Distribution Arc Flash

480-V Padmounted Transformers and Network Protectors

1020210

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Technical Update, August 2009

EPRI Project Manager

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This document describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner:

Distribution Arc Flash: 480-V Padmounted Transformers and Network Protectors. EPRI, Palo Alto, CA: 2009. 1020210.

PRODUCT DESCRIPTION

Arc flash from faults on 480-V circuits is a safety issue that can impact utility work. This report covers results from tests of arc flash and fabric performance from faults in 480-V network protectors and padmounted transformers. It supplements EPRI report 1018694, *Distribution Arc Flash: Industry Practices* and EPRI report 1018693, *Distribution Arc Flash: Analysis Methods and Arc Characteristics.*

Results and Findings

The main results of the 480-V testing are:

- *Network protectors* – For many of the fault configurations, arcs did not self-clear, causing high incident energies with a large fireball in front of the enclosure. Measurements were generally 30 to 75% of IEEE 1584 predictions. The fireball from a network protector failure is less focused than that found from previous tests on 480-V self-contained meters.
- *Padmounted transformers* – In 35 tests in the secondary compartment of a 480-V padmounted transformer, no sustained arcing occurred. Incident energies were significantly less than the 20 cal/cm^2 required in the consensus change proposal for the 2012 National Electrical Safety Code.
- *Clothing* – Fabrics were tested in conjunction with the network protector testing. Many of the fabrics under-performed relative to their ATPV rating.

Challenges and Objectives

A main objective of the testing was to evaluate incident energies from failures in different utility equipment. In the process, the performance of flame-resistant fabrics was also evaluated. The main challenge was finding configurations for realistic failures.

Applications, Values, and Use

The main use of these results is to help utilities select protective clothing and determine work practices for 480-V work. The test results generally support using single-layer flame-resistant clothing for padmounted transformers and current transformer (CT)-type meters, double-layer clothing for self-contained meters and small panels, and flash suits for large panels and network protectors.

EPRI Perspective

The report provides test results that should help utilities better analyze arc flash hazards. Future work is needed to better assess the performance of clothing in arc-flash scenarios.

Approach

The project team initiated faults in 480-V network protectors and padmounted transformers at PG&E's San Ramon test facility to establish whether arcs could sustain in network protectors and to determine incident energies and heat rates for various configurations. During the testing, the team also assessed the performance of protective clothing.

Keywords
Arc flash
Power distribution
Overcurrent protection
Short circuits
Faults
Arcs

EXECUTIVE SUMMARY

This report summarizes findings of tests on 480-V network protectors and padmounted transformers. This report supplements the research published as follows:

Distribution Arc Flash: Industry Practices. EPRI, Palo Alto, CA: 2009. 1018694.

Distribution Arc Flash: Analysis Methods and Arc Characteristics. EPRI, Palo Alto, CA: 2009. 1018693.

Tests of a 480-V network protector found that although some faults did not sustain, sustainable arcs are certainly possible in network protectors. Micarda dividers were not effective at containing the fireball from the arc. IEEE 1584 overpredicted incident energies for network protector faults; measurements were generally 30 to 75% of the default IEEE 1584 predictions. The fireball from a network protector failure is less focused than that found from previous tests on 480-V self-contained meters. For a given arc energy, a single point in front of the equipment may see less energy, but the fireball covers a larger area. Because arcs did not self-clear, incident energies were high, creating a large fireball in front of the enclosure (Figure ES-1).

Figure ES-1
Example 480-V Network Protector Event

Fabrics were tested in conjunction with the network protector testing. Many of the fabrics under-performed relative to their ATPV rating. Of the 20 tests where the fabric was subjected to between 30% and 100% of its ATPV rating, 75% let through more than 1.2 cal/cm^2, the value NFPA 70E cites as the threshold for a second-degree burn. This suggests the need for more fabric tests and possibly an improved industry test method.

Out of 35 tests in the secondary compartment of a 480-V padmounted transformer, we found no cases of sustained arcing. Most arcs self-extinguished in less than 2.5 cycles with a maximum of

12 cycles (see Figure ES-2). Incident energies were mostly less than 1 cal/cm^2 with the highest at 4.0 cal/cm^2. This is significantly less than the 20 cal/cm^2 required in the consensus change proposal for the 2012 NESC.

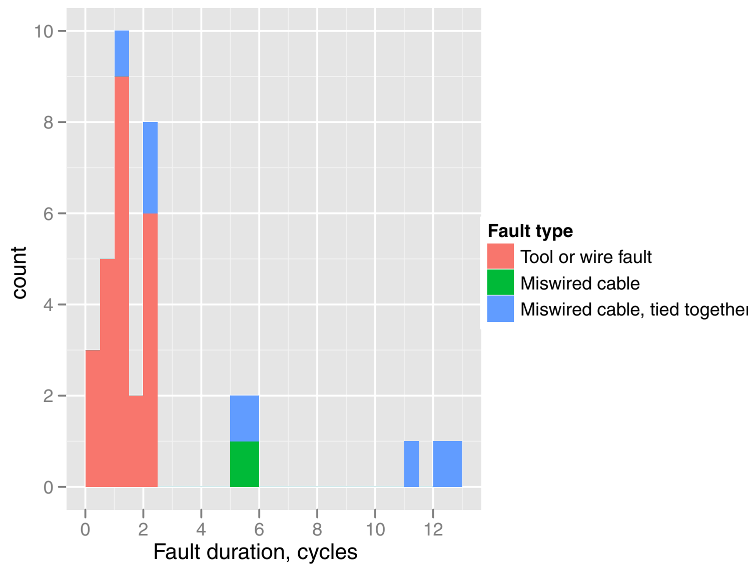


Figure ES-2
Fault Duration Histogram

Based on this work and previous testing, the following flame-resistant (FR) protection is generally suitable for 480-V equipment:

- *Padmounted transformers and CT-type meters* – single-layer FR clothing
  Faults self-clear quickly.
- *Self-contained meters and small panels* – double layer FR
  Faults self clear, but incident energies can reach 25 cal/cm^2 at 18 in. Incident energy drops at higher fault currents.
- *Network protectors and large panels* – flash suit
  Faults may not self clear. Incident energies increase with fault current, and depending on fault currents and clearing times, incident energies can easily exceed 50 or even 100 cal/cm^2.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1

NETWORK PROTECTORS

This section describes 480-V arc flash testing results in network protectors performed during the week of March 9, 2009 at PG&E's San Ramon test facility. Network protectors are of significant interest for utilities with 480-V secondary networks because available fault currents often exceed 50 kA with long clearing times, and network customers expect high reliability, so deenergizing to perform work is difficult. Network equipment is not included in the consensus change proposal developed by NESC subcommittee 8 for the 2012 edition of the NESC. That means a study must be performed. The main goals of the testing were to establish whether arcs could sustain in network protectors and to determine incident energies and heat rates for various configurations.

Test Setup

Figure 1-1 shows the network protector used during tests. The internal operating mechanisms have been stripped from the unit. The unit is energized from the top, which is the network side of the unit. A common work procedure is removing the fuses on the network feed. Bus bars from the top were included in the box as shown in Figure 1-2.

