

# Safety By Design

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IEEE CANADA 2013



Celebrating 125 Years  
of Engineering the Future



# Safety by design Substation Goal

*Design a Substation where all tasks identified in NFPA 70E tables for MCC and SWGR will be hazard / risk category 1 or 0*

*i.e.*

*Qualified technicians rely on PPE as a last ditch mean of protection only really needed for measuring for absence of voltage and applying safety grounds where not using ground trucks*

# Safety and Design Considerations

- Arc Flash Boundary Identified
- Arc Resistant
  - MV Switchgear
  - LV Switchgear
  - MV motor Control
- Rear Door Interlock
- Remote Racking
- Mimic Bus
- PPE Storage in the PCR
- Grounding truck



# Safety by Design Considerations

- High Resistance grounding for 5kV and below
- Med Resistance grounding for 15kV
- Touch safe terminals
- Labeling



# Enhanced Safety Options

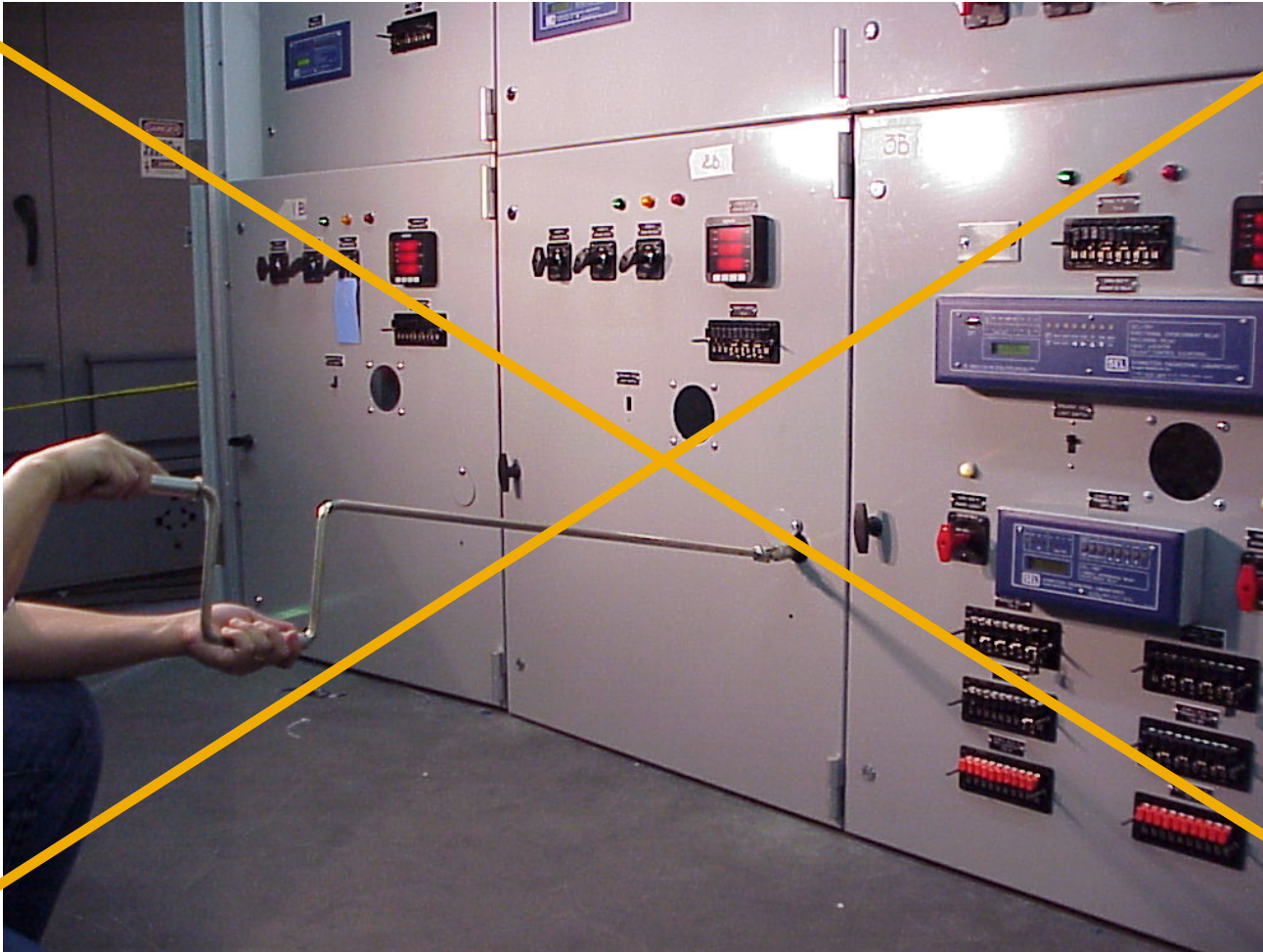
- Complete Short Circuit ,  
Coordination and Arc Flash Study
- Field Service installation  
supervision
- Smart Substation
- Infrared ports
- Instantaneous relaying
- Factory Training



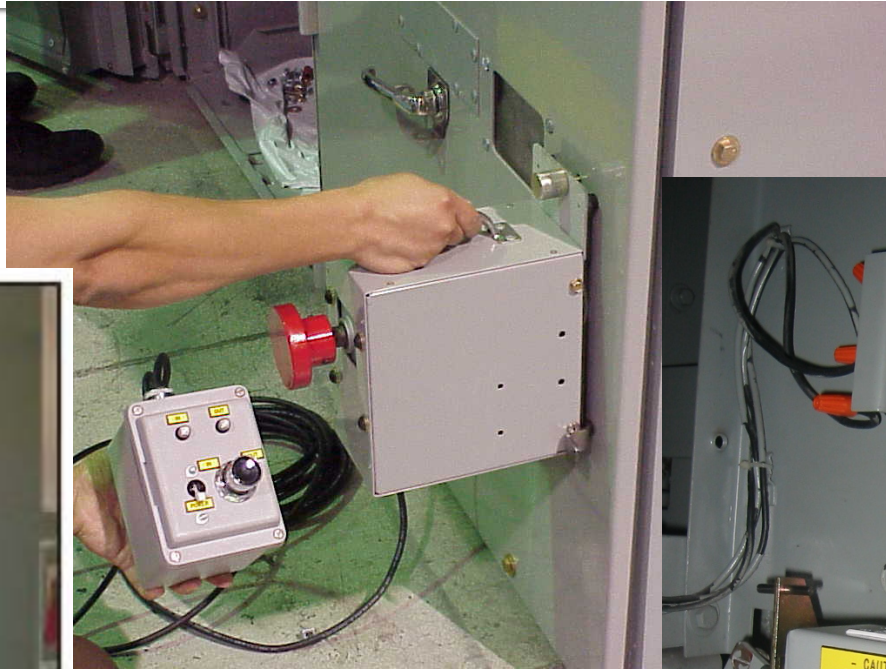
# 13.2kV 25kA Incident assume cleared by fuse at switch



# Through door racking of standard equipment



# Remote Racking



Racking 50-DHP-VR

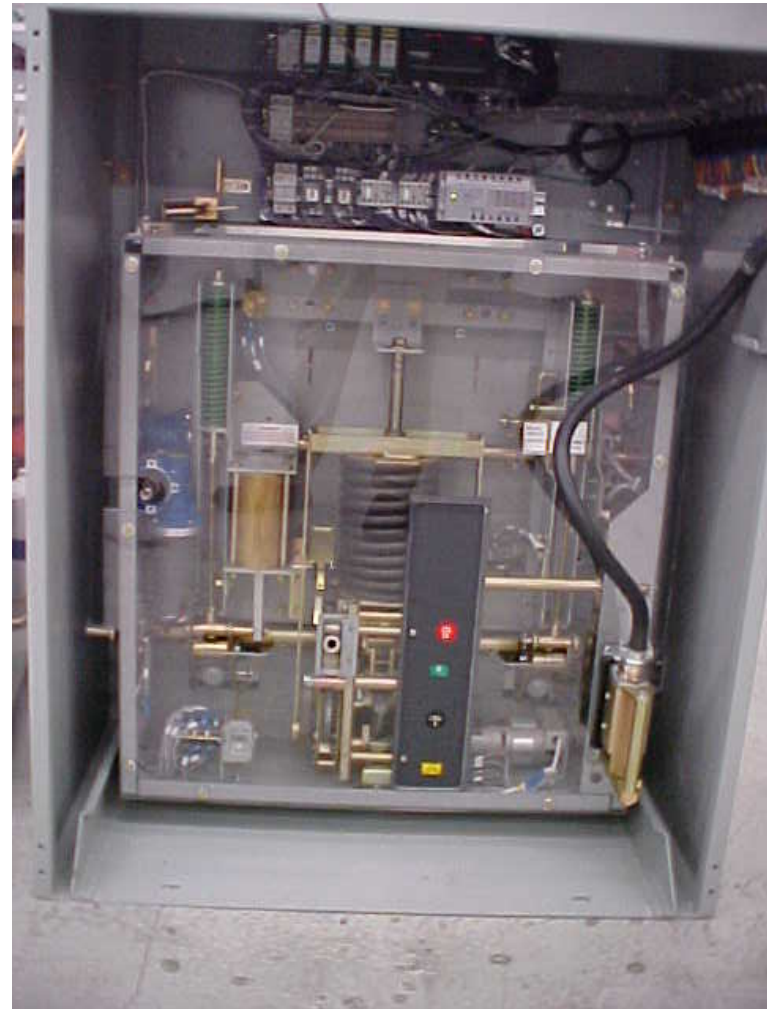
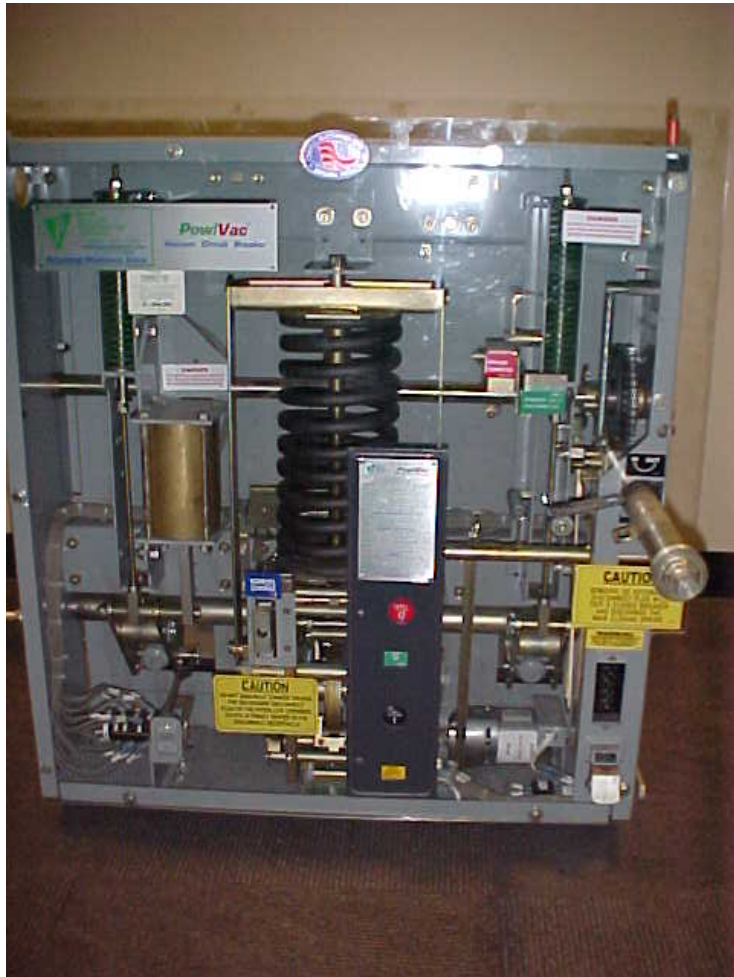


## Remote Open / Close

- Cannon Plugs added to the front of the switchgear
- One control station used to open and close breakers



# Closed Door Racking



# Labeling

- Front of gear mimic
- Protective “One Line” Nameplate
- Descriptive labels for components
  - Not just labeling fuse as FU-2 but label FU-2 CB Close Circuit
- Labeled shutters
- Cable compartment nameplates



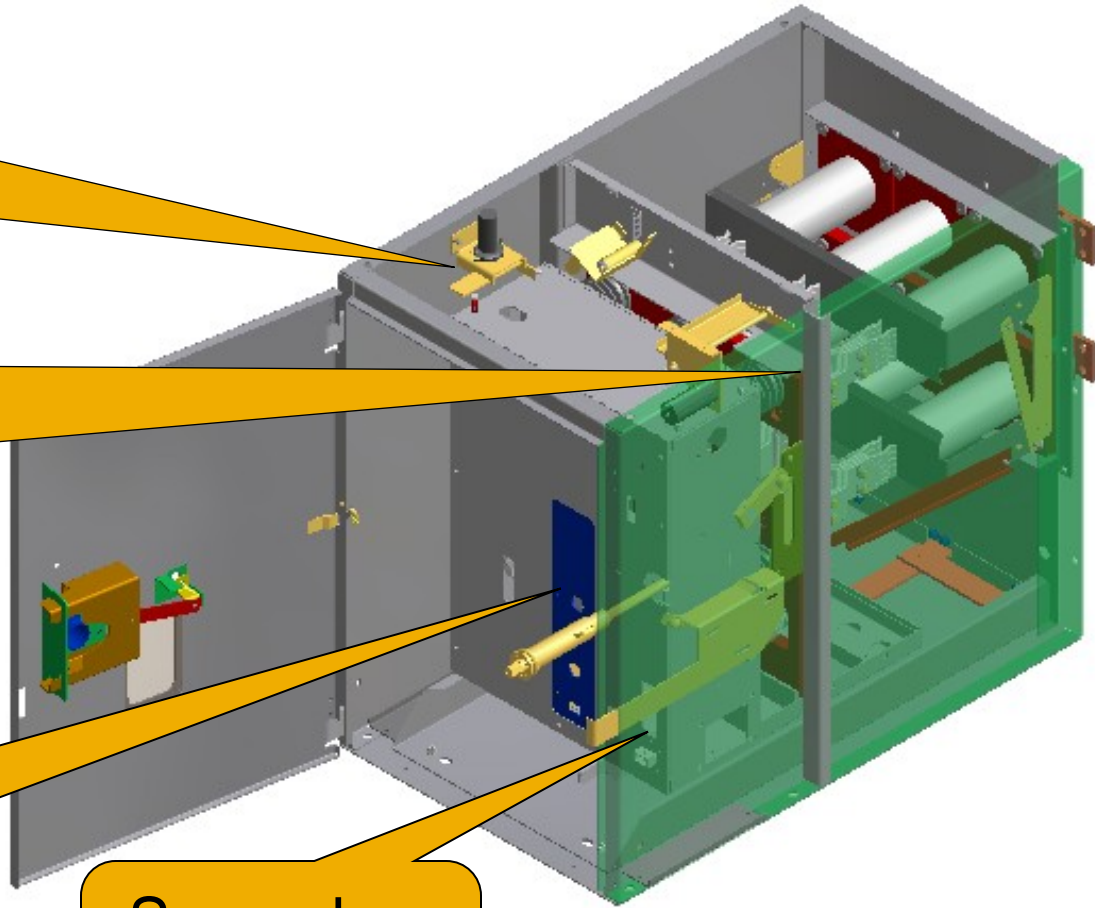
# Breaker Compartment Hazards

**TOC  
(Truck  
Operated  
Contacts)**

**MOC  
(Mech  
Operated  
Contacts)**

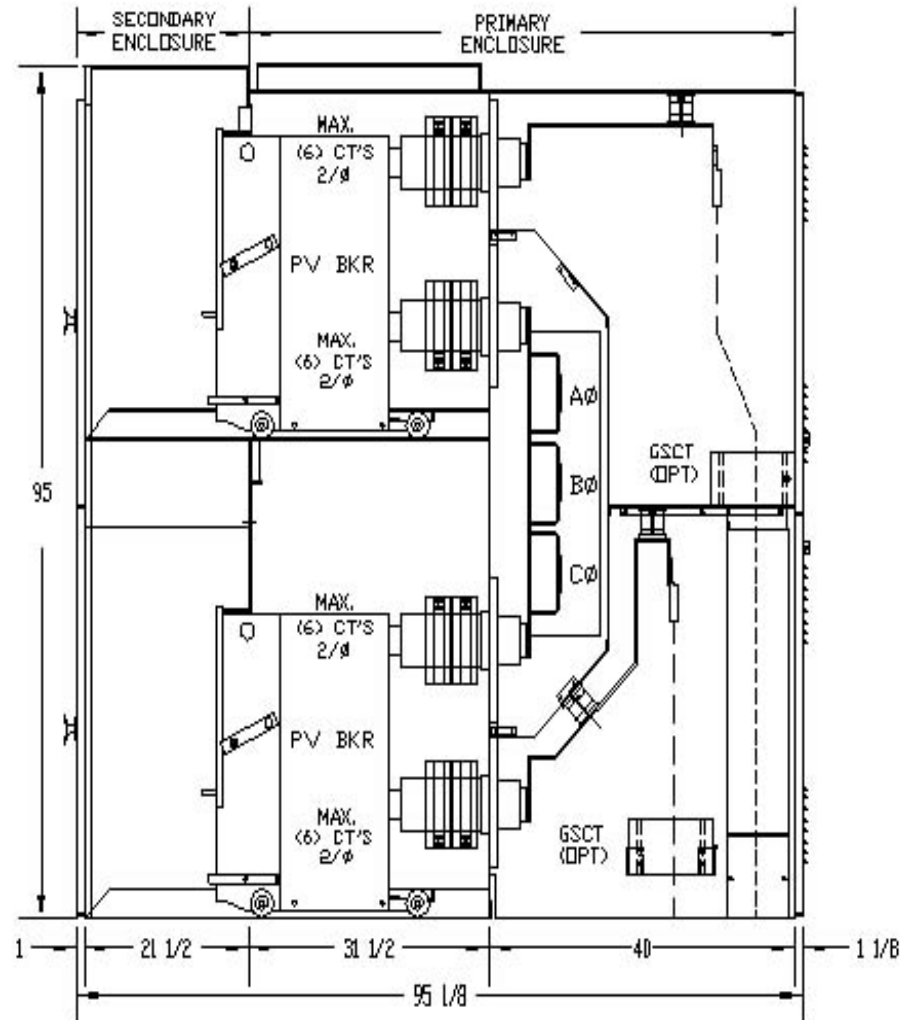
**Circuit  
Breaker  
Racking**

**Secondary  
disconnect**



# MV Swgr

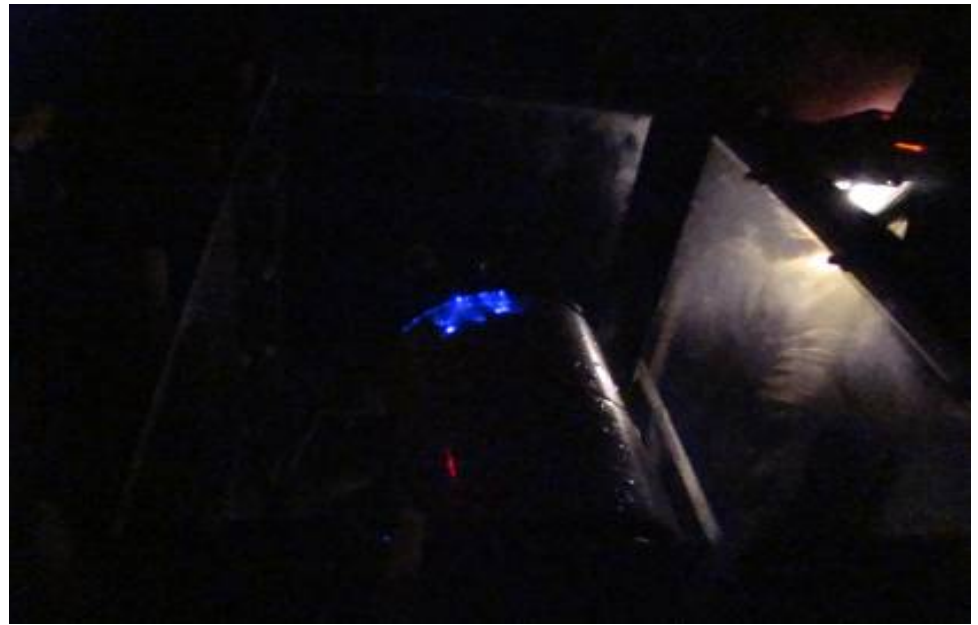
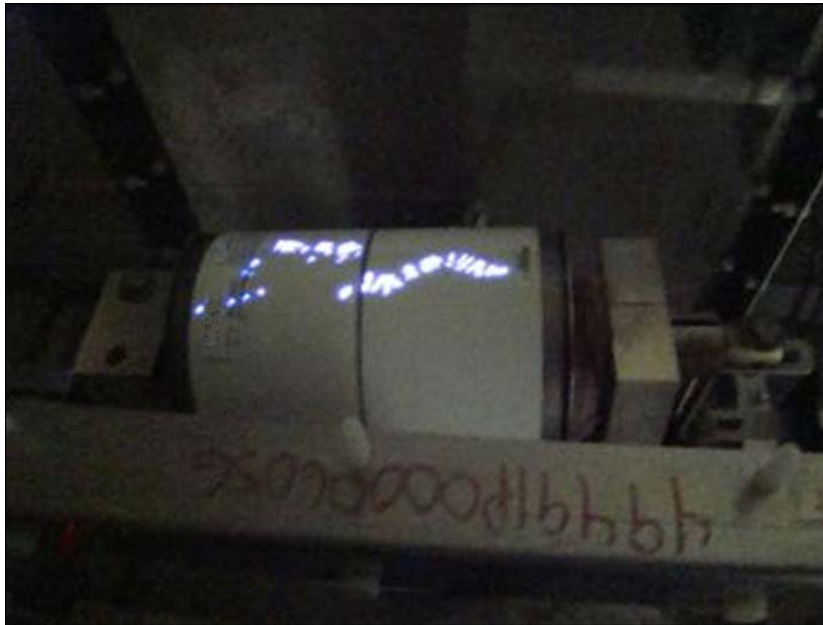
- Long creep paths to help eliminate tracking faults
- Minimal phase to phase supports
- Minimize hot spots
  - Conductor size
  - Surface area
  - Air flow rate
- Racking method
  - Assure alignment
  - Maintainable



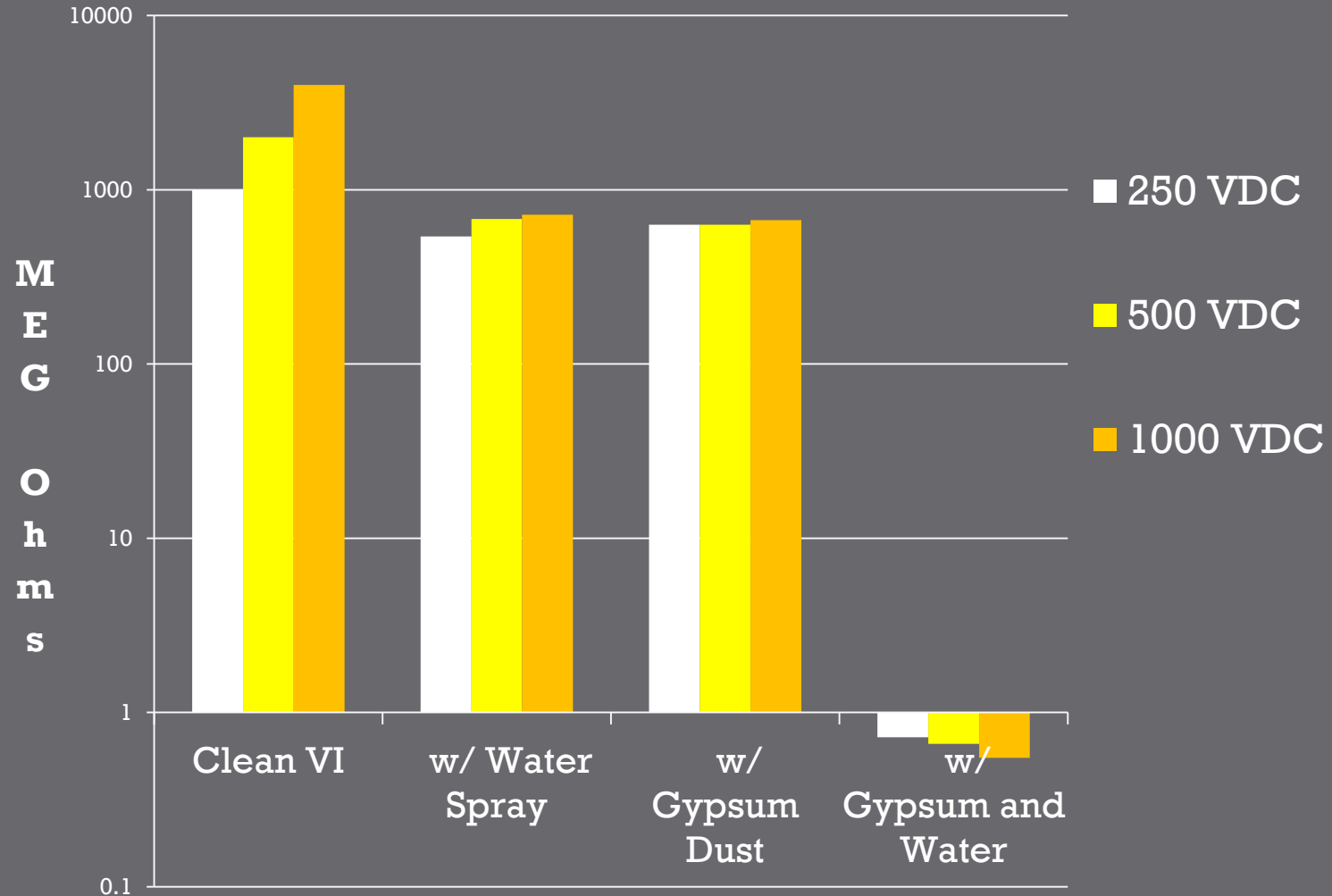
# Contamination and Aging

- Reliability center maintenance
- Climate controlled Substation
- Anti-condensation heaters
- Long creep paths
- Thermal limits
- Mechanism aging
  - Too many operation – mechanical wear
  - Too few operation – mechanical freezing

