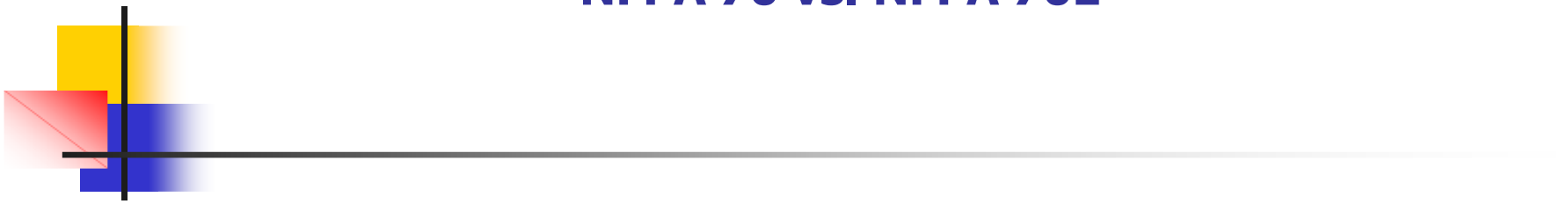
# EMERGENCY GENERATORS vs. PEOPLE PROTECTION
# NFPA 70 vs. NFPA 70E



**NFPA World Safety**
**Conference and Exposition**
**Track: NEC Forum**
**M50**

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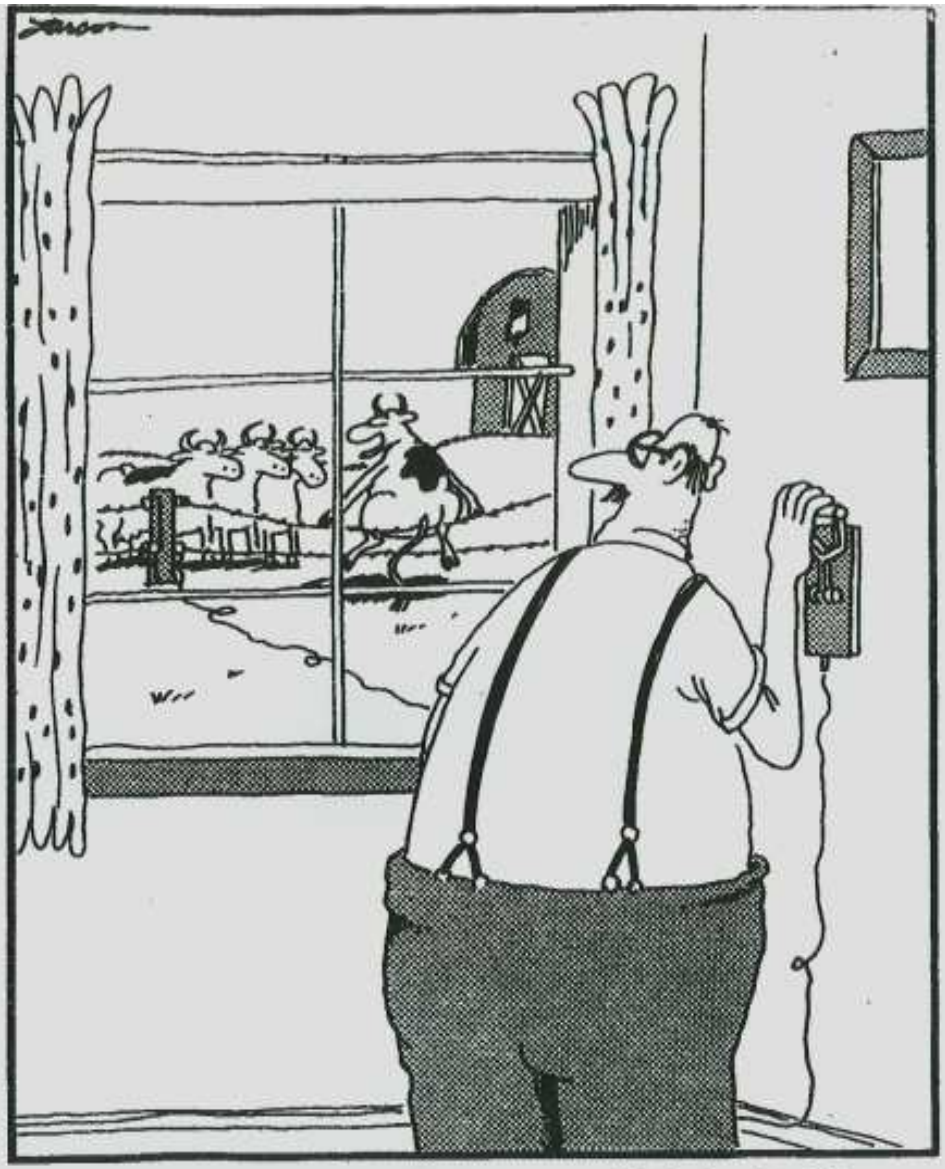
# TO BE COVERED

- NFPA 70 vs. NFPA 70E History
- Selective Coordination and Emergency Generator Circuits Characteristics
- Over Current Protection Device Characteristics
- NFPA 70E – 130,  Performing the Flash Hazard Study
- Design considerations for Joint Compliance
- An example of Joint Compliance

# LEARNING GOALS

- Performance Differences between Over Current Protection Devices (OCPDs)
- Selective Coordination Between OCPDs
- Small Generator Characteristics
- Performing an Arc Flash Hazard Study
- Effect of a Current Limited Source on OCPD Coordination and Arc Flash Energy
- NFPA 70 vs. NFPA 70E Joint Compliance



"Look, if it was electric, could I do this?"

