NESC Proposed Changes and New Arc Flash Testing

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Table 410-1—Clothing and clothing systems (cal/cm^2) for voltages 50 V to ~~1000~~600V (ac) ①
(See Rule 410A3.)

Equipment type	Nominal voltage range and cal/cm^2		
	50 V to 250 V	251 V to 600 V ⑭	~~601 V to 1000 V~~
Self-contained meters / cabinets	4 ②	20 ④	~~30~~ ~~⑧~~
Pad-mounted transformers	4 ⑨	4 ⑨	~~6~~ ~~⑧~~
CT meters and control wiring	4 ②	4 ⑤	~~6~~ ~~⑧~~
CT compartment/customer switchgear	4 ②	⑮	
Metal-clad switchgear / motor control centers	8 ③	40 ⑥	~~60~~ ~~⑧~~
Pedestals / pull boxes / hand holes	4 ②	8 ~~⑦~~⑰	~~12~~ ~~⑧~~
Open air (includes lines)	4 ②	4 ⑰	~~6~~ ~~⑧~~
Network protectors with transformer energized	4 ⑩	⑪	~~⑪~~
Network protectors with transformer de-energized	4 ⑯	8 ⑯	
Panel boards—single phase (all) / three phase (≤100 A)	4 ②	8 ⑫	~~12~~ ~~⑧~~
Panel boards—three phase (>100 A)	4 ②	⑬	~~⑬~~

⑮ Industry testing on 480V multi-meter panels, CT compartments, 320 A meter panels and any compartments with large amounts of bus bar will not self-extinguish. Perform arc hazard analysis. (See IEEE Transaction on Industry Applications, Vol 54 No 3, pages 2934-2946, 2018 "Low Voltage Arc Sustainability". ML Eblen, TA Short, [B1])

⑯ Industry testing on 480V network protectors when the transformer is de-energized will self-extinguish in 5 cycles or less for internal and external work activities. (See IEEE Transaction on Industry Applications, Vol 54 No 3, pages 2934-2946, 2018 "Low Voltage Arc Sustainability". ML Eblen, TA Short, [B1])

⑰ Industry testing on 480V equipment with similar spacing and configurations indicate that this will self-extinguish in 5 cycles or less. (See IEEE Transaction on Industry Applications, Vol 54 No 3, pages 2934-2946, 2018 "Low Voltage Arc Sustainability". ML Eblen, TA Short, [B1])

Table 410-4—Clothing and clothing systems—voltage, fault current, and maximum clearing time for medium voltage 1 kV to 36 kV enclosed equipment[1][2]

Fault current kA	Live-front transformer, live-front terminations, and horizontally racked circuit breaker[3]			Live-front pad-mounted style switch[4]		
	8 cal system	25 cal system	40 cal system	8 cal system	25 cal system	40 cal system
	Max clearing time (cycles)	Max clearing time (cycles)	Max clearing time (cycles)	Max clearing time (cycles)	Max clearing time (cycles)	Max clearing time (cycles)
2	94	294	470	125	291	412
5	36	111	178	45	105	149
8	22	67	108	27	63	89
10	17	53	85	21	49	69
15	11	35	55	13	31	44
20	8	25	41	10	23	32
25	6	20	32	8	18	25
30	5	17	26	6	14	20
35	4	14	22	5	12	17
40	4	12	19	5	10	15
45	3	11	17	4	9	13
50	3	10	15	4	8	12

[1] This table shall not be used for working distances less than 48 in. The values in this table are based on a 48 in working distance.

7. Conduct a job briefing with the employees involved before beginning each job. A job briefing should include at least the following items: work procedures, personal protective equipment requirements, energy source controls, hazards associated with the job, ~~and~~ special precautions, and information necessary to respond to emergencies.

NOTE: An employee working alone need not conduct a job briefing. However, the tasks to be performed should be planned as if a briefing were required.

(2) All exposed energized lines ~~or~~, parts, or conductive objects (includes neutral), other than those temporarily exposed to perform work and maintained under positive control, located within the reach or extended reach of the employee's work position, shall be covered with insulating protective equipment.

REJECTED: Sent to APPA for changes

f. Cover-up equipment, when used, shall be applied to ~~the~~ all exposed conductive facilities (including the neutral) as the employee first approached the facilities from any direction, be that from the structure or from an aerial device, and shall be removed in the reverse order. This protective cover-up shall extend beyond the reach of the employee's anticipated work position or extended reach distance.

REJECTED: Sent to APPA for changes

4. <u>Sources of backfeed, such as distributed energy resources, shall be considered when de-energizing lines and equipment.</u>

Table 444-1—Minimum clearances for open air gaps

Voltage in kilovolts phase-to-phase ①②③	Electric supply stations		Overhead lines	
	(mm)	(in)	(mm)	(in)
1.0 to 8.3 ④	178	7	127	5
8.4 to 15.5	305	12	178	7
15.6 to 27	381	15	229	9
27.1 to 38	458	18	305	12
38.1 to 48.2	534	21	534	21
48.3 to 72.5	788	31	788	31

④May be used for voltages less than 1 kV for created air gaps.

Real Equipment Arc Flash Testing

Prepared for City Utilities

By Marcia Eblen

Background

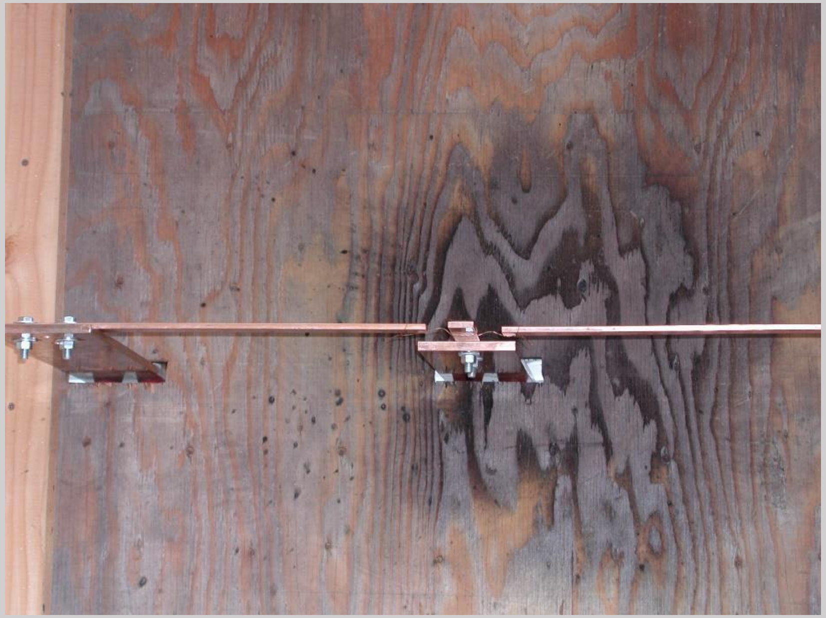
- IEEE1584-2002 Formula
  - Based on staged laboratory set up
  - Not geared toward utility equipment

