- Does not protect rear of head as required (Knit balaclava)
- Hooded sweat shirt works for 8 cal/cm2

FR garments tested and rated in cal/cm^2 by NRTL

Levels	Products
8	Face-fitting face shield
31	Bib-overalls, jacket, coat, hood
45	Insulated FR coveralls
50	Bib-overalls, coat, hood
100	Bib-overalls, coat, hood

Arc Flash Protection for up to 31 cal/cm^2

(FR pants also needed)

Protection for lower energy levels

Clothing	Head Protection	Rating in cal/cm^2
Street clothing	Safety glasses	0
6 oz. FR shirt and pants	Same	1.2
Same	Faceshield and balaclava	6
Same + 6 oz FR coveralls	Hood, 31 cal/cm^2	20

Protection for higher levels

FR Clothing	Head protection	Rating in cal/cm^2
6 oz coveralls + coat with two 10 oz layers	50 c/c hood	50
31 c/c coat + pants	31 c/c hood	31
6 oz coveralls + 31 c/c coat and pants	50 c/c hood	40
50 c/c coat + pants	50 c/c hood	50
100 c/c coat + pants	100 c/c hood	100

Calories/cm^2 (c/c)

Typical rainwear and chemical splash products

- Raincoats
- Jackets, pants
- Arc flash hoods
- Acid gear

Arc rated rainwear

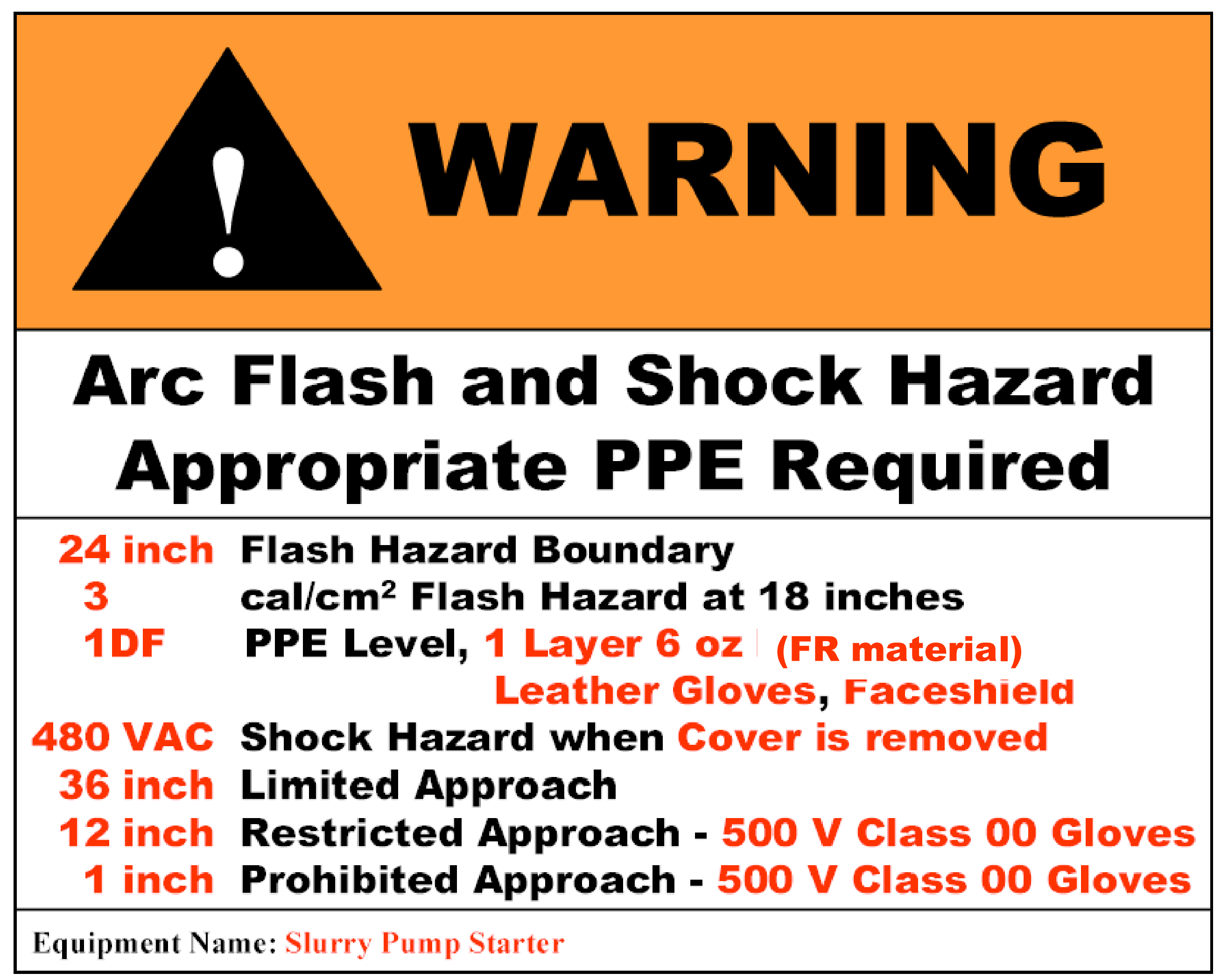
Usability Issues - Heavy PPE

- Traps body heat
- Fogs up, limited ventilation
- Visibility
- Communication
- Stiffness

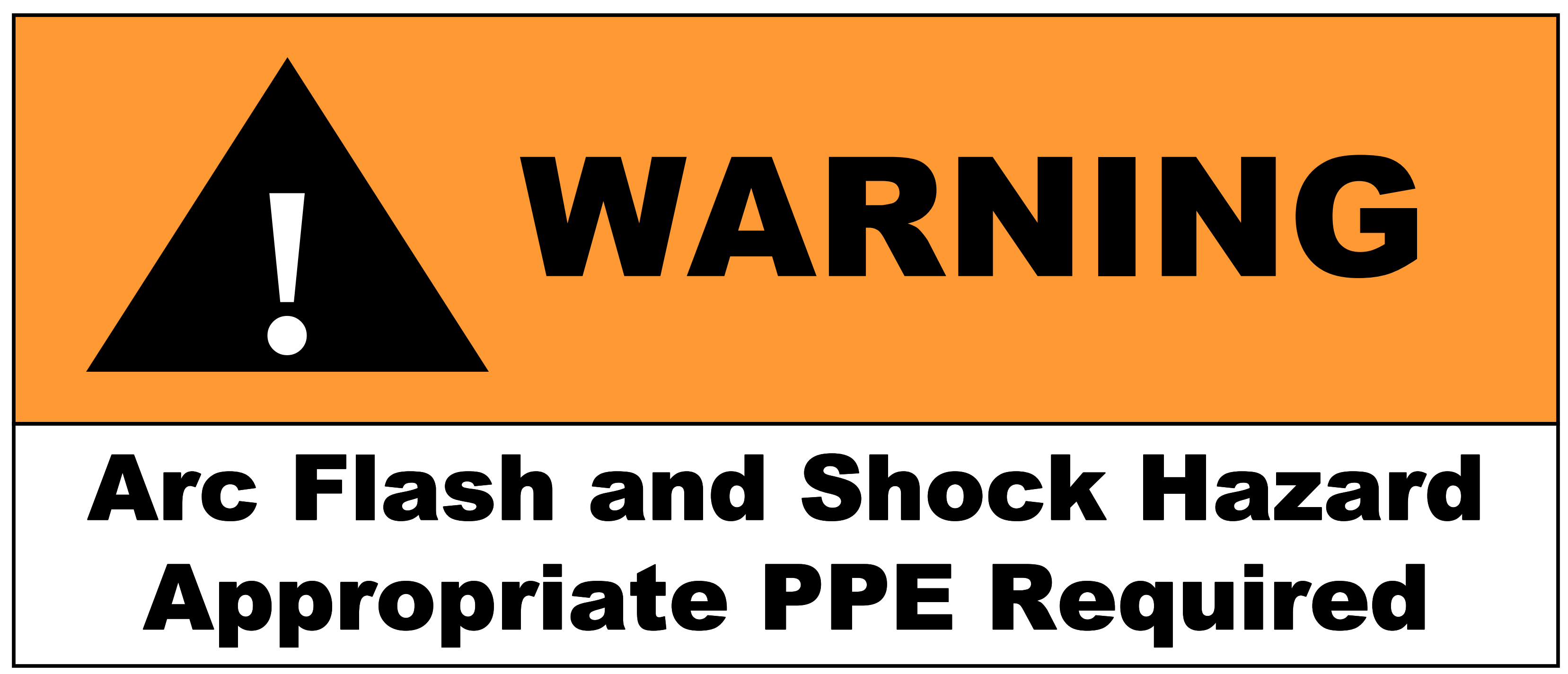
PPE Program

- Functional needs
- Garment plan
- Training
- Institutionalize
  - Document all plans
  - Post E levels
  - Enforce
  - Update