The FAR SIDE

FEBRUARY

26

MONDAY

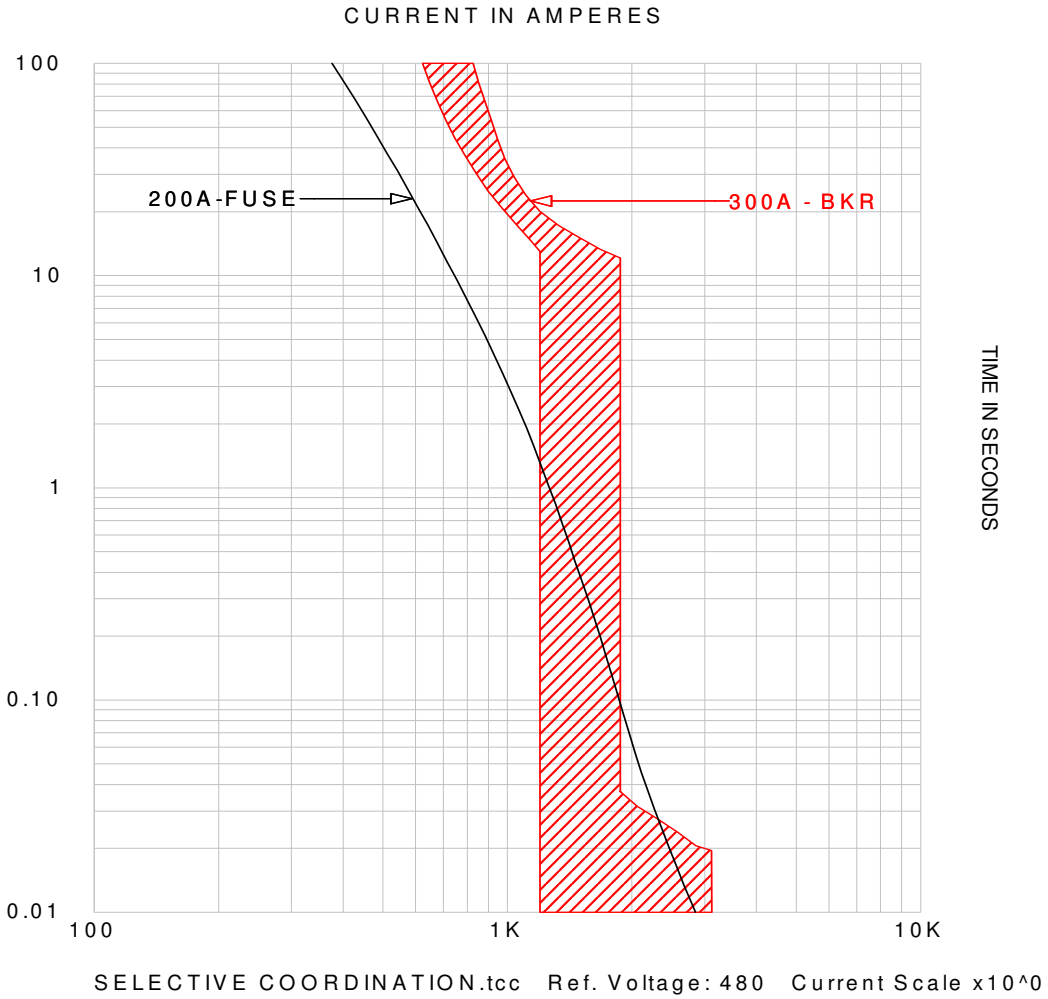
# HISTORY OF NFPA 70 & 70E

- NEC – Originally drawn up in 1897
- 70E – First edition published in 1979
- 70E is a spin off from NEC for OSHA
- Both are concerned with safeguarding people.
- NEC is further concerned with safeguarding of property.

# Selective Coordination

- NEC 100 – Localization of an over current condition to restrict outages to the circuit or equipment affected, accomplished by the choice of over current protective devices and their rating or setting.
- NEC 700.27- Emergency System(s) over current devices shall be selectively coordinated with all supply side over current protective devices.
- NEC 701.18- Legally required standby system(s) over current devices shall be selectively coordinated with all supply side over current protective devices.