The unit is fed by PG&E's 480-V source that's capable of supplying a bolted fault current of 44 kA (later upgraded to 52 kA).

Figure 1-1
Network Protector Test Setup

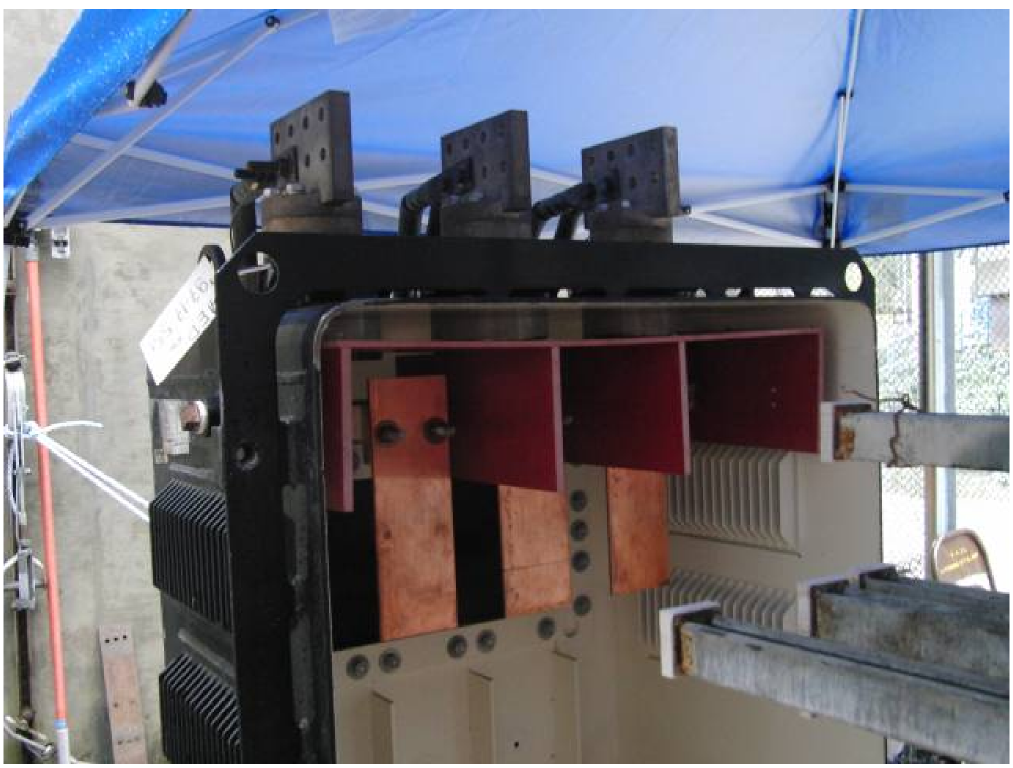
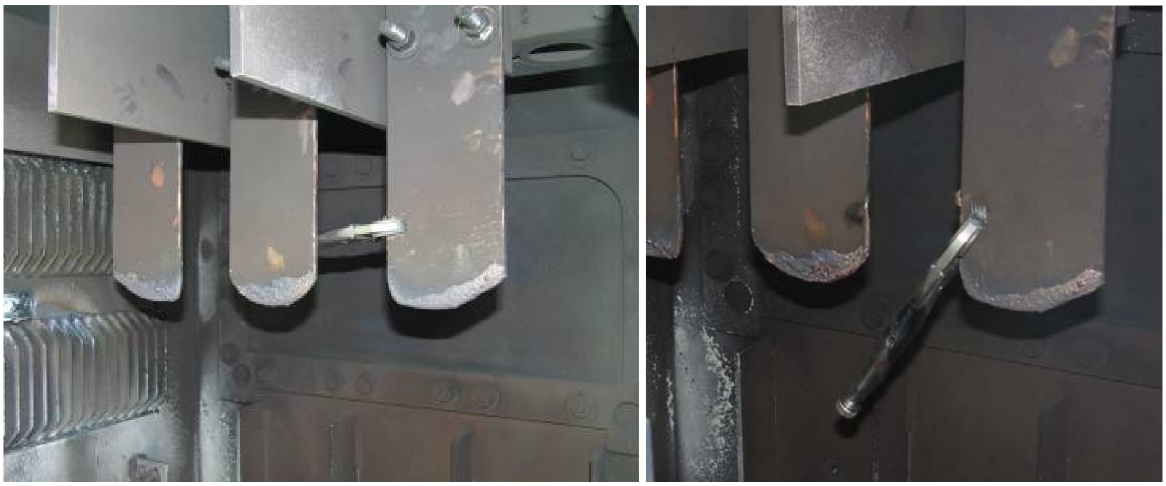


Figure 1-2
Initial Box Configuration

Fault Events

Fault events were normally initiated with a #12 copper wire connected between bus bars. Vice grips were also used to initiate faults. With the initial wide-open box configuration, faults self extinguished. Figure 1-3 shows an example of a fault initiated by a set of vice grips that cleared in one half cycle (see Figure 1-4). With the wide open spacings, arcs self extinguish. The magnetic forces push the arc towards the bottom of the enclosure, and the arc balloons out in the process, reaching a length where the fault cannot sustain.



Prior to test After test

Event 254

Figure 1-3
Example Fault with a Tool Wedged between Phases

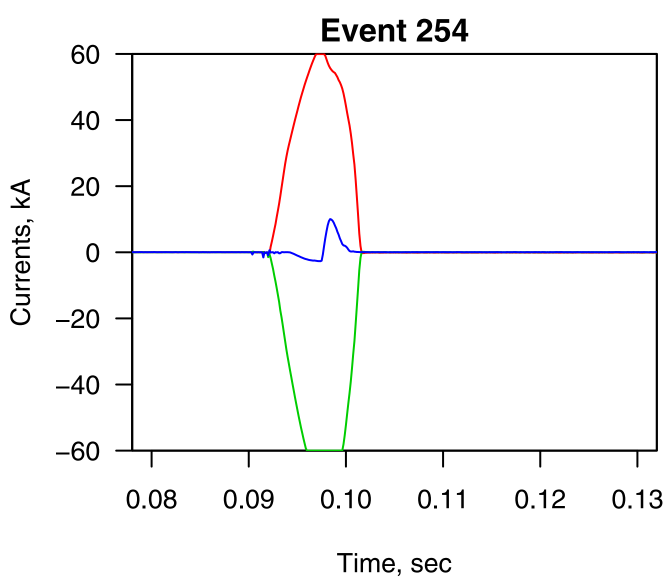


Figure 1-4
Current Waveforms for a Wrench Test

In order to assess how confinement impacts arc sustainability, a metal ground plane was added behind and below the bus bars as shown in Figure 1-5. In this configuration, faults were able to sustain and did not clear until PG&E's circuit breaker tripped. Figure 1-6 shows the fireball from a test with a ground plane.