- NEED for more information

Low Voltage

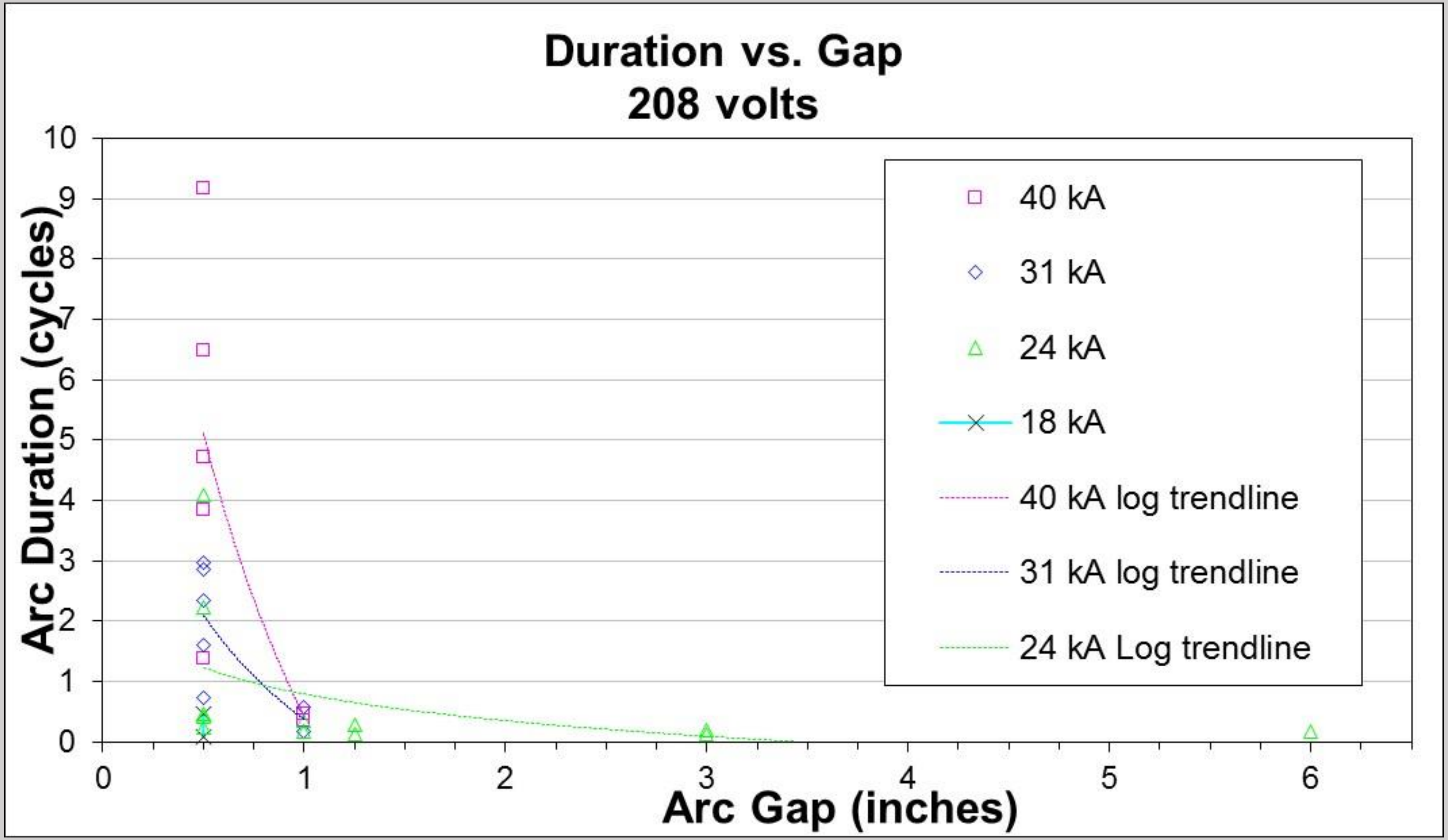
Staged Arc Gap Testing

Staged Arc Gap Testing

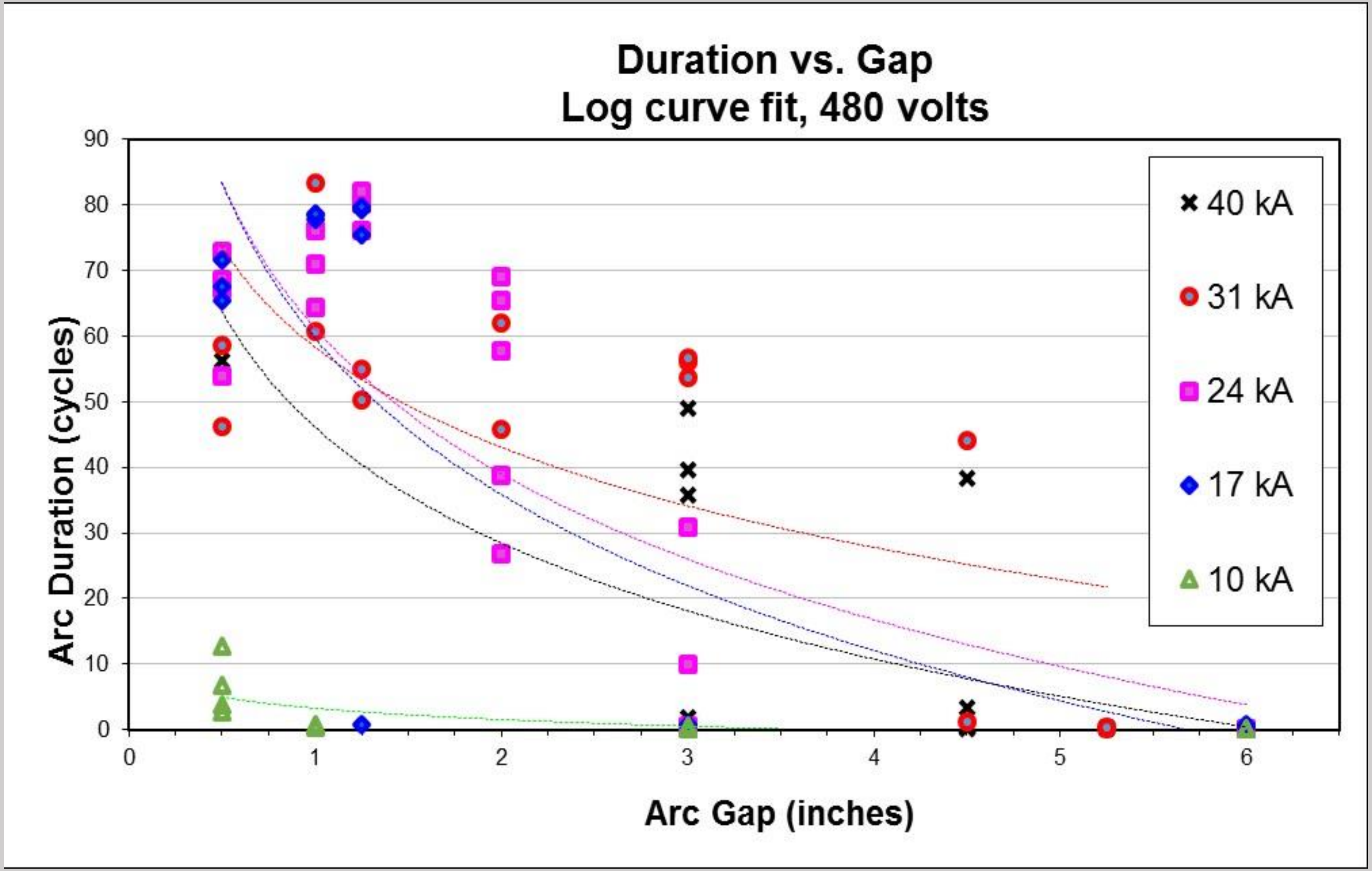


Configuration drives arcs to opposing phases for worst case initiation

Staged Arc Gap Testing-208V



480V Staged Arc Gap Testing



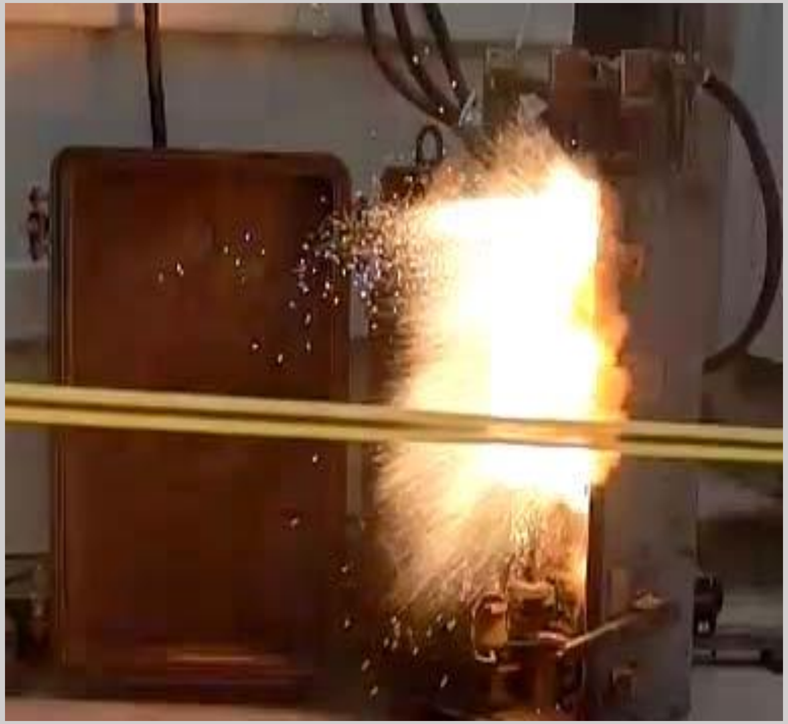
208V 3ϕ

Real Equipment

208V Three-Phase Self-Contained Meter Base

Summary of Data		
Duration (cycles)	**Bolted Fault (kA)**	**Incident Energy (cal/cm^2)**
1.0	14.9	0.0
1.1	14.9	0.0
1.6	14.9	0.1
1.0	30.7	0.2
0.9	30.7	0.1
0.6	30.7	0.1
0.3	40.4	0.1
0.5	40.4	0.2
0.2	40.4	0.1

208V 3Φ Network Protectors



Summary of Data		
Duration (cycles)	Bolted Fault (kA)	Incident Energy (cal/cm²)
0.39	30.7	
0.39	30.7	
0.96	30.7	
0.36	30.7	
0.52	40.4	
11.5*	40.4	
0.36	40.4	0.15
0.36	40.4	0.01
0.29	40.4	0.02
3.79*	40.4	0.10
2.34*	40.4	0.01
0.14	40.4	0.00
4.89*	40.4	0.06
0.62	40.4	0.01

Comparison Low Speed to Hi Speed 208V

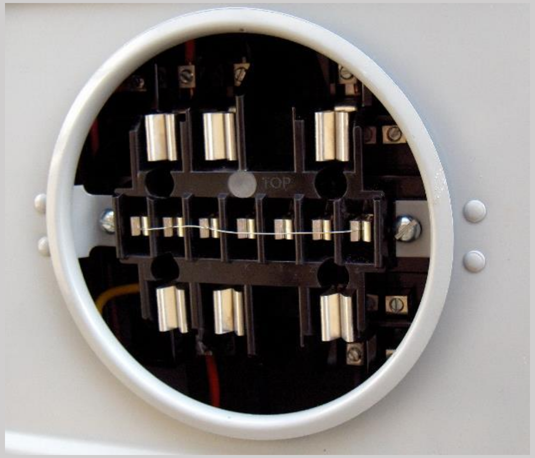
208V 3Φ Conclusions

- Very limited sustainability < 2 cycles for even worst case (network protector 3ϕ)
- Very limited incident energy exposures – still hazards exist
- Most other equipment should be same
    - Sustained arc gaps < ½” required for any more

480V 3ϕ

Real Equipment Meters

480V Transformer Rated Meter Sockets –9S



- Self-extinguish < 18 cycles
- Incident Energy < 2.5 cal/cm^2
- Most Energy at lower current (6kA)

480V Self-Contained Ringed Meter Sockets- Style 16S

- Self-extinguish < 60 cycles
- Incident Energy < 20 cal/cm^2
- Most Energy at lower current
- More consistency at higher currents
    - 44kA→4-10 cycles→ 3-7 cal/cm^2
    - 25kA→8-23 cycles→ 5-13 cal/cm^2
    - 12kA→1-57 cycles→ 0.1-20 cal/cm^2
    - 6kA→1-31 cycles→ 0-7 cal/cm^2