# Over Current Protection Device

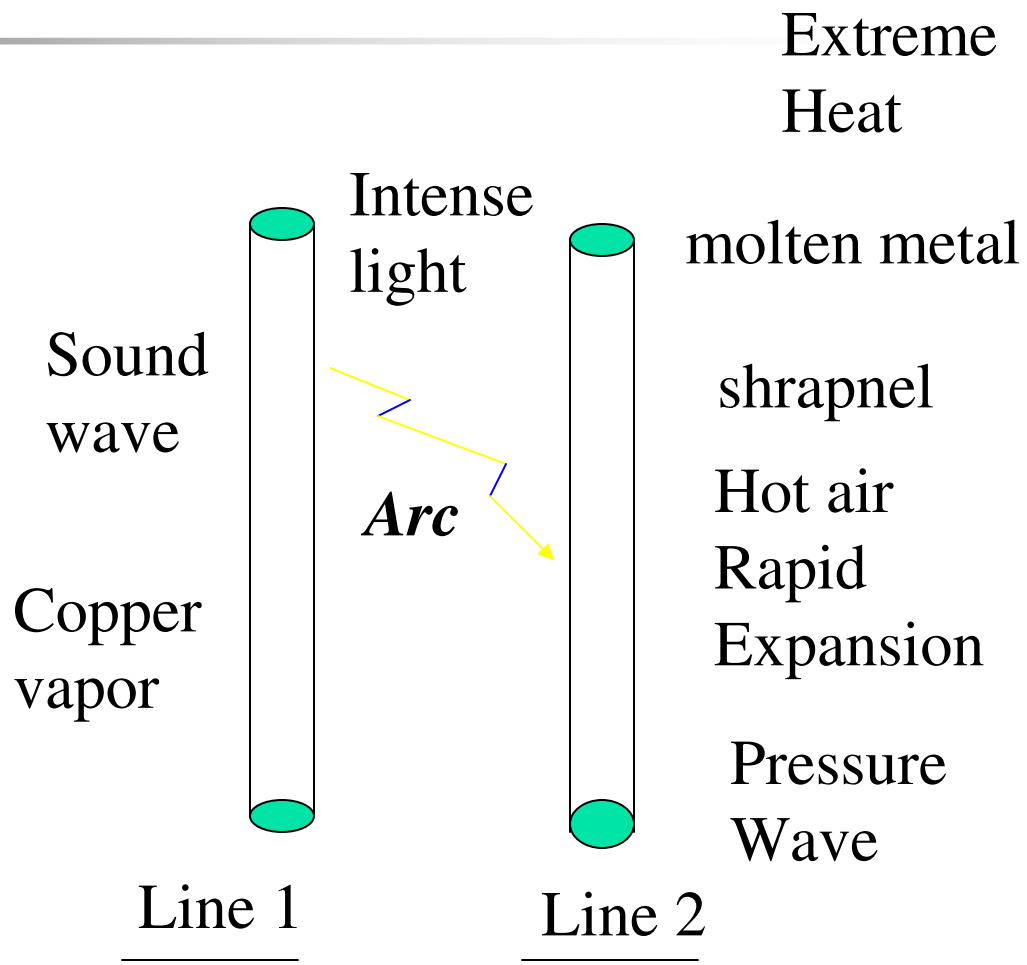


# ARC FLASH HAZARD LABELS

- NFPA 70E-2004, 130.3: "A flash hazard analysis shall be done to protect personnel
- NFPA 70-2005 (NEC-110.16) requires labels be installed by equipment installer.
- OSHA 29 CFR 1910.331-335 mandates
- Triggers a need to review PPE requirements
- Gives information needed to minimize risk
- Prevent thermal injury due to electrical arcs

# Arcing Short Circuit

- Energy is released in various forms.
- Trip time of the fuse or breaker is crucial.
- Limiting current will limit the Incident Energy



# Arc Flash 101

- Arc Fault is an abnormal electrical circuit condition.
  - Short circuit current and energy levels are extreme.
  - Arc Faults begin as "Single Line to Ground" type fault and evolve to "Line to Line to Line to Ground" type fault.
  - Circuit breakers and fuses attempt to limit the energy level in a faulted circuit.
- What determines the current and energy level?
  - Current = Voltage / Impedance.
  - Energy = Current x Voltage x Time
- What determines the Incident Energy?
  - Incident Energy = K x Energy/ D^2.2 (cal/cm^2)
  - Incident Energy determines what PPC is required.

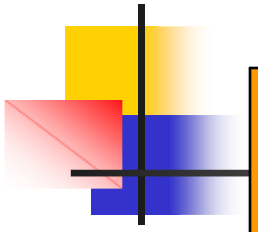
# NFPA 70E- TABLE 130.7(C)(11) Protective Clothing Characteristics

| HRC Hazard/Risk Category | Required Minimum Arc Rating of PPE (Cal/cm^2) |
|---|---|
| 0 | 2 |
| 1 | 4 |
| 2 | 8 |
| 3 | 25 |
| 4 | 40 |

# NFPA 70E – 130.3 Procedure

1. Gather the data
2. Confirm the data accuracy
3. Perform a Short Circuit Study
4. Perform an Arc Flash Energy Study
5. Install Arc Flash Hazard Labels
6. Train Personnel

# ARC FLASH HAZARD LABEL



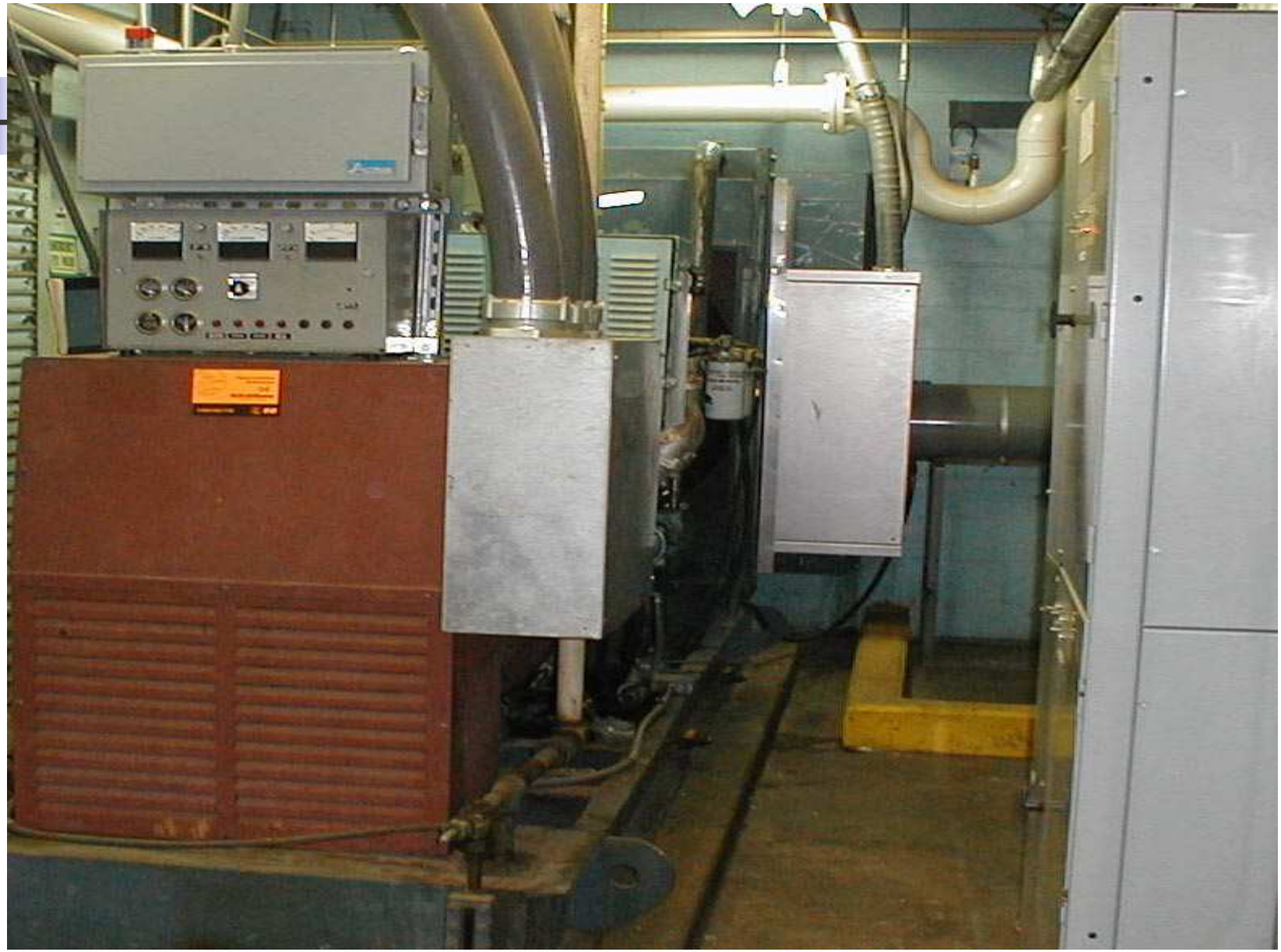
| ! WARNING | |
|---|---|
| **Arc Flash and Shock Hazard Appropriate PPE Required** | |
| 30 inch | Flash Hazard Boundary |
| 2.75 | cal/cm^2 Flash Hazard at 18 inches |
| Class 1 | FR Shirt & Pants |
| 480 VAC | Shock Hazard when cover is removed |
| 00 | Glove Class |
| 42 inch | Limited Approach (Fixed Circuit) |
| 12 inch | Restricted Approach |
| 1 inch | Prohibited Approach |
| Bus: BUS-2H Prot: PD-2H | |