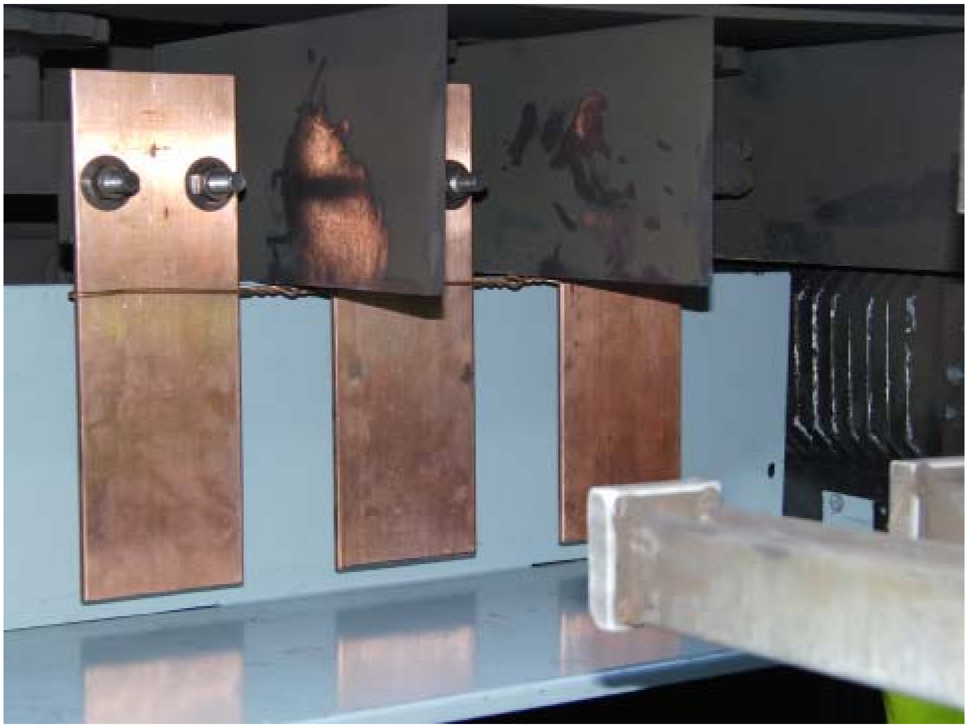
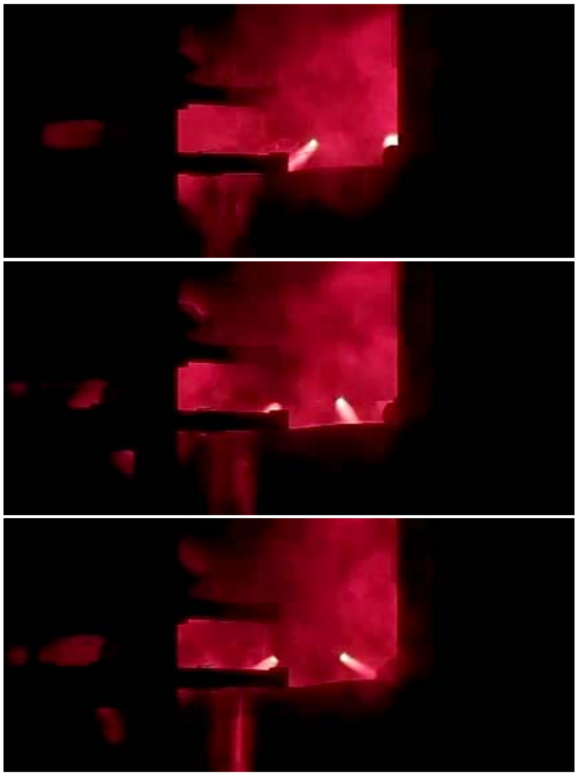


Figure 1-5
Configuration with a Conducting Plate Behind and Below the Bus Bars

Figure 1-6
Example 480-V Network Protector Event

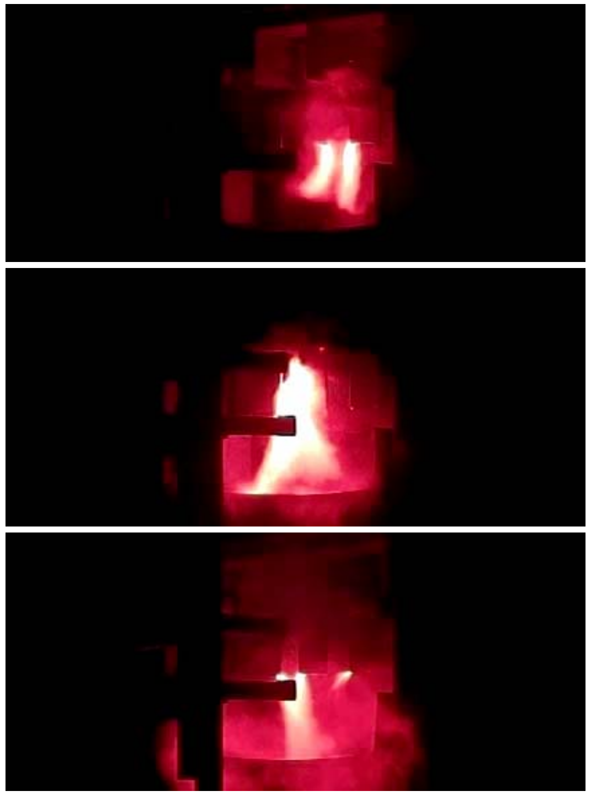
Figure 1-7 shows an event captured through an infrared-passing filter that shows how the arc shoots off the end of the bus bars. Arcs were sustainable for spacings between the bus bars and the lower ground plane of two, four, and six inches. At a ten-inch gap, the arc was not sustainable (Figure 1-8 and Figure 1-9). The back plate was not conducting in these cases.



Event 258

Figure 1-7
600-fps Camera Snapshots through an Infrared-Passing Filter

Figure 1-8
Wider Spacings between Busbars and the Ground Plane (Event 270)

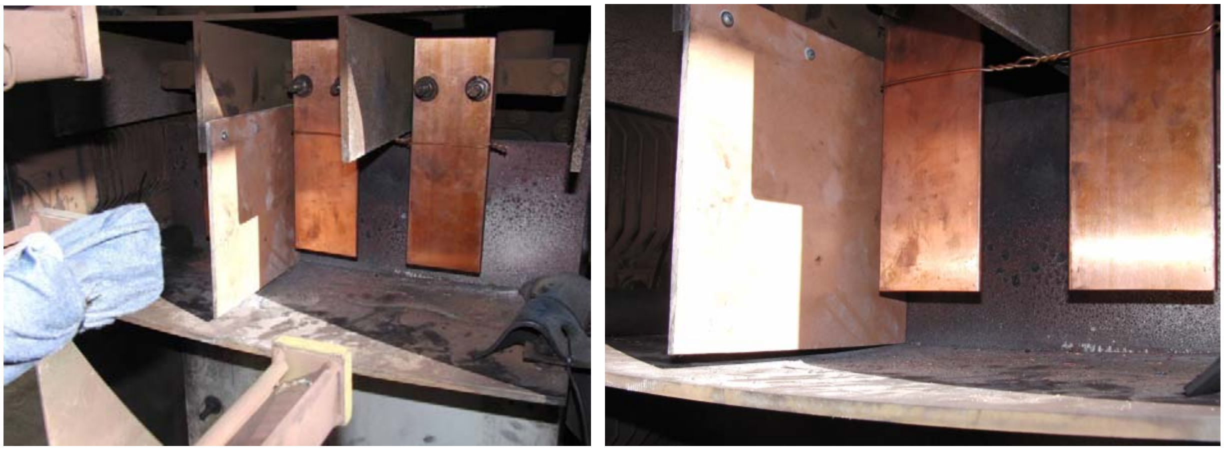


Event 270

Figure 1-9
600-fps Camera Snapshots through an Infrared-Passing Filter with 10-in Spacing to the Ground Plane

Micarda Dividers

Network protectors normally have micarda dividers that separate bus bars. We wanted to see if these dividers would help prevent an arc from propagating to additional phases. Figure 1-10 shows a test setup with a micarda divider separating one bus bar from the other two bus bars faulted with a #12 copper wire. Figure 1-10 shows that even with the micarda divider, the fault escalated to phase C in less than one half cycle. With a reduced gap between the micarda divider and the ground plane, the fault still escalated quickly (Figure 1-11 and Figure 1-12).