480V Meter Test 12kA bolted

480V Ringless Meter Socket

- Does Self-extinguish
- Incident energy < 14 cal/cm^2

Comparison
Ringed to Ringless Meter Sockets

MAJOR difference in energy pattern

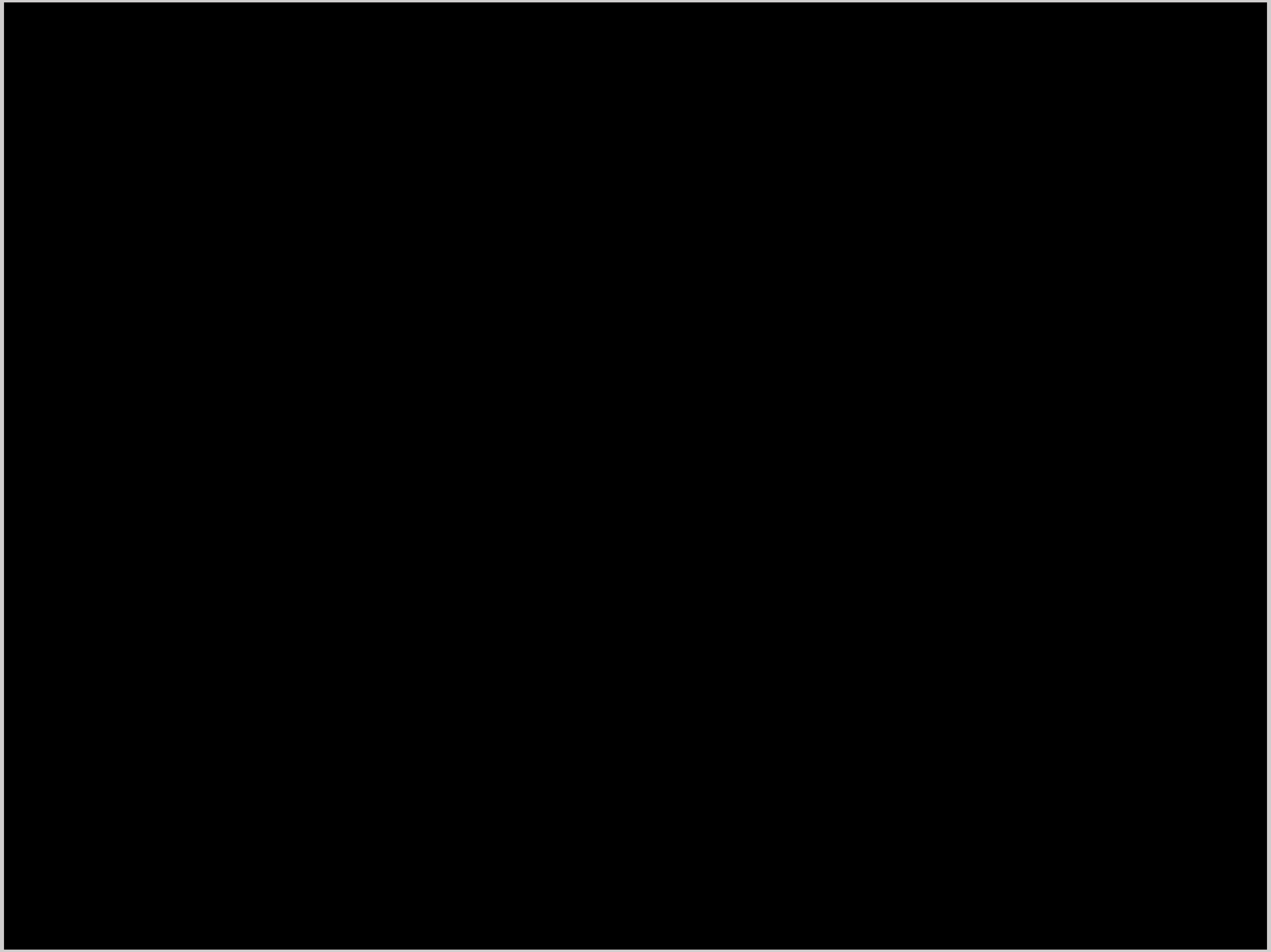
320A Meter Test Results

320A Meter

- **NOT SELF-LIMITING!!!**
- **IE 20-90 cal/cm^2**
- **NOT all current values tested**
- **Before and After Photo**

320A Meter

- Out doesn’t mean OUT
- Restrikes occur in the 2 second energization



Bypass meters/CT cabinets

BYPASS METER SOCKET

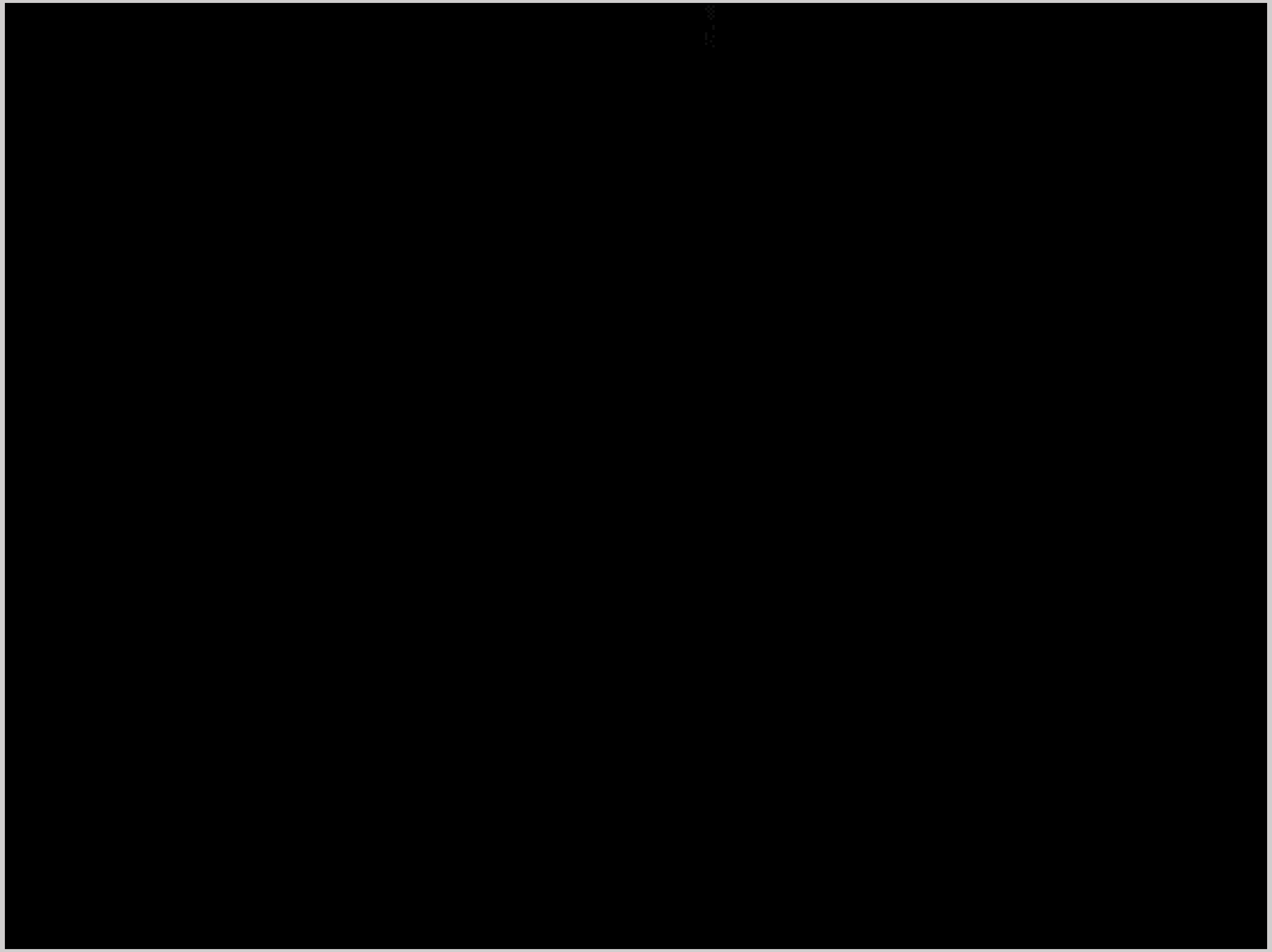
- 1 test
- < 8 cal/cm^2

CT Cabinet

- 1 specimen
- <10 cal/cm^2

- **NOT ENOUGH TESTS**
- **NOT ENOUGH CURRENT RANGE**
- **NOT ENOUGH EQUIPMENT VARIATIONS**
- **MUST CALCULATE BASED ON DEVICE CLEARING**