# Why Comply With NFPA 70-E ?

# Why Electrical Safety ?

# GEN-1

# ATS-1

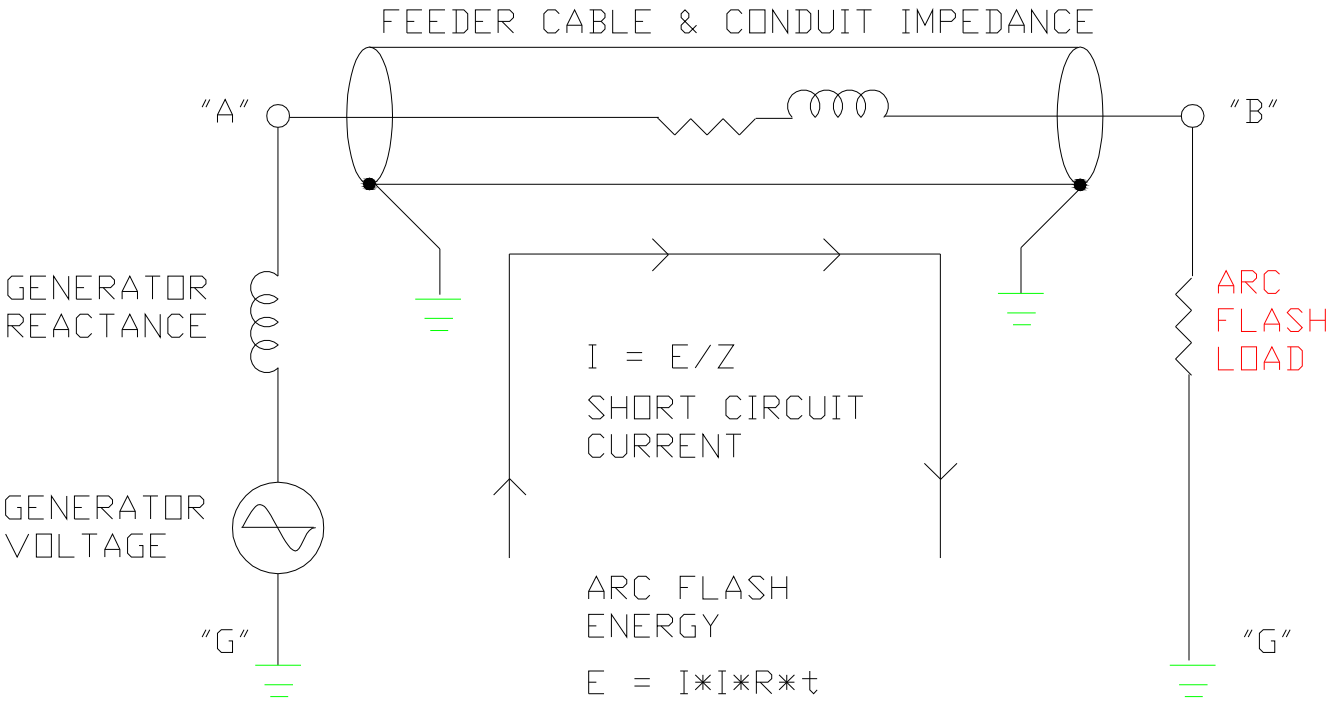


# MEDP-B ATS-1

# EDPA ATS-8


CAUTION!
No Storage Within 3 feet of Electrical Panel
CAUTION!

