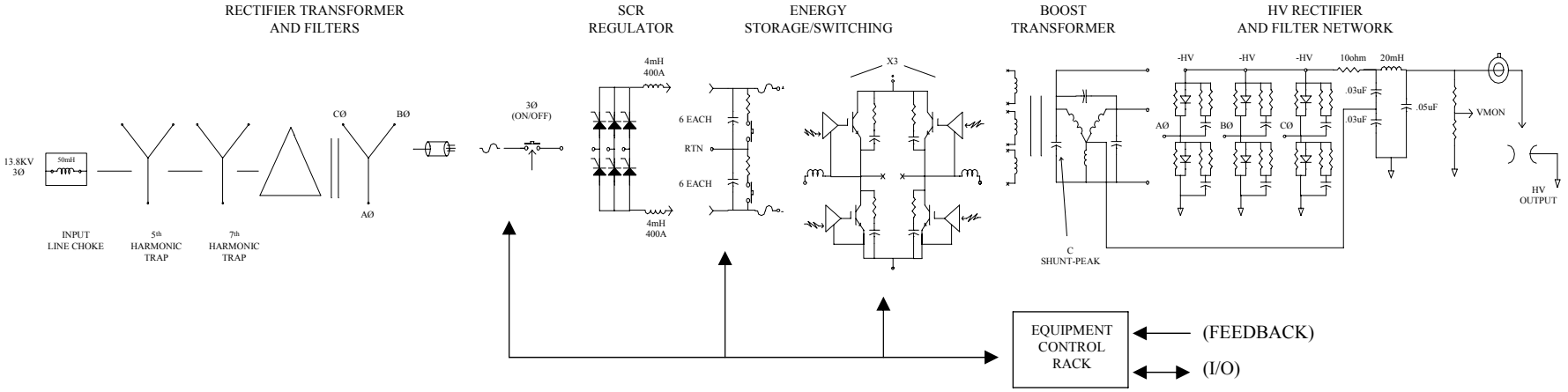
Electrical Safety of the HVCM Systems

David E. Anderson

Basic Block Diagram



RECTIFIER TRANSFORMER AND FILTERS

SCR REGULATOR

HIGH VOLTAGE CONVERTER/MODULATOR

EQUIPMENT CONTROL RACK

HVCM Hazards

- Electrical – up to 150 kV pulsed, 1500 V dc
- Potential explosive energy release – from capacitors
- Thermal – Heating of IGBTs, other components under oil
- Insulating oil – potential for allergic reaction
- Trip / Fall – Cables, grounding bus, etc.
- Water pressure – 120 psi supply line
- Lifting / rigging – maintenance on tank components

Electrical Safety Implementation

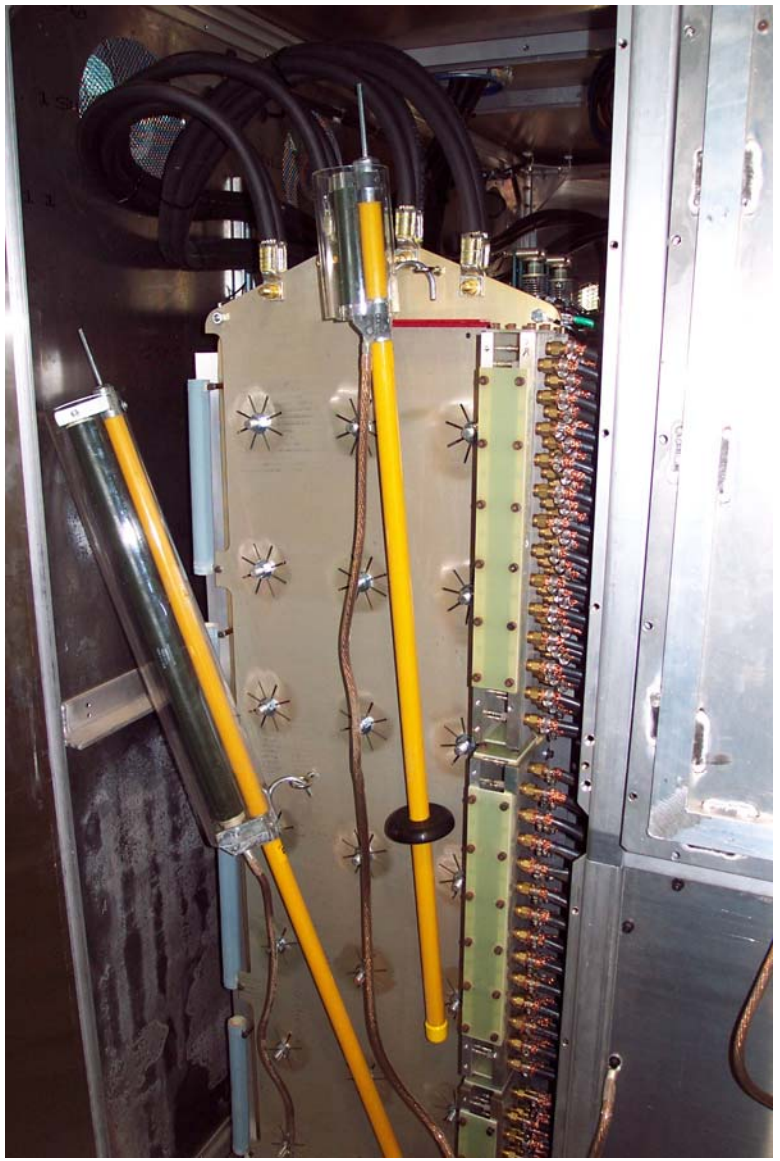
- Worker certification -- Certified Electrical Worker
- Worker training, general & job-specific
- Engineering systems
- Procedural systems
  - JHA
  - LOTO
- Emergency Shutdown Procedures
- Operator Training
- Non-NRTL Certified Equipment Certification