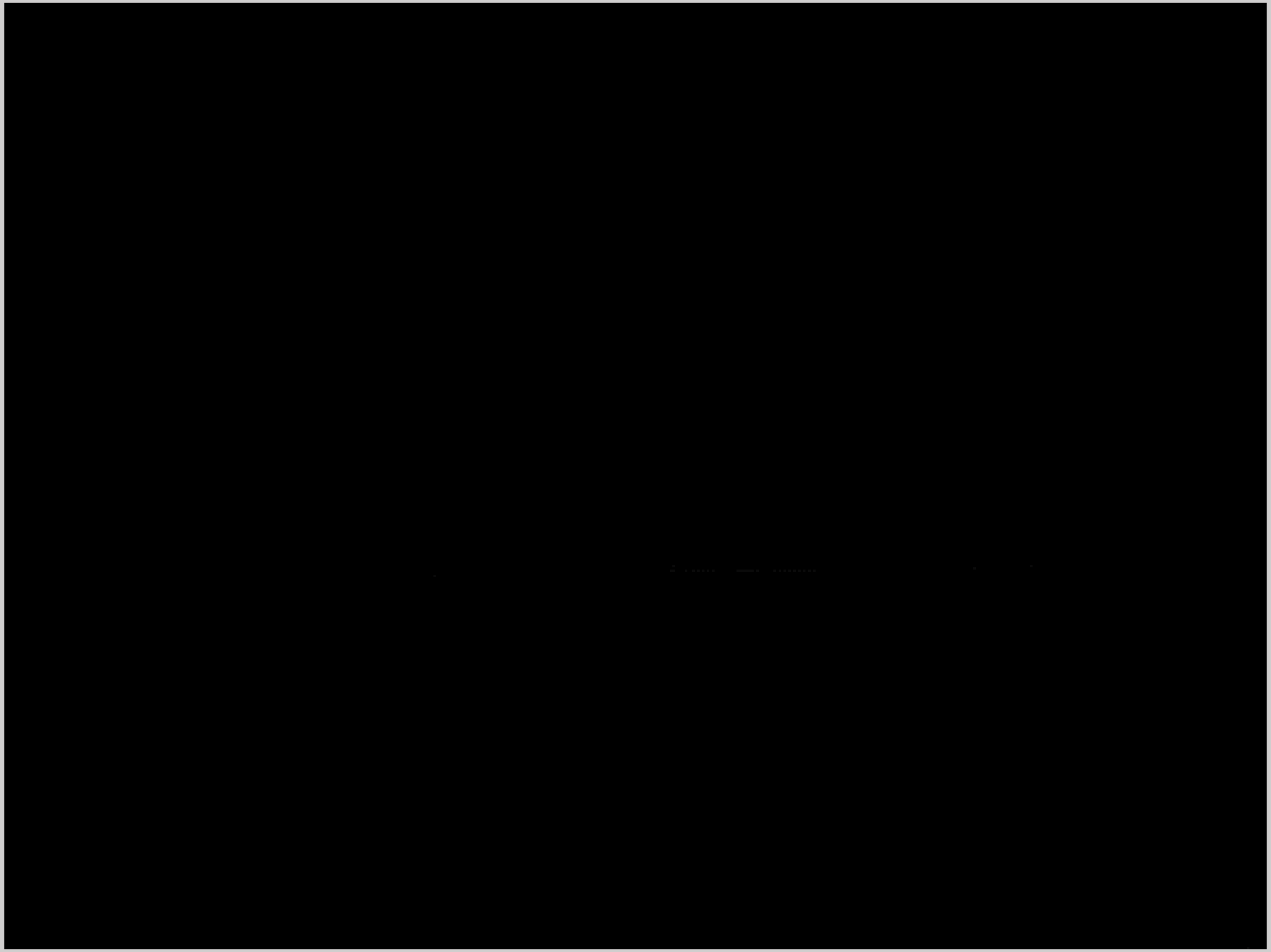
CT Cabinet 10 cal/cm2



480V Multi-meter Sockets

- Does NOT self-extinguish
- Very high incident energy
- Heat flux rates > 60 $cal/cm^2/sec$

MultiMeter Panel-120 cyc >100 cal/cm2



480V 3ϕ

Real Equipment Other

480V Overhead quadraplex cable

- Self-extinguish < 1 cycle
- Very low incident energy

480V Padmounted Transformers Secondary

- Self-extinguished < 2 cycles
- Incident energy < 4 cal/cm^2

480V Power Distribution Panels-Small

- Self-extinguish 30 cycles or less
- 50 amp 14kA IC rated
- Incident energies < 8 cal/cm^2

- Does NOT self-extinguish
- Event terminated at 2 sec
- Incident energy ~ 140 cal/cm^2
- Copper calorimeters melted

480V Cable Tray

- Self-extinguish 3.52 cycles

480V Cable in Tray

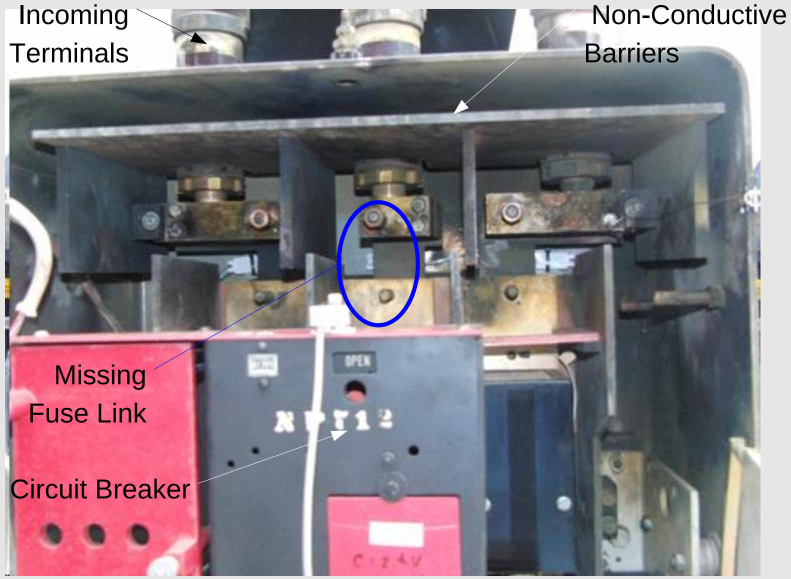
- Self-extinguish 1.54 cycles

480V Simulated Ceiling Mounted Bus Bar

- Self-extinguish 1.92 cycles

480V Network Protectors-with Transformer DE-ENERGIZED-Very LOW incident energy

- Outside fuses
- Outside terminations
- Inside fuses



480V Network Protectors-with Transformer ENERGIZED-Very HIGH incident energy

- Simulated spacing for back bus bar
- Arc does NOT self-extinguish
- Heat flux rates
  > 60 cal/cm^2/sec

Major Conclusions

- 240V Equipment will self extinguish
  < 2 cycles and < 4 cal/cm^2
- 480V Equipment dependent on electrode configuration, mass, spacing, and enclosure size

480V Low sustainability < 5 cycles

- Open air
- Single phase
- Padmounted transformers
- Insulated cables in cable tray
- CT rated meter sockets
- Network protector with transformer de-energized
- Network protector external fuses and terminations
- Ceiling mounted bus bar with > 8 inch phase spacing

480V Medium Sustainability (up to 90 cycles)

- Self contained meter socket like style 16S fed by 1/0 AWG cables
- Small power distribution panels

480V High Sustainability (> 2 second clearing)

- Self contained meter socket with large terminal or large amounts bus bar, including socket rated > 200A
- Network protectors with transformer energized
- Large power panels, especially with flat facing bus bar

Medium Voltage

Real Equipment

PMH switches

Livefront Xfmrs

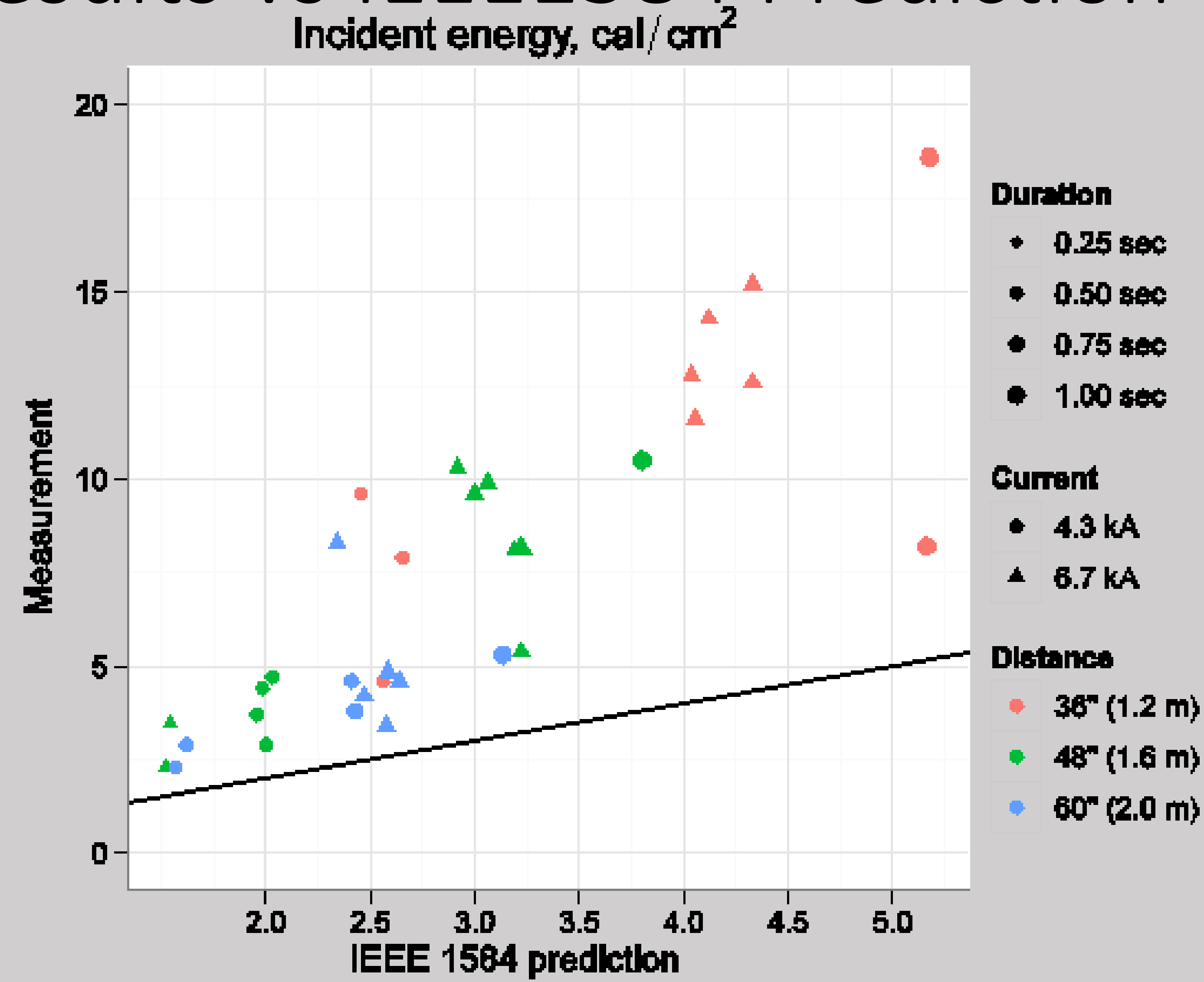
Switchgear

21kV Incident on PMH switch

- Injuries worse than expected
- Conducted extensive testing
- Heat exceeded ARCPRO predictions by factor of 8 or more
- Electrode configuration is the culprit
  - Bus bar pointing out of enclosure
- Newly developed formula