2002 NEC has arc hazard label requirement - Here is one solution



Top half of label -
Printed in quantity



Bottom half of label - Custom printed

24 inch	**Flash Hazard Boundary**
3	**cal/cm^2 Flash Hazard at 18 inches**
480 VAC	**Shock Hazard when Cover is removed**
36 inch	**Limited Approach**
12 inch	**Restricted Approach - 500 V Class 00 Gloves**
1 inch	**Prohibited Approach - 500 V Class 00 Gloves**

Date: 6/28/2001

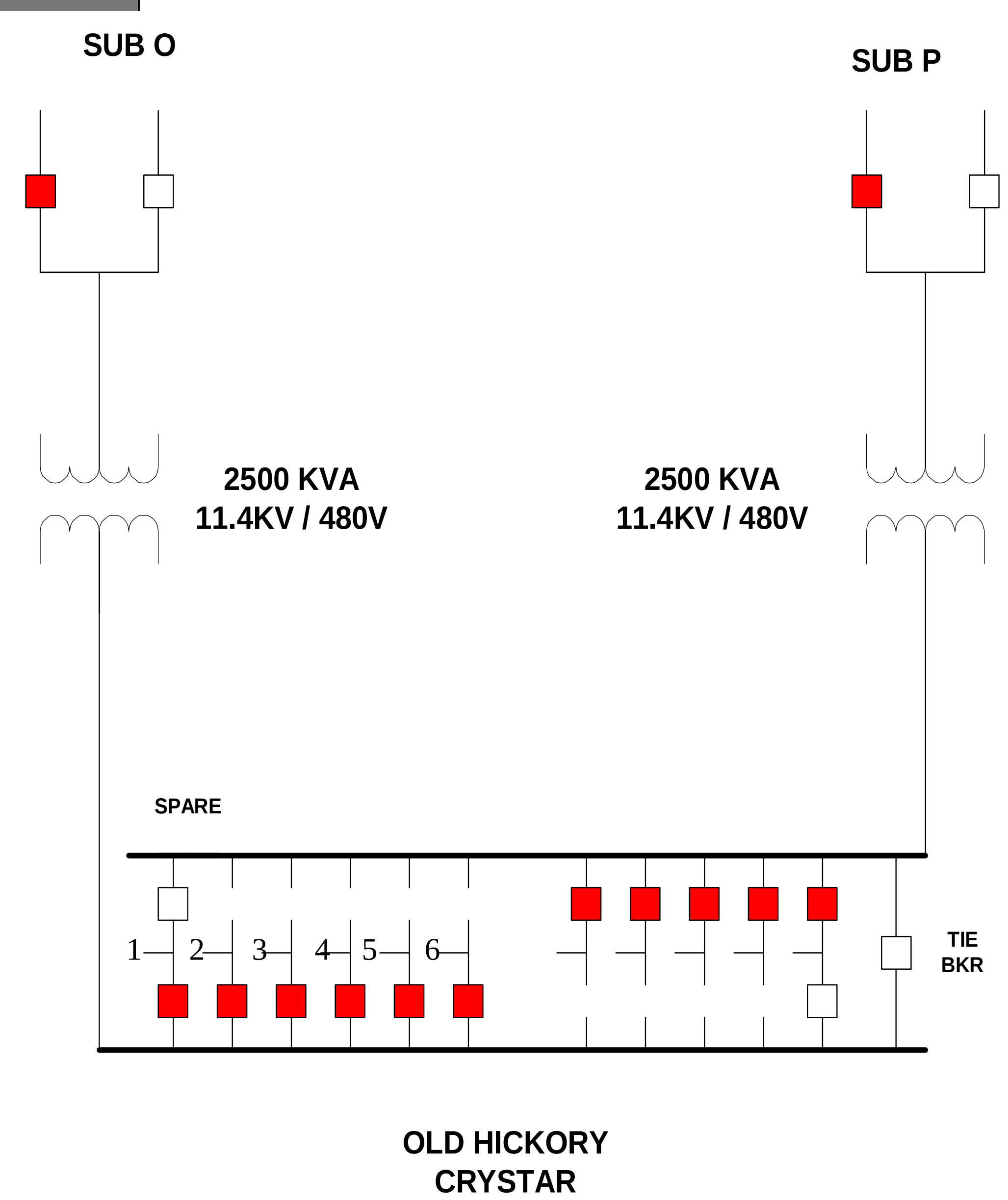
Bldg. ECR #1 **Equipment Name: Slurry Pump Starter**