Electrical Safety HVCM “Controls”

- Equipment-specific training for all installation, maintenance, and testing personnel
  - Read procedures
  - Demonstrate competency
  - Engineering authorization to perform work
- Automatic system shutdown (OFF)
  - Removes AC power from all ancillary systems
  - Opening equipment doors
  - Pressing Smoke/water detection
  - Emergency Off button(s) (and opens switchgear)

Modulator System

- Capacitor safety
  - Bleeder resistors across cap banks, quad redundancy, τ = 20 minutes
  - Ross relay shorting devices thru 2 parallel 50Ω resistors dual redundancy, τ = 2.8 s
  - Caps grounded, but ground not visible when maintaining
  - Shorting sticks
    - Hi & Lo Z points
    - Hand guards
    - Length consistent with voltage hazard
    - Neutral and HV sticks



Modulator System Arc Calculations

- $I_{arc,peak}$ = 60 A w/ high Z
  - Presently, 20 Ω resistors installed from LANL
- No guidance for DC arc calculations, except DOE Handbook
  - Peak current <500 A
  - #2 AWG minimum

Modulator System

- Switch Plate Capacitors
  - Treated same as cap rack capacitors (prior VG)
- Oil Tank Capacitors
  - On filter, transformers, and rectifiers
  - Bleed through other circuitry
  - Short both terminals to ground w/ sticks
  - Install drain wire prior to maintenance
- DOE Handbook major source of guidance

NFPA 70E / OSHA V-rating Categories

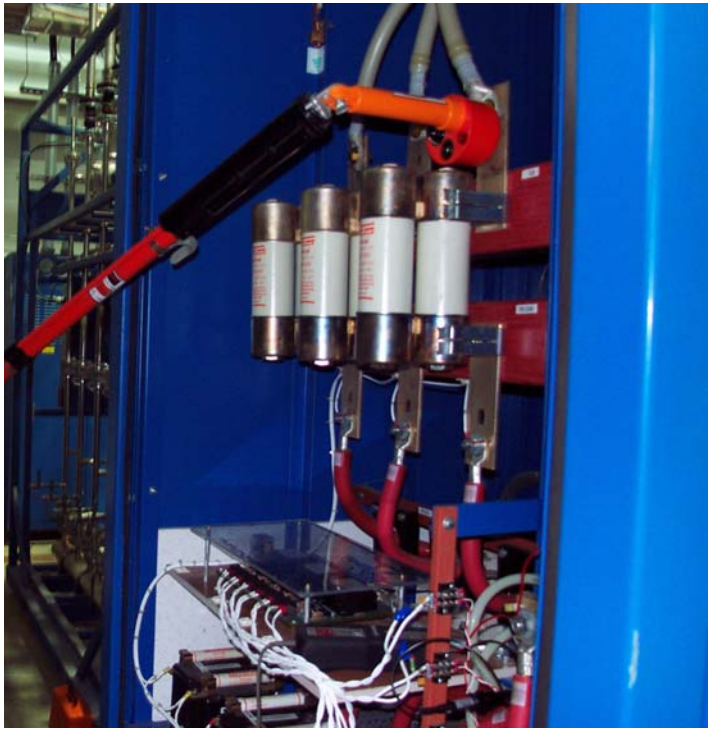
- 70E based on 50% probability of 2nd degree burn
- OSHA classifications based on variety of ASTM standards for PPE