# GENERATOR ARC FLASH CKT.



# CIRCUIT CHARACTERISTICS

| CIRCUIT ELEMENT | CHARACTERISTIC |
|---|---|
| GENERATOR VOLTAGE | NRG SOURCE; VOLTAGE DIPS; DELAYED REGULATION. |
| GENERATOR REACTANCE | |
| SUBTRANSIENT | MOSTLY REACTANCE; HIGH X/R; |
| TRANSIENT | INCREASES BY INCREMENTS. |
| SYNCHRONOUS | Xst < Xtr < Xsy |
| CABLE & CONDUIT IMPEDANCE | MOSTLY REACTANCE; HIGH X/R; |
| ARC FLASH LOAD | NRG USER; MOSTLY RESISTANCE; LOW X/R; NON-LINEAR. |

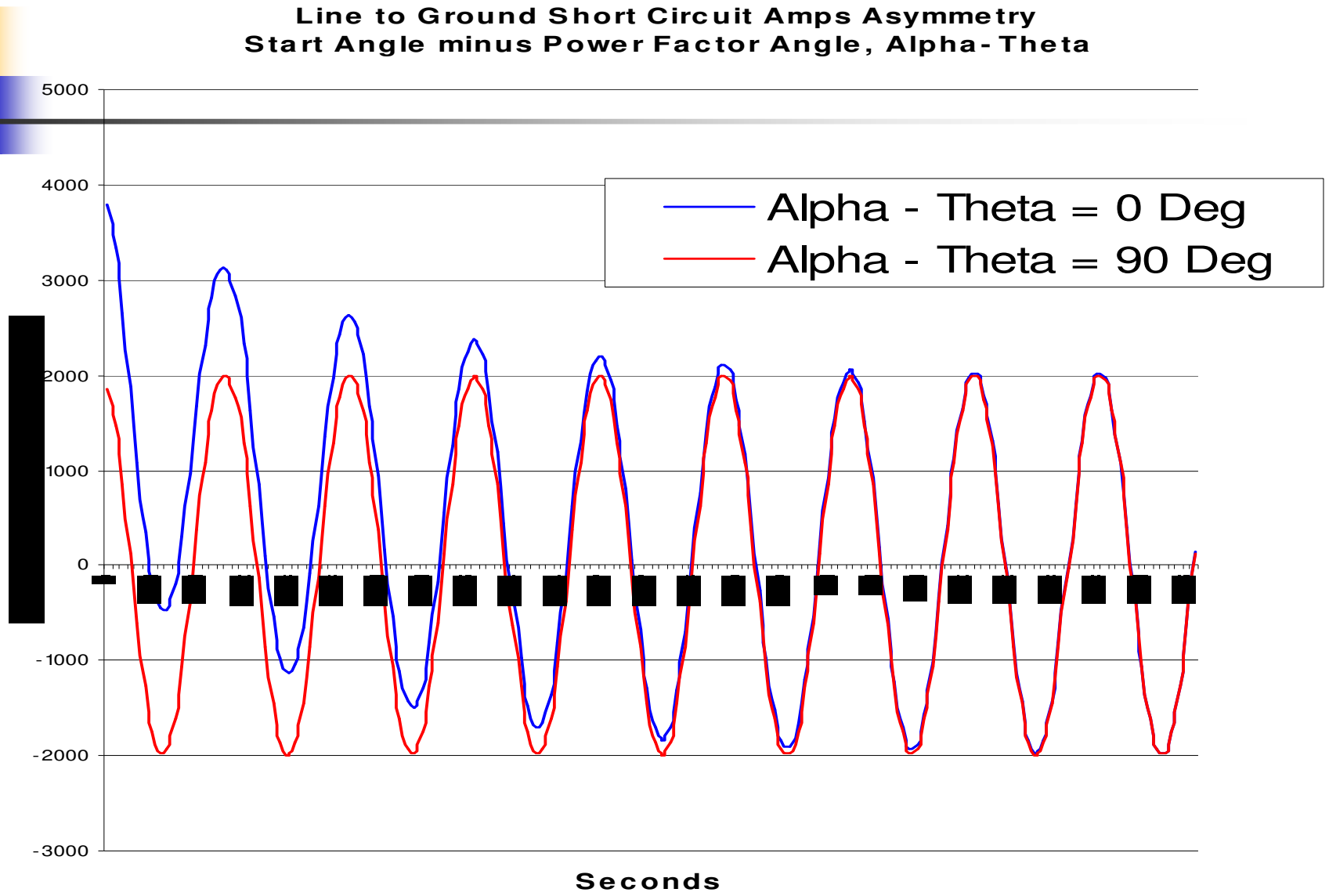
# GENERATOR REACTANCE INCREMENT TIME CONSTANTS

| Increment Time Constant | Large Turbo Solid Rotor | Small (510 KW) Salient Pole | Ratio |
|---|---|---|---|
| Sub transient (d&q Axis) | 0.035 Seconds | 0.0067 Seconds | 5.2 |
| Transient (d Axis) | 1.1 Seconds | 0.162 Seconds | 6.8 |