# Visible corona across a contaminated VI



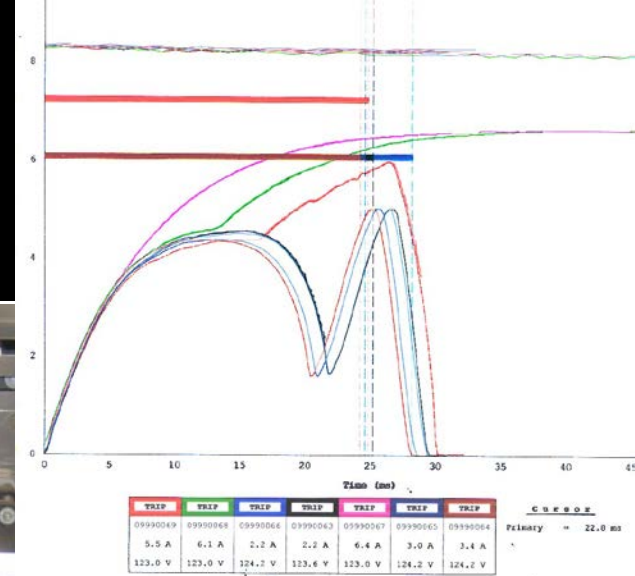
## Megohms test of horizontal VI with contamination





# Failure Mechanisms

- Dielectric System
  - Temperature
  - Altitude
  - Contamination
  - Partial Discharge
- Mechanical System
  - Temperature
  - Contamination



# Additive Effective – Surface Flashover

- Non-uniform Electrical stresses
  - Localized partial discharges
- Elevated temp and ozone
  - Reactions with the polymeric insulation
- Low impedance high stress areas
  - Free electrons
  - Less stable molecules
- Electron Avalanche

# Additive Effects - Flashover in Air

- Per design low level voltage stress limits  
 $1'' = 20\text{kV}$ 
  - Few free electrons
  - No current flow
- As field strength increase or chemical bonding
  - More free electrons and more collisions
- Process continues resulting in conductive path
- Resulting in electron Avalanche

# Failure Mechanism – Dielectric System

- Contamination
- Condensation



# Substation

- Climate control of substations
- Chemical filtration where required by coupons tests
- Windowed door to allow radio communication and door safety

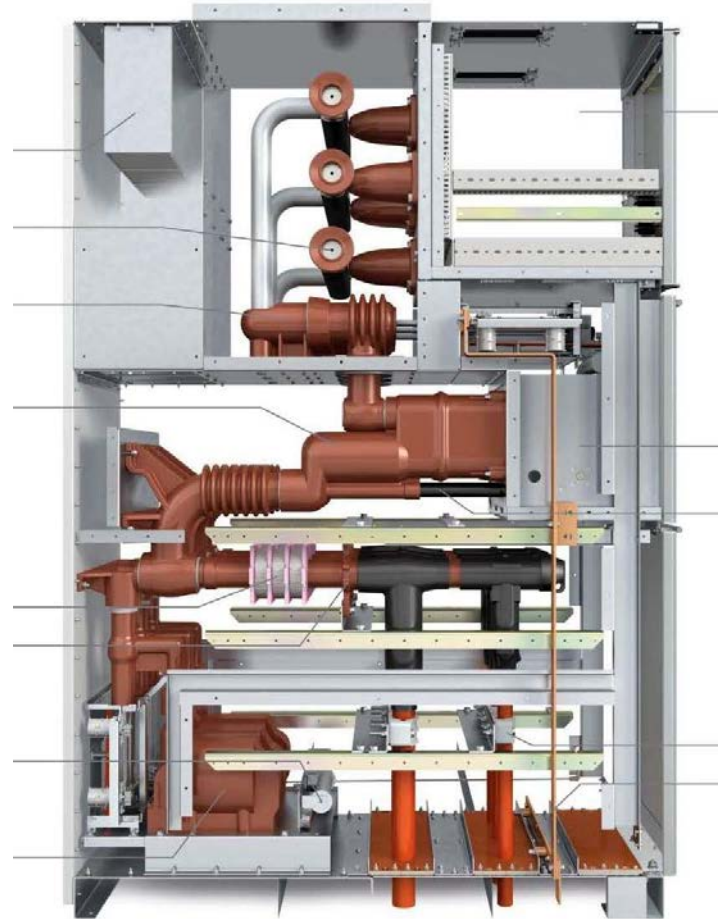
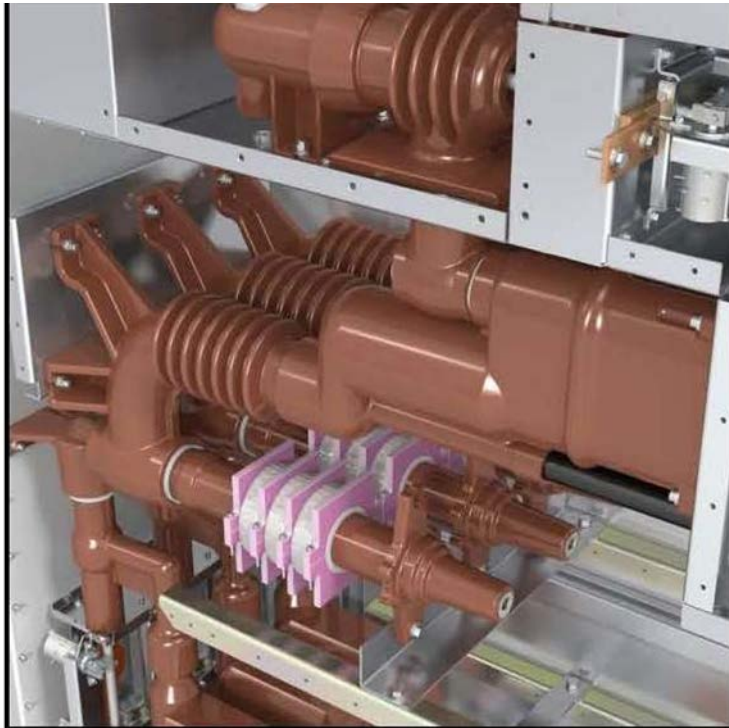


# Plug and play vertical sections

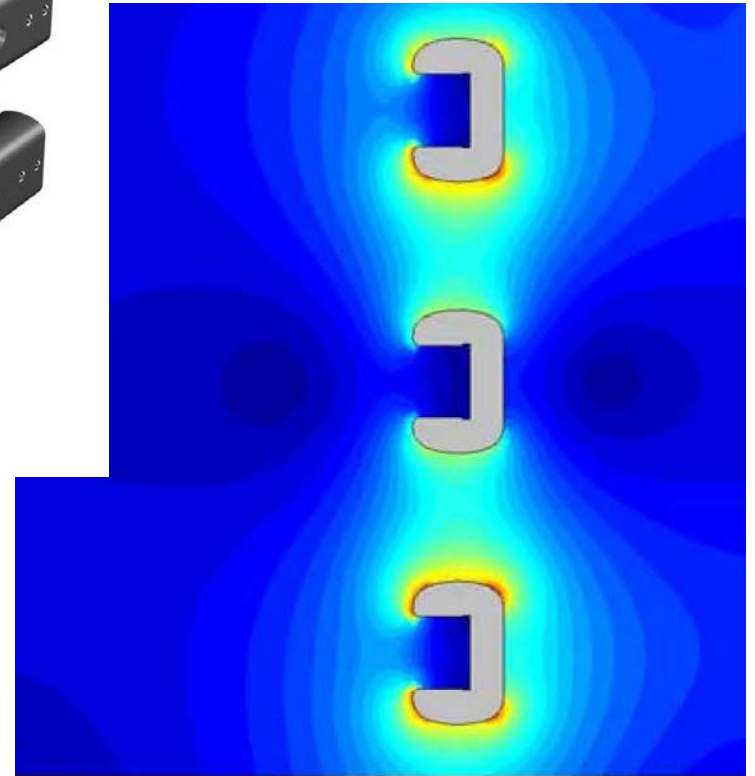
- Only a 630A, 20kA device at this time



# Minimized bare copper helps prevent arcing fault



# Managing the E Field



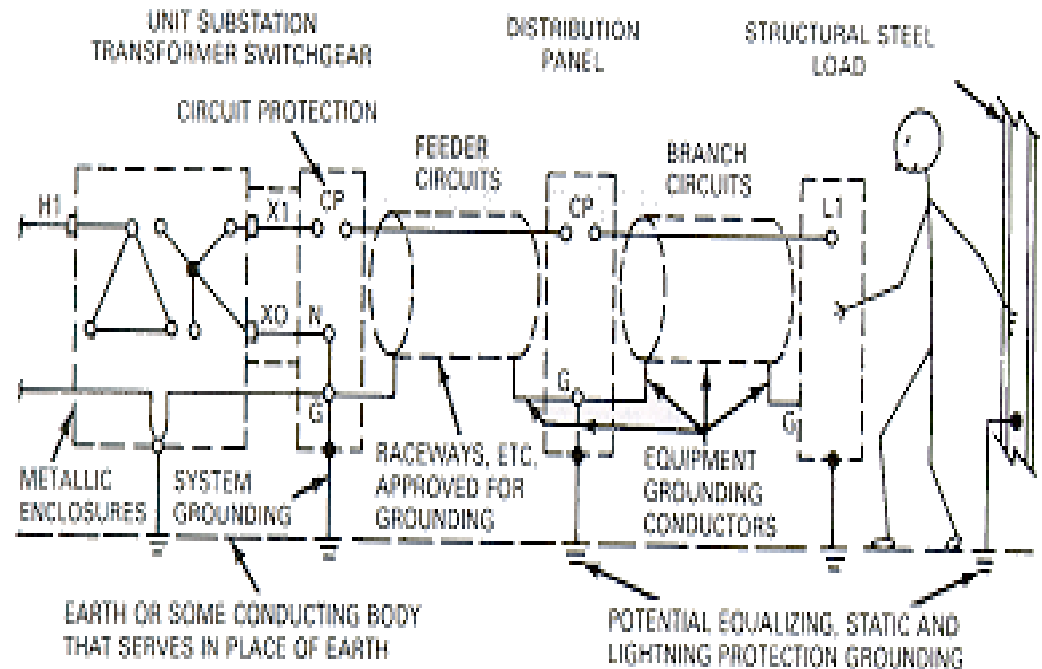


# System Grounding

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# Risk of a Poor Grounding System

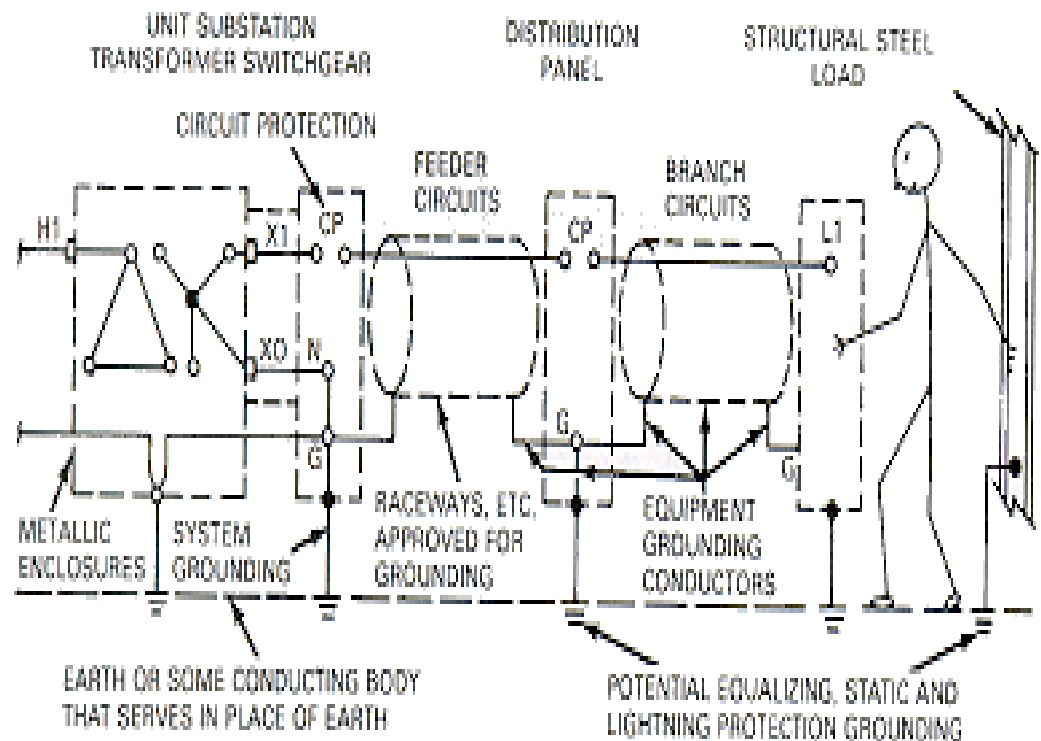
- Panel is  $20 \Omega$  to ground
- Transformer ground =  $10 \Omega$  to ground
- No ground return path
- $I_g$  = Ground Fault



$$I_g = \frac{\text{Volts}}{R \text{ of the ground path}} = \frac{277\text{Vac}}{20 \Omega + 10 \Omega} = 9.233\text{A}$$

# Panel touch potential with 9.23Amps of fault current

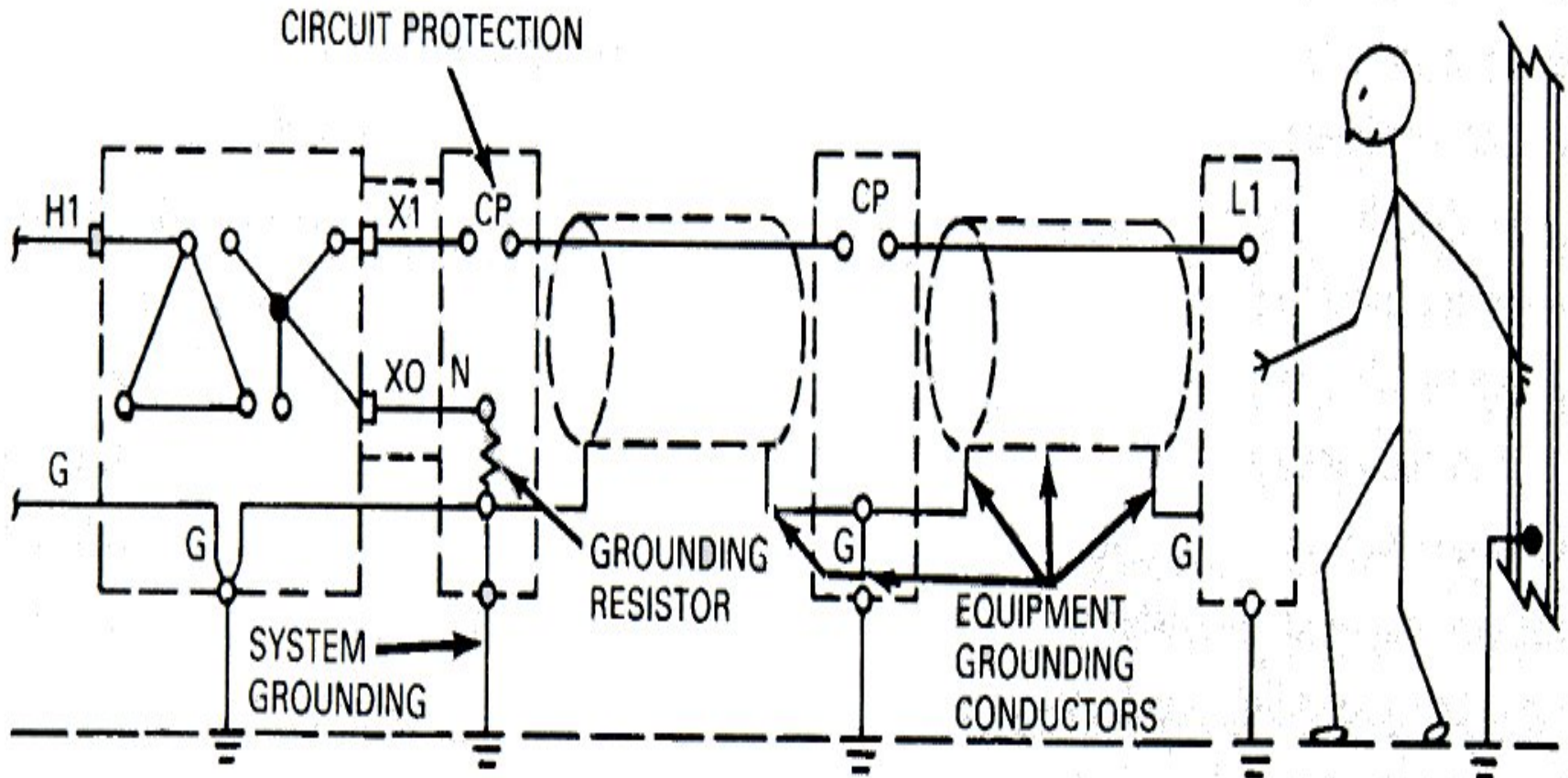
- $V = IgR$
- $V = (9.233A)(20 \Omega)$
- $V = 184Vac$
- If a good return path - 0 volts across panel



# Arc Flash Equation Open A (Above 600 Volts)

- $E = (793 \times F \times V \times t_A) / D^2$
- E = Incident Energy in cal/cm<sup>2</sup>
- F = Bolted fault short circuit current in kA
- V = phase-to-phase voltage in kV
- $t_A$  = Arc Duration in Seconds
- D = Distance from the arc source in inches

# Resistance Grounded System

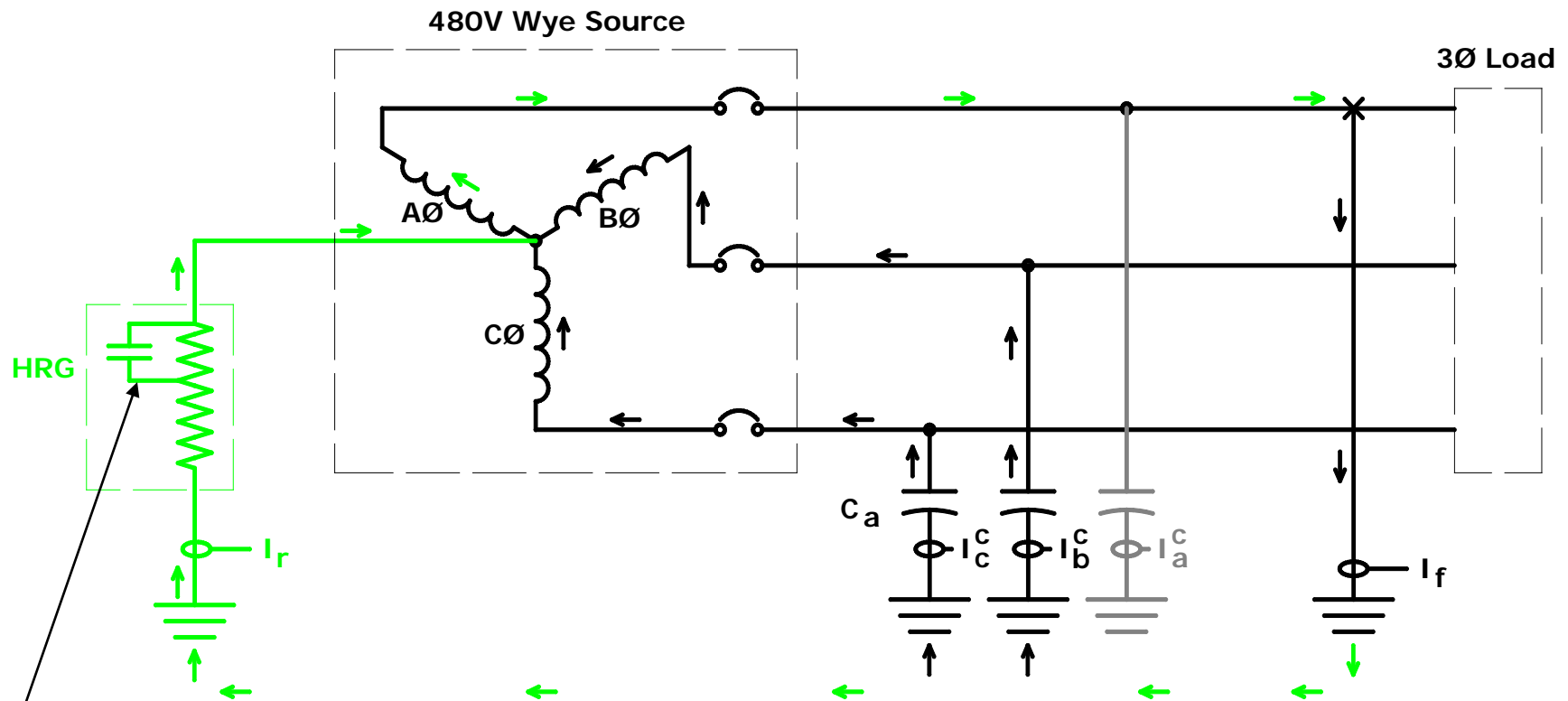


# High Resistance Grounding

- Available in 4160, 2300 and LV
- Arc Energy Reduction for Effectively Grounded
- Fault Location for Ungrounded
- Reduced Equipment Damage
- Minimize fault escalation
- Minimize ground fault arc fault energy
- Process Ride Through

# High Resistance Grounding

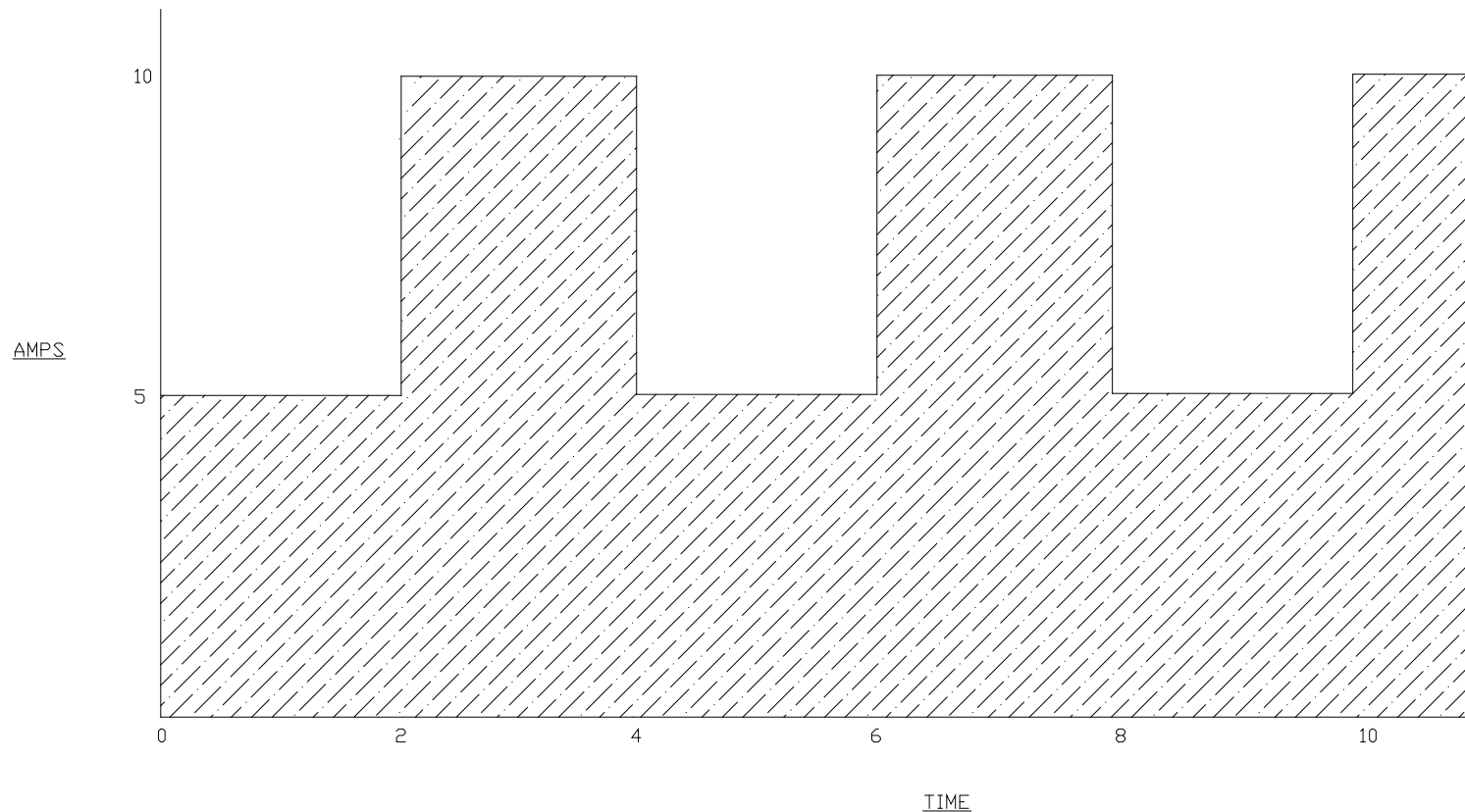
- Another advantage of return path: ground fault location



Contactor shorts out part of the resistor changing the resistance, hence, changing the current. Ground fault current now is a pulse signal that allows for detection!