Cat. or Class.	OSHA V-rating (kVrms)	NFPA 70E max. energy (cal/cm2)
00	0.5	N/A
0	1.0	1.2
1	7.5	5
2	17.0	8
3	26.5	25
4	36.0	40
5	N/A	100

SCR Controller

- 2100 Vac input to unit
- Fed from Delta-Wye 13.8 kV:2100 V transformer outside
- LOTO Procedure
  - Open switchgear (SG) remotely from inside gallery
  - Inspect knife switch (all 3ϕ)
  - Lock cam in OPEN position and remove keys
  - Lock 208 V control power disconnect or 208 V breaker
  - Place SG and operator keys inside lockbox
  - Remove back cover to SCR Controller
  - Verify absence of power to unit
  - Install grounding set on all 3ϕ inputs

SCR Controller Work-in-practice



NFPA-70E Calculations

$I_{SC} = 1e6 \times (MVA)/\sqrt{3} \times V) \times (100/\%Z) = 5800$ A[1]
(8.7% impedance XFMR on 1.5MVA base @ 2100 V)

$I_{arc} = 10\text{^}(0.00402+0.983\log(I_{SC}) = 5.1$ kA[2]

$\log E_n = -0.555+1.081\log(I_{arc})+0.0011G \rightarrow E_n = 1.65$
G is electrode spacing, 6" used

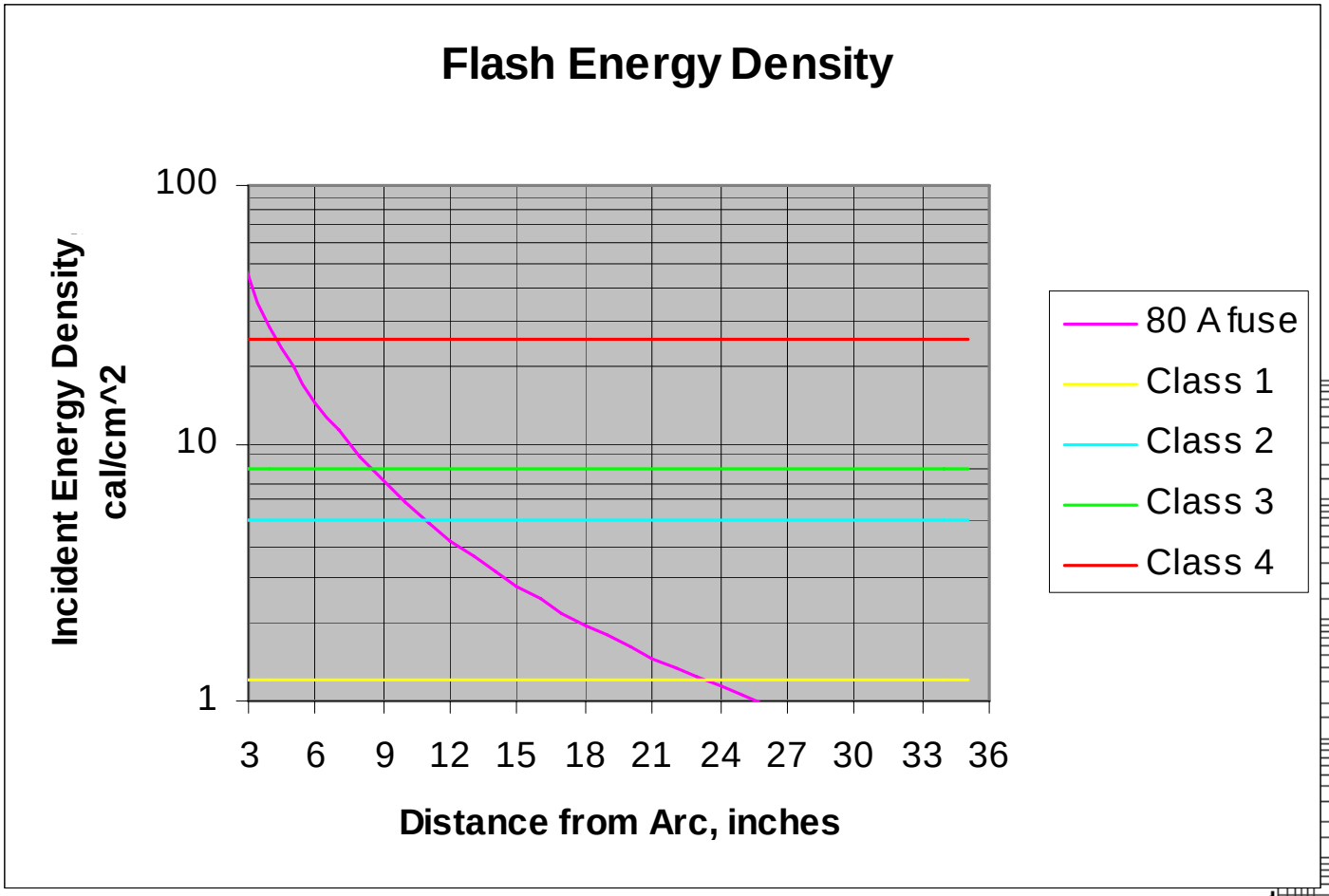
$E = C_f E_n (t/0.2)(610/D)^x$, where
x=2, based on nature of arc
t=fuse clearing time from fuse charts
D=distance from arc in mm
C_f is calculation factor, =1 for V>1 kV