Event 265

Figure 1-10
Test Configuration with a Micarda Barrier Separating Two Faulted Bus Bars from an Unfaulted Bus Bar

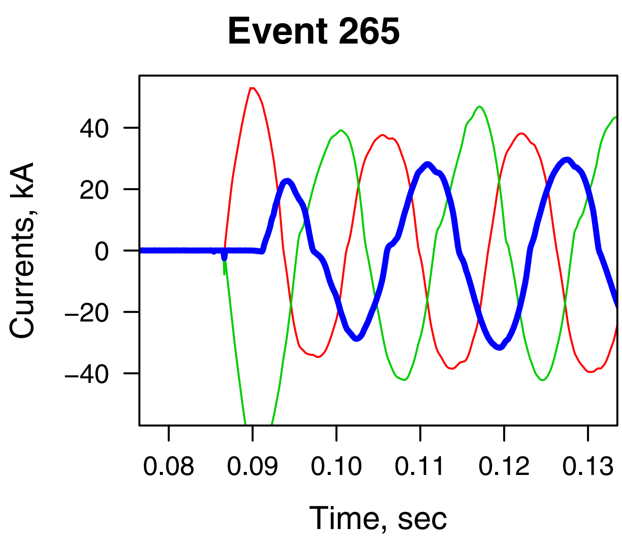


Figure 1-11
Current Waveforms for a Micarda Barrier Test

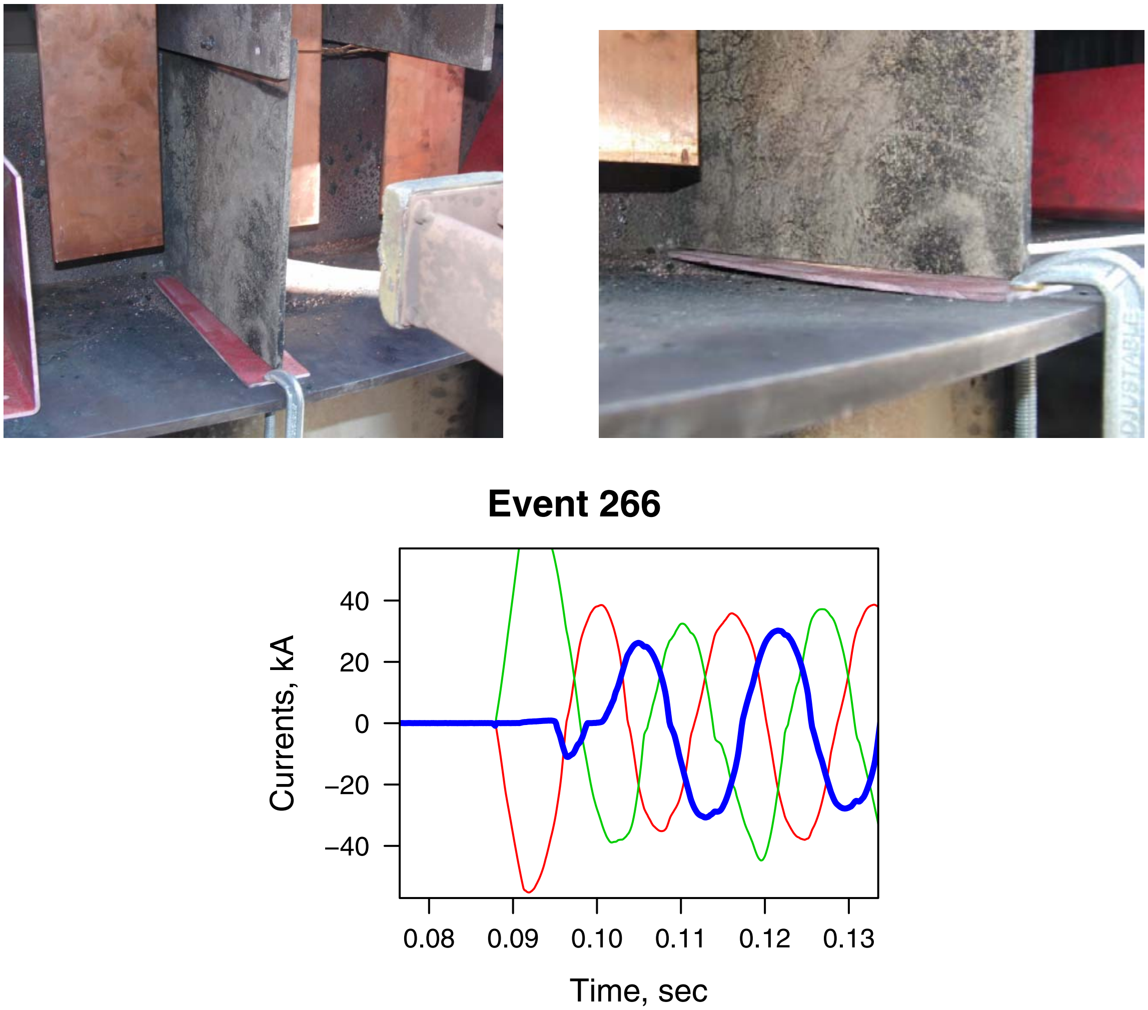


Figure 1-12
Another Micarda Barrier Test

Analysis

This section documents many of the calorimeter incident-energy readings obtained during the network protector tests. Unless otherwise stated, these incident energies were measured 18 in from the arc initiation point. Figure 1-13 shows how incident energy varied with duration. For the cases with a bolted fault current of 44 kA, the incident energy was reasonably linear. Figure 1-14 shows the relationship between arc energy and incident energy, and it is reasonably linear across fault current ranges. Figure 1-15 shows that the ratio between arc energy and incident energy is not strongly duration dependent, meaning that the incident energy is directly related to arc energy without an extra effect caused by duration. Figure 1-16 shows that arc power and incident heat rate also track linearly. These graphs support two basic assumptions used in IEEE 1584 and other analysis: (1) incident energy increases linearly with fault duration, and (2) incident energy is linearly related to arc energy.