Managing the hazard -- Administrative controls

- Operate and maintain in a way that minimizes the hazard
  - Site team can provide
    - Site procedures
    - Training
    - Process hazards analysis for electrical rooms
    - PPE program requirements

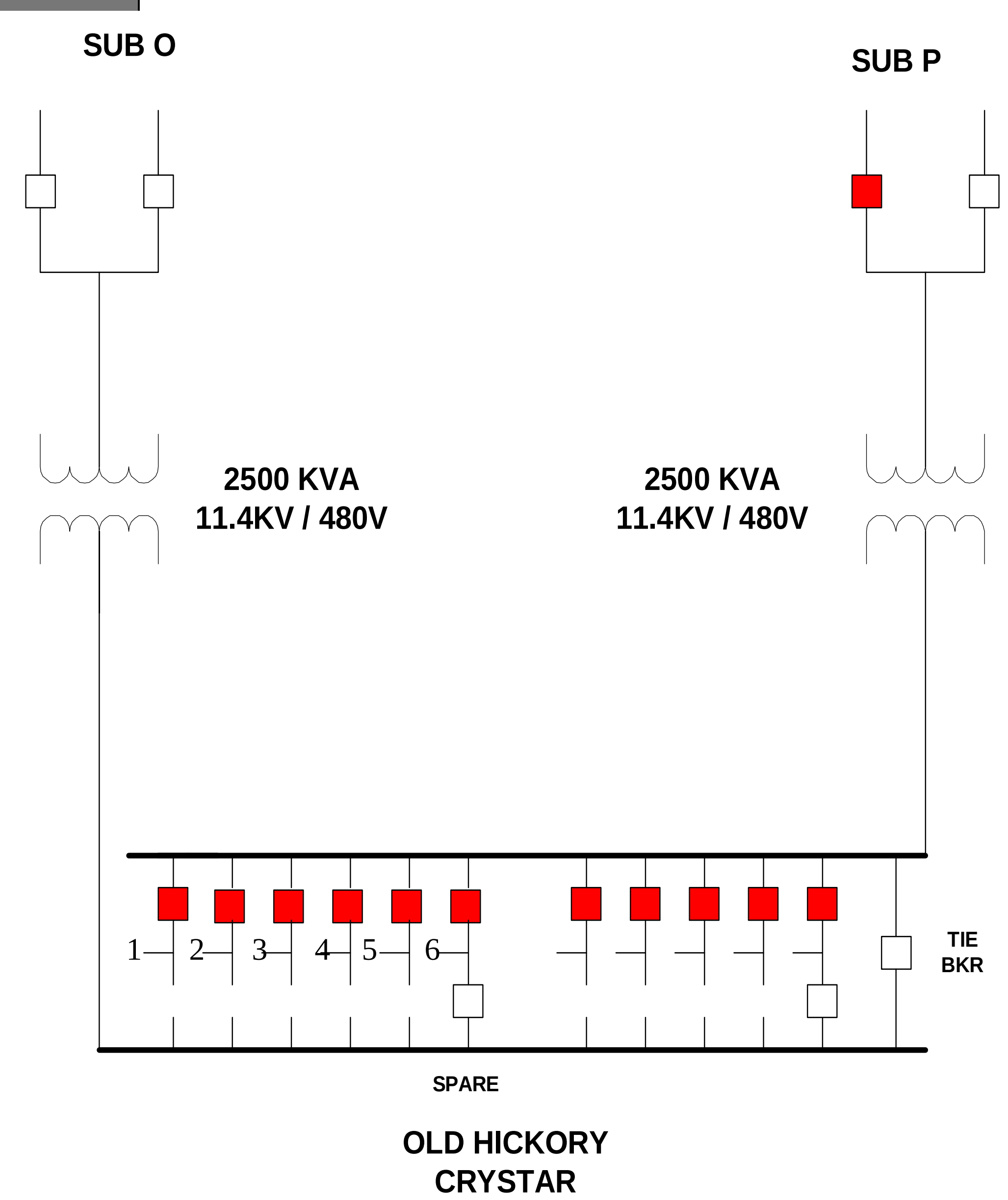
Site operating and maintenance procedures

- Lock and tag
  - General and equipment specific
- Maintenance Grounds
  - How? Where? When? With what?
  - How assure removal?
- Switching
  - Recognize the hazard of tying two buses together and minimize the time