# High Resistance Grounding

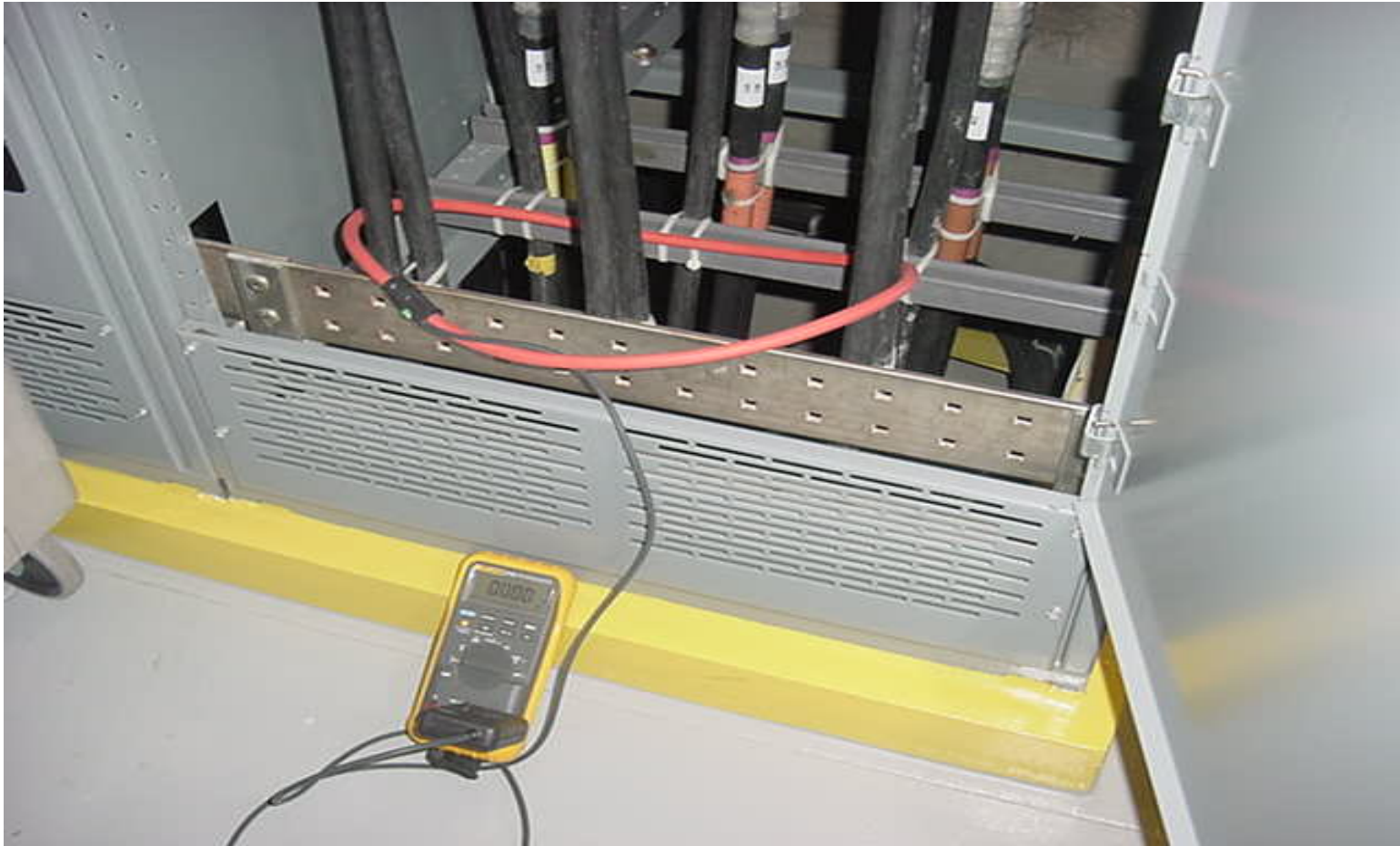
- Contactor shorts out  $\frac{1}{2}$  resistance, thus, doubling current to 10A at ~30 pulses / minute.





# High Resistance Grounding

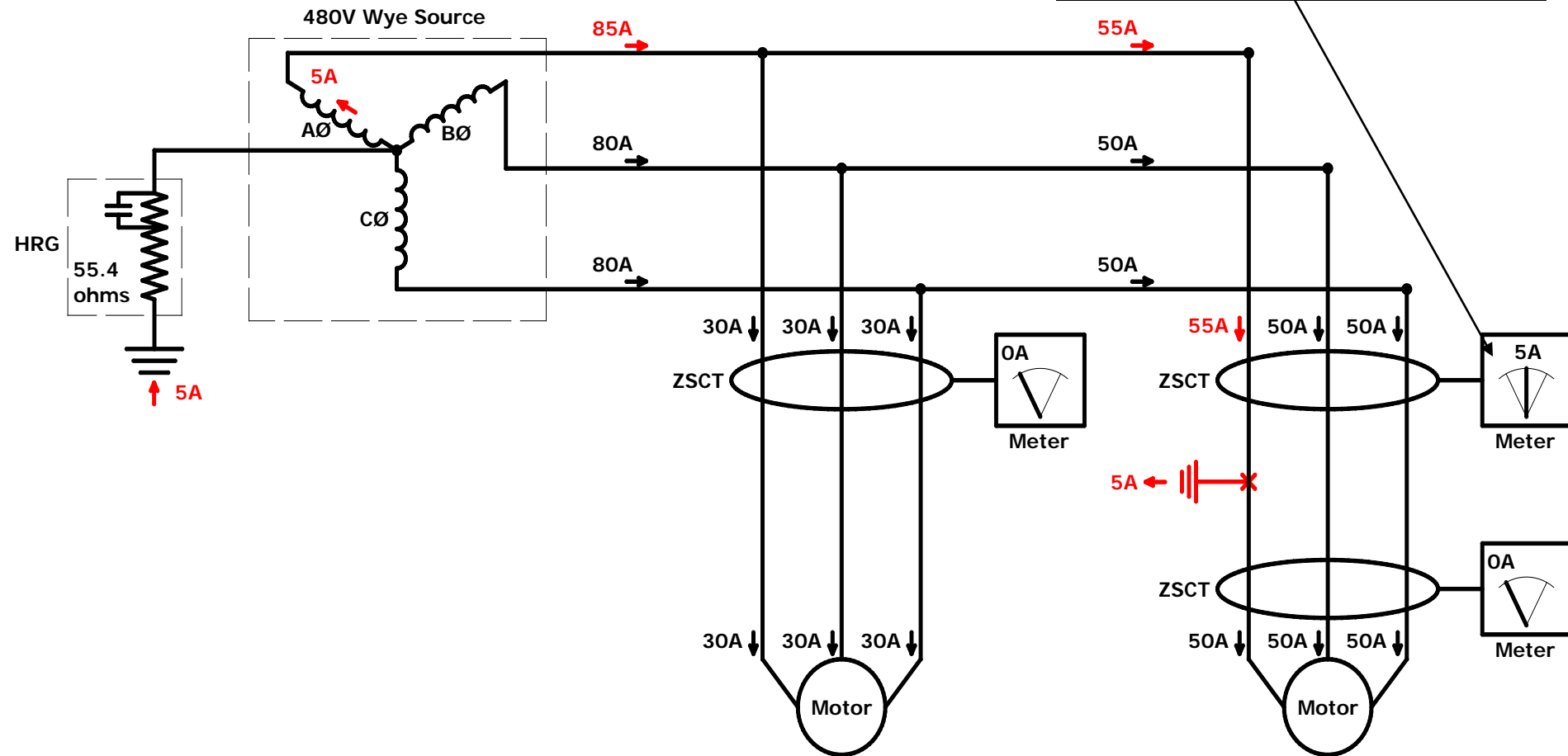
- Picture of old style Fault Location Process



# High Resistance Grounding

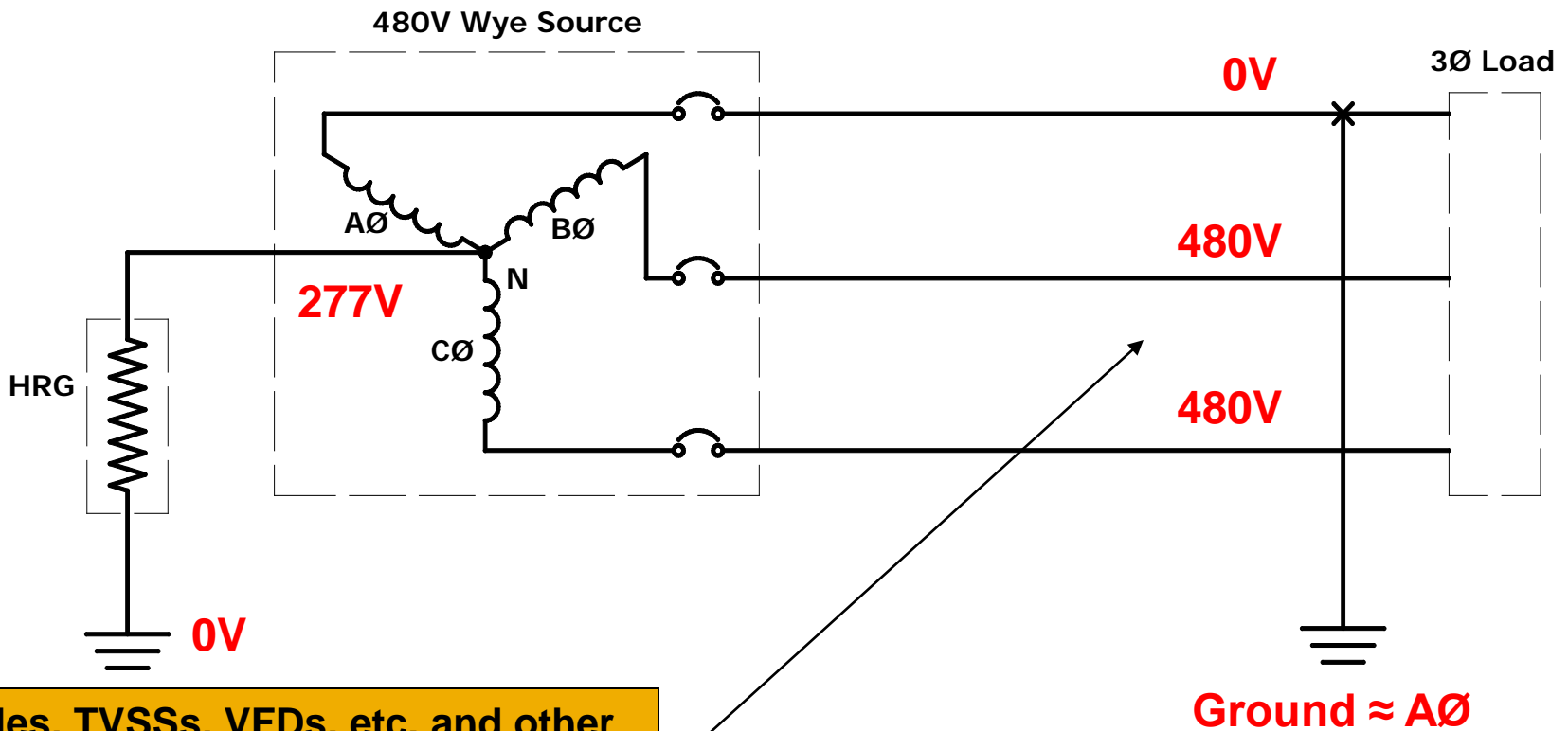
- Method to quickly locate ground faults.

Meter reading will alternate from 5A to 10A every 2 seconds.



# Elevated Voltage Hazard

- Properly rated equipment prevents Hazards.



Cables, TVSSs, VFDs, etc. and other equipment must be rated for elevated voltages (Ungrounded Systems).

# 15kV System Design

- 400A Resistance grounded wye connected system
- Greatly reduce fault energy for ground faults
- Table assumes 25MVA 7% transformer with .3 sec clearing time

	watt sec	Cal/CM <sup>2</sup>
Solid grounded 15kA fault	107,000 MW-sec	151
Resistance grounded 400A Limit	2.8MW-sec	4

# Transformer Secondary Connection

- Bus Duct
  - No low impedance bus duct (Sandwich Bus)
  - Segregated Phase Bus Duct
  - Iso-phase
  - Cable bus
- Design for phase to ground faults
- Insulated terminations

# Smart Substation

# Smart Switchgear System

- Operating Distance / PPE
- Substation Monitoring and Notification
- History and Trending
- Diagnostics and Troubleshooting
- Documentation
- Future Technologies



# Improper Operation

- Interlocks Standard and Optional
- On hand documentation
- Factory training certifying the individual as qualified for the equipment
- Smart substation





# TAHITI PROJECT SYSTEM OVERVIEW

10:25:38  
6/23/2006

ONLINE DOCUMENTATION

LOAD SHED SELECTION

QUIT

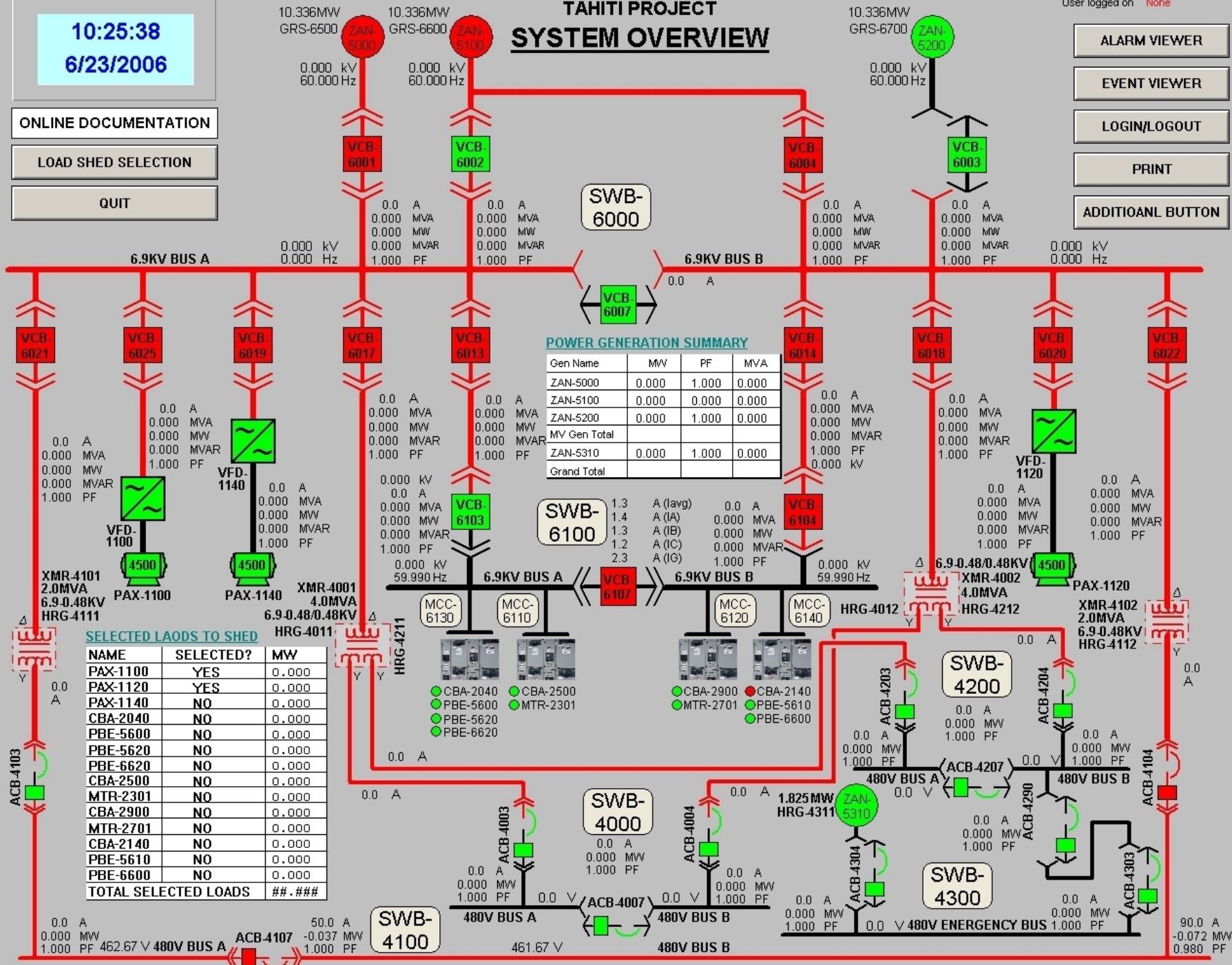
ALARM VIEWER

EVENT VIEWER

LOGIN/LOGOUT

PRINT

ADDITIONAL BUTTON



### POWER GENERATION SUMMARY

Gen Name	MW	PF	MVA
ZAN-5000	0.000	1.000	0.000
ZAN-5100	0.000	0.000	0.000
ZAN-5200	0.000	1.000	0.000
<b>MV Gen Total</b>			
ZAN-5310	0.000	1.000	0.000
<b>Grand Total</b>			

### SELECTED LOADS TO SHED

NAME	SELECTED?	MW
PAX-1100	YES	0.000
PAX-1120	YES	0.000
PAX-1140	NO	0.000
CBA-2040	NO	0.000
PBE-5600	NO	0.000
PBE-5620	NO	0.000
PBE-6620	NO	0.000
CBA-2500	NO	0.000
MTR-2301	NO	0.000
CBA-2900	NO	0.000
MTR-2701	NO	0.000
CBA-2140	NO	0.000
PBE-5610	NO	0.000
PBE-6600	NO	0.000
<b>TOTAL SELECTED LOADS</b>	<b>##.###</b>	

0.0 A  
0.000 MW  
1.000 PF 462.67 V 480V BUS A

90.0 A  
-0.072 MW  
0.980 PF

# Alarm History

- Xfmr Fault
- Loss of Control Power
- Fire Alarm
- Ground Fault alarm on HRG
- Upstream breaker opened
- Condensate heaters

VSS - PosteChaudiere

System Paramètres Serveur Help Debug

Inhibit buzzer  Silent  New   
 Remote Control  Inhibited  Active   
 Exclude permanent alarms  Permanent  Monitored   
 Split screen   
 Deselect RES\_018  Sound Recall Ack/Recall Ack Recall

Status	Position	Name	Description	Date	Time	Duration
		RES_028	Entrée numérique RES_028	99/10/3	10:02:33:411*	.....
		L1_94SE*	T1 Décl. prot. de secours	99/10/3	10:02:46:239*	.....
		T1_83	T1 Pression de gaz anormale	99/10/3	10:02:50:776*	.....
		L4_A94*	L2367 Décl. prot. A	99/10/3	10:10:33:431*	.....
		L4_B94*	L2367 Décl. prot. B	99/10/3	10:11:14:120*	0:00:02:512*
		L4_66	L2367 Perte équilibre de tension	99/10/3	10:11:19:750*	0:00:37:545*
		L4_85	L2367 Panne ou HC téléprot.	99/10/3	10:10:46:229*	.....
		L4_94SE*	L2367 Décl. prot. de secours	99/10/3	10:10:50:205*	.....
		RES_018	Entrée numérique RES_018	99/10/3	10:11:24:979*	0:00:01:189*
		L5_A94*	L2333 Décl. prot. A	99/10/3	10:11:03:202*	.....
		L5_B94*	L2333 Décl. prot. B	99/10/3	10:11:04:659*	.....

Position	Name	Description	Date	Time	Interval
	B25 V	Dépassement de seuil (KVolt): ( 87.5 KV )	99/10/3	10:07:23:298*	0:00:07:982*
	L4_A94*	L2367 Décl. prot. A	99/10/3	10:10:33:431*	0:03:10:133*
	L4_B94*	L2367 Décl. prot. B	99/10/3	10:10:37:527*	0:00:04:096*
	L4_60	L2367 Perte équilibre de tension	99/10/3	10:10:41:783*	0:00:04:255*
	L4_85	L2367 Panne ou HC téléprot.	99/10/3	10:10:46:229*	0:00:04:440*
	L4_94SE*	L2367 Décl. prot. de secours	99/10/3	10:10:50:205*	0:00:03:976*
	RES_018	Entrée numérique RES_018	99/10/3	10:10:53:380*	0:00:03:175*
	L5_A94*	L2333 Décl. prot. A	99/10/3	10:10:57:025*	0:00:03:645*
	L5_B94*	L2333 Décl. prot. B	99/10/3	10:11:00:690*	0:00:03:665*
	L4_B94*	L2367 Décl. prot. B	99/10/3	10:11:08:943*	0:00:08:853*
	L4_B94*	L2367 Décl. prot. B	99/10/3	10:11:12:047*	0:00:02:704*
	L4_B94*	L2367 Décl. prot. B	99/10/3	10:11:14:120*	0:00:02:073*
	L4_60	L2367 Perte équilibre de tension	99/10/3	10:11:19:728*	0:00:05:608*
	RES_018	Entrée numérique RES_018	99/10/3	10:11:24:979*	0:00:04:847*

Annunciator States Analysis Diagrams

Visual SubStation (c) Cybectec inc. Connected Limited S Unloaded 13:04:99:10:13:16 AM

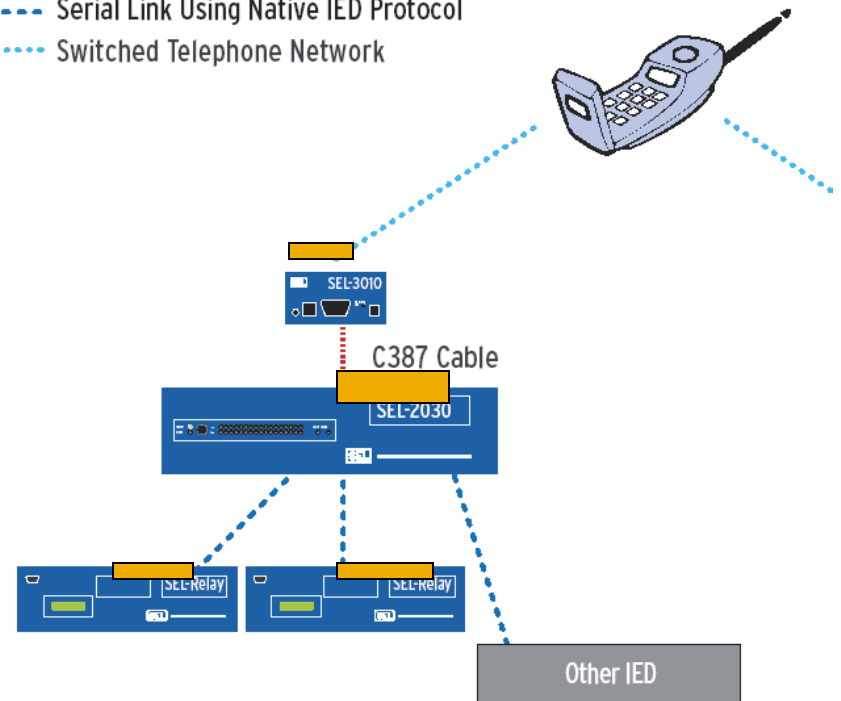
# Notification

- Alarm window with common alarm to control house
- Email
- Pager
- Cell Phone

## Event Messenger

### Application Summary

- ..... Serial Link for Text Alarm Messages
- - - - Serial Link Using Native IED Protocol
- ..... Switched Telephone Network



# Substation Monitoring

- HVAC failed
- Xfmr
  - Blanket
  - Purge
  - Temp
  - Fans
- Relay Failed
- Circuit breaker trip coil monitor



Cell Modem **ACTIVE ALARMS**

- Transformers
- Xfmr

Rockridge **ACTIVE ALARMS**

Schwartz **ACTIVE ALARMS**

Sherwood

Thomdike **ACTIVE ALARMS**


Victor

Dayton **ACTIVE ALARMS**

## Cell Modem Transformer Monitor

**Substation List**

✉ Load MVA 12.4



*esubstation.com*

Transformer		
Manufacturer	Rating	Year
<b>ACTIVE ALARMS</b>		

**LTC Ops & Position**

✉ LTC Position 3

**Cooling Status**

Cooling Bank 1 Off

Cooling Bank 2 Off

**Setup**

**Detail**

**Subgate Status**

✉ Subgate Comm Normal

**Xfmr Temperatures**

✉ LTC Tank Wall Temp C 24.1

✉ Main Tank Wall Temp C 31.7


✉ LTC/Main Temp Diff C -7.6

**Full Screen**

**Full Screen**

**BE Cell Modem Transformer Power**

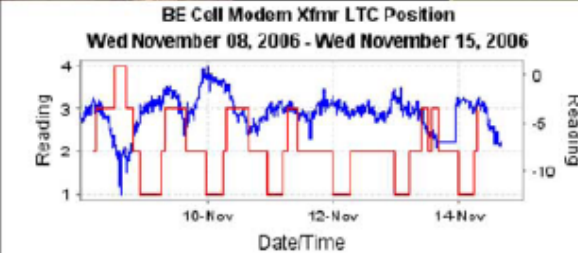
Wed November 08, 2006 - Wed November 15, 2006



▲ Main Tank Wall Temp	Min: 14.251	Max: 40.270	L
▲ Calculated Load MVA	Min: 4.692	Max: 15.035	R

**BE Cell Modem Xfmr LTC Position**

Wed November 08, 2006 - Wed November 15, 2006



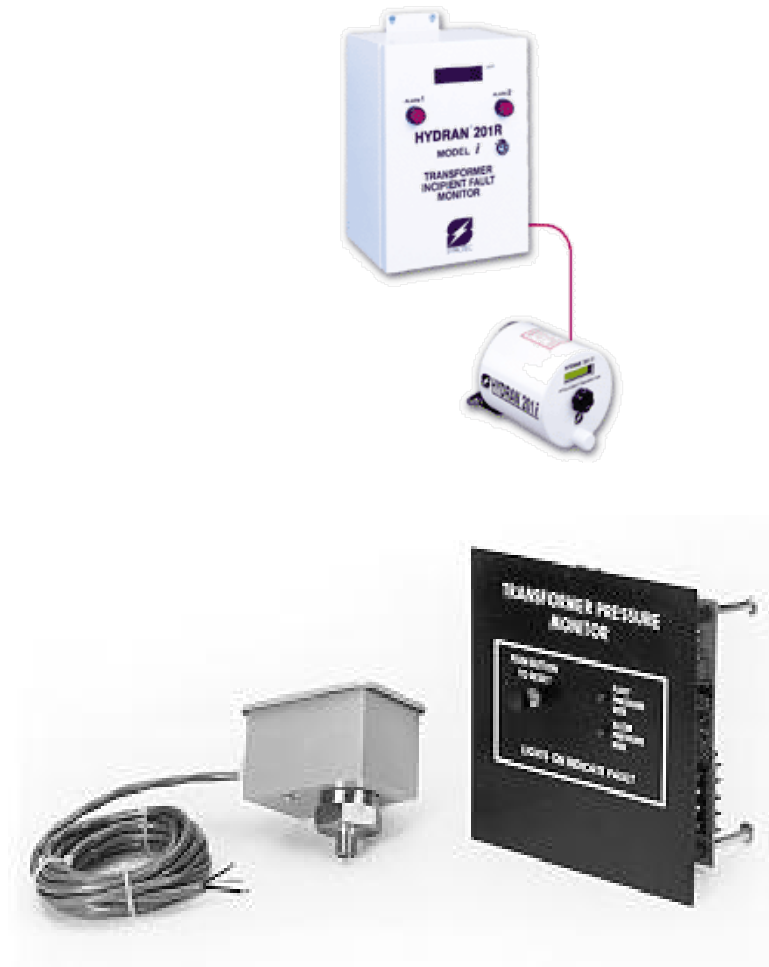
▲ LTC Position	Min: 1.000	Max: 4.000	L
▲ LTC/Main Diff Temp	Min: -12.283	Max: 0.870	R