PMH Video

PMH Results vs IEEE1584 Prediction



PMH Energy Formula

$$E = 3547 \frac{I^{1.50}}{d^{2.10}} t^{1.35}$$

where,

E = incident energy, cal/cm^2

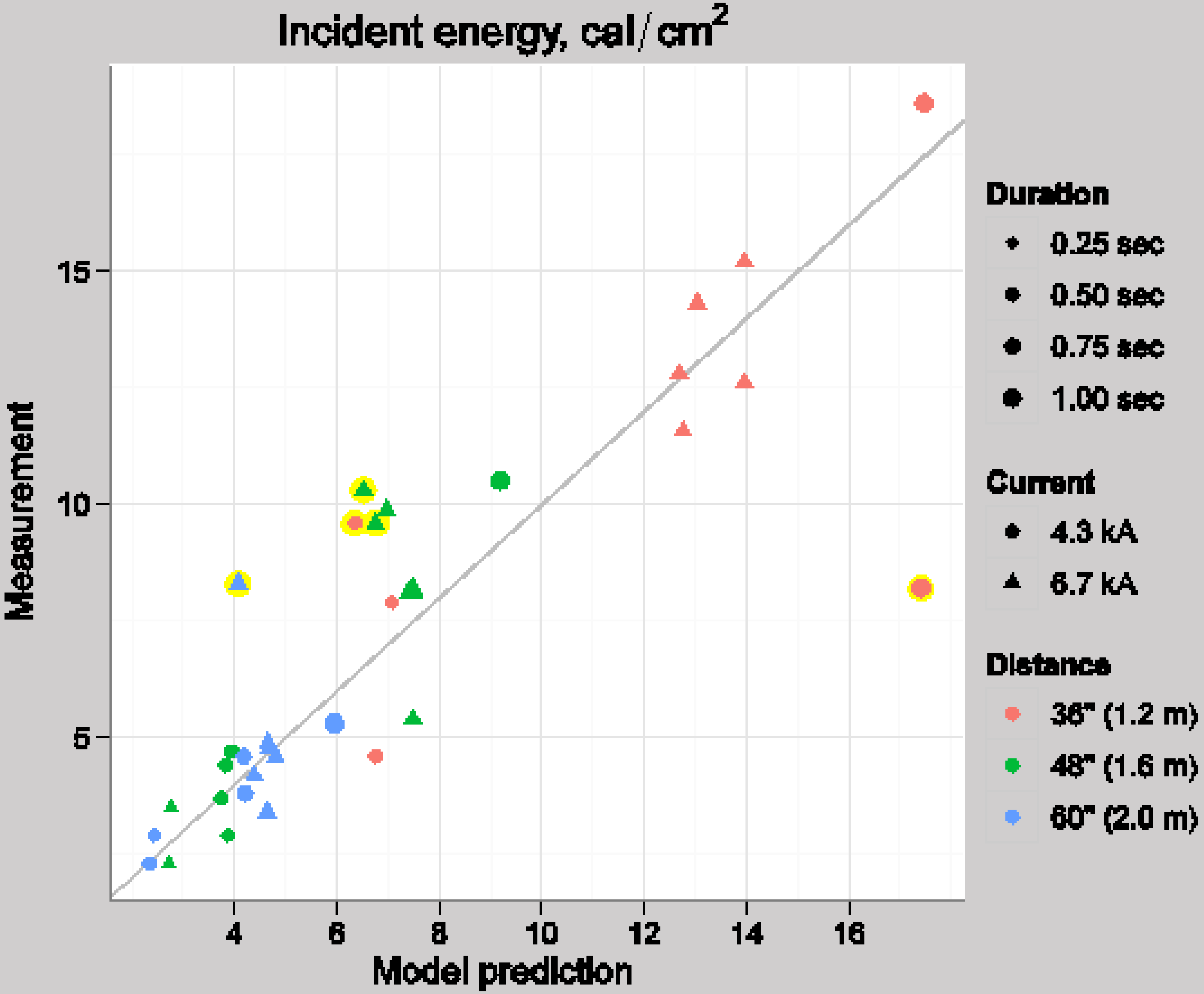
I = fault current, kA

d = working distance, inches (1 inch = 2.54 cm)

t = duration, sec

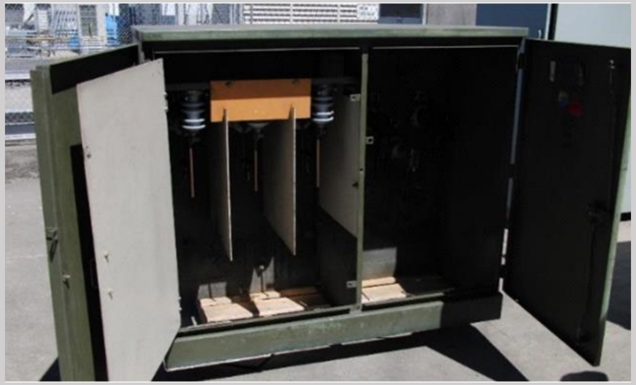
- The R^2 value for this model is 0.91, meaning that all but 9% of the variance is explained by the model.