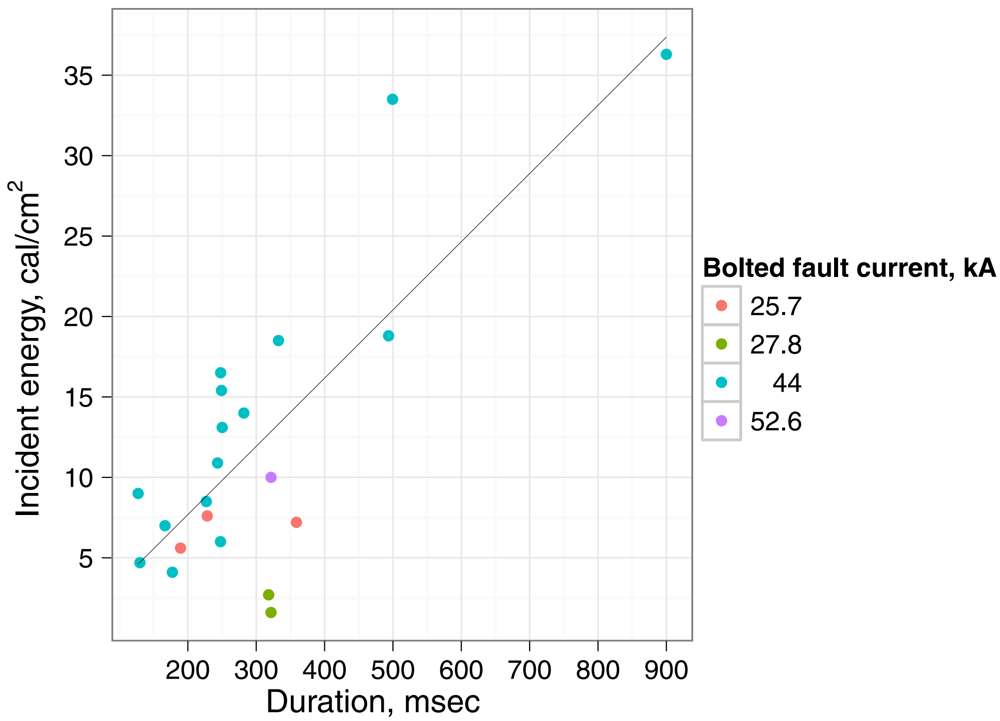


Figure 1-13
Relationship between Duration and Incident Energy

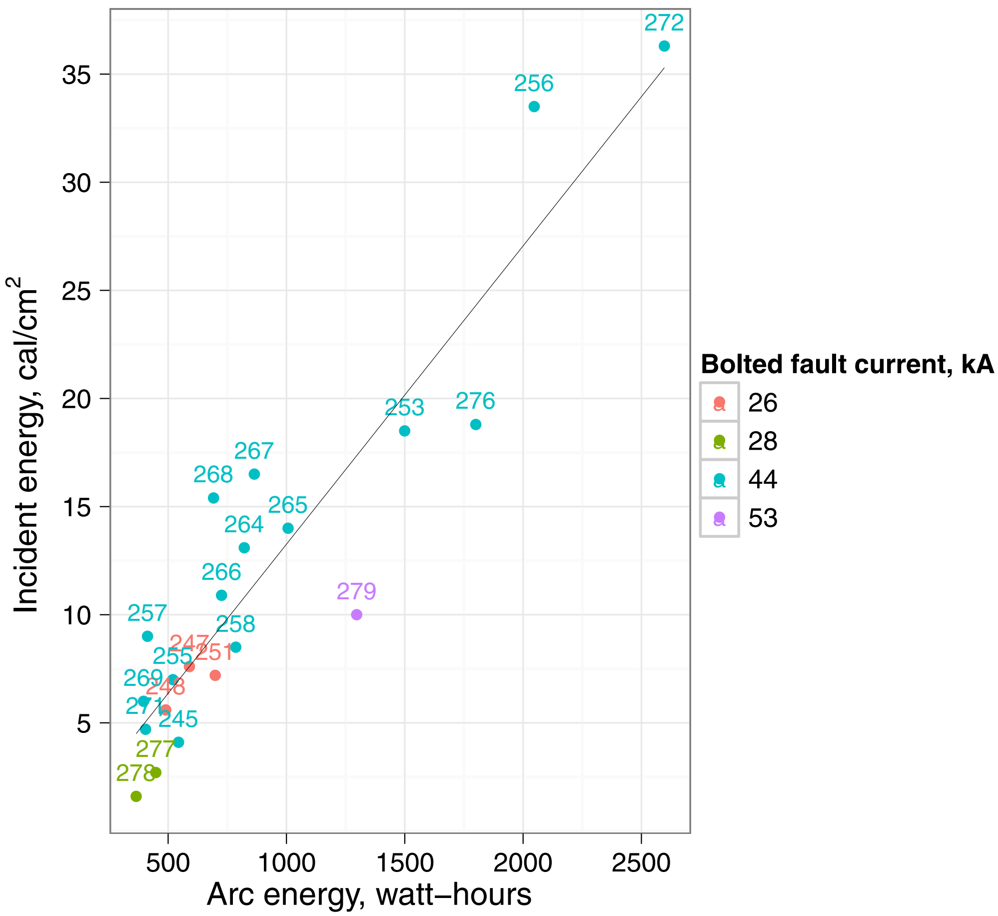


Figure 1-14
Comparison of the Incident Energy to the Arc Energy

Specific test comments:

- 245: The test did not have the plate behind the buswork (only below), possibly allowing more of the blast to go down the enclosure rather than out the front.
- 256: The shelf below the bus bars blew out; the maximum readings were on the bottom calorimeters which was unusual.
- 257: Arc power was underestimated some because the middle-phase voltage was lost for two out of seven cycles.
- 267 & 268: Configuration had a larger bus gap: 4" and 6", so the plasma may have been directed differently.
- 272: Arc energy was underestimated by about 10% because not the whole waveform was captured.