Transfer of Loads From Sub O To Sub P

- Check Voltages & Loads on Subs O & P.
- Lead & Backup Person Put on Appropriate PPE.
- Remove Locks & Close Tie Breaker.
- Open & Lock Both Sub O Primary Breakers.
- Remove Spare Breaker From Top Fdr 1 Compt
- Megger Spare Breaker & Re-Install.
- Remove Cover Plates For Fdrs 2-6 Top Compts.
- Close Top Spare Breaker For Fdr 1.
- Open Bottom Breaker For Fdr 1.
- Move Bottom Fdr 1 Breaker to Top Fdr 2 Compt.
- Close Top Breaker for Fdr 2.
- Open Bottom Breaker For Fdr 2.
- Move Bottom Fdr 2 Breaker to Top Fdr 3 Compt.
- Close Top Breaker for Fdr 3.
- Open Bottom Breaker For Fdr 3.
- Continue Until All Loads Are On Top Bus, Sub P.
- Open & Lock Tie Breaker.
- Replace Cover Plates For Fdrs 1-5 Bottom Compts
- Remove PPE.



Restoring Subs O & P Back to Normal

•Lead & Backup Person Put on Appropriate PPE

•Remove Cover Plates For Fdrs 1-5 Bottom Compts

•Remove Locks & Close Tie Breaker.

•Close Bottom Breaker for Fdr 6.

•Open Top Breaker For Fdr 6.

•Move Top Fdr 6 Breaker to Bottom Fdr 5 Compt.

•Close Bottom Breaker for Fdr 5.

•Open Top Breaker For Fdr 5.

•Move Top Fdr 5 Breaker to Bottom Fdr 4 Compt.

•Close Bottom Breaker for Feeder 4.

•Open Top Breaker for Feeder 4.

•Continue Until All Loads Are Back to Normal..

•Replace Cover Plates For Fdrs 2-6 Top Compts

•Spare Breaker Will Be In Top Fdr 1 Compt.

•Remove Locks & Close Sub O Primary Breaker.

•Open & Lock Tie Breaker.

•Remove PPE.

•Check Voltages and Loads on Both Subs O & P.

Training

- What training is needed?
  - OSHA
  - NFPA 70E
  - Company level practices
  - Site specific procedures
  - Equipment specific (Model 7700)
  - Use and care of PPE

Process hazards analysis for ECRs, Switchyards

- Get help on running analysis
- What are the hazards?
  - Shock, arc flash, fire, fall
- How can you mitigate them?
  - How call for help? -- Phone and FA available
  - Exit signs and lights
  - PPE available
- Can you reduce the likelihood?
  - How turn off power? -- Single lines posted
  - Identification and warning labels
  - Provision for locks where needed
  - Minimize obstructions, stored material

Engineering Controls --
Design to minimize the hazard

- Reduce need for work on energized equipment
- Reduce probability of three phase faults
- Reduce fault current
- Reduce fault duration
- Reduce impact of arc flash on people
- Provide information on available fault energy

Studies reveal all electrical injuries involve energized equipment!

- Most organizations prohibit hot work, (except testing.)
- Why do injuries still occur?
  - Testing
  - Racking in breakers
  - Operating switches and circuit breakers
  - Equipment failures when no work underway
  - Job expanded beyond original intent - *#1 reason!*