**An Emergency Generator's Reactance changes about 6 times faster than a Utility Generators.**

Source: "Analysis of Faulted Power Systems", Paul M. Anderson

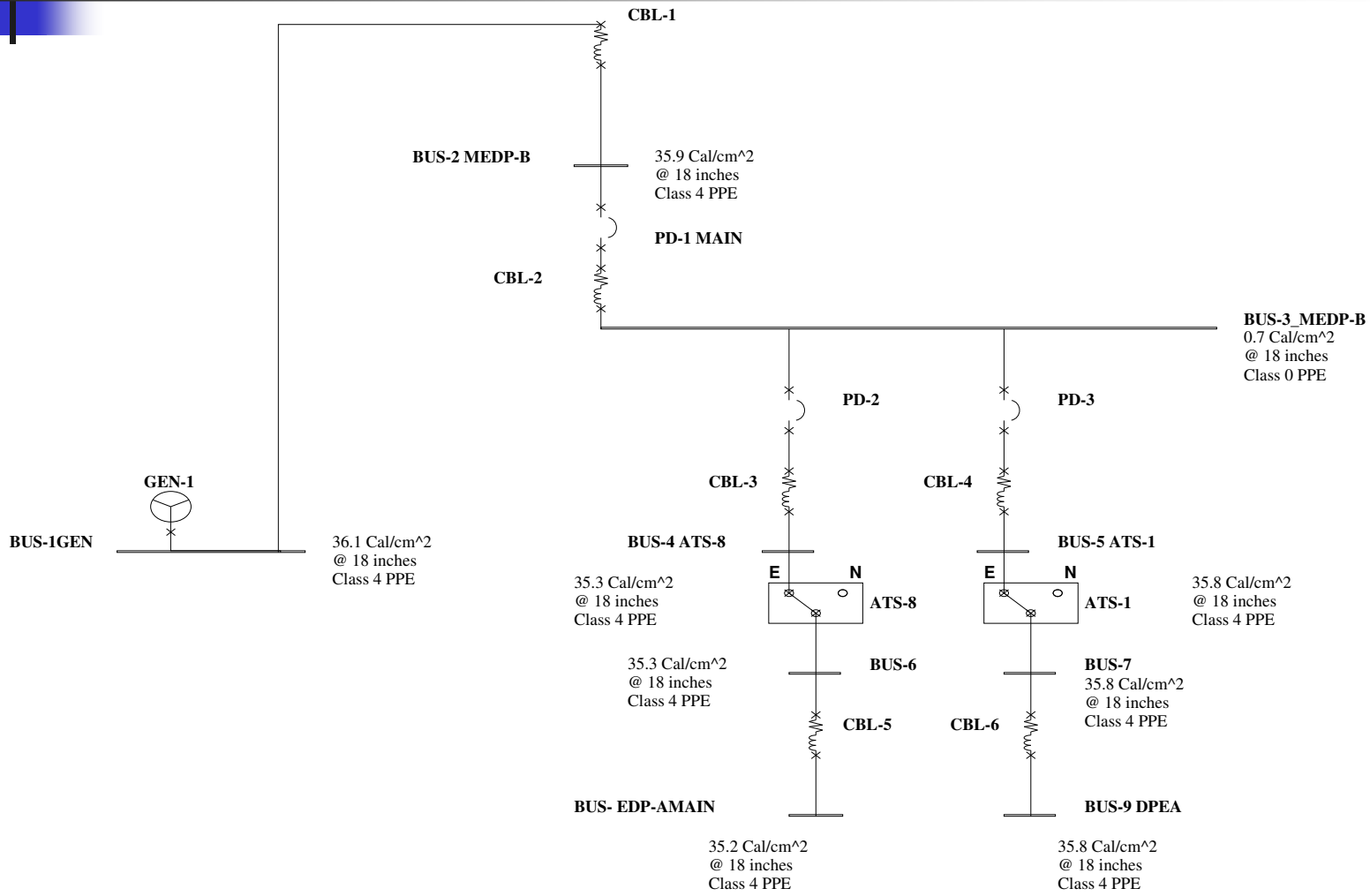
# Generator Fault Response



# SHORT CIRCUIT STUDY FOR EMERGENCY POWER SYSTEM

- Figure 3 – Arc Flash Energy
- Figure 4 - Coordination Study
- Emergency Source was a 510 KW Generator with PMG exciter.
- Source has a typical short circuit response time of about 1 second.

# Fig. 3 – EMERGENCY POWER ARC FLASH ENERGY



# Fig. 4 – As Found OCPD Coordination

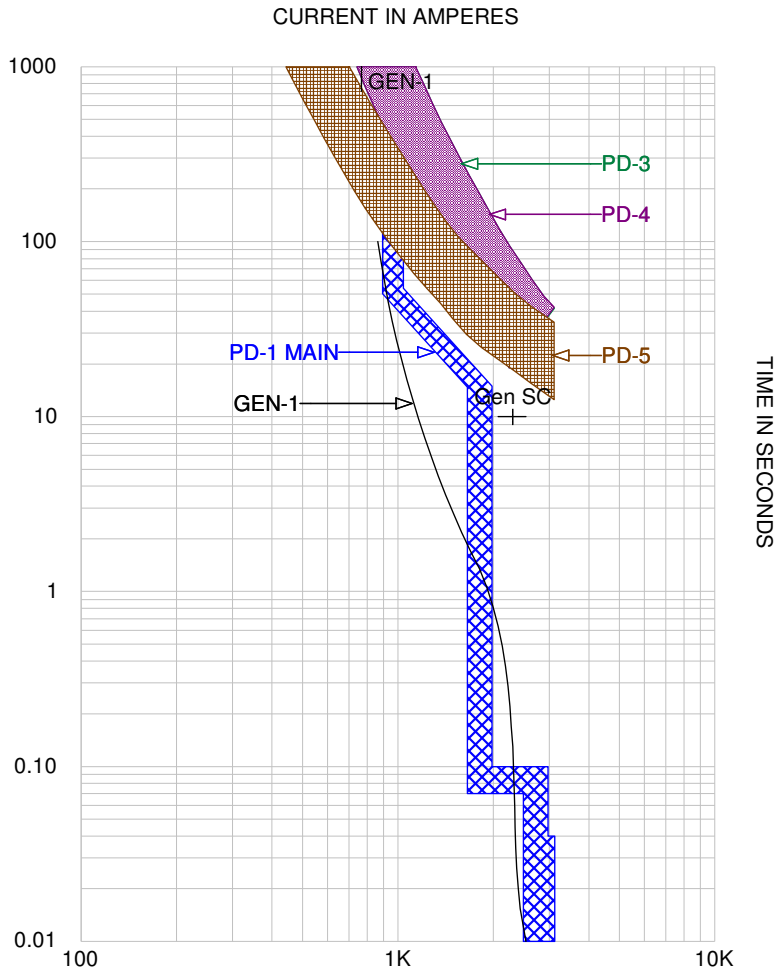



FIGURE IV- AS FOUND (AC ONLY).tcc Ref. Voltage: 480 Current Scale x10^0

# ARC FLASH HAZARD STUDY FOR EMERGENCY POWER SYSTEM

- Figure 3 – Arc Flash Energy Anomalies
  1. Extremely high energy levels from a small 510 KW Generator; HRC level 4.
  2. Energy levels higher at locations remote to the generator.
  3. Low energy level at the generator's main distribution panel; HRC level 0.