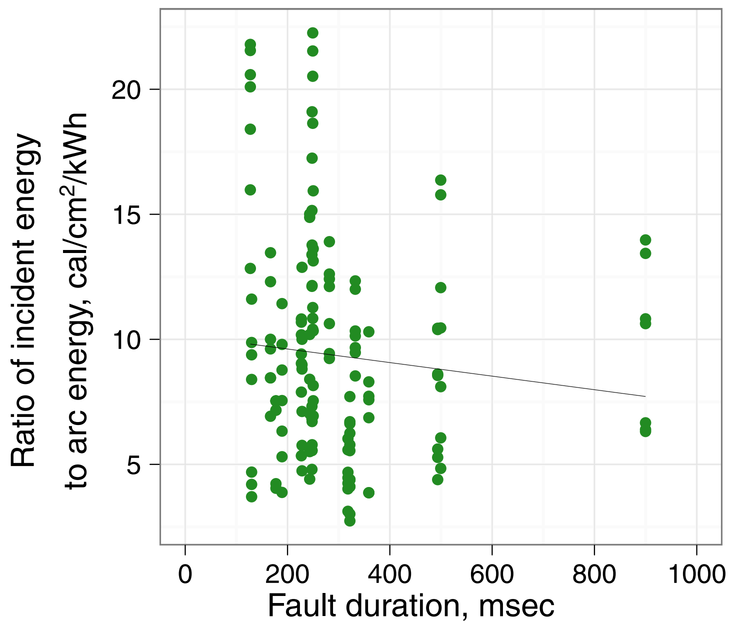


Figure 1-15
Energy Transfer Ratio as a Function of Fault Duration

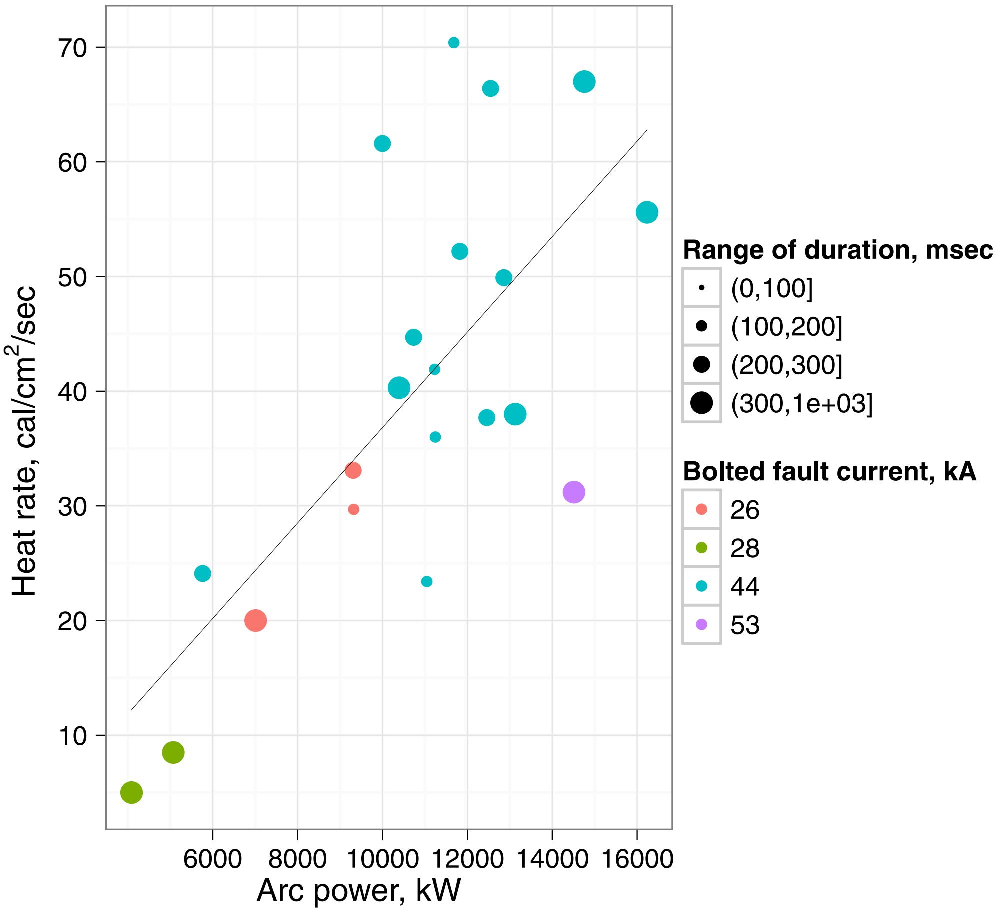


Figure 1-16
Relationship between Arc Power and Incident Heat Rate

In many tests, calorimeter measurements were taken at different distances as shown in Figure 1-17 with the closest calorimeters at 18 in and the back calorimeters at 24 in from the arc initiation point. The measurements at each location track closely as shown in Figure 1-18. The slope of the linear fit to Figure 1-18 is 0.52, which equates to a distance factor of 2.3. This is higher than the distance factor of 1.473 used in IEEE 1584 for low-voltage switchgear. Note that in this configuration, the front calorimeters are located such that they may have shielded the back calorimeters. This shielding may have reduced the energy to the back calorimeters enough to produce an artificially high distance factor.

Figure 1-17
Calorimeter Arrangement

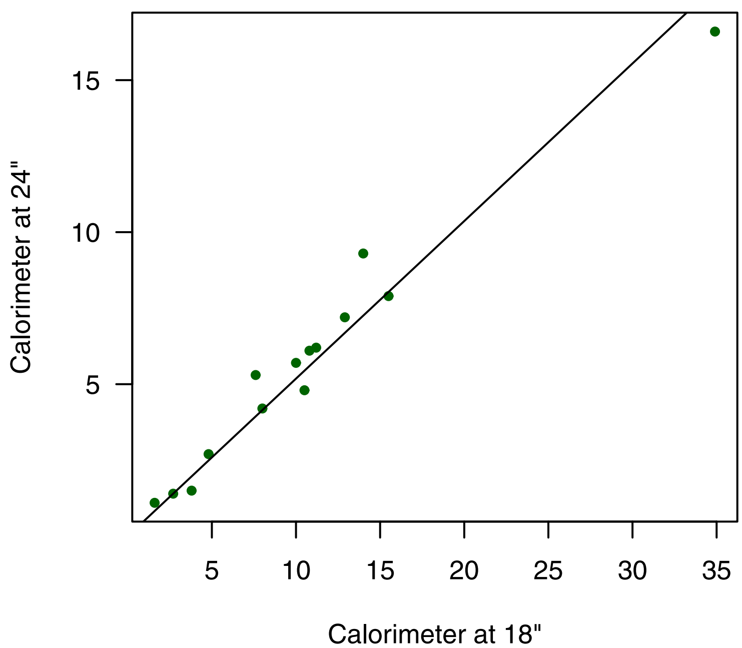


Figure 1-18
Incident Energies Measured at Different Distances

Figure 1-19 shows two different evaluations of the IEEE 1584 incident energy estimates and the network protector test results. The y-axis values are the measured incident energies. The x-axis values come from IEEE 1584 estimates using the duration and currents from the test. The differences are as follows:

- Comparison A – Meant to replicate the test more precisely – Actual fault current for each test is used along with the network protector bus bar gap of 2.5 in.

- Comparison B – Meant to replicate the default IEEE 1584 calculation – Bolted available fault currents are used along with the default gap distance of 1.25 in specified in IEEE 1584 for low-voltage switchgear.

Both comparisons show that IEEE 1584 generally overpredicts incident energies. Measurements are generally 30 to 75% of the IEEE 1584 prediction.