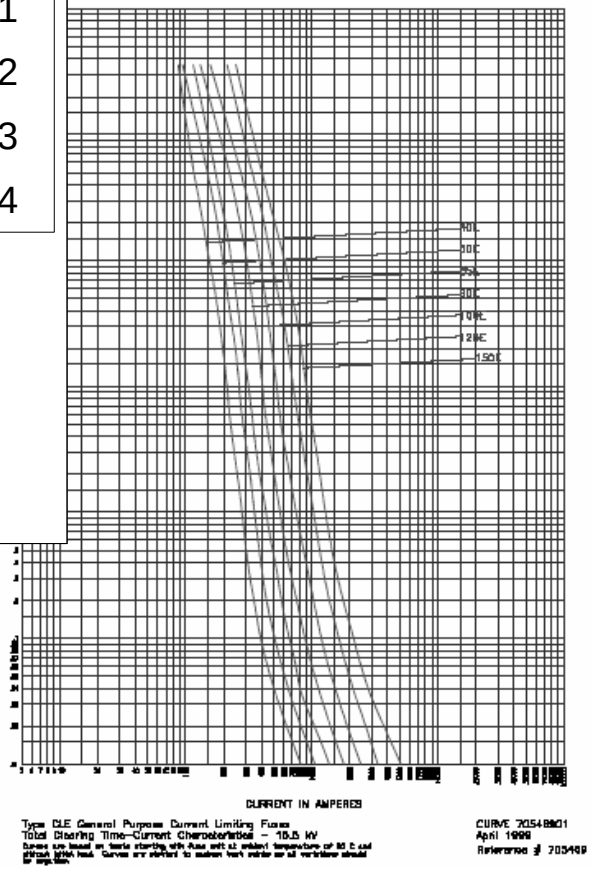
t calculated from fuse curves based on $I_{arc} \times V_s/V_p$ for ΔY

[1]NFPA 70E, 2000 Edition

[2]IEEE Std 1584-2002

NFPA-70E Calculations





NFPA-70E PPE Considerations

- NFPA-70E basis - 50% probability of 1st or 2nd degree burn
- We should be more conservative!
- Need to install coordinated fuses – further risk reduction
- NFPA-70E overly conservative for V>600 V
  - Verification of voltage done with hot stick Class 2 (voltage rating) minimum
    - Distance isolation does not requires PPE
    - 20 cal/cm^2 suit used, although overkill for this task
    - Voltage sensor attached, tested prior to and after verification
  - Can only attach ground set w/ hands, PPE req'd.
    - Class 1 (voltage rating) gloves and leathers
    - Class 4 (arc protection) hands and arms protection
    - Class 2 face shield req'd.
  - Another Solution?

Alternatives

- Presently using 80 A fuse, install coordinated fuses on secondary
- Signage required per Section 3-4.7 NFPA-70E per ANSI Standard Z535, w/ minimum info req'd:
  - Flash protection boundary
  - Load/Line Side Energies
  - Operating voltage
- Leather gloves good for about 35 cal/cm^2
- Install "ball & socket" grounding cluster set w/ hot stick to isolate worker

Conclusions

- Modulator safety practices in good shape
- Analysis should be carried out facility wide for flash hazards, like EasyPower® ArcFlash™ computer program
- Policies should be implemented uniformly throughout – addressed w/ new “On or Near” document