**CANNON**  
TECHNOLOGIES  
Powered by Yukon

**cybectec**

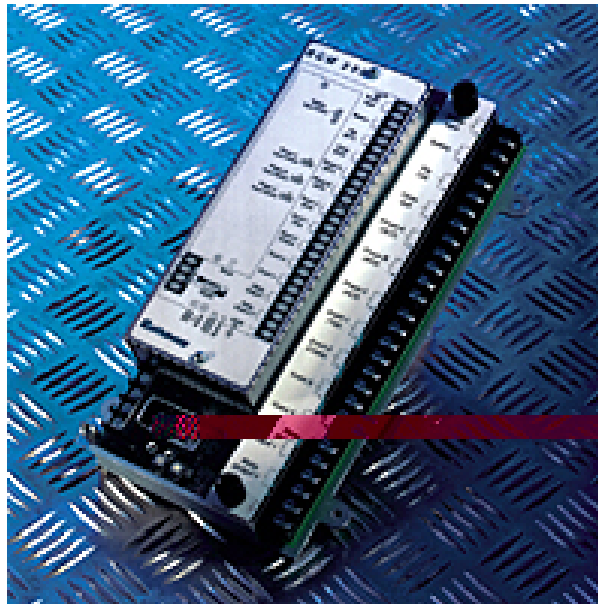
# On-Line Diagnostics

- Xfmr, gas and water Analysis
  - Oil Oxidation
  - Water
  - Over heating
  - Turn to turn arcing
- Battery System
  - Cell voltage
  - Plate decomposition



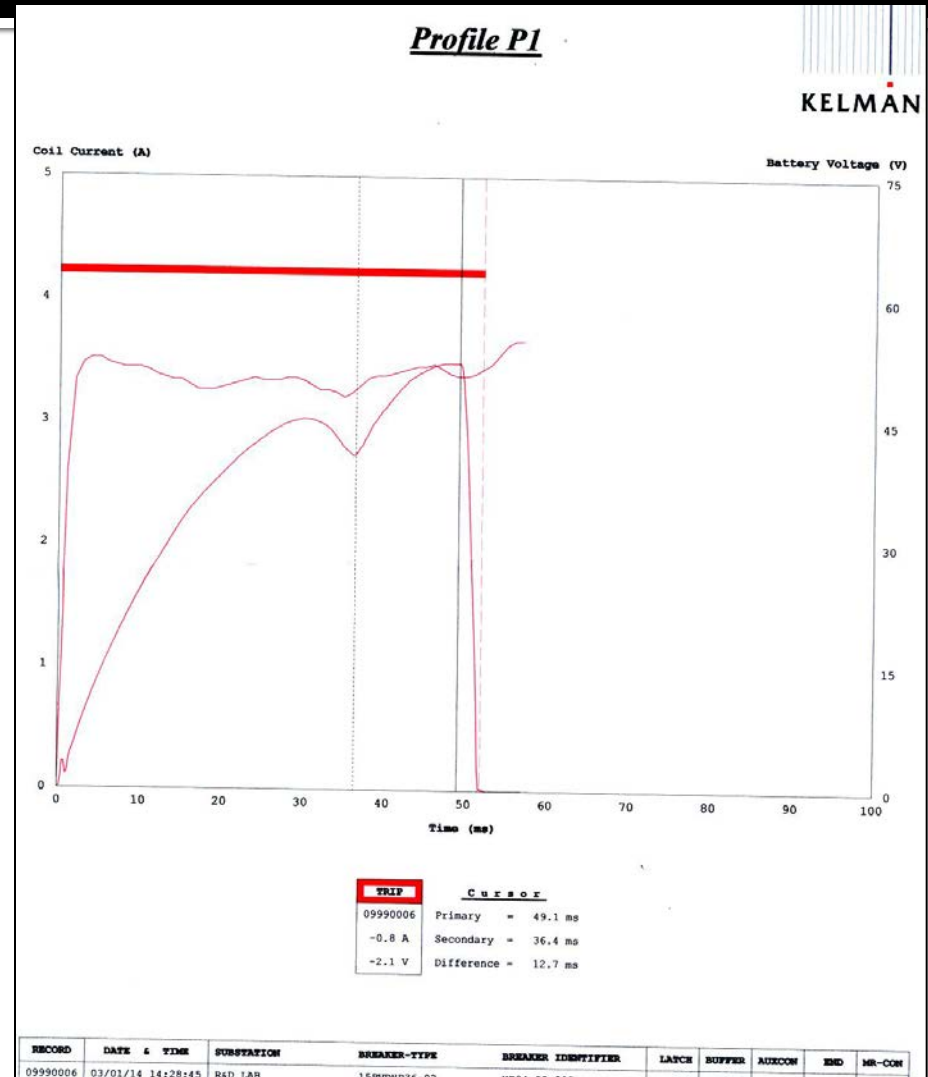
# What are the primary reliability interests

- Protection system
- Battery System
- Tripping Circuit
- Breaker & Switchgear Integrity



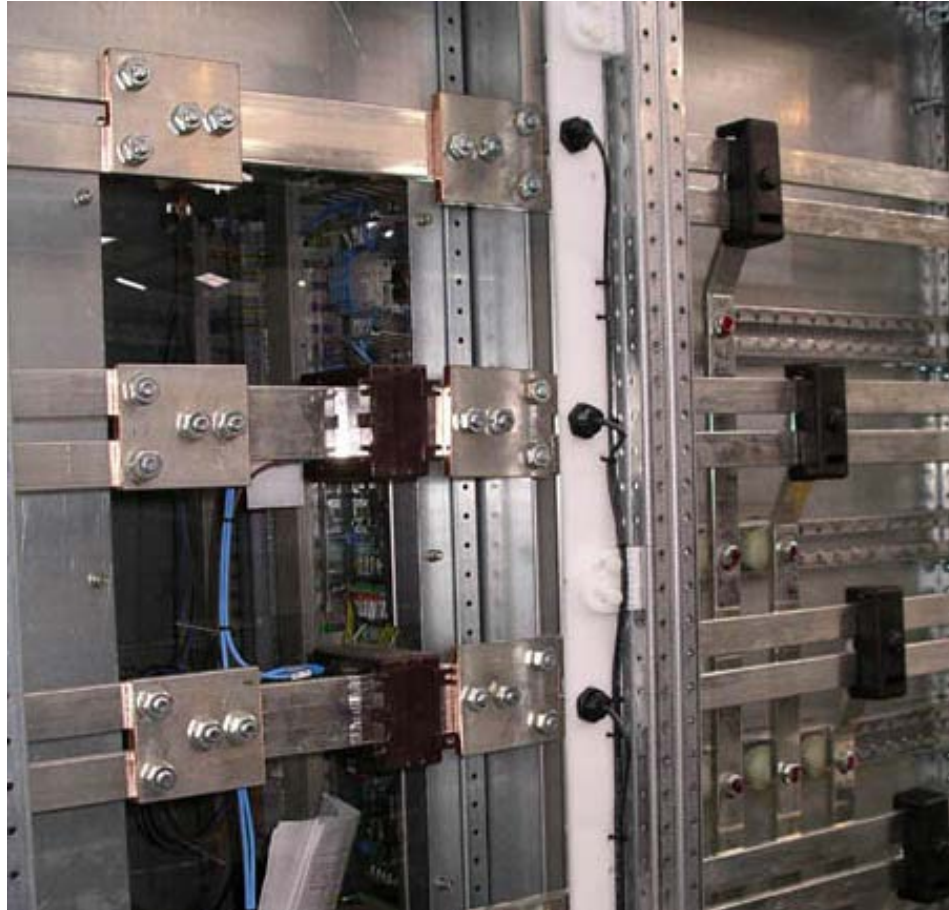
# On-Line Diagnostics

- Breaker Timing
  - First time operation
  - Latch operation
  - Speed
- Breaker Trip and close Coil
  - Current vs. Voltage





# Continuous Thermal Monitoring



# Documentation

- System one lines
  - Auto cad files
- Equipment drawings
- Breaker data
- Instruction Bulletin
- Device “cut sheets”

Fig. 21 Recommended method for Lifting Circuit breaker To Upper Cell



1. Truck Lift Ready to Receive Circuit Breaker



2. Roll Circuit Breaker on Truck Lift



3. Circuit Breaker & Tray Latched in Place



4. Lift Truck & Switchgear Position



5. Circuit Breaker Approaching Hook

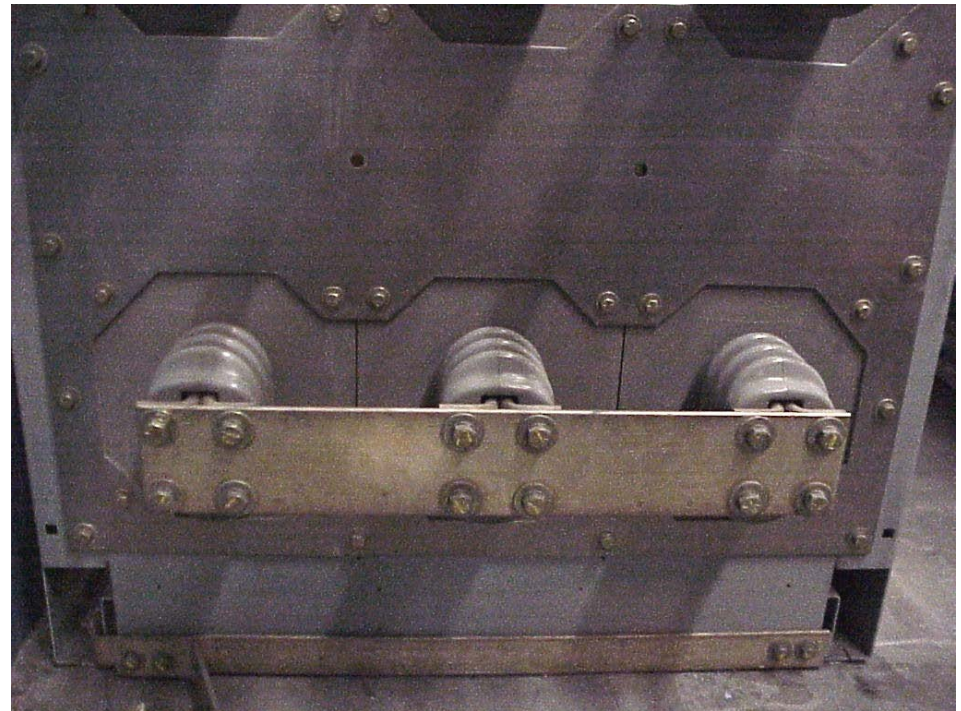


6. Roll Circuit Breaker in Cell

# Arcing Faults

# Bolted Fault vs. Arcing Fault in Medium-Voltage Switchgear

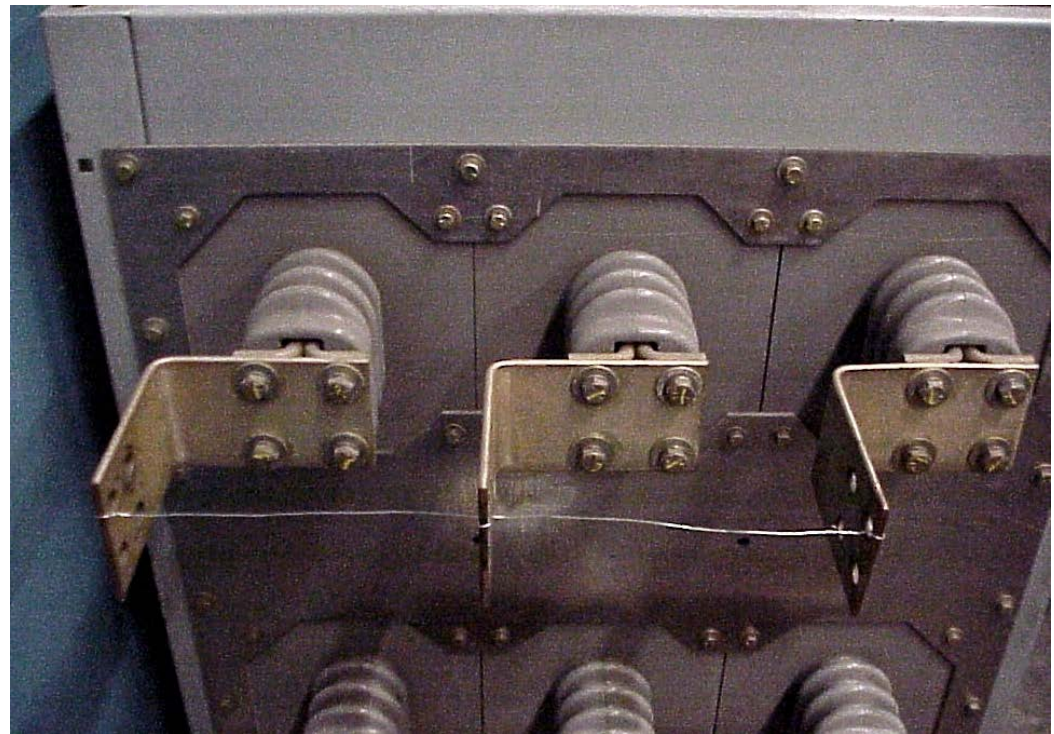
- **Bolted Faults**
  - Current  $I^2t$
  - Mechanical forces
- **Testing**
  - Interrupting capability
  - Thermal capacity of bus
  - Mechanical bracing of bus



# Bolted Fault vs. Arcing Fault in Medium-Voltage Switchgear

## ■ Arc Faults

- Mechanical forces and Current  $I^2t$
- Heating and burning of conductors and enclosure
- Radiation
- Rapid overpressure of equipment and surroundings



# Arc Resistant is the equivalent to a 70E Zone 0 at 3.9" due to test recordings of 2 cal/cm

Zone 1 as minimum dress for all electrical work

- Leather gloves
- Long sleeve FRC clothing (shirt and pants)
- Approved eye protection



# Arc Faults

# Cell before the fault





# Fault the result of racking in a 5kV 40 yr old breaker with one pole closed



Feeder  
Breaker  
where fault  
began  
Cell 3



# Incoming breaker Cell 1



# Next cell over Cell 2



# Cell 4



# Arcing Faults



# Christmas 2003



# Bus bracing failure





# Failed 50kA 5kV available fault current 0.5sec



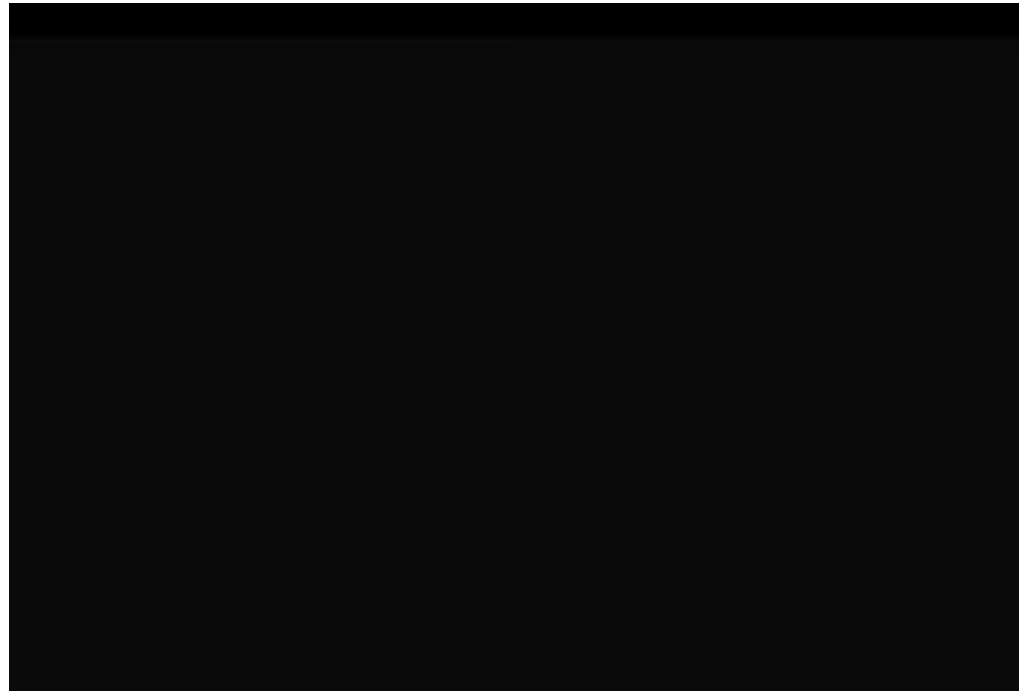
# Heat, Pressure, Smoke and Shrapnel

## 15kV, 50kA



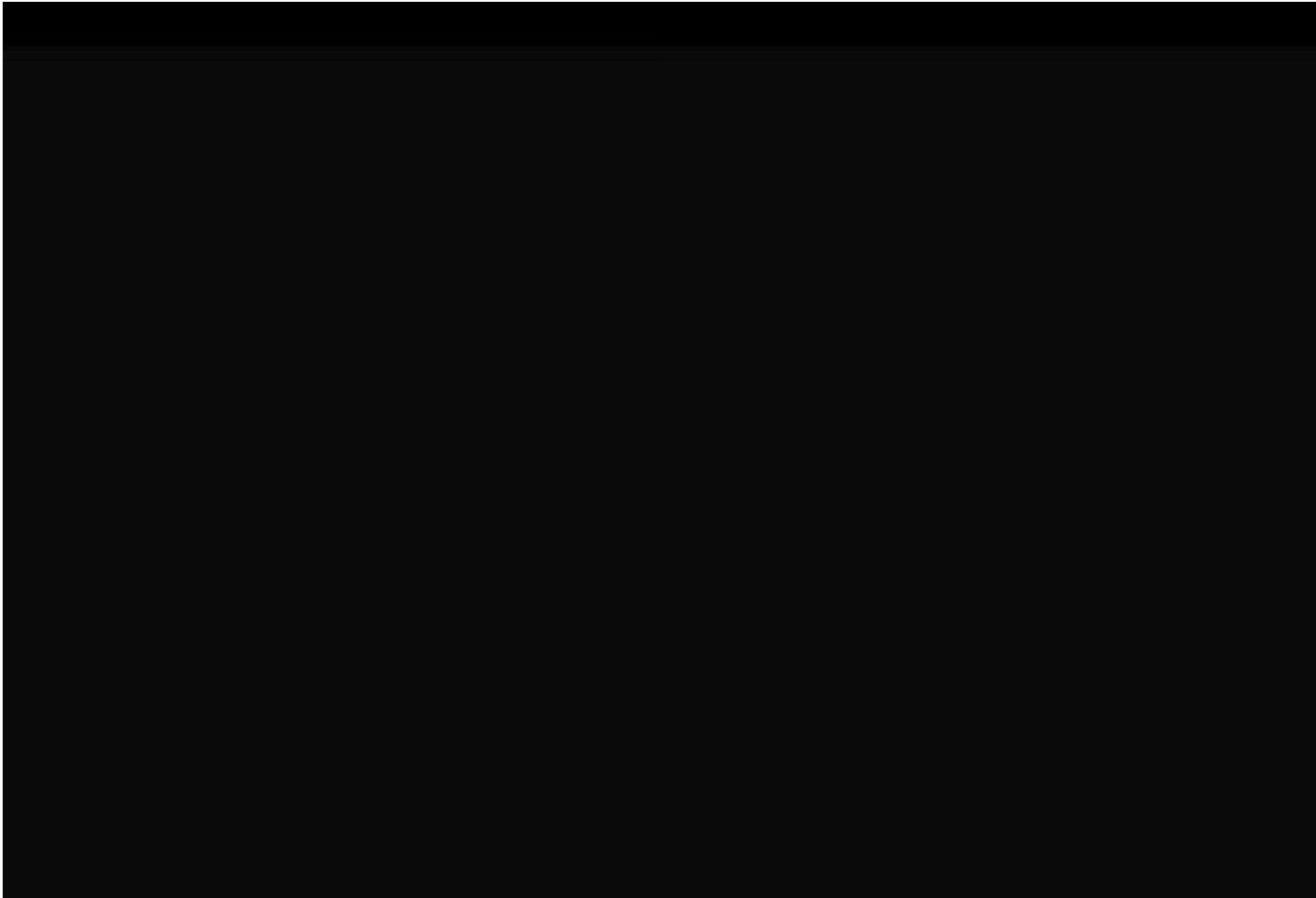
# *Hazardous Effects of an Arcing Fault*

- 13.8 kV system
- Side view bus compartment fault
- 38 kA symmetrical fault
- Duration of 1 second



# *Effects of the Pressure Wave*

*notice the door*



# Accessibility Type

## EEMAC

No Building Effect

Type A - Front only

Type B - Front, back and sides

Type C - Front, back and sides and between the compartments

Note: bus compartment allowed to break into the bus compartment of an adjacent feeder cell

## ANSI C37.20.7

Building Effect Considered

Type 1 - Front only

Type 2 - Front, back and sides

Type b – Instrument compartment protection

Type c - Front, back and sides and between the compartments

Note: bus compartment allowed to break into the bus compartment of an adjacent feeder cell

# Test Assessment

- Doors & covers do not open.
- Parts, which may cause hazard, do not fly off.
- No burn through accessible external parts
- Heat indicators do not ignite from escaping gas
- All Earthing connections must remain effective.