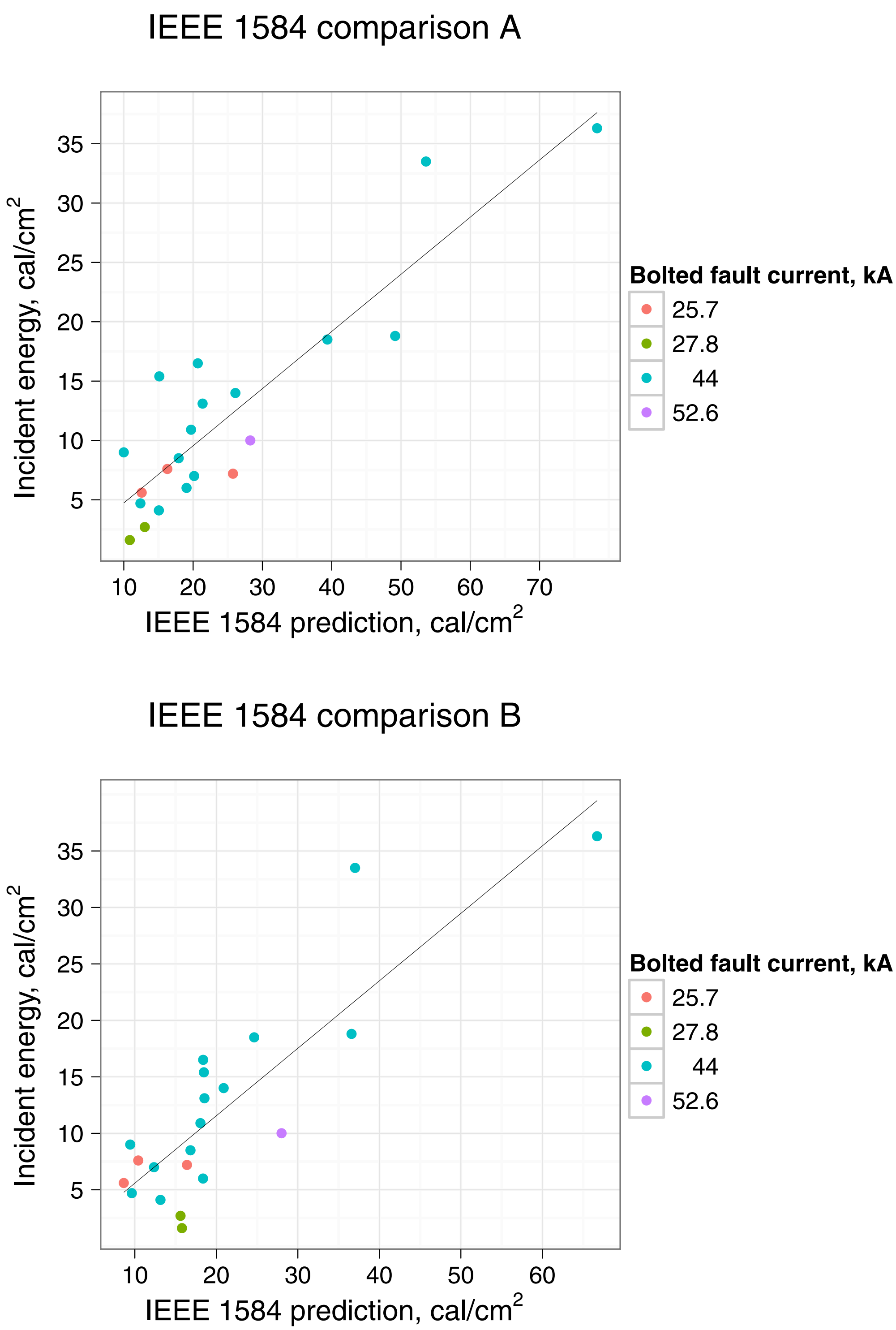


Figure 1-19
Comparison of IEEE 1584 predications with test results (A: gap=2.5", actual arcing current, B: gap=1.25", using bolted fault current)

Figure 1-20 compares the network protector test results to other 480-V equipment that PG&E has tested (see *Distribution Arc Flash: Analysis Methods and Arc Characteristics.* EPRI, Palo Alto, CA: 2009. 1018693.) This graph shows how much of the energy is transmitted from the arc to the measuring calorimeter. Differences include:

- *Self-clearing* – Faults in meters and small panels will self extinguish. Faults in large panels and network protectors may not.
- *Energy focusing* – The small meter housing focuses the arc energy straight out of the box in a relatively tight pattern. The larger network protector enclosure has less of a focusing effect, but the incident energy impacts a much wider area. Figure 1-21 compares two typical events.
- *Fault current* – For meters and small panels, incident energy decreases with higher fault current because the faults self extinguish faster. For network protectors and large panel boards, the incident energy increases with higher fault current because the faults may not self clear.

The shape of the enclosure and the magnetic fields determine how the arc energy is released.

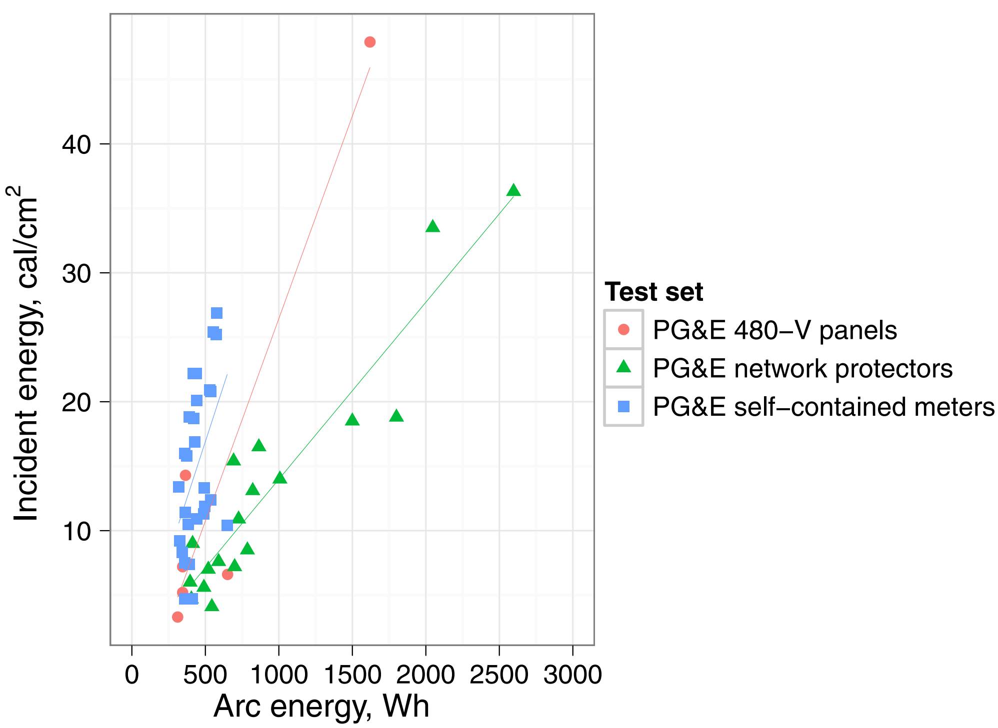


Figure 1-20
Comparisons for Network Protectors

Figure 1-21
Comparison of a Meter Arc Flash and a Network Protector Arc Flash

Network Protector Summary

The main findings of the network protector tests are as follows:

- Although some faults did not sustain, we think that sustainable arcs are certainly possible in network protectors.
- The calorimeter incident energy is linear with arc energy.
- The heat rate stays the same with fault duration (you double the duration, the incident energy doubles).
- Micarda dividers are not effective at containing the fireball from the arc.
- Measurements were generally 30 to 75% of the default IEEE 1584 prediction.
- The fireball from a network protector failure is less focused than the meters. For a given arc energy, a single point in front of the equipment may see less energy, but the fireball covers a larger area.