# AS FOUND OCPD SETTINGS

- Lacked Selective Coordination; Main Breaker setting was to the left of feeder breakers.
- Instantaneous trips curves were clipped
- NFPA 70E – Table D.8.7 checked to confirm the Energy Levels.
- Generator current limited precludes use of Table D.8.7; Qualifying formula (c) & (d).

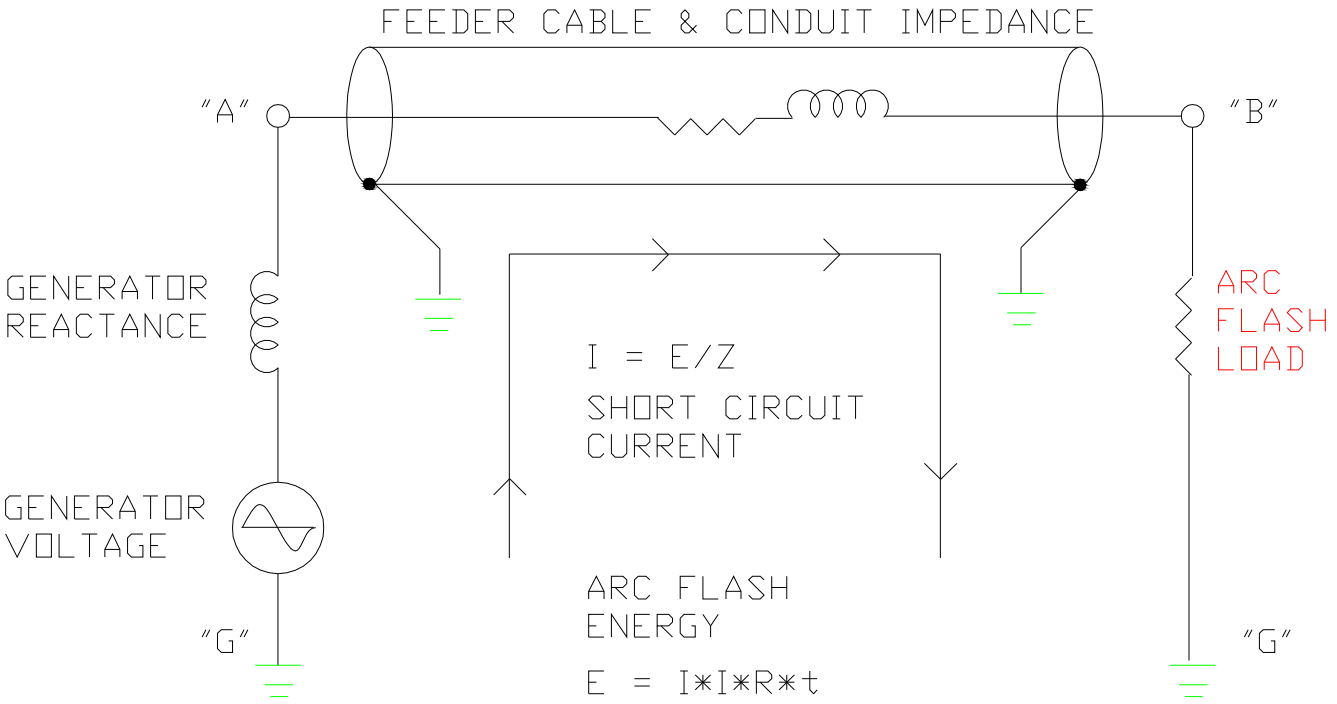
# CIRCUIT FACTS
# NFPA 70 vs. NFPA 70E

- The facts of this case are:
  1. Selective Coordination does not exist.
  2. High levels of Arc Flash Energy exist at unexpected locations.
  3. Selective Coordination would make Arc Flash Energy levels worse
  4. A quickly decaying, low level short circuit current from the generator is inadequate to enable the emergency system's over current protection system.

# FIXING THE PROBLEM

- Goals and Constraints:
  1. Make system comply with both NFPA 70 and NFPA 70E.
  2. Reduce HRC to lowest level possible.
  3. Downtime is limited.
  4. Low Tech/Low Budget solutions only.
  5. Re-use existing equipment when possible.

# GENERATOR ARC FLASH CKT.



# DESIGN APPROACHES

1. Increase the output and response from the generator.
2. Reduce the total circuit impedance.
3. Change over current protection scheme.

# NEW FIX- SAME RESULTS

- Generator output and response:
  1. Increase engine/generator size.
  2. Install a new current boost exciter.
  3. Install a new generator.

# IT'S OHM'S LAW

- Reduce the Z in I = E/Z:
  1. Relocate the generator closer to the load.
  2. Install the feeders in steel pipe and bond pipe to the EGC.
  3. Install an additional EGC.