# Free Standing Plenum

- Number of exhaust ducts
- Clearance issues
- TOS
  - 124" for 95" high gear
  - 133" for 105" high gear

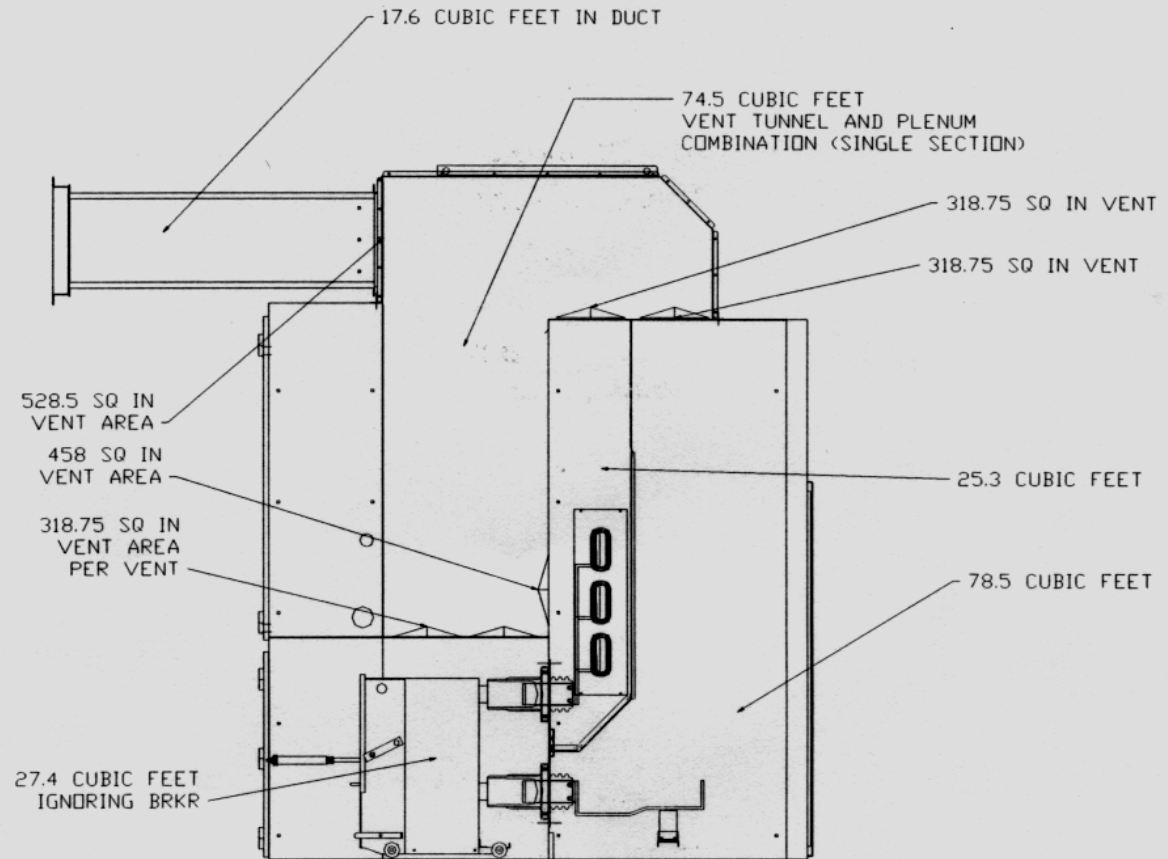


Figure 9 – Volume and Venting Area

# Test Sample

## PT Rollout for Arc Resistant Switchgear

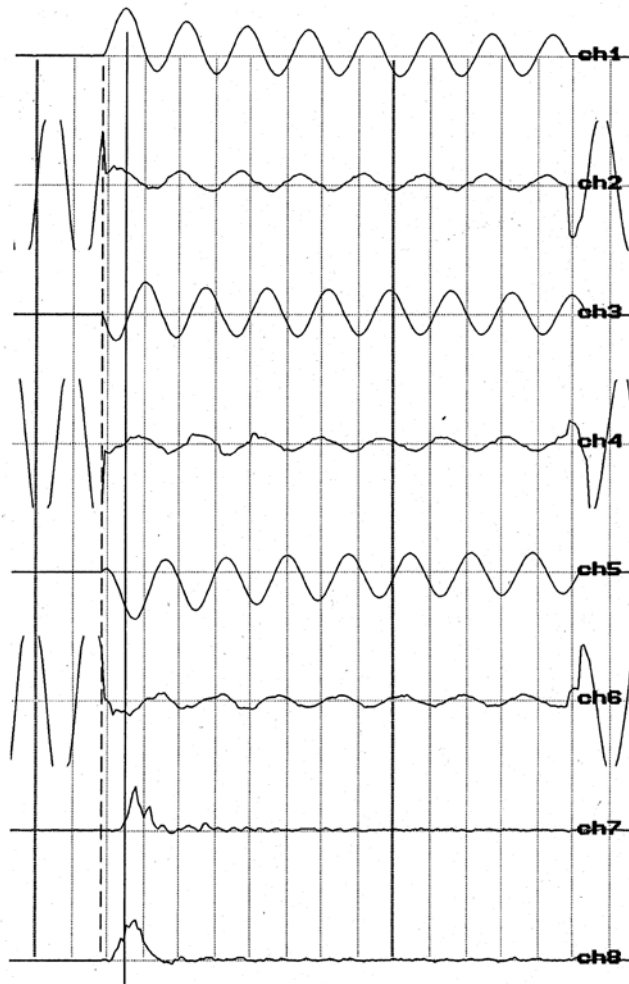
Pressure  
Transducer  
(front)

Rollout Drawer



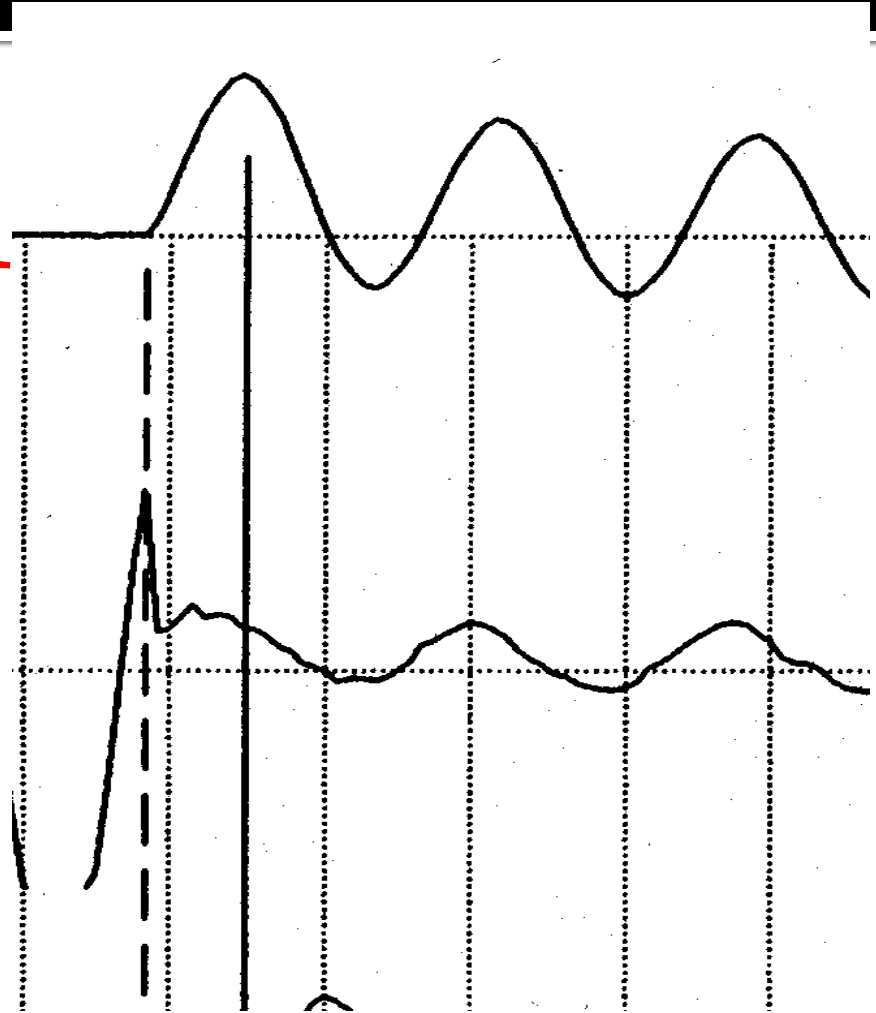
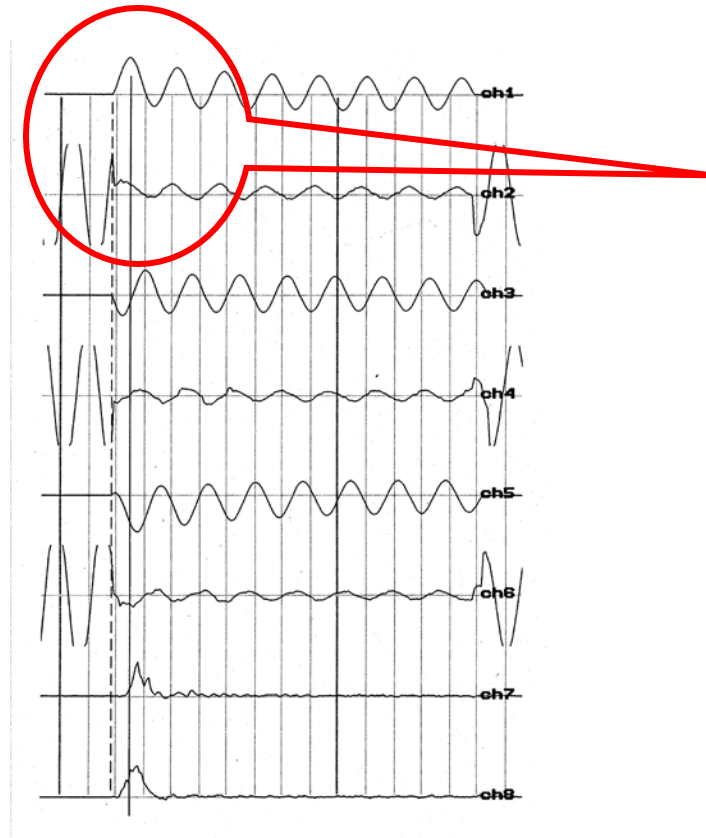


# Test Results

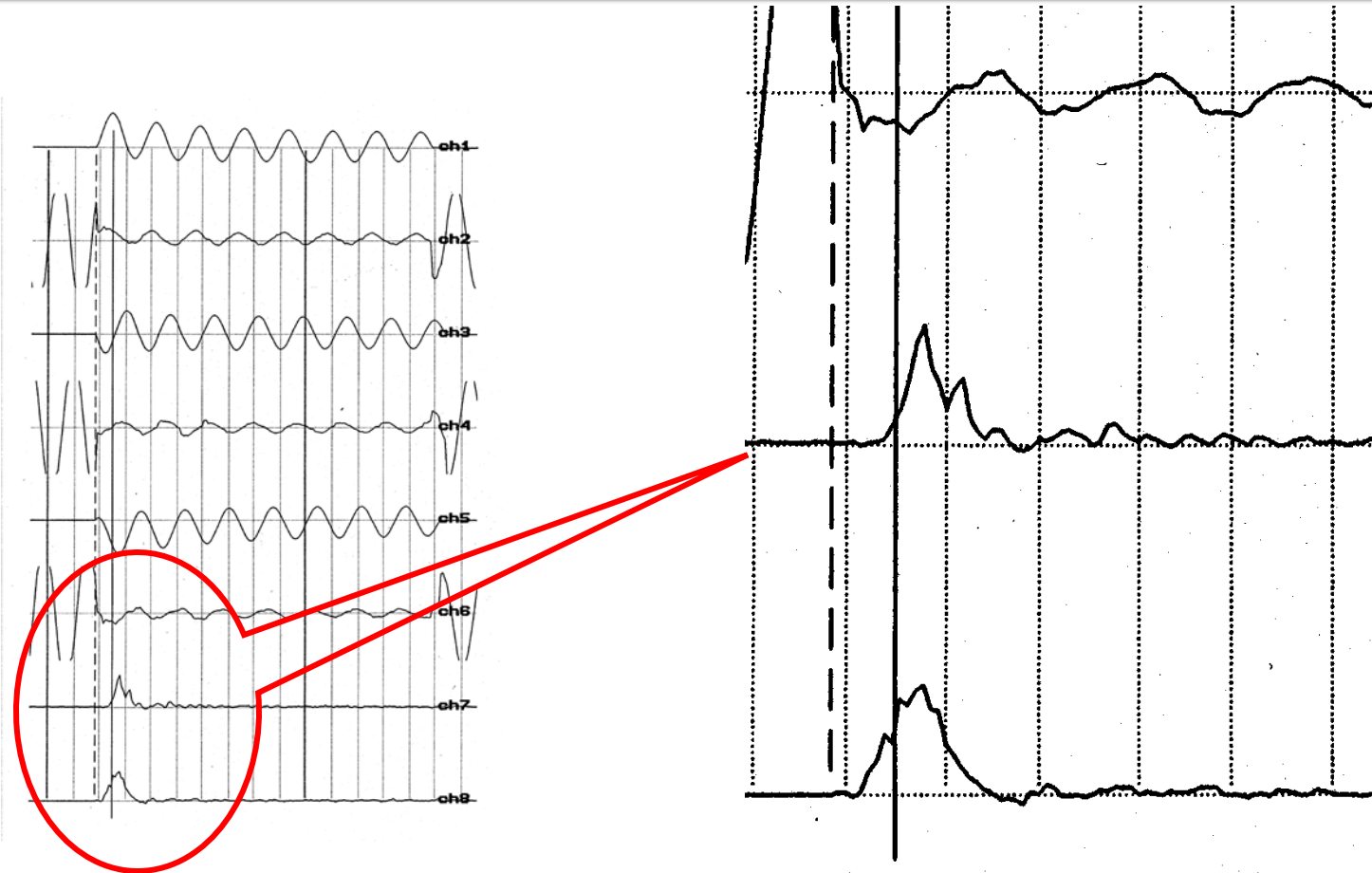


- Ch1 - A phase current 119kA peak
- Ch2 - A phase voltage 620V arc voltage
- Ch3 - B phase current
- Ch4 - B phase voltage
- Ch5 - C phase current
- Ch6 - C phase voltage
- Ch7 - Pressure at front 37.6psi @ 9.7ms
- Ch8 - Pressure at rear 38.0psi @ 9.3ms

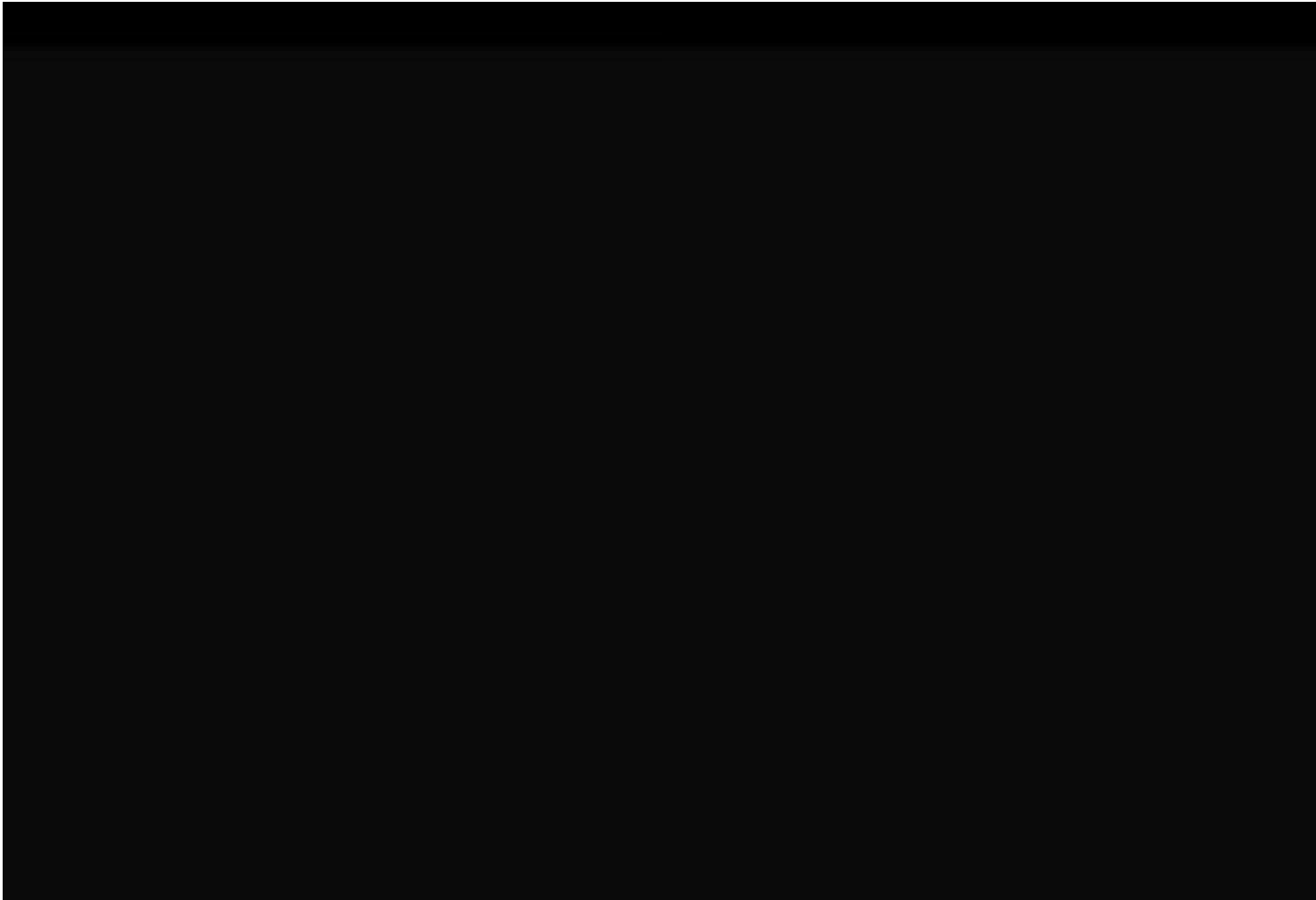
# Test Data (cont)



# Test Data (cont)

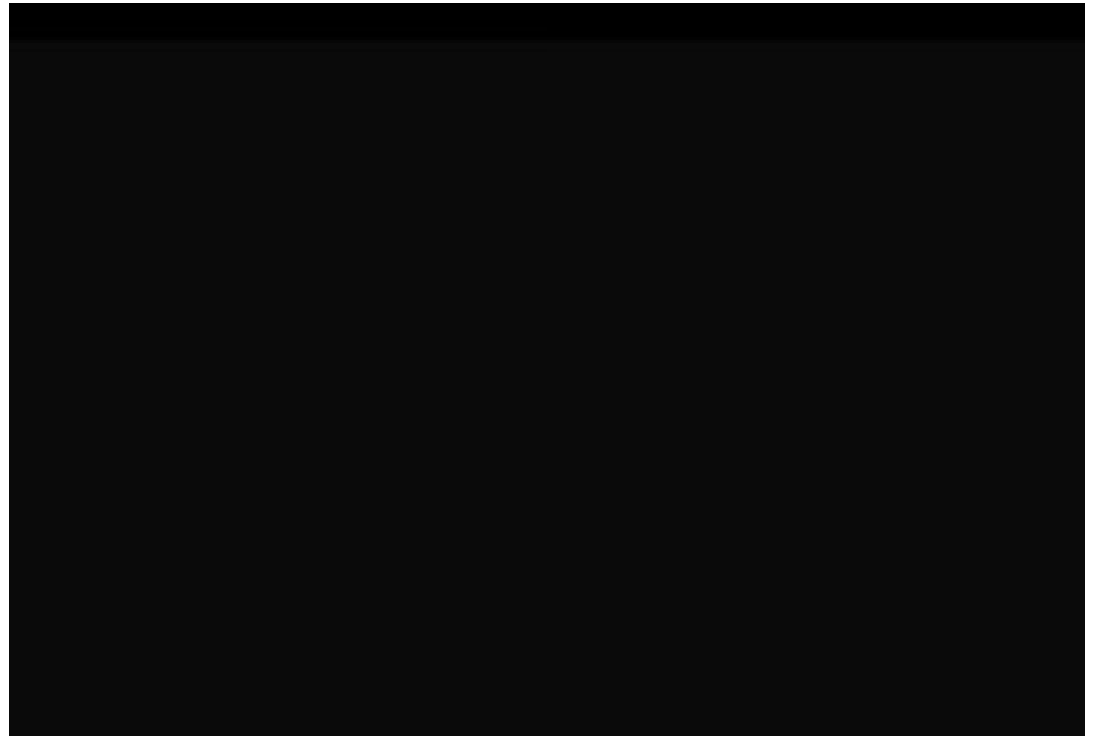


# What Is An Arcing Fault ?



# Hazards of an Arcing Fault

- Direct/indirect exposure to the arc flash
- Mechanical stress from pressure waves
- Thermal stress from the radiated heat
- Potential contact with energized parts
- Release of toxic gases
- Airborne debris



# Inside of Arc Resistant after .5sec shot



# Incoming cable connection



# Arc Resistant Switchgear

- Protect the individual during
  - Racking operation
  - Open and Close
  - PT's and Cpt's on and off the bus
  - Troubleshooting control problems
  - Infrared Inspection with approved view ports
  - Operator error
    -
  - All hazard of the fault not just heat



# 63kA 3000Amp



# Closed Door Racking



Closed  
Door PT  
Drawer

# Arc Resistant Switchgear



- Single Throw handle
- Door to racking position interlock

# Arc Resistant Switchgear

- Internal lights
- View windows
- Manual trip



# Back View With Plenum

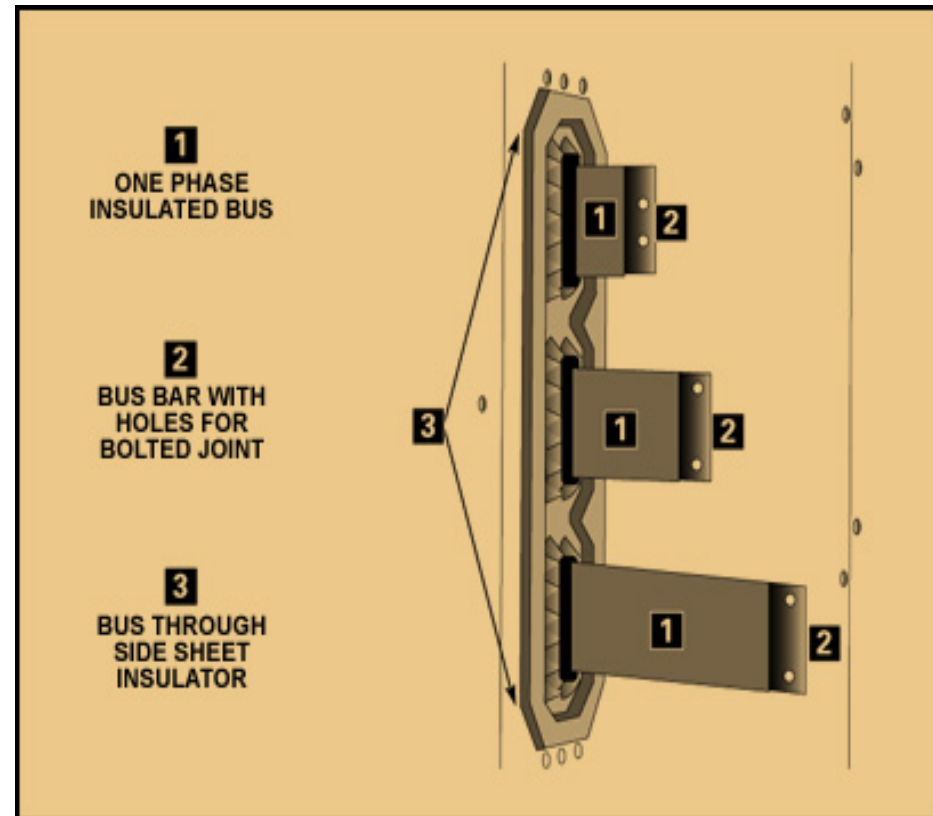


**Free  
Standing  
Swgr**



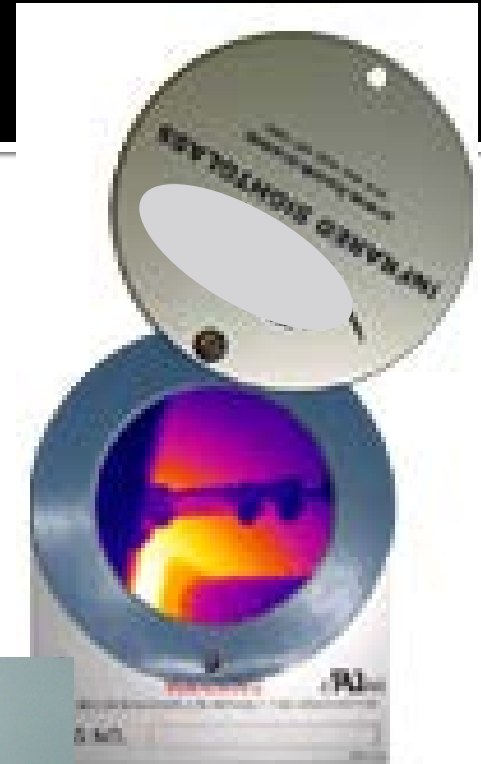
# Switchgear (Insulation)

- Epoxy Coated Bus Bar Insulation
- Epoxy insulation in lieu of glastic stand off
- High potential testing for shipping damage (*AC vs. DC*)
- Old Norel Systems

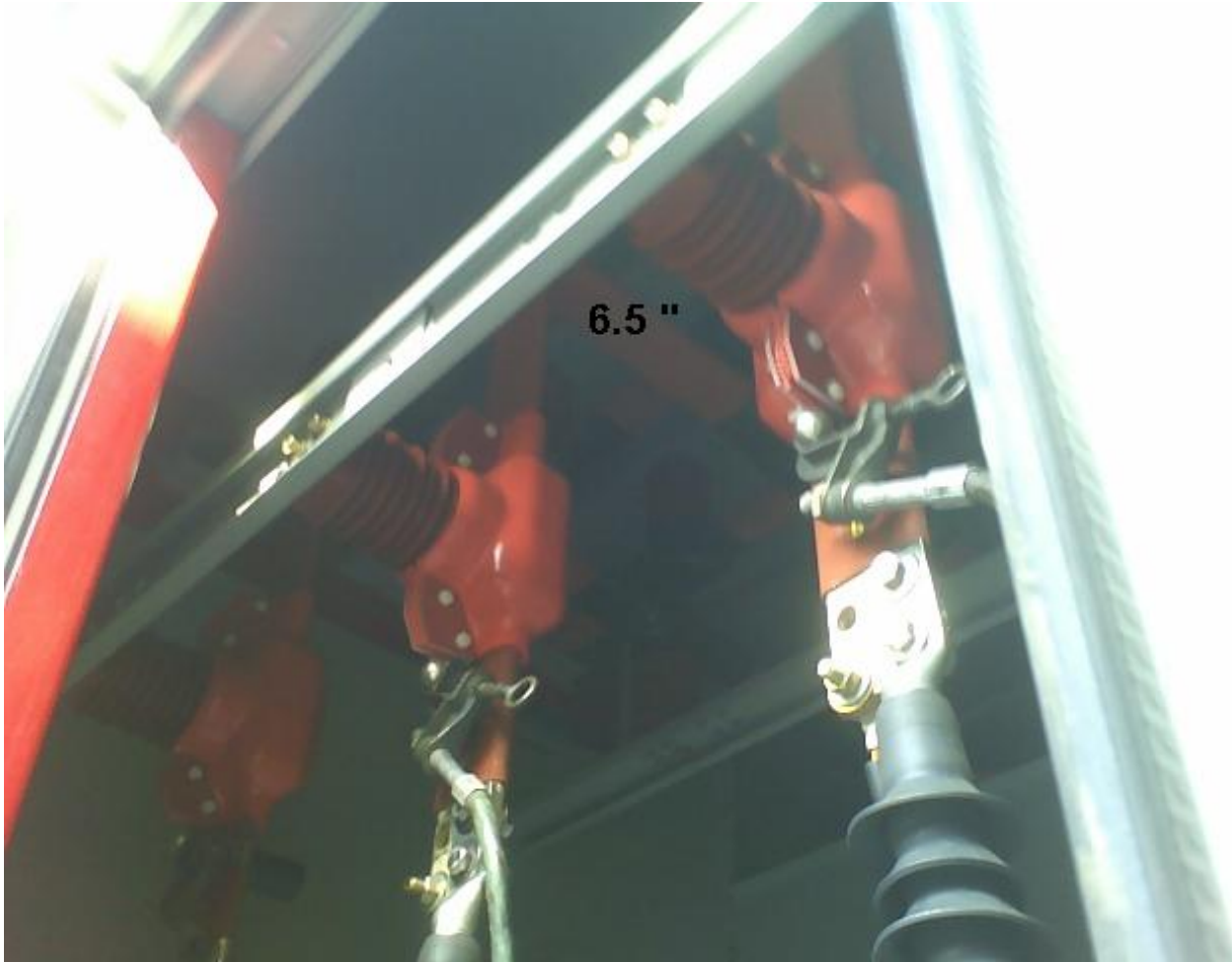


# Infrared Ports

- Monitoring without exposure
- Fixed mount for inaccessible high current density location