Reduce need for work on or near energized equipment

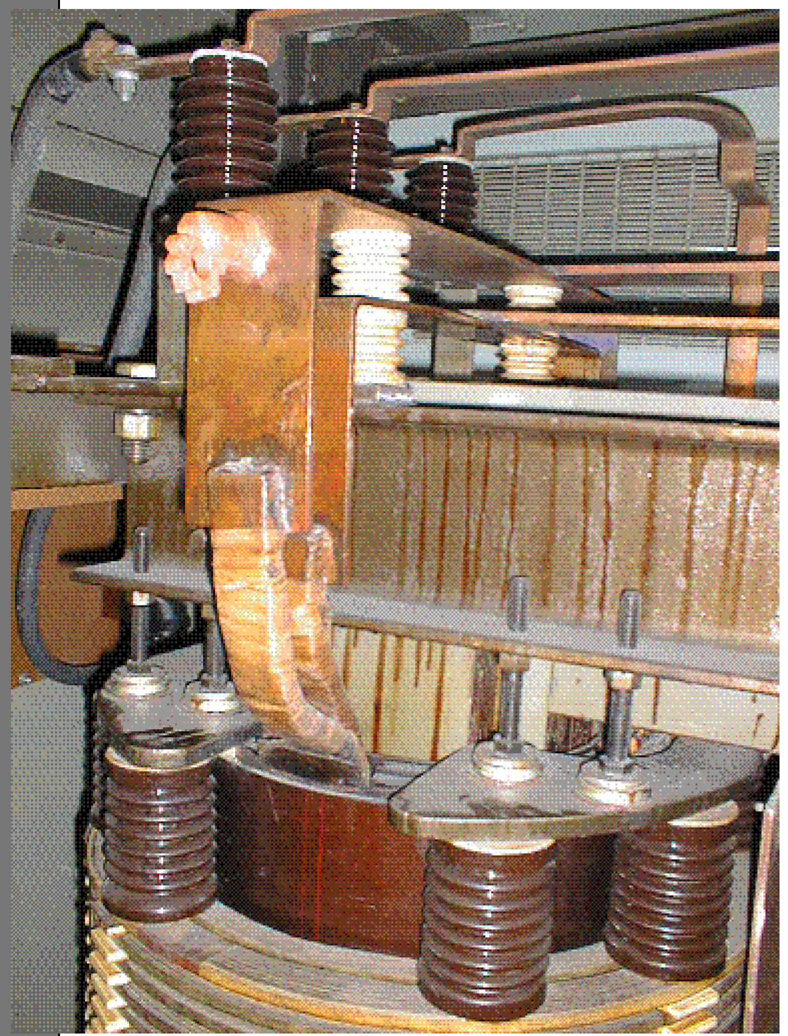
- Design to enable shutdowns
  - Unitize loads - group by process function
  - Provide dual feeds to critical equipment - controls
  - Money is always available for safety
- Design for easy testing and grounding
- Design for remote racking and operation
- Install warning labels

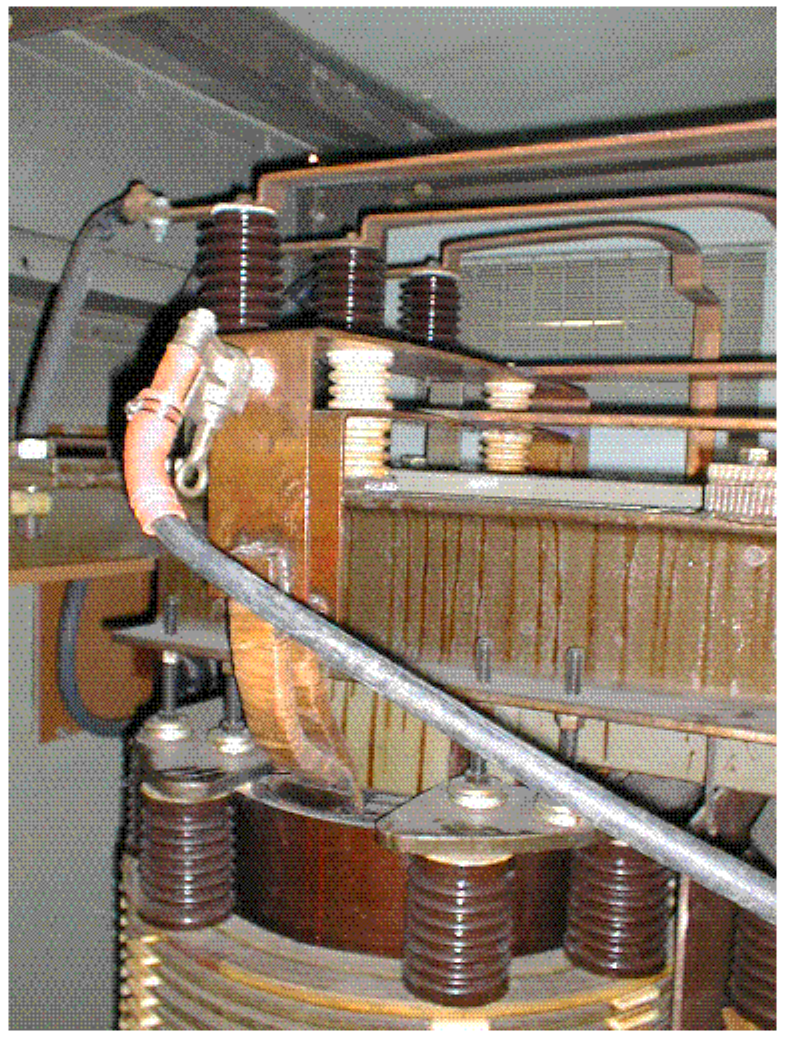
Reduce probability of three phase faults