PMH Results vs NEW Formula



PMH – Ejected Arc

Livefront Transformers Equipment



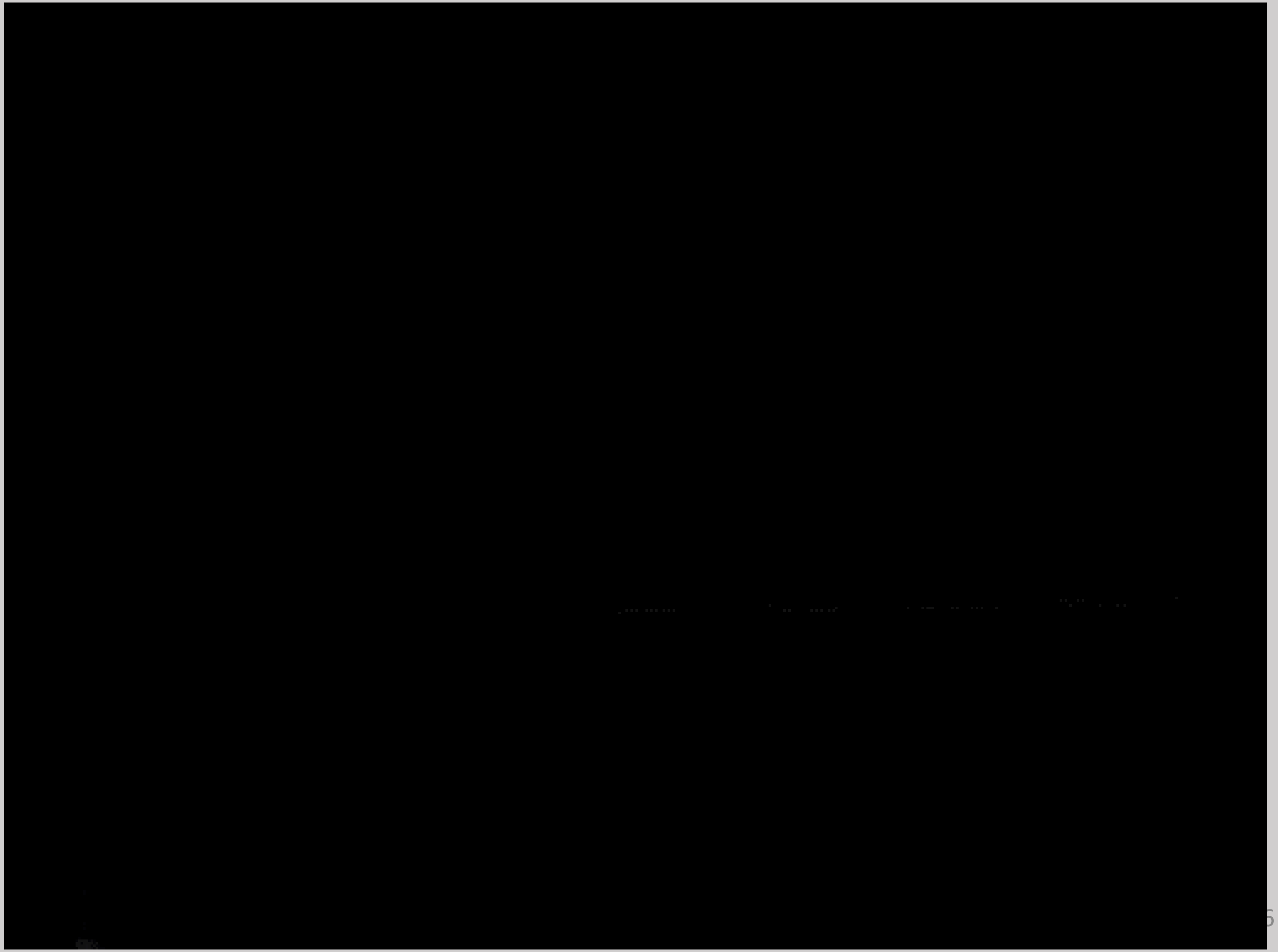
Specimen 1
6kA, 40 cycles, 7.4 cal/cm^2

Livefront Transformers Equipment

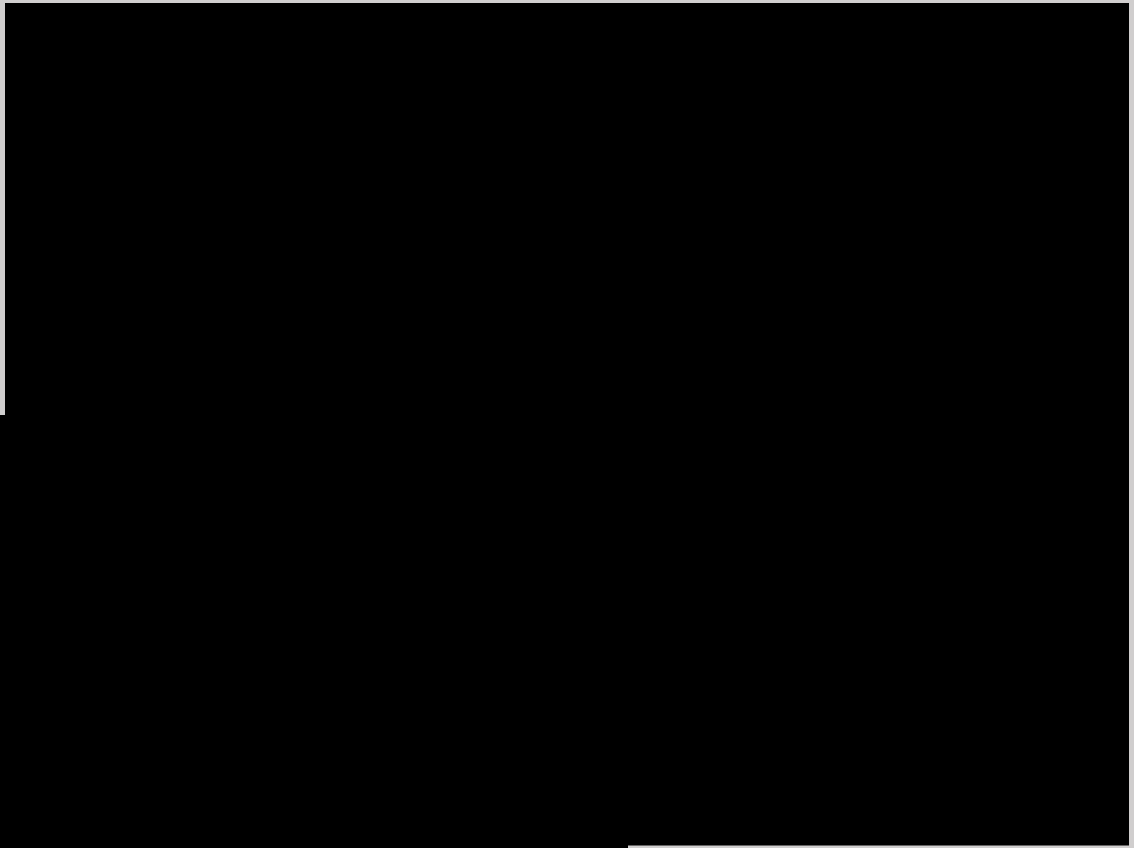
Specimen 2
6kA, 40 cycles, 6.7 cal/cm^2

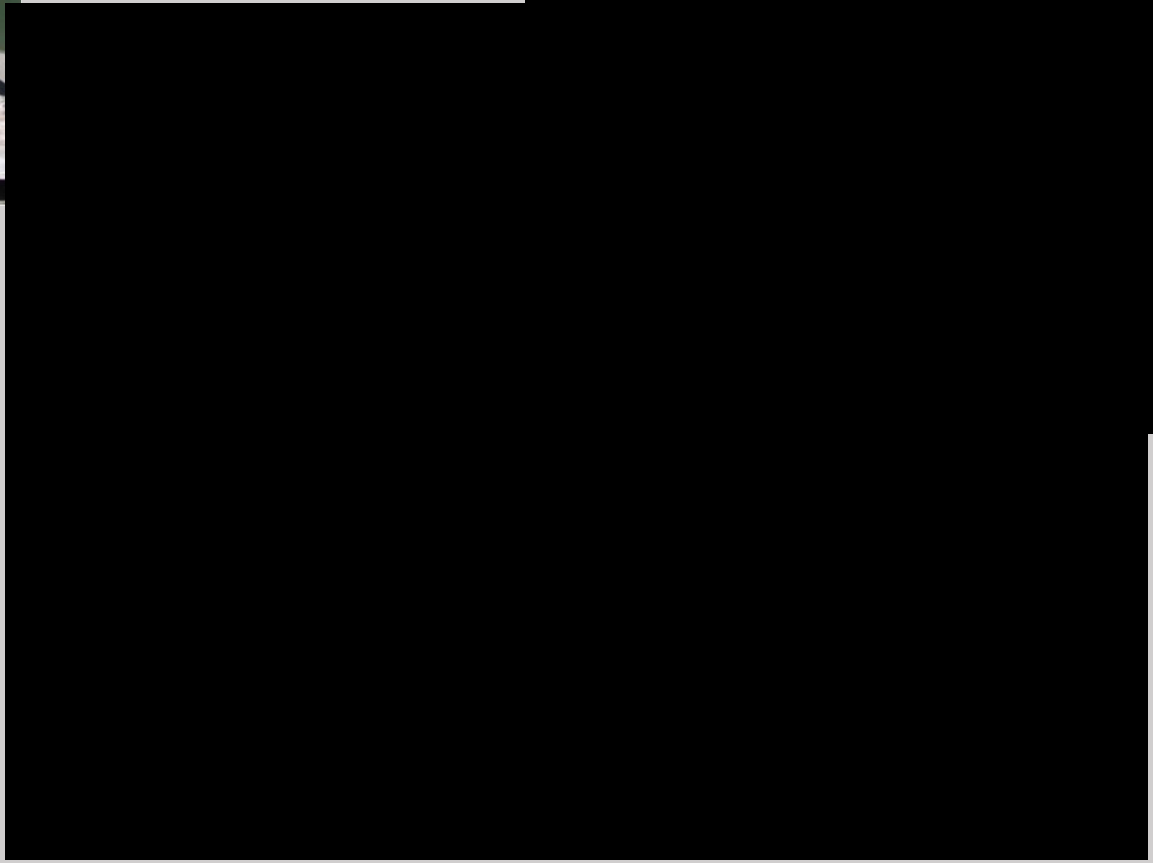
Livefront Transformers Equipment

Specimen 3
4kA, 40 cycles, 5.6 cal/cm^2



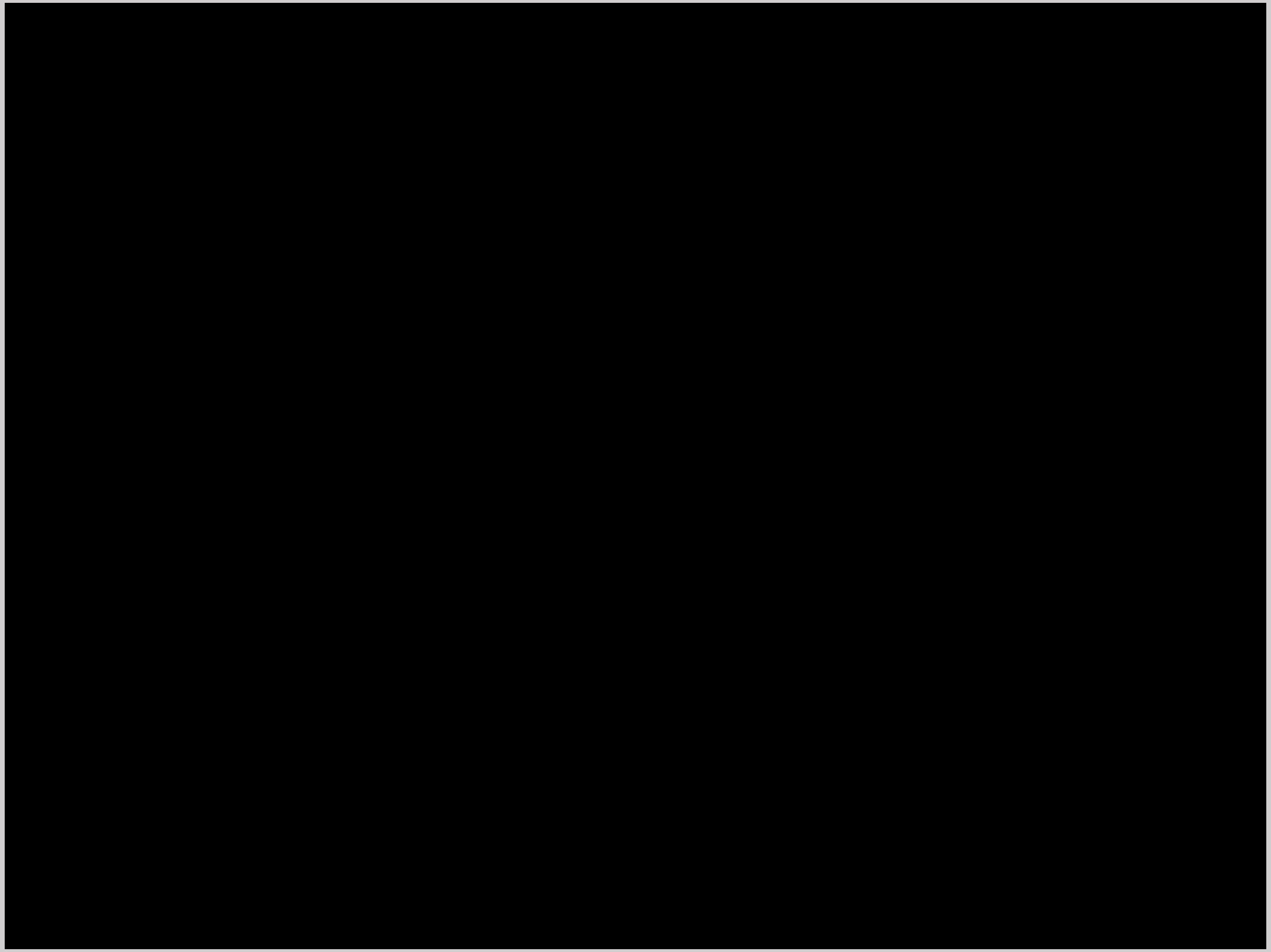
Livefront Transformers





Specimen 4
2kA, 20 cycles, 1.9 cal/cm^2