# OVER CURENT PROTECTION

- OCPD Scheme Changes:
  1. Ground Fault detector alarm
  2. Current Limiting Fuses
  3. New Low Instantaneous Trip Breaker

# Fig. 5 – TRIP TIME COMPARISON LIMITED CURRENT SOURCE

| Over Current Device Type | Short Circuit Amps < 5 x Rating | Short Circuit Amps >10 x Rating |
|---|---|---|
| Fuse - Time Delay | 8 - 12 Seconds | 0.010 - 0.800 Seconds |
| Fuse - Current Limiting | 8 - 12 Seconds | 0.004 - 0.008 Seconds |
| MCCB w/Mag Trip | 8 - 12 Seconds | 0.010 - 0.030 Seconds |
| MCCB w/Static Trip | 8 - 12 Seconds | 0.030 - 0.040 Seconds |
| Fuse -CL w/Low Threshold | 0.004 - 0.008 Seconds | 0.001 - 0.004 Seconds |
| MCCB - w/Low Inst Trip | 0.010 - 0.030 Seconds | 0.010 - 0.030 Seconds |

# Fig. 6 – TRIP TIME COMPARISON OF DEVICES UNDER SHORT CIRCUIT CONDITIONS

- Current limiting fuses and breakers will not operate as intended if the source of the short circuit current is itself limited.
- Current limiting fuses with a low Threshold Ratio (SSC/Rating) work best at reducing Arc Flash Energy.
- Molded Case Circuit Breakers with a Low Instantaneous works equally well.

# FINAL SOLUTION & RESULTS

- Replace breakers in the main distribution panel with an equally rated breaker with a low Instantaneous Trip Setting.
- Adjusted the instantaneous trip settings on other existing breakers for Selective Coordination.
- Arc Flash Level and HRC cut in half.
- See Fig. 7 and Fig. 8. for results.

# Fig. 7 – AS LEFT SETTINGS

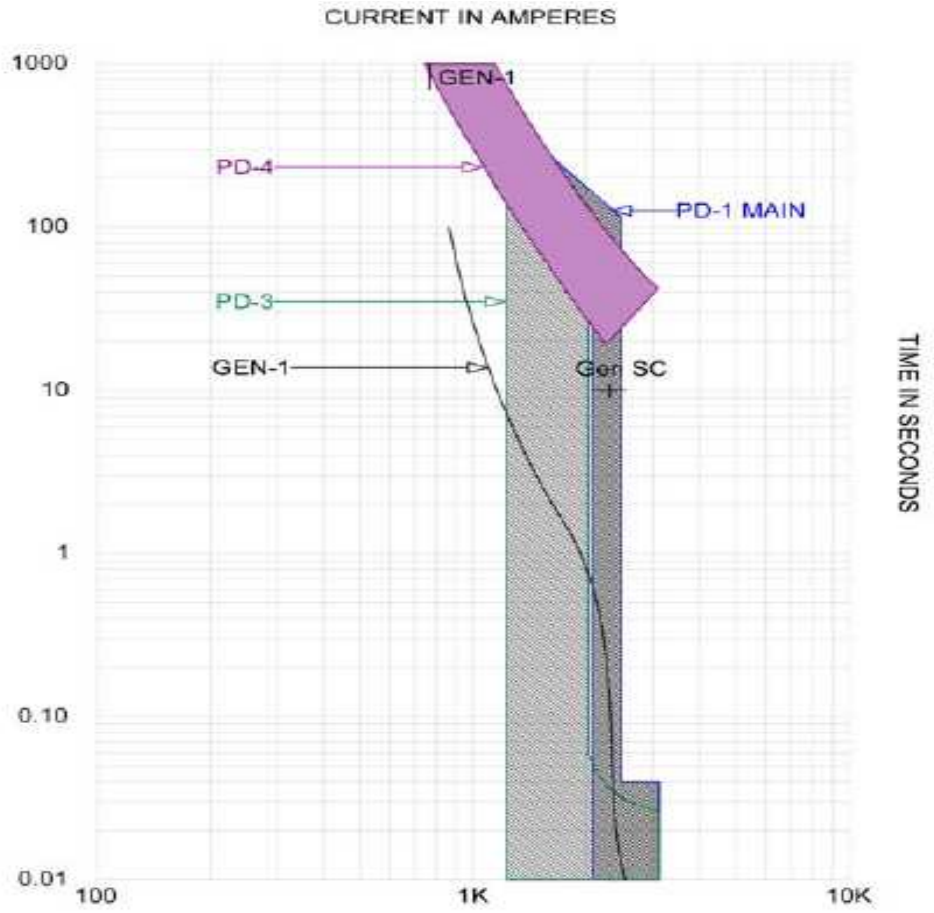



Fig. 7 – AS LEFT SETTINGS.tcc
Ref. Voltage: 480 Current Scale x10^0

# Fig. 8 – ARC FLASH EVALUATION BEFORE vs. AFTER SELECTIVE COORDINATION

| Bus Name | Incident Energy (Cal/cm^2) | | Required Protective FR Clothing Class | |
|---|---|---|---|---|
| | *Before* | *After* | *Before* | *After* |
| BUS-1-GEN | 36.1 | 36.1 | Class 4 | Class 4 |
| BUS-2-MEDP-B | 35.9 | 35.9 | Class 4 | Class 4 |
| BUS-3_MEDP-B | 0.7 | 16.1 | Class 0 | Class 3 |
| BUS-4 ATS-8 | 35.3 | 6.02 | Class 4 | Class 2 |
| BUS-EDP-AMAIN | 35.2 | 6.0 | Class 4 | Class 2 |
| BUS -5 ATS-1 | 35.8 | 6.13 | Class 4 | Class 2 |
| BUS - 7 | 35.8 | 6.13 | Class 4 | Class 2 |
| BUS - 9 - DPEA | 35.8 | 6.12 | Class 4 | Class 2 |
| BUS - 10 _DPEA | 35.8 | 6.12 | Class 4 | Class 3 |
| BUS11 DPEA4-HA | 34.6 | 5.91 | Class 4 | Class 2 |

# CONCLUSIONS

- Small generators can deliver extreme levels of Arc Flash Energy.
- Over current protection schemes must consider the generator's characteristics.
- Selective Coordination and Reduced Arc Flash Energy are not mutually exclusive.
- Always jointly consider Codes' intents.