– Metal clad vs. metal enclosed switchgear
– Insulated bus
– Resistance grounded system
    - Low resistance grounded - > 1 kV
    - High resistance grounded - 480 V, 400 V
– Adequate ground fault return path
– Connection points for ground jumpers

Maintenance grounding stud

480vac Side of 12,000 to 480 transformer



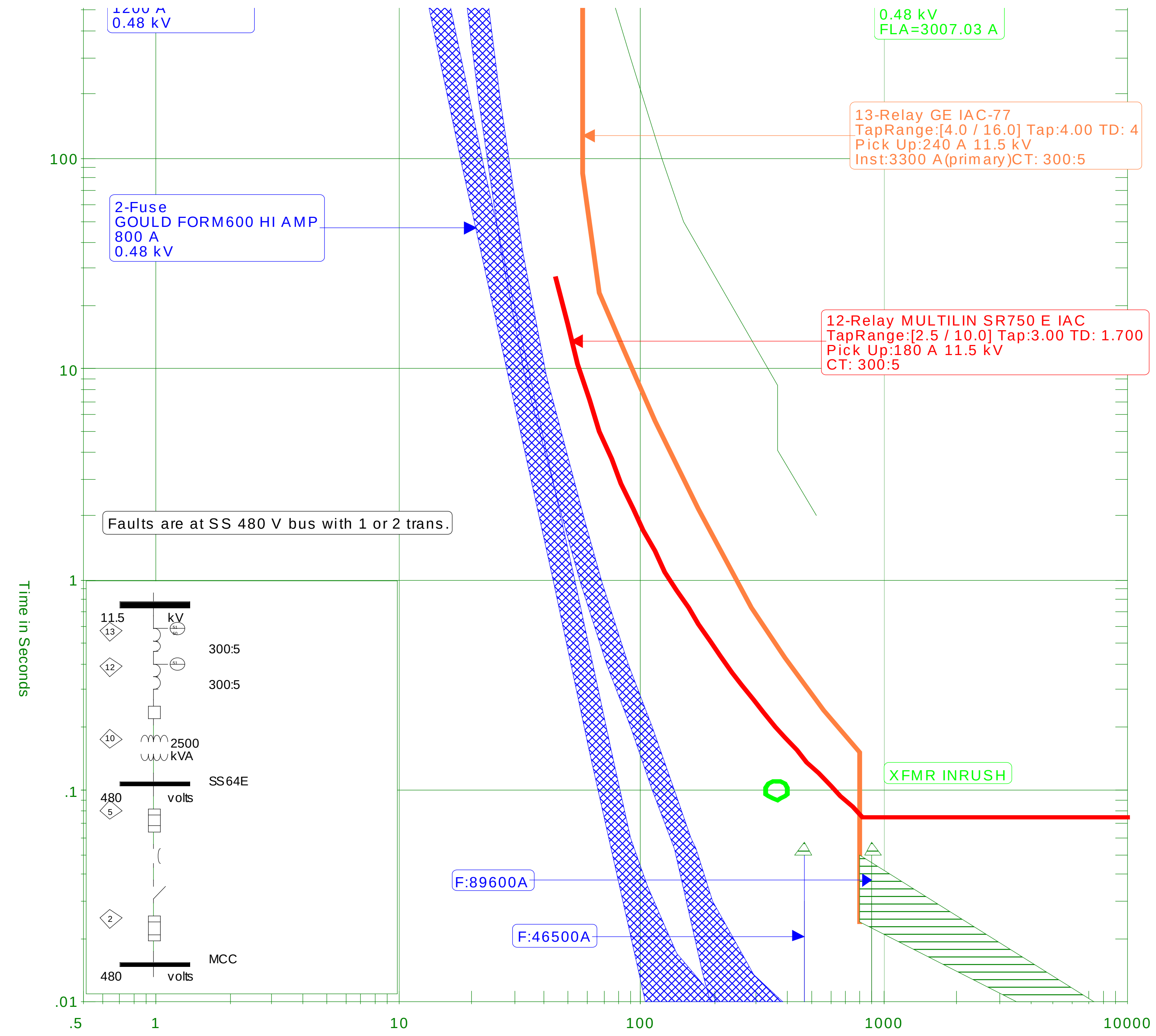


Reduce fault current

- Fast current limiting fuses
  – Limiter fuses on 480 V feeder breakers
- Resistance grounding
  – HRG on 480 V systems
  – LRG on 2.4 kV to 22 kV systems