4kA, 60 cycles, 12.6 cal/cm^2

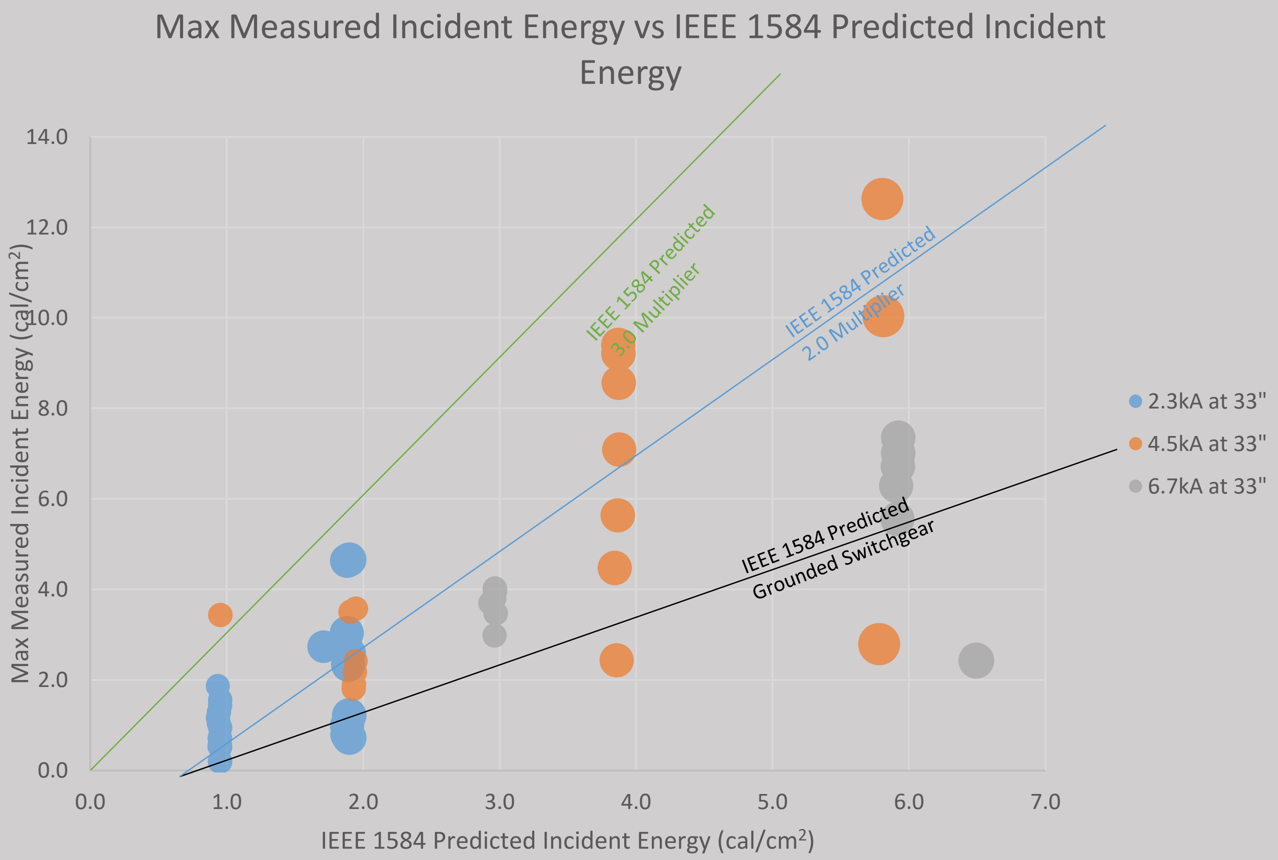
Livefront Transformers Equipment



Specimen 5
3kA, 40 cycles, 9.2 cal/cm^2

Livefront Transformers

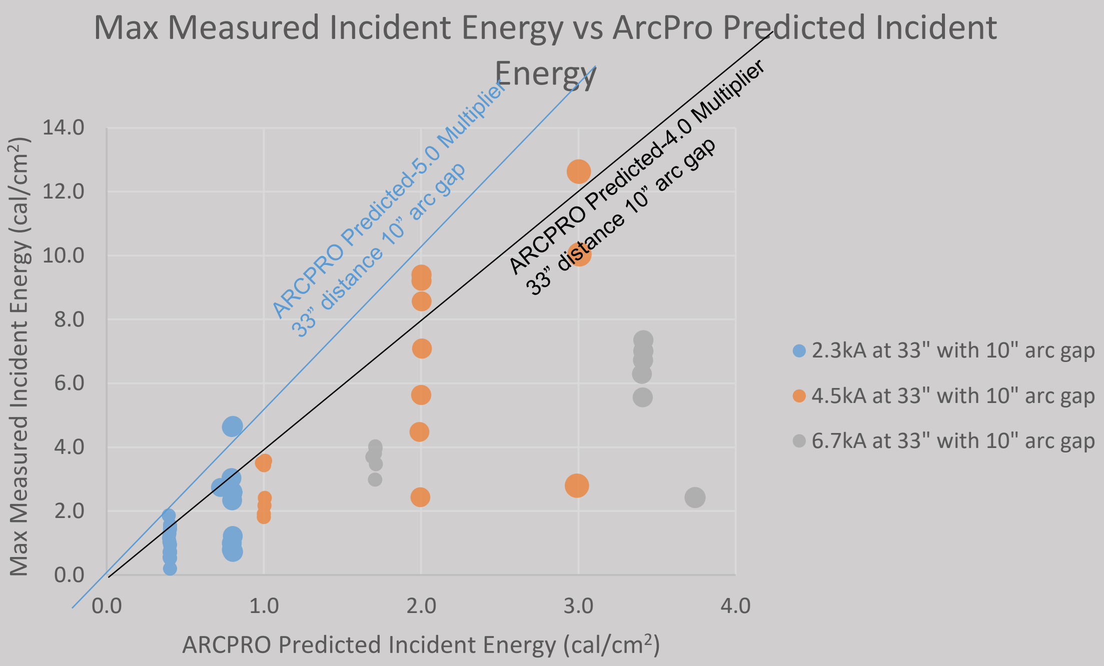
IEEE 1584 Predicted vs Measured Incident Energy



Note 1: Bubble size reflects arc durations 20, 40, 60 cycles respectively.

Livefront Transformers

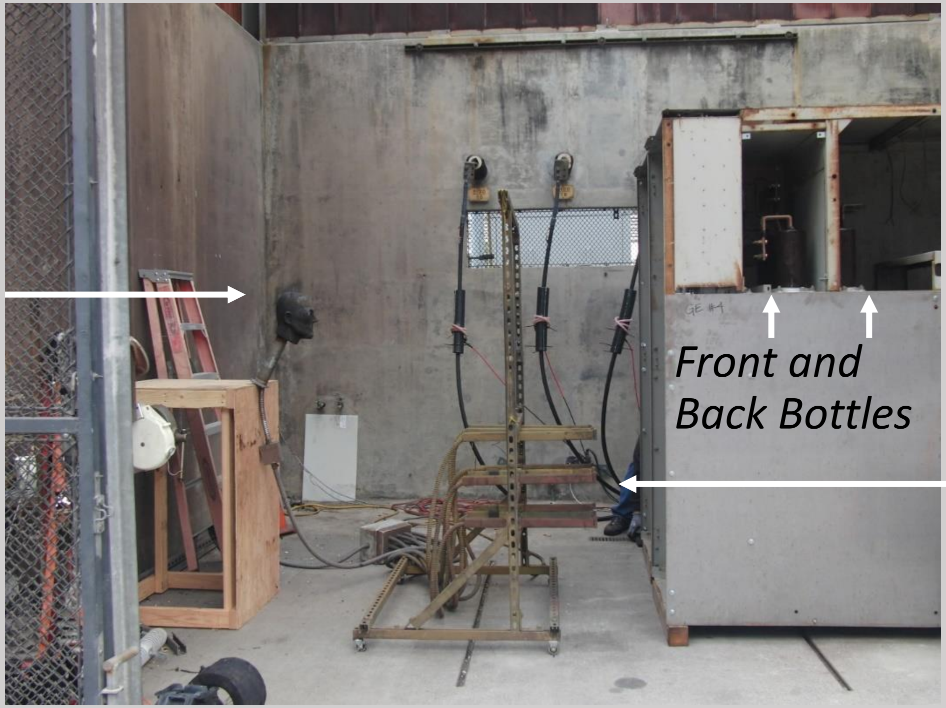
ARCPRO Predicted vs Measured Incident Energy



Note 1: Bubble size reflects arc durations 20, 40, 60 cycles respectively.