# Ground Studs In cable compartment





# MV Swgr (safety grounds)

- Safety grounding method
  - Manual Ground & Test device
  - Electrical Ground Device
  - Ground switch
  - Grounding pawls rated for the service

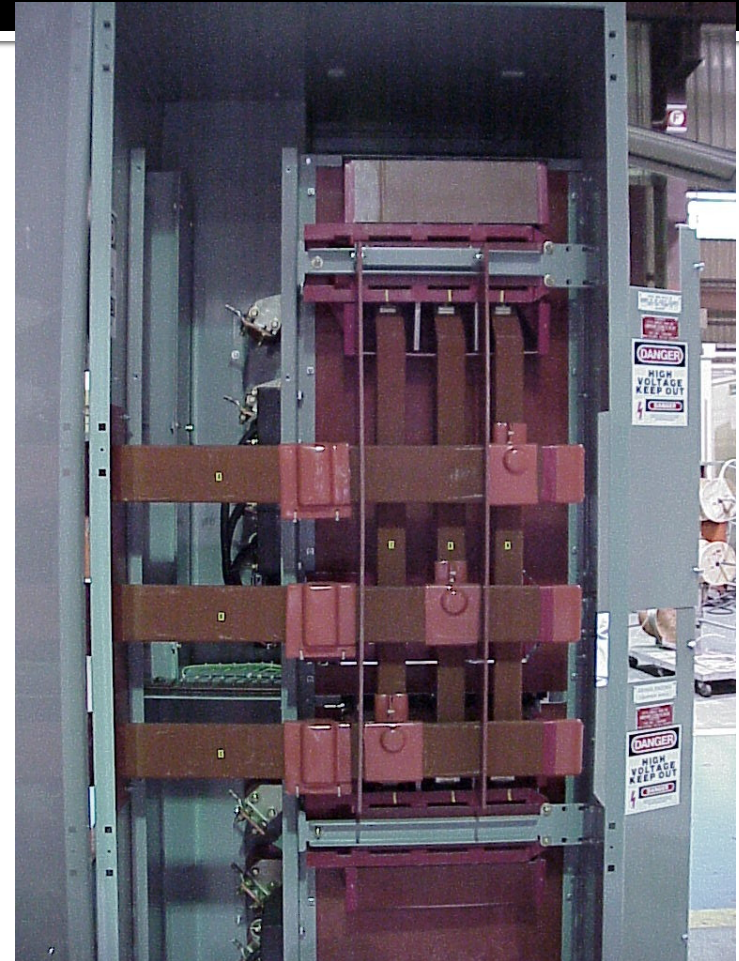


# 5 KV Switchgear And MCC

---

# Medium Voltage Motor Control

- 2 high construction
  - Separate raceway for top and bottom cable
- Locate 2 high spares to minimize exposure
  - Top entry installation = top spares
  - Bottom entry installation = bottom entry spares



# Medium Voltage Motor Control

- Two Hole Lugs
- Insulated Lugs
- Ground studs



# Medium Voltage Motor Control

- MVMCC has switchgear short circuit rated bus
- Additional Barriers and Insulation
- Posted approved voltage measuring method



# MVMCCAR

- Separate controls compartment
- View windows
- Main bus short time rating



# MVMCC Arc Resistant



# Main Bus Configuration





# Fault location

- Line side of fuses



# Equipment Damage

- Top of fuse barrels



# Adjacent Cell



# Arc Fault Test 50kA 5kV MCC



# 4160 Voltage Measurement Fault

- Results of using a 1000 V meter on 4160 V



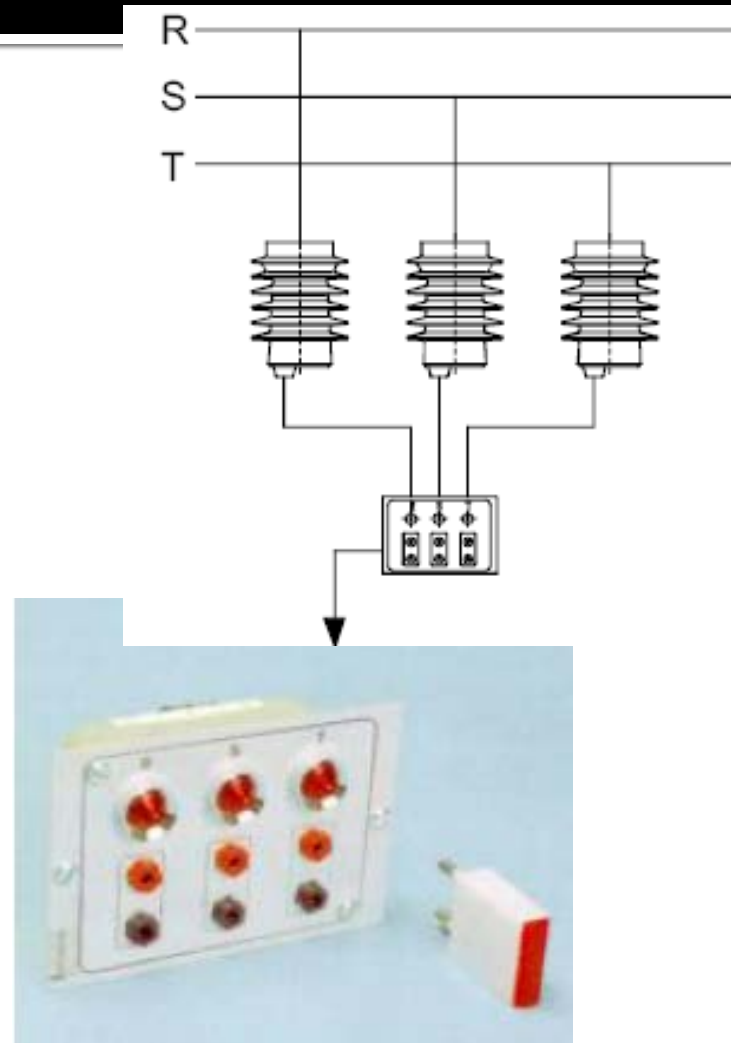
# 4160 Voltage measurement fault

- PPE of the tech doing the measurement



# Fixed voltage measurement

- Non Contact voltage confirmation for MV
- MVMCC solution for de-energized circuit

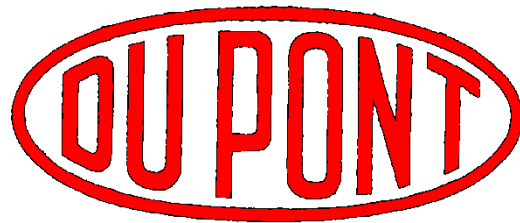


# **“Test Before Touch”**

## **What Does This Mean to You?**

**Ken Crawford, P.E. - DuPont**

**Kent Haggerty, P.E. - DuPont**







# Considerations in Testing Medium Voltage Systems

- Proximity Testers Often Preferred Due to Strong Electric Fields
  - Direct Contact Not Required
  - Only One Probing Stick Needed
  - Can Test Taped Connections
- Shielded Conductors Cannot Be Tested Except at Terminal Connections
  - Spiking Tool May Be Necessary to Verify Shielded Conductors Are De-energized

**Medium Voltage  
Shielded Cables Require  
Special Attention**

**Shielded Cable - Proximity  
Tester Will Not Indicate**

**Cable Shield  
Terminates Here**

**Proximity Tester Will  
Work Here**

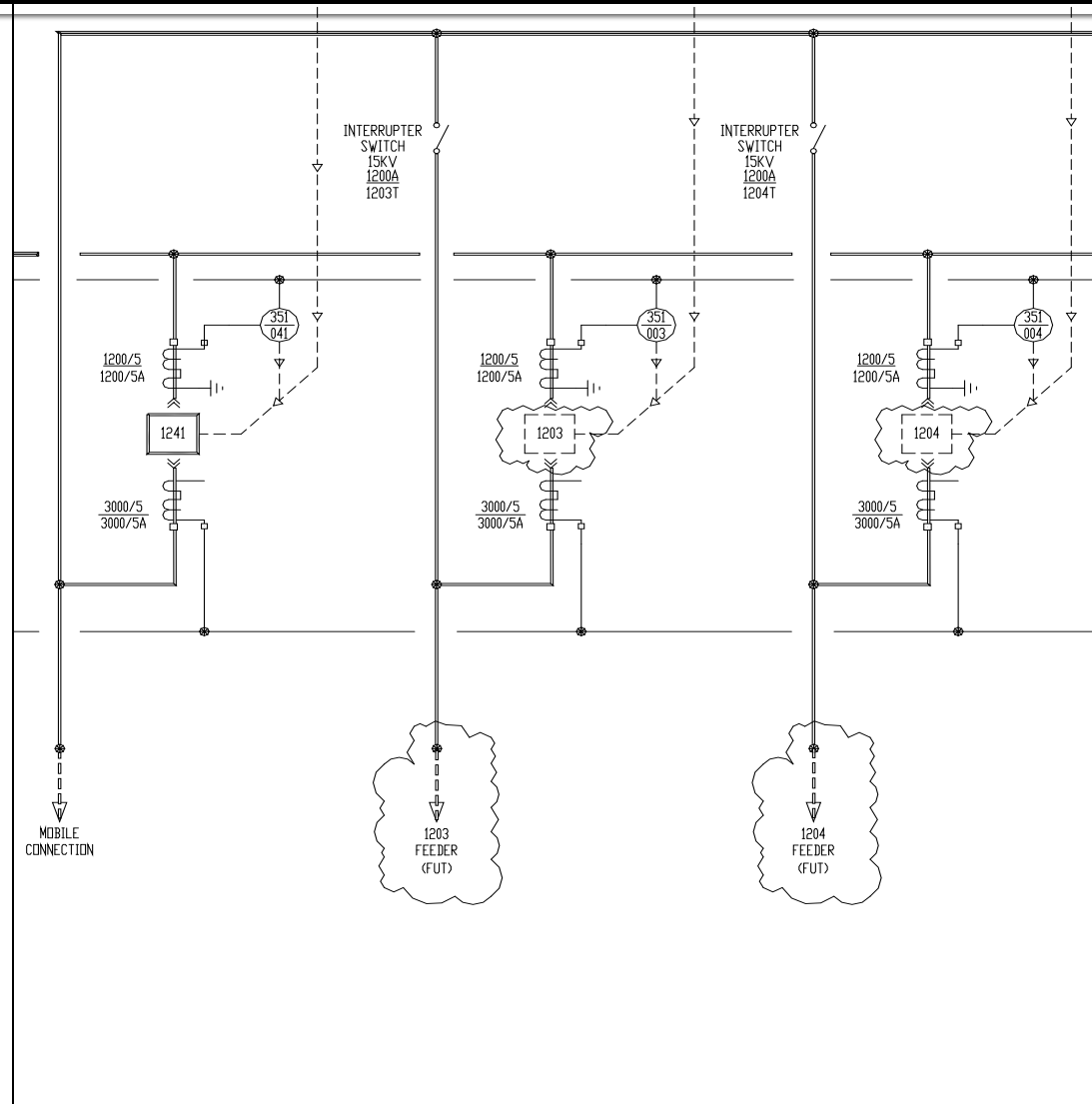
S048 [redacted] Ref #1  
6.9kv LVB Output



# Relaying Improvements

# Make the design so they shut it off

- Maintenance bus
- Main-tie-main



# Relaying Solutions

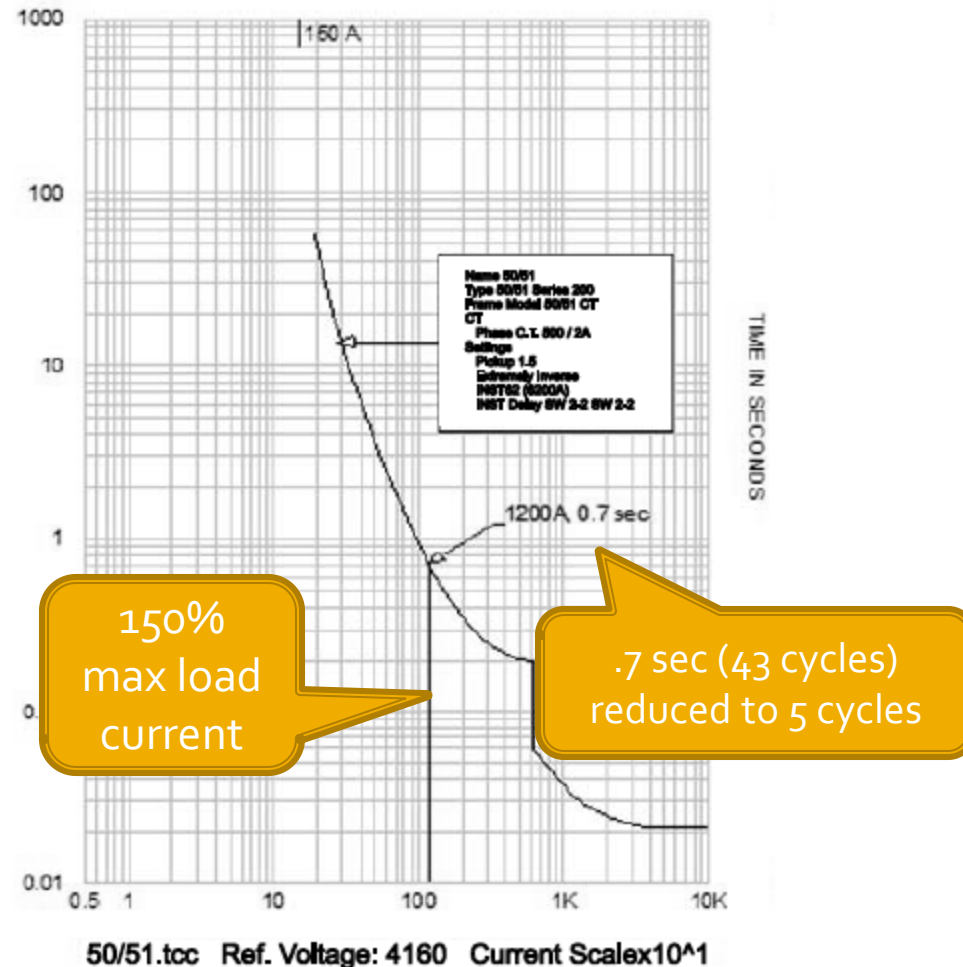
- Maintenance Switch enabled settings
- Instantaneous supervised by light, pressure, or sound
- Fast trip schemes using relays and communications
- Current Differentials
- Reduced time intervals of existing time overcurrent
- Breaker Failure

# Maintenance Switch

Advantage	Disadvantage	Cost
Fast response 1.5 cycles plus breaker clearing	Selectivity compromised <ul style="list-style-type: none"><li>•Process hazard</li><li>•Nuisance trip for auto start</li></ul>	43 switch Replacement relay Anunciator window 5k\$
Use existing main and feeder overcurrents normally	Change must be made to operating procedure	
	Limited use on process system	

# Maintenance Switch

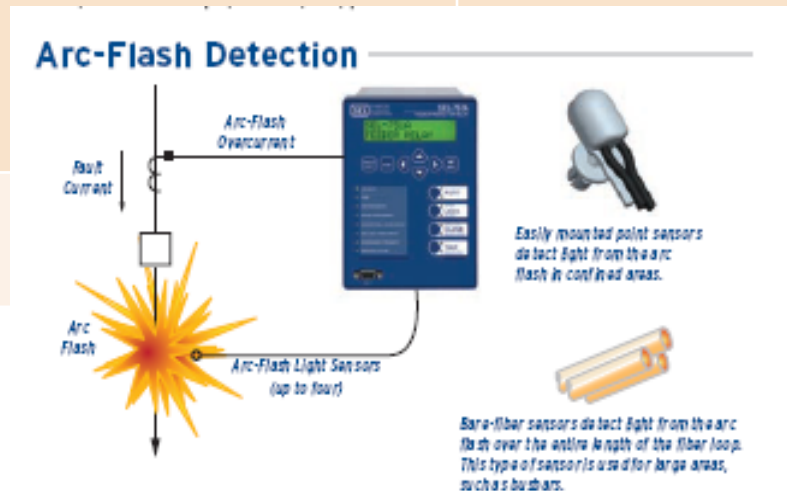
- Risk of large motor auto start
- May put process operators in greater hazard
- What at risk procedures are you protecting for?





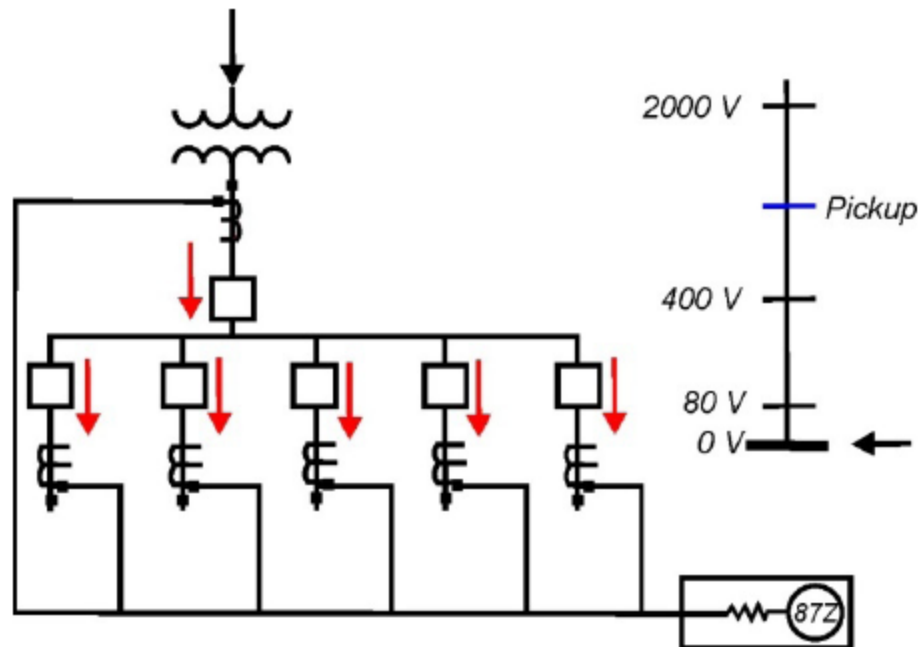
# Light detection supervised instantaneous current

Advantages	Disadvantages	Costs
Fast response - .5 cycles plus clearing time	Fiber installation requires downtime	<ul style="list-style-type: none"> <li>•Replacement relay with light detection</li> <li>•Install fiber</li> <li>•8k\$ per feeder</li> </ul>
Remains in service continuously, no decision about risk	May trip on LV Breaker and MV air breaker starter or fuse interruption	
Can protect xfmr secondary and cable compartment		
Cheaper to retrofit than bus diffs		



# High Impedence Bus Differential

Advantages	Disadvantages	cost
Fast less than 2 cycles	High cost	Function of number of breakers bus 10K\$
Very secure	Not fast enough to protect against pressure blast	
Calibrated to fault level		
Can be set for Ground fault on resistance grounded system depending on station service		

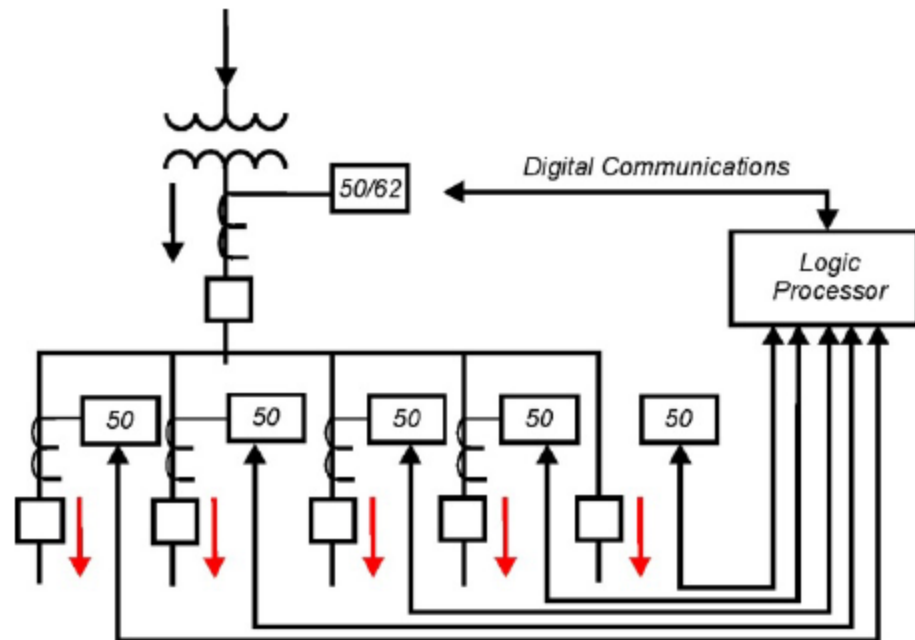


# Arc Fault on Xfmr 480V secondary



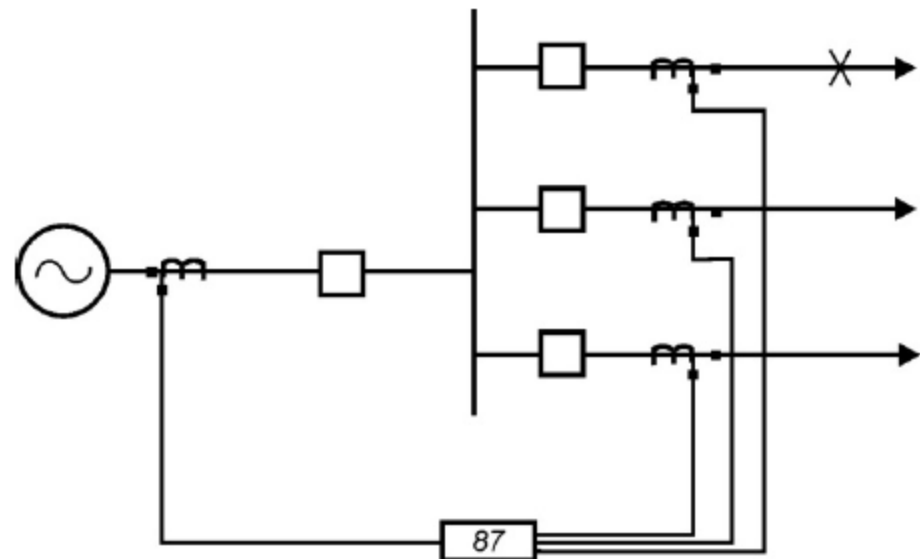
# Zone Interlocking

Advantages	Disadvantages	Cost
Fast response – 5 cycle	No way to test functionality to final element	<ul style="list-style-type: none"> <li>•Control wiring</li> <li>•Protection logic</li> <li>•Depends on # relay in service</li> </ul> 9k\$
Use of existing relay in many cases		
Wider reach		



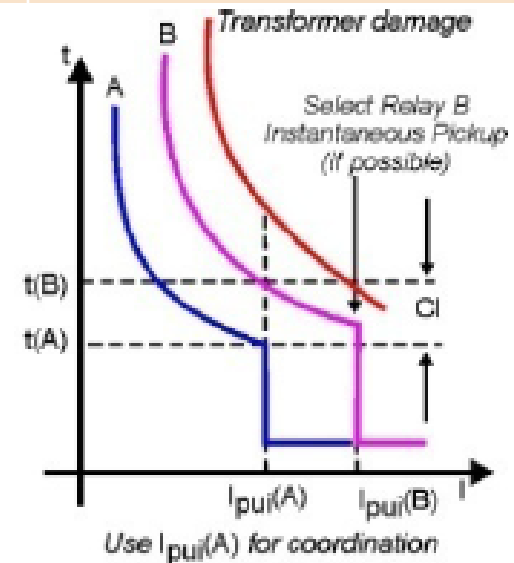
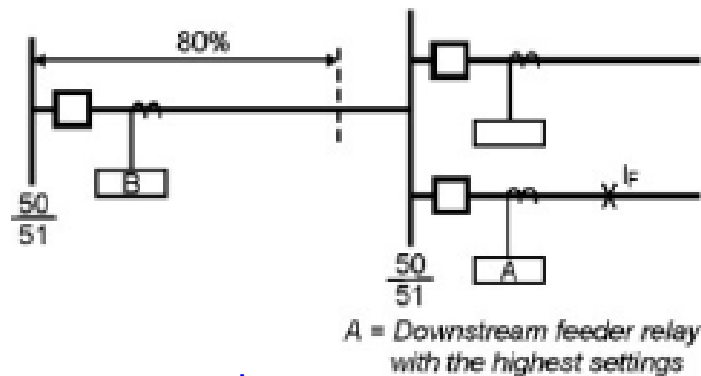
# Low impedance bus differential

Advantages	Disadvantages	Costs
Fast	Can be a problem with saturation of ct if not ratio properly	Similar to bus diffs except add field cable cost
Can be set for ground faults		



# Reduce coordination Time Interval

Advantages	Disadvantages	Cost
No Capital cost	Incident energy still relatively high	Coordination study
Can be applied using existing hardware	Compromises the .3 second time interval	
Setting second instantaneous at 125% A		