Reduce fault duration

- Use current limiting fuses
- Tighten up the coordination
- Select protective devices for people protection as well as equipment protection and reliable operation.
  - Select relay settings for fast trips
  - Select lower rated fuses
  - Cut possible fault energy in half



1200 A
0.48 kV
0.48 kV
FLA=3007.03 A
13-Relay GE IAC-77
TapRange:[4.0 / 16.0] Tap:4.00 TD: 4
Pick Up:240 A 11.5 kV
Inst:3300 A(primary)CT: 300:5
2-Fuse
GOULD FORM600 HI AMP
800 A
0.48 kV
12-Relay MULTILIN SR750 E IAC
TapRange:[2.5 / 10.0] Tap:3.00 TD: 1.700
Pick Up:180 A 11.5 kV
CT: 300:5
Faults are at SS 480 V bus with 1 or 2 trans.
Time in Seconds
XFMR INRUSH
F:89600A
F:46500A
11.5 kV
300:5
300:5
2500 kVA
SS64E
480 volts
MCC
480 volts
100
10
1
.1
.01
.5
1
10
100
1000
10000

Reduce impact of arc flash on people

- Avoid openings/vents in equipment doors
  – Prefer door openings at the side of the door to openings in the center
- Arc resistant switchgear
  – Big benefit for switching
- Remote operating controls for switchgear
- Remote racking - 480 V and higher

Summary

- We know a lot more about arc flash hazards than we did a few years ago
- Regulations have new arc flash requirements
- Better PPE is available
- New application standards are available
- While progress will continue, the time for improved protection is now.

When do arc flash injuries occur?

- When not expected
- When equipment is deenergized
- When at end of long feeder, where bolted fault current is lowest

Line-of-defence

- PPE for the arc flash hazard is the last line-of-defense. It is not intended to prevent all injuries but is intended to mitigate the impact of an arc flash should one occur.
- Per NFPA 70E, the incident energy exposure shall be based on the working distance of the employee's face and head from a prospective arc source for the specific task to be performed. FR clothing and PPE shall be used.... based upon the incident energy exposure... . That means injuries to hands and arms are expected if an arc at the level calculated and protected against occurs.
- PPE designed to prevent all injuries would be so restrictive people could not work and it is not available.

Caution

- The equations embedded in this worksheet enable calculation of the estimated maximum incident energy and the estimated arc flash boundary distance.

- Users should be aware that the equations are based upon measured incident energy under a specific set of test conditions and on theoretical work. *Real arc exposures may be more or less severe than indicated by this worksheet.* In addition, the potentially hazardous effects of molten copper splatter, projectiles, pressure impulses, and toxic arc byproducts have not been considered in the equations.

- Available bolted fault currents should be determined at the point of each potential fault. *Using conservatively high bolted fault currents may give lower results in incident energy than are possible*, depending on the protective device time-current response.

Disclaimer

- The information offered in this program is based on technical data believed to be reliable. It is offered as a possible tool for conducting an arc flash hazard analysis. It is subject to revision as additional knowledge and experience is gained.

- THE INFORMATION IS PROVIDED WITH NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED.

- NO USE SHOULD BE MADE OF THE INFORMATION EXCEPT BY FULLY QUALIFIED PROFESSIONALS HAVING FORMED THEIR OWN EVALUTION OF THE INFORMATION FOR THEIR OWN PURPOSES AND APPLICATIONS.

References

OSHA citations:

- US OSHA Cites Ford in Arc Flash Accident - March 2000
- OSHA Cites Rhode Island Electric Utility in Electric Arc Flash Injury - March 2000

ASTM Standards

- F1506-98 Standard Performance Specification for Textile Material for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards

- F1958/F1958M-99 Standard Test Method for Determining the Ignitability of Non-flame-Resistant Materials for Clothing by Electric Arc Exposure Method Using Mannequins

References - PCIC Technical Papers

All on CD, some on PCIC website

- "The Other Electrical Hazard: Electric Arc Blast Burns"; Ralph H. Lee; 1982
- "Report on Enclosure Internal Arcing Tests"; Epperly, Heberlein and Higgins; 1994
- "Protective Clothing Guidelines for Electric Arc Exposure"; Neal, Doughty, and Bingham; 1996
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