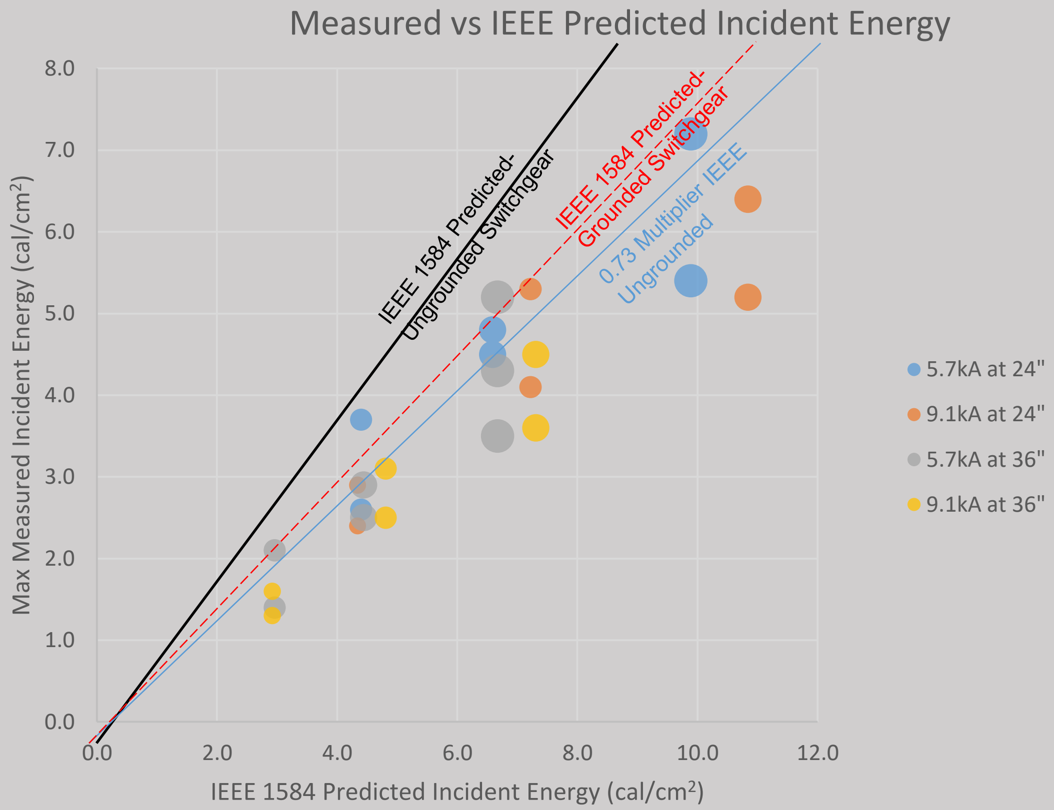
Rack-up Style Switchgear

Calorimeter Array and Sensor Head Positioned in Front of Right Side Cubicle



Rack-up Style Switchgear - No Breaker

IEEE 1584 Predicted vs Measured Incident Energy



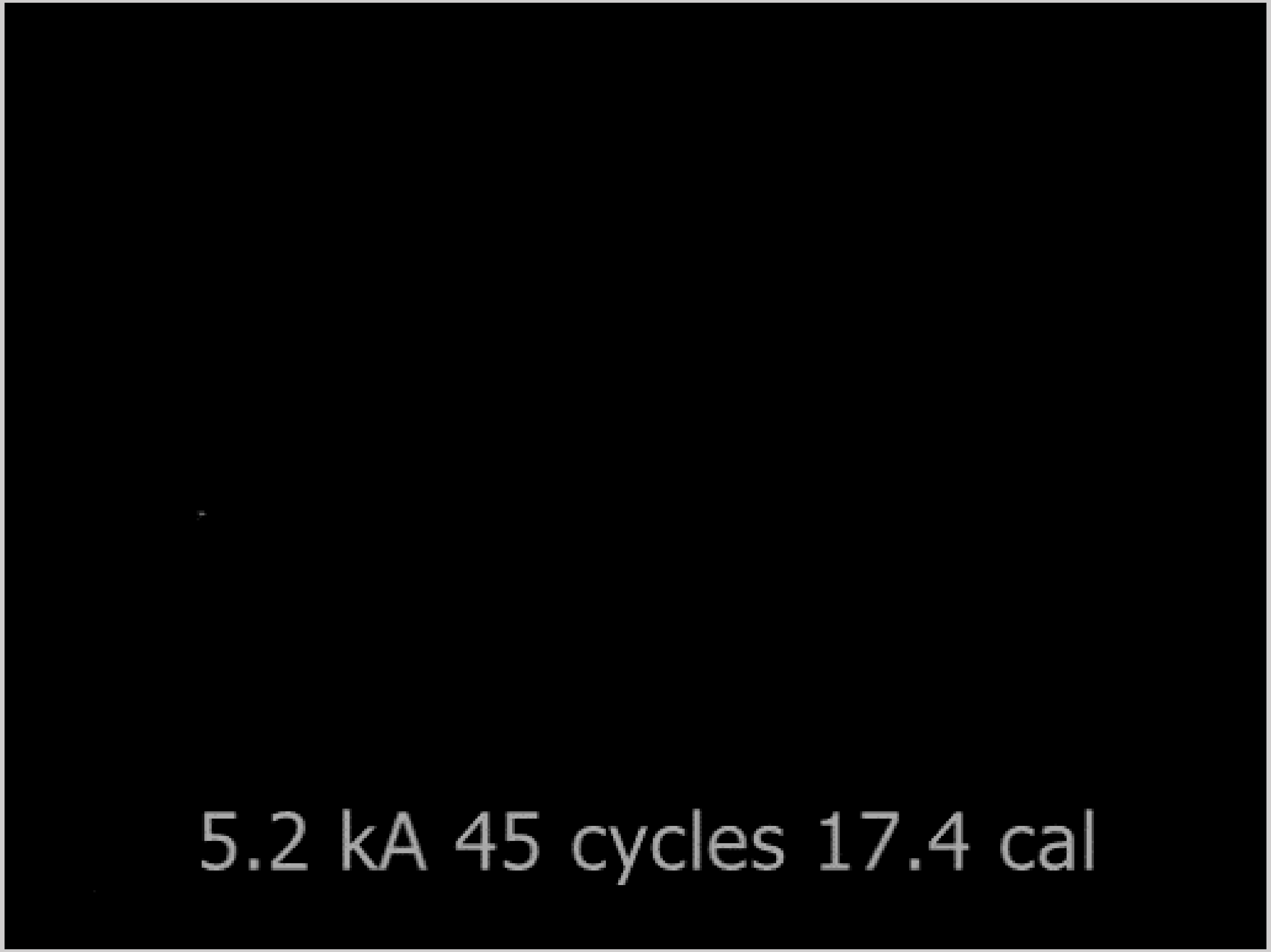
Note 1: Bubble size reflects arc durations of 12, 20, 30, 45 cycles respectively.

Rack-in Style Switchgear

Rack-in Style Switchgear Cubicle - Shutter Removed

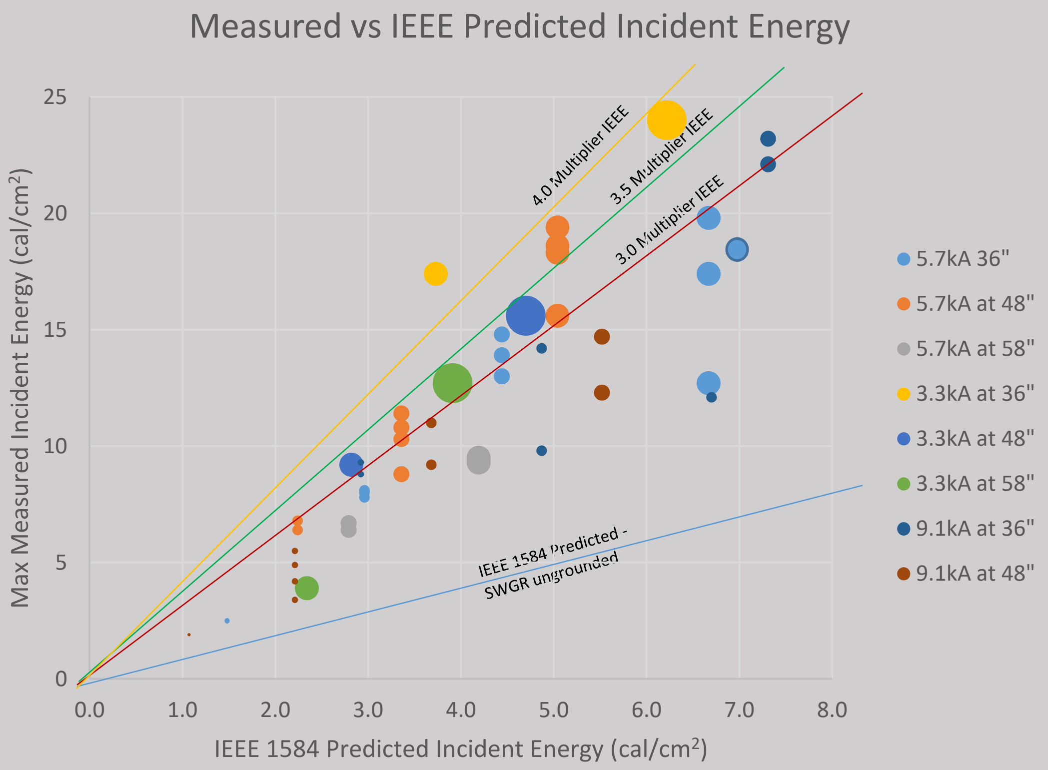
Line Side
Primary
Stationary
Contacts

Horizontal Electrode Switchgear 12kV



Rack-in Style Switchgear - No Breaker

IEEE 1584 Predicted vs Measured Incident Energy



Note 1: Bubble size reflects arc durations of 5.8, 10, 12, 20, 30, 45, 75 cycles respectively.
Note 2: Excludes Test ID's 27,28,29,30, and 134 which were artificially low because of overused CT's and misplaced calorimeters. See notes a and d of Table 2-2

Conclusions/Questions

- Incident Energy is equipment DEPENDENT
- MUST keep abreast of most recent test data
- Questions

QUESTIONS