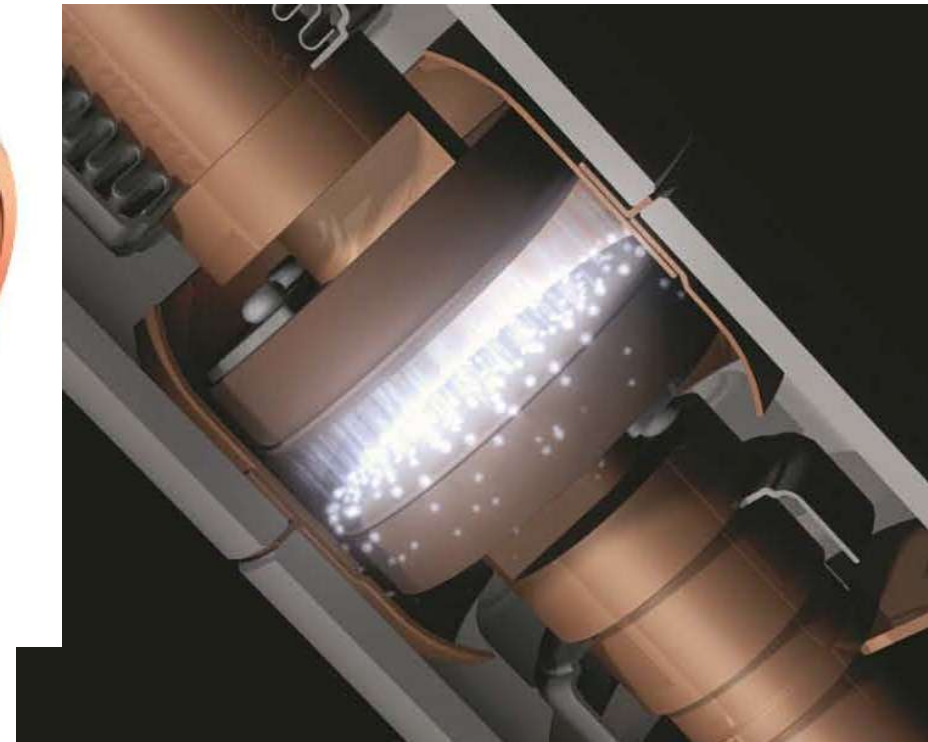
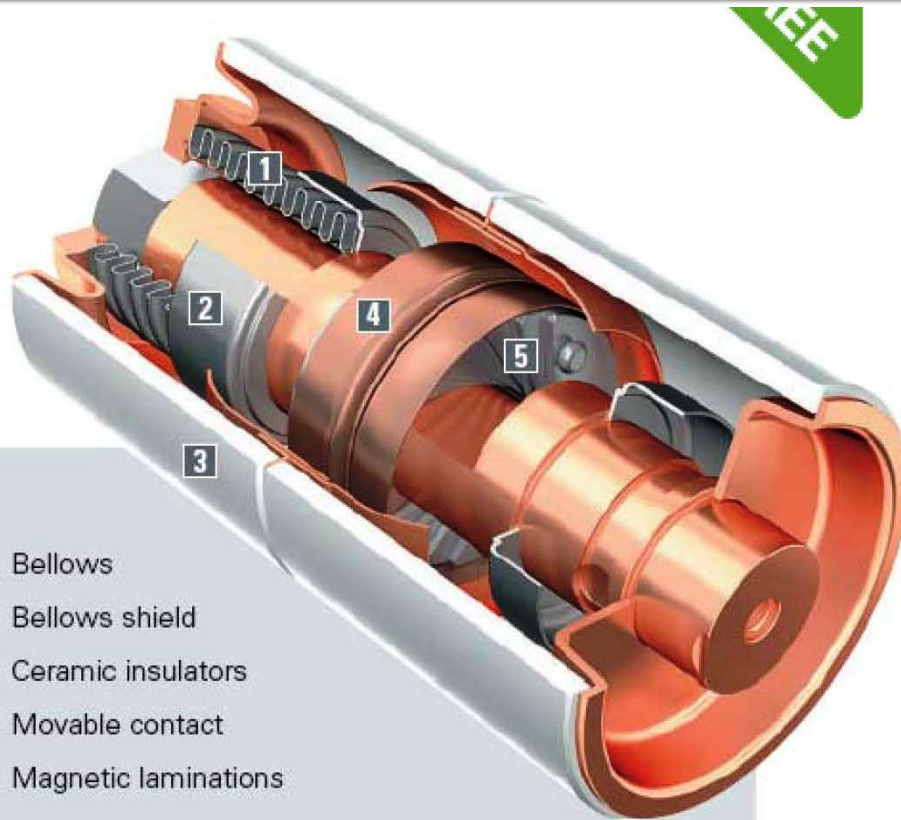


In LV systems setting second instantaneous at 125% of A

# CPT's Installed in Switchgear

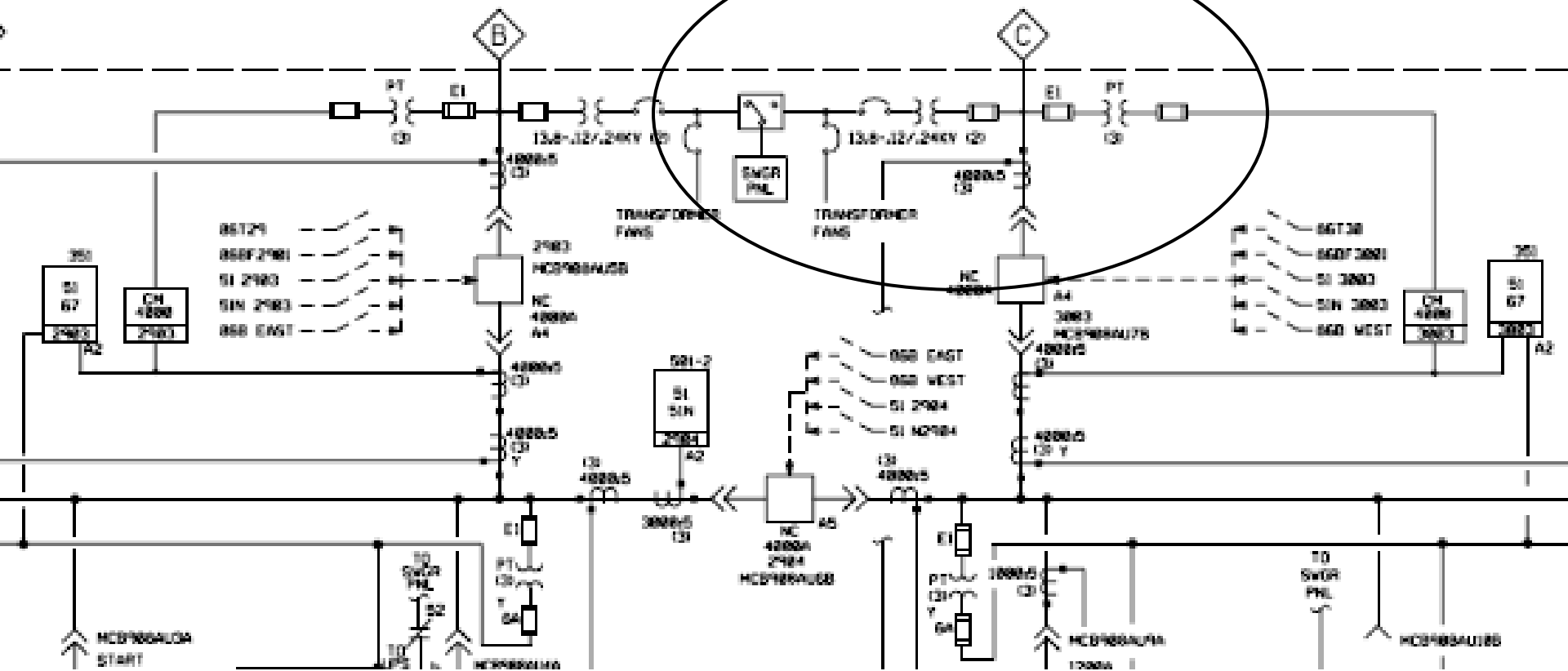
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# Modern Vacuum Bottles





FOR CONTINUATION SEE DWG. 2-61-F-437II-A-1



# Garyville installation

- 75kVA CPT
- Front accessed
- Less chance for smoke egress into other energized cubicles



# CPT's in switchgear

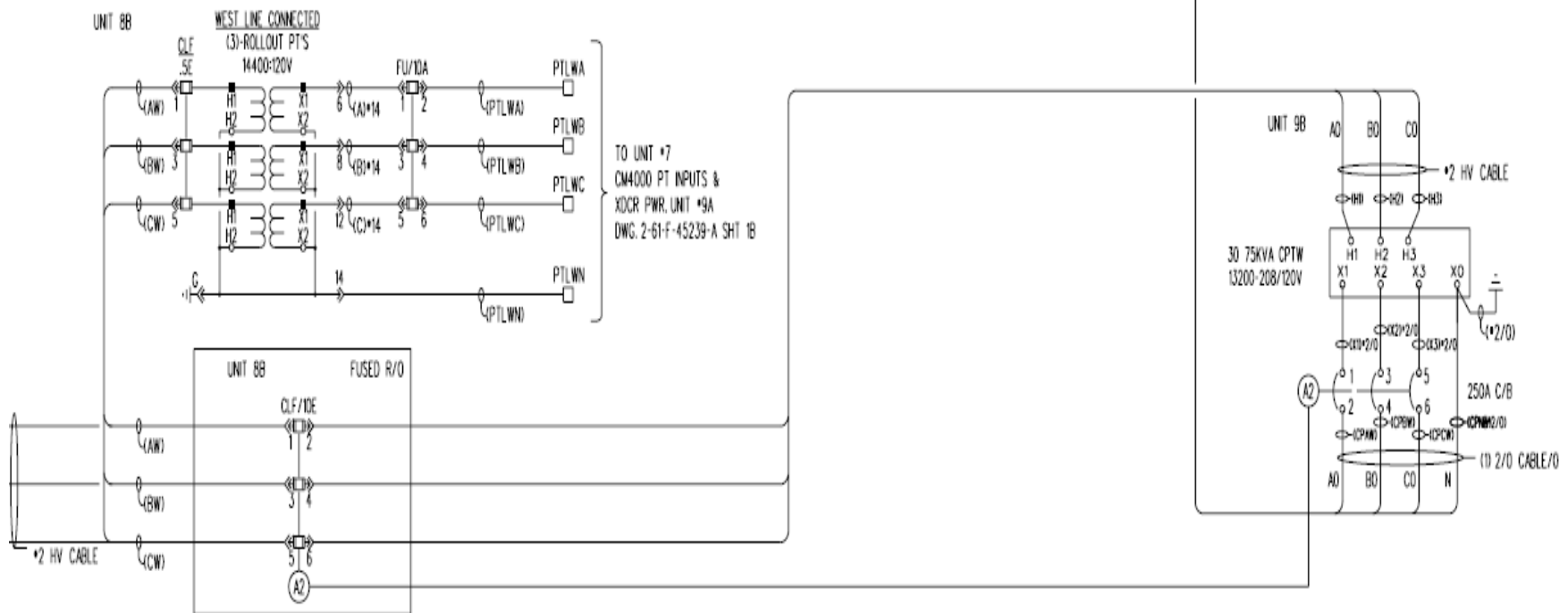


# Magnet wire underneath fault location

- Fault did not burn into the lower layers
- Fault set fire to epoxy on surface



# For future installations Consider Remote the CPT



# Coordination issues

- Fuse should clear for cpt faults
  - Often time the fault is burried in the winding resulting in very long clearing time and open flames
- Too large a fuse size can not coordinate with high impedence diffs.
- Minimum diff setting on 200V with 3000/5 and 15 breakers results in a pickup of xxx amps

# Coordination issue continued

- Desirable for diffs to be sensitive to switchgear groundfaults
- With 600A grounding resistor small window of opportunity for coordination

**Low Voltage**

---



# LV Switchgear

- High Resistant Grounding
- Max Transformer Sizing at 1500KVA
  - Best cost realization
    - Closer to load
    - Cable and tray cost vs. installation cost
    - Reduced fault current
    - Replacement strategy
- Use power breaker to feed big loads instead of mccb

# LV MCC

- Separate turnaround power centers for aux load
- Size 5 starters Air Contactor / Vacuum Contactors/ Soft start
- Soft start vs. Auto Transformer reduced voltage start
- Reacceleration for transfer and voltage dips

# LOW VOLTAGE SWITCHGEAR

- Current limiting fuses
- Operate away from arc flash hazard distances
  - Extended racking handle
  - Close door racking



# Relation between LV Bolted and Arcing Fault Current

Bolted Fault Current	Arc Fault Current
<b>@ 480 V</b>	
10 kA	= 6.56 kA
20 kA	= 11.85 kA
30 kA	= 16.76 kA
40 kA	= 21.43 kA

# LOW VOLTAGE SWITCHGEAR

- Electrically operate breakers only
- Insulated buses to minimize phase to phase fault potential and touch potential.
- Shutters
- Boots or mastic tape
- Two (2) Breaker indicating lights
  - Red for closed breaker
  - Green for breaker open



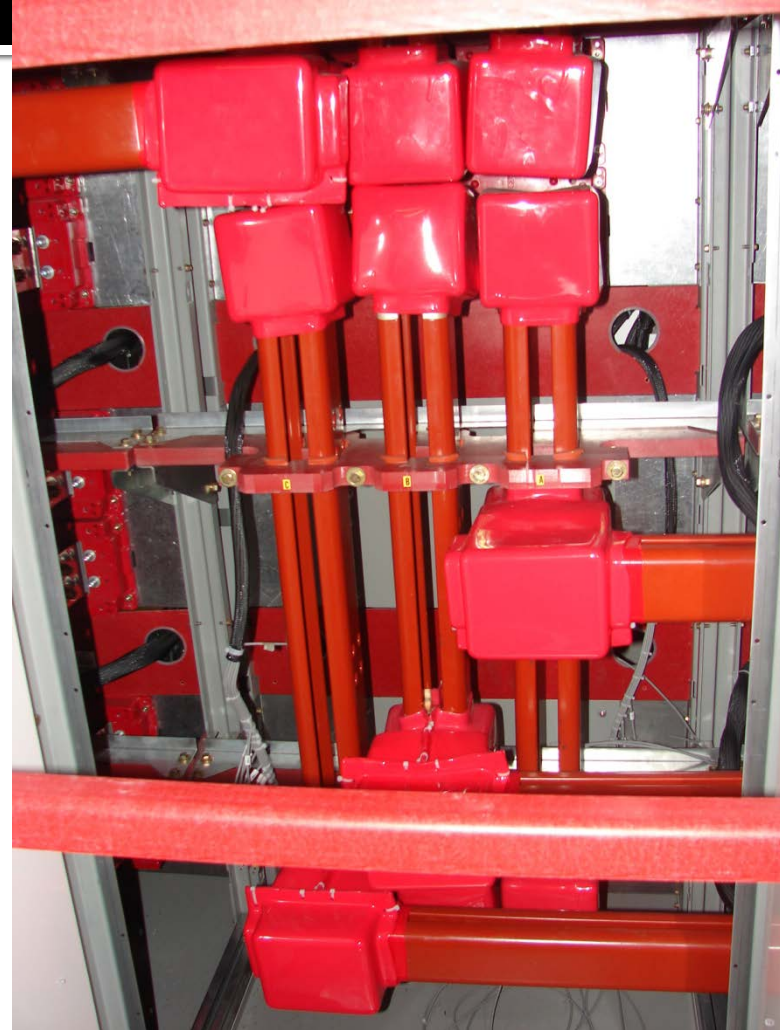
# LOW VOLTAGE SWITCHGEAR

- Barriers between cubicles
- Barriers between main bus & cable compartments.
- Stagger bus on feeder runbacks for cable connections
- Extra depth cable compartment



# Shaped Copper

- Less Layer bolted together
- Stronger short circuit shapes



# Short Circuit Short time

500 fps  
frame : 1

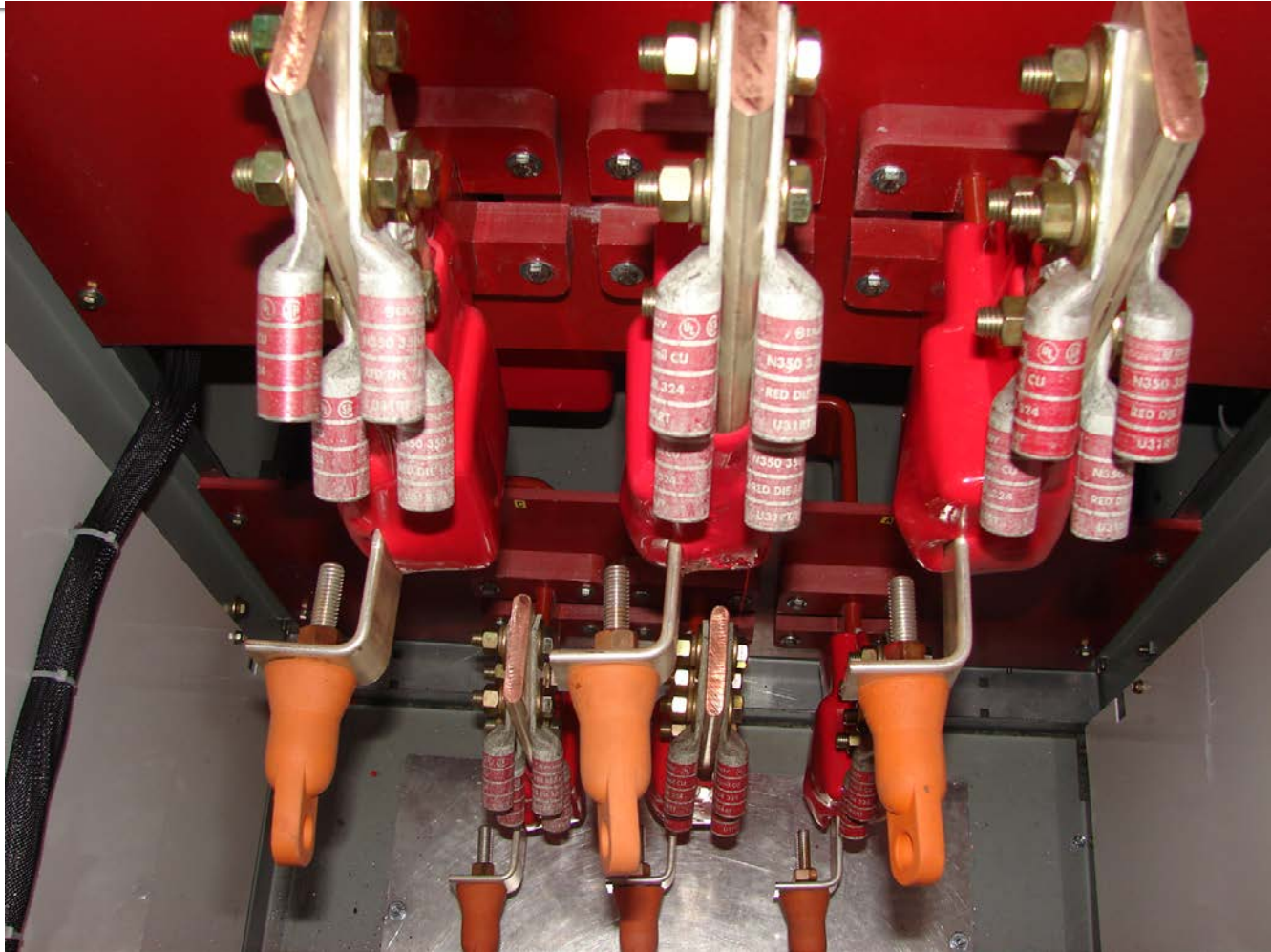
1/1000 sec  
+00:00:00.000000sec

1000 fps  
frame : 1

1/1000 sec  
+00:00:00.000000sec







# Cable Spacing

- The requirements in the standard can allow you to design more cable than you can install.



# Low voltage faults on high side

- Bare lugs
- Mechanical lugs
- Upstream clearing time given cable impedance
- Maint switch





# 80kA for .4 sec at 508VAC



# Solid ground vs. high resistance ground 85kA .5sec at 508volts



HRG



Solid Ground

# Uninsulated vs. Insulated Bus



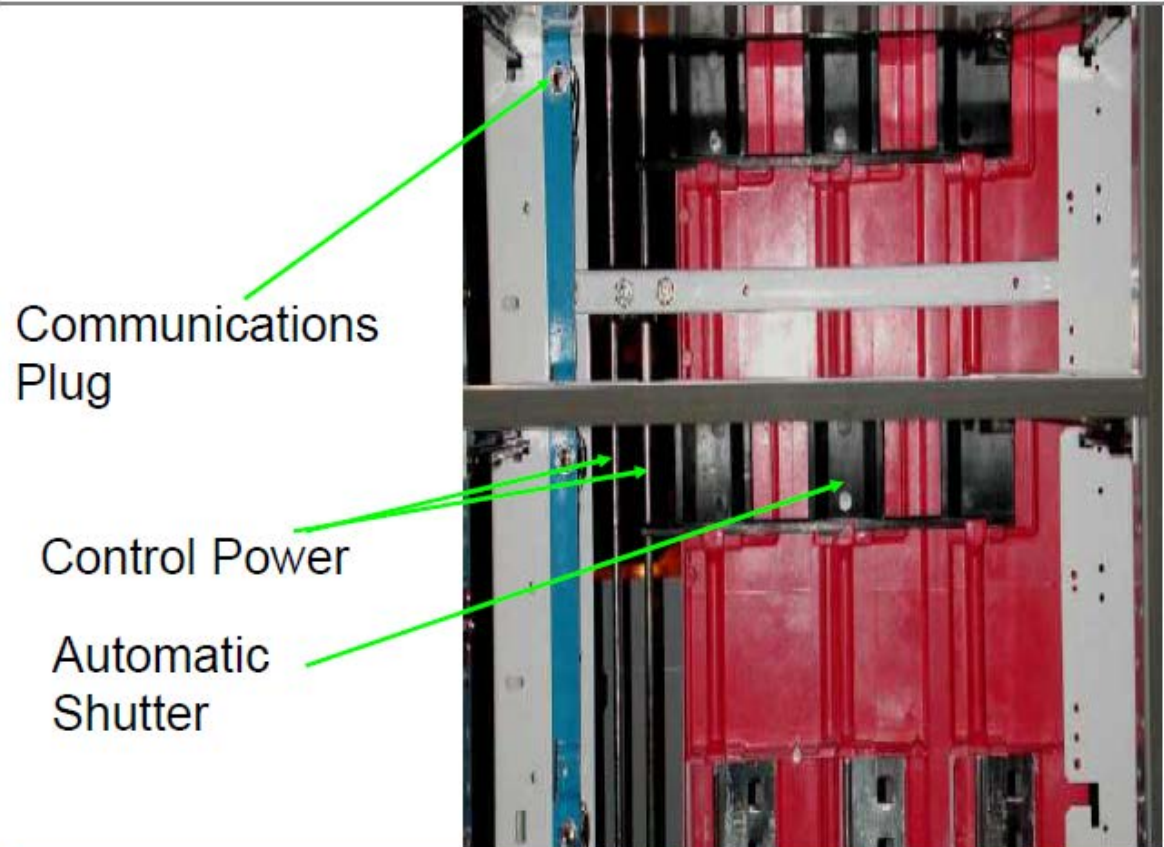
Uninsulated Main Bus  
85kA 635V  
530msec 63psi  
1.5 to 3 cal/cm<sup>2</sup>



Insulated Main Bus  
85kA 635V  
13.7msec 13.2psi

- Fully shuttered
- Stabs encapsulated prior to engagement

## 480 Volt Isolation





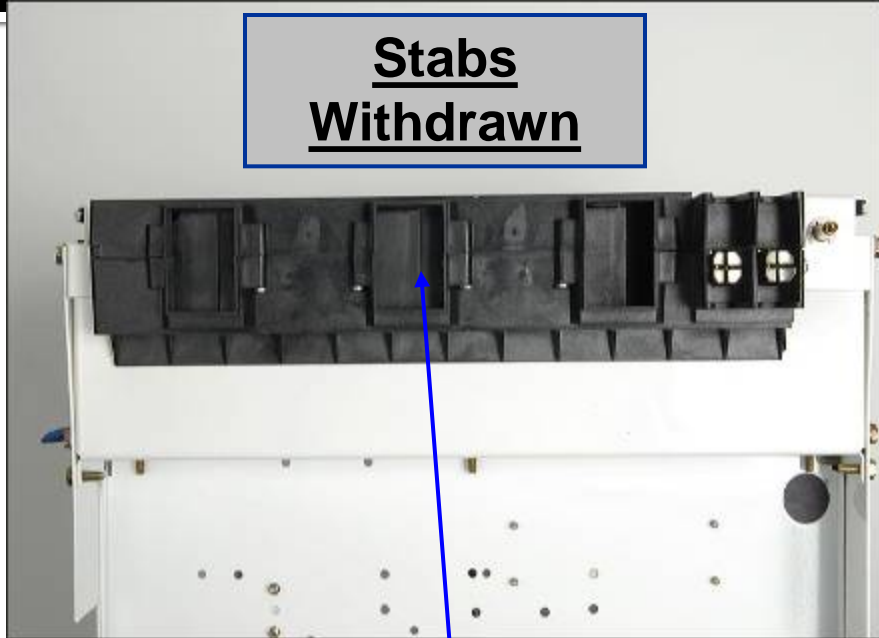
# LV MCC

- Handle extension for operating disconnect
- Smarts for first tier testing
- Remote low energy source for troubleshooting

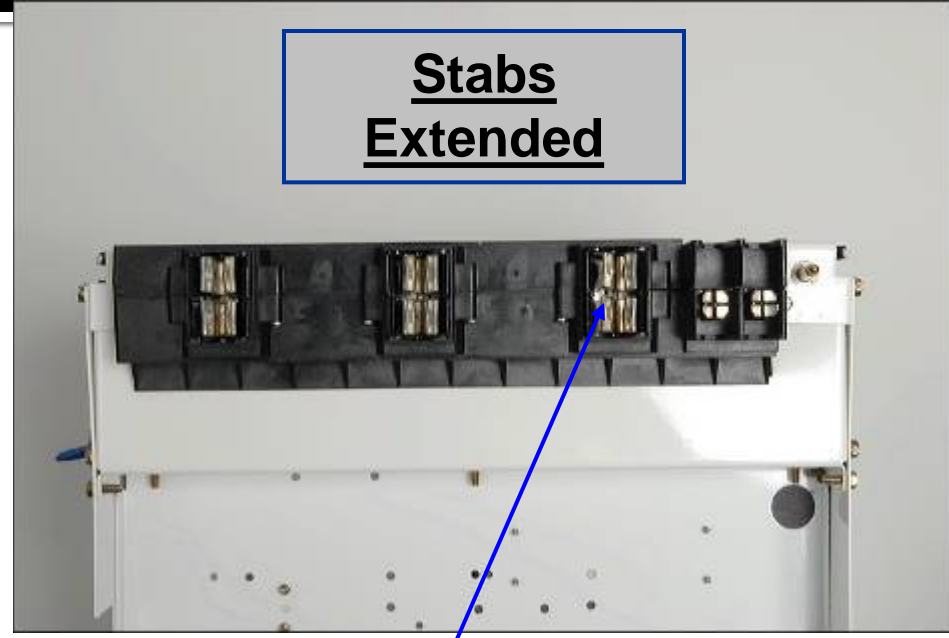


# What is our solution?

Stabs  
Withdrawn



Stabs  
Extended



- **480 Volt Isolation via stab shutter**
- **Extendable and Retractable power stabs – up to 400 Amp Stab**  
Allows you to engage or disengage the stab with the vertical bus while the door is closed keeping you at a safe distance while performing this operation

**38kV 40kA 55000 lbs of thrust  
notice the front corner of the gear**



**The End**

# Next Generation Arc Resistant



# Case Study

# Major Arc Flash + Good Practices = No Injuries Case Study

Joe Rachford

Gallatin Steel

Joe.Rachford@Gallatinsteel.com



# Major Arc Flash Fault + Good Practices = No Injuries

## Major Arc Flash Details:

- Arc Flash Incident Energy = 43 cal/cm<sup>2</sup>
- Arc Flash Boundary Zone = 48 foot
- Power Fed From Two Parallel 129 MVA Transformers for Arc Furnace Operation
- Arc Fault Traveled 15 foot to Breaker
- Large White Flash and Loud Noise Observed During the Fault
- 5 lb Piece of Porcelain Landed 70 foot Away



# Substation Layout



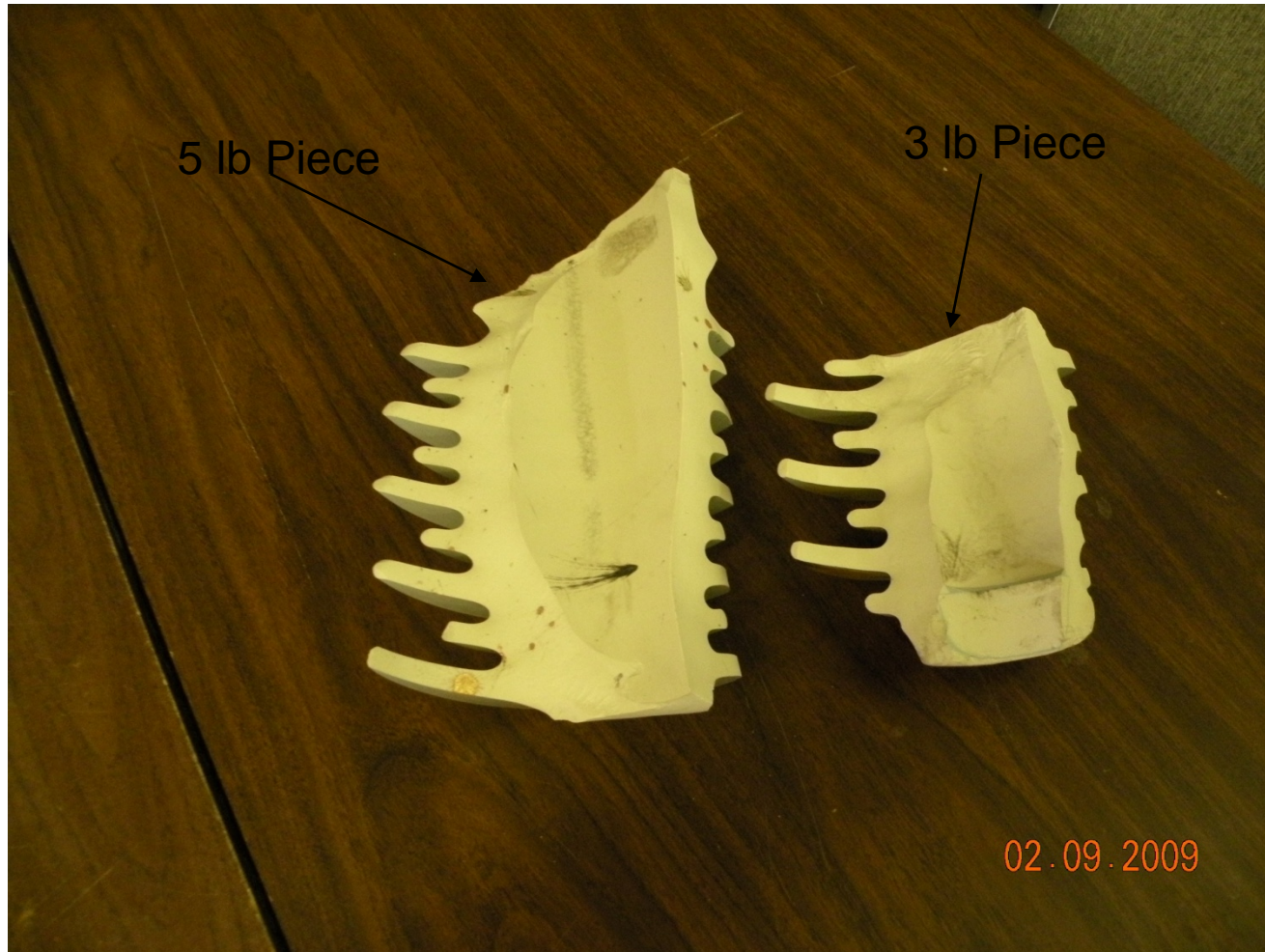
# Arc Flash Starting Point



# Arc Flash Traveled to Breaker



# Porcelain Found 70 foot Away



# Secondary Damage



# Close Up Secondary Damage



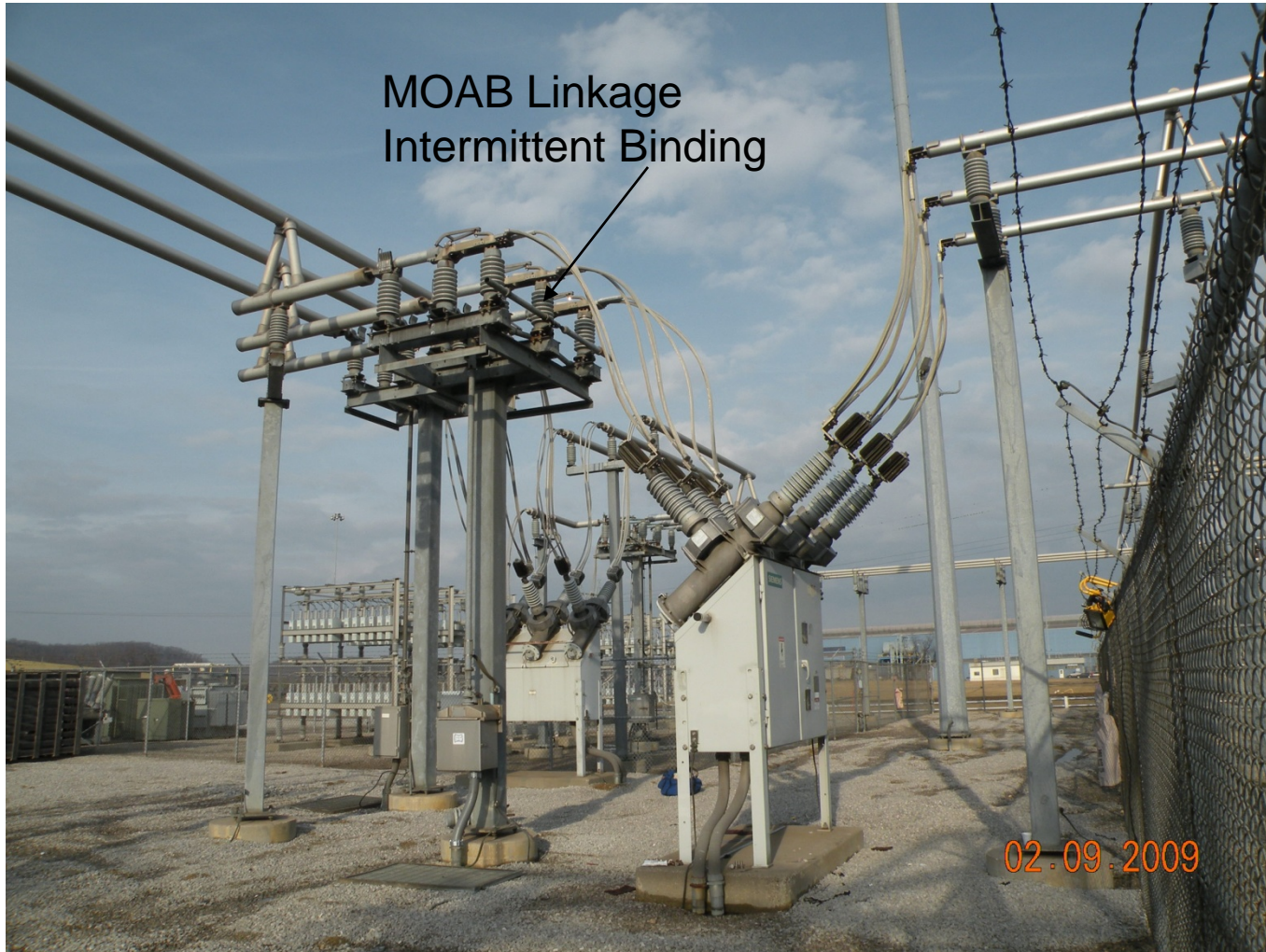
# Root Cause 1



MOAB Control Box Changed  
That Day Due to Motor Failure  
The Previous Week

02-09-2009

# Root Cause 2





# Summary

- Arc Flash Initiated by Misalignment of MOAB Arms Due to Adjustment of Control Box and Linkage Problems
- Arc Flash Traveled 15 foot Down the Bus to the Breaker Bushings
- Mechanical Parts Found 70 foot Away and Truck Panel Had Hole Punched in Door

# MV MCC Case study

---

# Here to share a good news story!

- THE JOB: Change the rotation on a 1000 Hp 2300 V motor
- UNEXPECTED: Motor controller did not fit the procedure
- POOR DECISION: Improper grounds, improperly placed, no indication of grounds

# What Happened?

- Motor leads were swapped at the contactor
- Several days passed
- ESWP released without removing grounds
- Returned to operations
- Operator closed no-load switch
- Switch flashed phase to phase to phase to ground

# The Fault:

- 38 kA
- 210 mS
- Cleared by an upstream breaker
- Plant experienced an emergency outage
- Hot gasses pushed door open right were operator was standing











# NFPA 70 E 2011

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# Exxon Mobil - Columbia



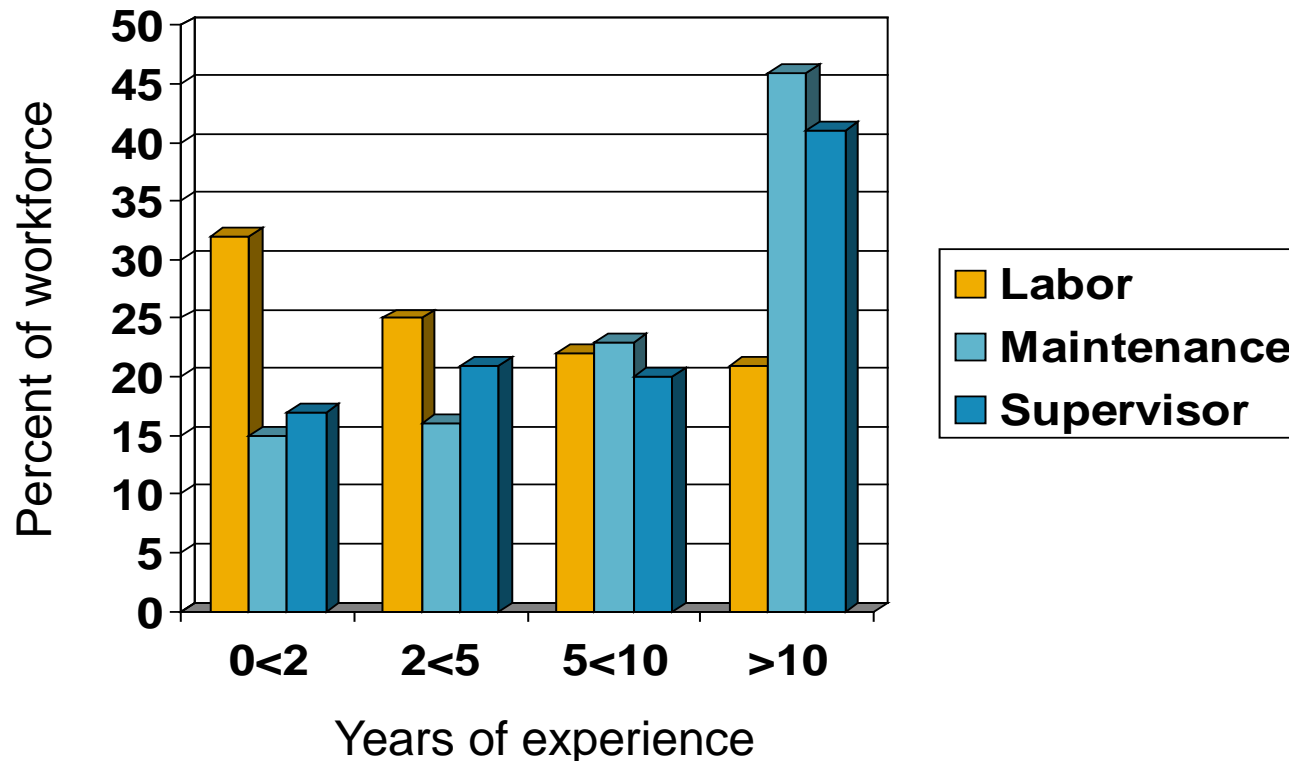
# Safety Triangle



# Preliminary findings

## Organization of work issues

Experienced maintenance personnel and supervisors had a larger proportion of injuries; less experienced laborers also had more injuries



# Indicator Burn Energy

- Indicators are pieces of  $150\text{g}/\text{m}^2$  black cotton cloth (cretonne)
- $1.2\text{ cal}/\text{cm}^2$  and below will not ignite an indicator
- $1.5$  to  $2.0\text{ cal}/\text{cm}^2$  will ignite an indicator

MV 36KA on REAR  
 15KV 0.5s 25KA Dual  
 Burner 1 indicator AT  
 TOP LEFT of Door

**Kema Powertest Powell Temperature Program  
 Data Summary**

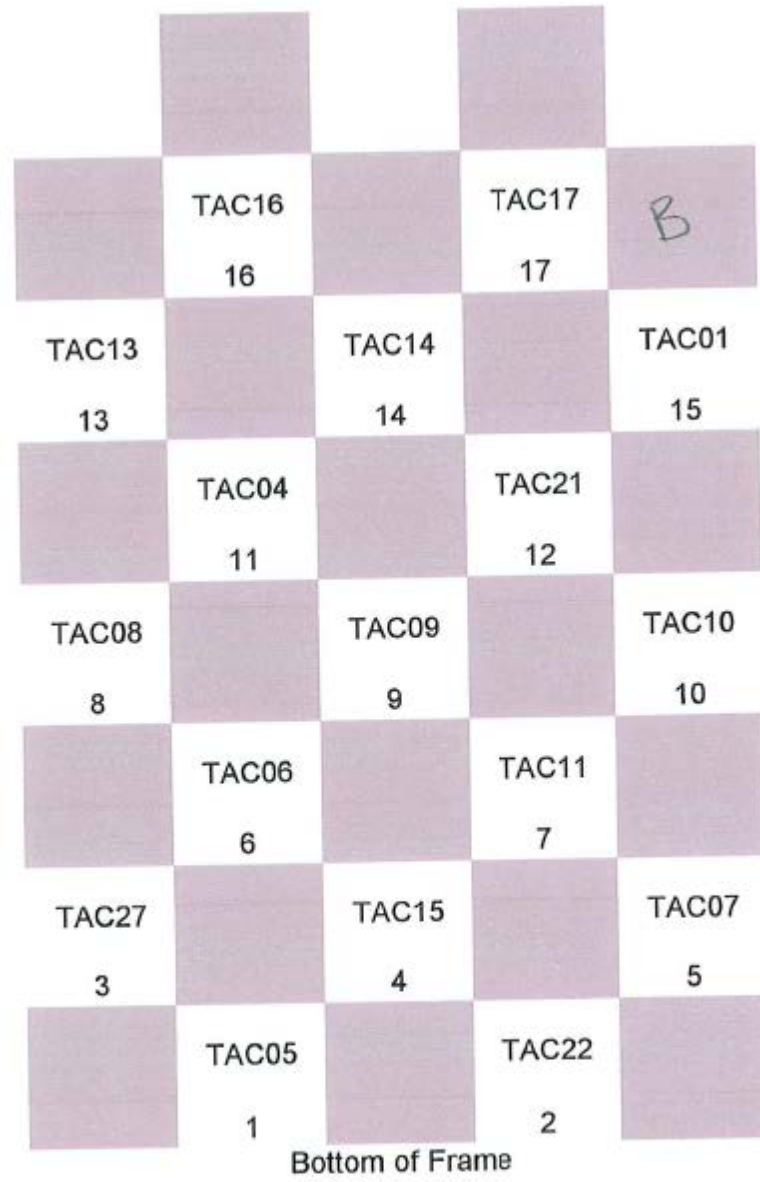
**DAS Operator:** Alex Jushcyshyn  
**Date:** 2/14/2007  
**Time:** 2:15pm  
  
**Test Number:** 07025-b3  
**Trial Number:** #2



Data Channel	Avg Start Temp Deg C	Max Temp Deg C	Max Heat Energy cal/cm <sup>2</sup>	Time to max heat sec
1	8.11	8.40	0.04	0.95
2	7.21	8.30	0.14	0.15
3	5.96	6.50	0.07	0.80
4	8.11	9.30	0.16	0.15
5	7.96	8.40	0.06	0.00
6	7.60	8.20	0.08	0.85
7	8.10	8.70	0.08	0.25
8	6.90	8.20	0.17	0.25
9	8.34	9.40	0.14	0.00
10	7.28	9.80	0.33	0.85
11	8.68	9.90	0.16	0.85
12	8.44	10.20	0.23	0.85
13	6.93	9.40	0.32	0.15
14	8.63	11.60	0.39	0.45
15	9.50	13.30	0.50	0.55
16	9.47	16.50	0.92	0.85
17	10.02	19.60	1.26	0.50

Max Temp, Max Heat, and time to max is based on data from 1 sec after test event.

### Indicator and calorimeter location





# Effects of an Internal Arc Fault

- Mechanical stress from pressure increase
- Thermal stress from the radiated heat
- Release of toxic gases
- Direct injury from:
  - The pressure wave
  - Contact with energized parts
  - Radiation from intense light
- Indirect injury from airborne debris

# What is Incident Energy?

- Energy (heat) per unit area received on a surface located a working distance away from the flash location
- Working distance is between worker's torso & arc-flash location



# What is Incident Energy?

- Unit of measure is  $\text{cal}/\text{cm}^2$
- One  $\text{cal}/\text{cm}^2$  is equivalent to the amount of energy produced by a cigarette lighter in one second

<b>Incident Energy (<math>\text{cal}/\text{cm}^2</math>)</b>	<b>Degree Burn</b>
1.2	2 <sup>nd</sup> degree burn to skin
4	Ignite a cotton shirt
8	3 <sup>rd</sup> degree burn to bare skin



# What is Incident Energy?

- Inversely proportional to the working distance squared (*Double the distance =  $\frac{1}{4}$  the incident energy*)
- Directly proportional to the time duration of the arc and to the available bolted fault current (*Double the arc duration or fault current = double the incident energy*)



# Direct Exposure to the Arc

An arc emits a strong radiation, mostly UV light. System voltage, phase spacing, fault current, fault duration and the distance from the arc all contribute to the effect.

## Skin Temperature

Volts	Fault Current	Duration	Distance	Temp rise
480	40kA	0.1 sec	24 in	310C
13.8kV	40kA	0.1 sec	24 in	8000C
13.8kV	40kA	0.1 sec	120 in	200C

# Look-up Table Example Cal/cm<sup>2</sup> 480 & 600 V Switchgear

Short Circuit Current (kA)	Fault clearing time		
	0.5 s	0.33 s	0.1 s
65 kA	74 cal/cm <sup>2</sup>	49 cal/cm <sup>2</sup>	15 cal/cm <sup>2</sup>
55 kA	63 cal/cm <sup>2</sup>	42 cal/cm <sup>2</sup>	13 cal/cm <sup>2</sup>
45 kA	52 cal/cm <sup>2</sup>	34 cal/cm <sup>2</sup>	11 cal/cm <sup>2</sup>
35 kA	41 cal/cm <sup>2</sup>	27 cal/cm <sup>2</sup>	8.1 cal/cm <sup>2</sup>
25 kA	30 cal/cm <sup>2</sup>	20 cal/cm <sup>2</sup>	5.8 cal/cm <sup>2</sup>
15 kA	20 cal/cm <sup>2</sup>	12 cal/cm <sup>2</sup>	3.6 cal/cm <sup>2</sup>



# WARNING

## Arc Flash and Shock Hazard Appropriate PPE Required

- 24 inch Flash Hazard Boundary
- 3 cal/cm<sup>2</sup> Flash Hazard at 18 inches
- 1DF PPE Level, 1 Layer 6 oz Nomex<sup>®</sup>,  
Leather Gloves Faceshield
- 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

**Equipment Name:** Slurry Pump Starter

Courtesy E.I. du Pont de Nemours & Co.

# What is PPE?

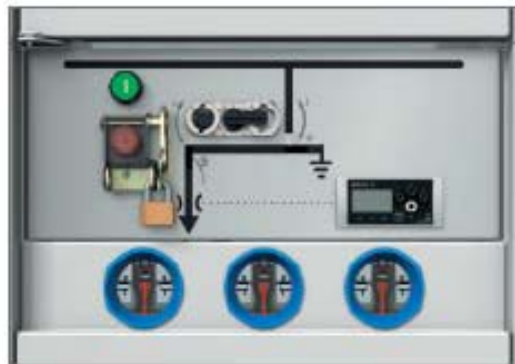
- Personal Protective Equipment (PPE) is clothing, gloves, tools, face protection, and glasses designed to protect personnel from arc-flash hazards.

Category	Cal/cm <sup>2</sup>	Clothing
0	1.2	Untreated Cotton
1	5	Flame retardant (FR) shirt and FR pants
2	8	Cotton underwear FR shirt and FR pants
3	25	Cotton underwear FR shirt, FR pants and FR coveralls
4	40	Cotton underwear FR shirt, FR pants and double layer switching coat and pants

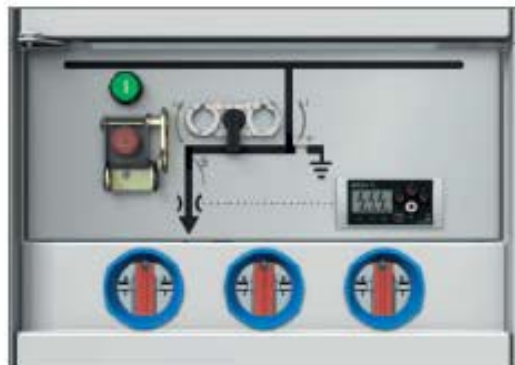
NFPA 70E PPE Categories



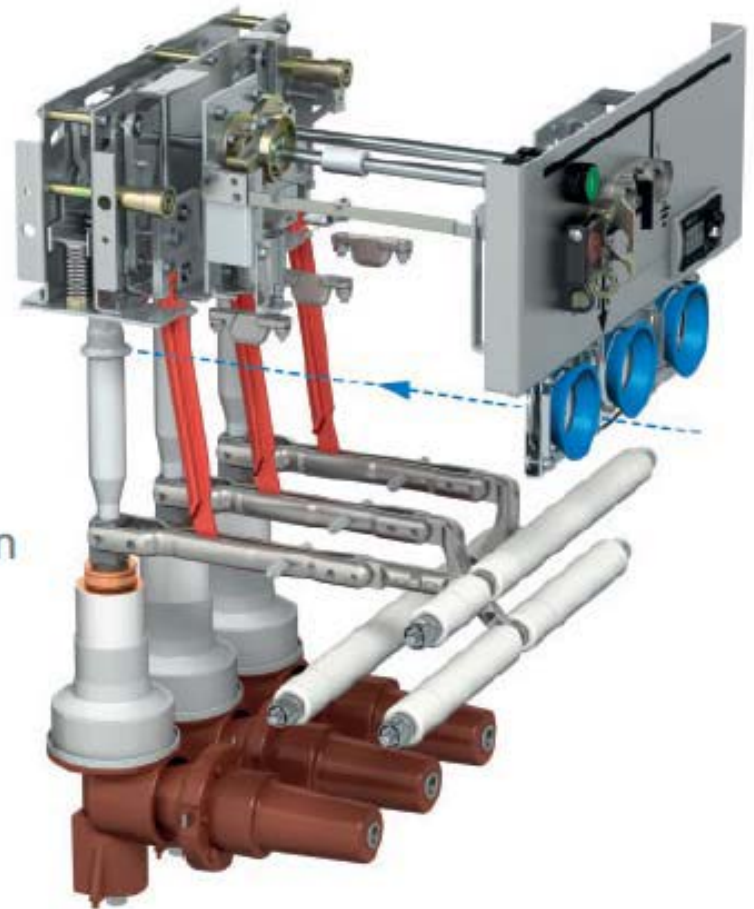
# Insulation clad switchgear



Earth position



Operating position



# Remote racking LV MCC

## ■ Features

- Status Indication
  - Stab position indication
  - Stab shutter position indication



# The Freedom FlashGard™ Bucket

Racking Tool Receiver

Unit Latch

Power Stab Position

- Connected
- Disconnected

Internal Shutter Position

- Open
- Closed

Handle Mechanism

Pilot Device Island

- Start, Stop, Auto/Man

Breaker

Starter