One question to consider is how representative the tested fault scenarios are to real-life operation. Our test enclosure had the network protector innards removed. We think that the innards may change how the fireball propagates, but overall, we don’t think it will change findings significantly. The innards will fill up more airspace and make sustainable arcs more likely as faults were more sustainable in confined areas.

2
PADMOUNTED TRANSFORMERS

This section presents results from 480-V arc flash testing in a padmounted transformer enclosure at PG&E's San Ramon test facility during the week of May 25, 2009.

Background

The 480-V secondary compartment in padmounted transformers (see Figure 2-1) is of particular interest because this is common utility equipment that is regularly worked live, and fault currents can be high.

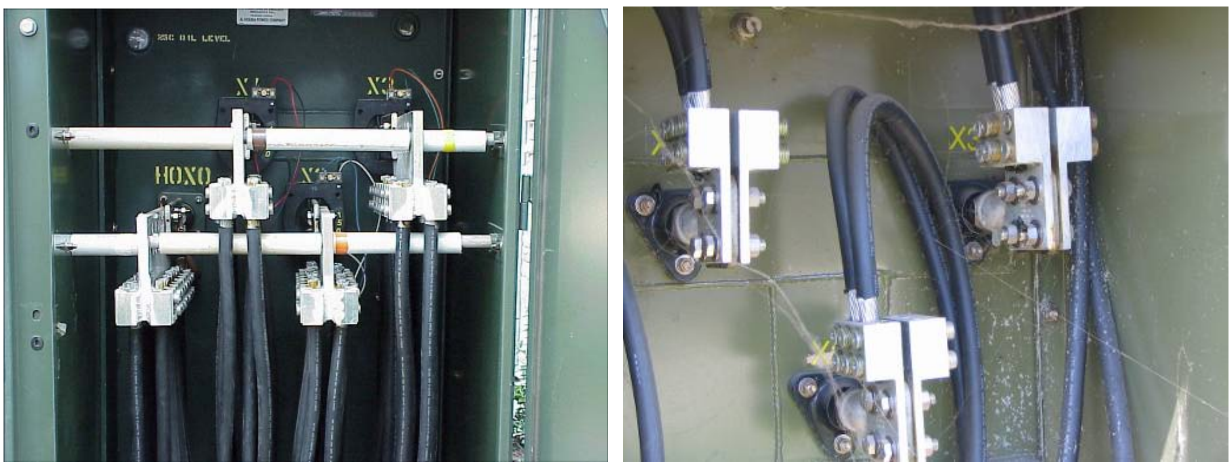


Figure 2-1
480-V Padmounted Transformer Secondary Configurations

Table 2-1 shows the average available fault current for different size three-phase transformers for one utility. There is a discontinuity between 500 and 750 kVA as IEEE standards require higher impedance for units 750 kVA and larger. The incident energy is a function of the fault current and duration. Table 2-2 shows an analysis performed by one utility using both the bolted fault current and their estimate of minimum fault current. They used IEEE 1584 for calculations, and they assumed a clearing time of 1.5 sec for minimum faults and the fuse clearing time for bolted faults.

Table 2-1
Average Bolted Fault Currents for One Utility's 480-V Padmounted Transformers

Transformer kVA	Percent impedance	Fault current kA
150	2.1	8.6
300	2.0	20.1
500	2.7	25.3
750	5.5	16.3
1000	5.6	21.5
1500	5.6	32.1
2000	6.0	40.4
2500	5.5	54.4

Table 2-2
Another Utility's 480-V Padmounted Transformer Arc Flash Calculation

Transformer kVA	Fault type	Bolted fault current kA	Duration, sec	IEEE 1584 estimate of cal/cm^2 at 15 in
500	max	26.7	0.311	21.9
500	min	2.6	1.5	12.3
1000	max	28.3	0.142	10.5
1000	min	8.1	1.5	35.2
2000	max	56.6	0.086	12.0
2000	min	12.1	1.5	50.8

NESC subcommittee 8 established a Low Voltage Arc Flash Work Group to evaluate the necessary minimum clothing or clothing system requirements for employees working on energized lines and parts operating at voltages less than 1000 V. The working group draft consensus change proposal for the 2012 NESC is shown in Table 2-3.

The change in the requirements below 1000 V requires 20-cal/cm^2 FR clothing in lieu of a study. One of the main purposes of the padmounted-transformer tests is to evaluate that requirement.

Table 2-3
Consensus Proposal from NESC Subcommittee 8 for a Table Addressing Low-Voltage Analysis

Table 410-1: Clothing and Clothing Systems (per cm^2) for voltages 50 to 1000 V (AC)[1] (See Rule 410A3)

	Nominal Voltage Range and Calories/Cm^2		
Equipment Type	*50 – 250 V*	*251 – 500 V*	*501 – 1000 V*
Self-contained meters / Pad-mounted transformers / Panels and Cabinets	4[2]	20[4]	30[8]
CT meters and control wiring	4[2]	4[5]	6[8]
Metal-clad Switchgear / Motor Control Centers	8[3]	40[6]	60[8]
Subsurface / Pedestal-mounted equipment	4[2]	8[7]	12[8]
Open Air (includes lines)	4[2]	4[2]	6[8]

Notes:

1. This table is based on maximum fault current of 51kA.
   Calculations are based on an 18-in separation distance from the arc to the employee. See IEEE 1584-2002.
   Other methods are available to estimate arc exposure values and may yield slightly different but equally acceptable results.
   The use of the table in the selection of clothing is intended to reduce the amount or degree of injury but may not prevent all burns.
2. Industry testing by two separate major utilities has demonstrated that voltages 50 - 240V will not sustain arcs for more than 0.5 cycles thereby limiting exposure to less than 4 calories/cm^2.
3. Value based on industry test results and IEEE Std. 1584-2002 formula for Motor Control Centers. (Gap = 1 in.) (Xd = 1.641) (18 in. distance) 51kA (Based on a 208V, 1000kVA, 5.3% Z, served from a 500mVA system) Maximum duration (from tests) is 10 cycles: 46.5 cal/s/cm^2 * 0.167 sec = 7.8 cal/cm^2
4. Industry testing on 480V equipment indicates exposures for self-contained meters do not exceed 20 calories/cm^2.
5. Industry testing on 480V equipment indicates exposures for CT meters and control wiring does not exceed 4 calories/cm^2.
6. Value based on industry test results and IEEE Std. 1584-2002 formula for Motor Control Centers. (Gap = 1" and Xd = 1.641, 18 inch distance) 12.7kA at 480 V (worst case energy value from testing). Maximum duration from tests is 85 cycles: 26.2 cal/s/cm^2 * 1.42 sec = 37 cal/cm^2
7. Incident analysis on this equipment indicates exposures do not exceed 8 calories/cm^2.
8. Incident analysis and industry testing indicates that applying a 150% multiplier to the 480V exposure values provides a conservative value for equipment and open air lines operating at 501 – 1000V.

Test Setup

Figure 2-2 shows the spacings of the secondary configuration of the unit used for testing. The internals of the transformer were removed, and voltage was supplied to the secondary terminals from the back side from PG&E's 480-V fault current source.

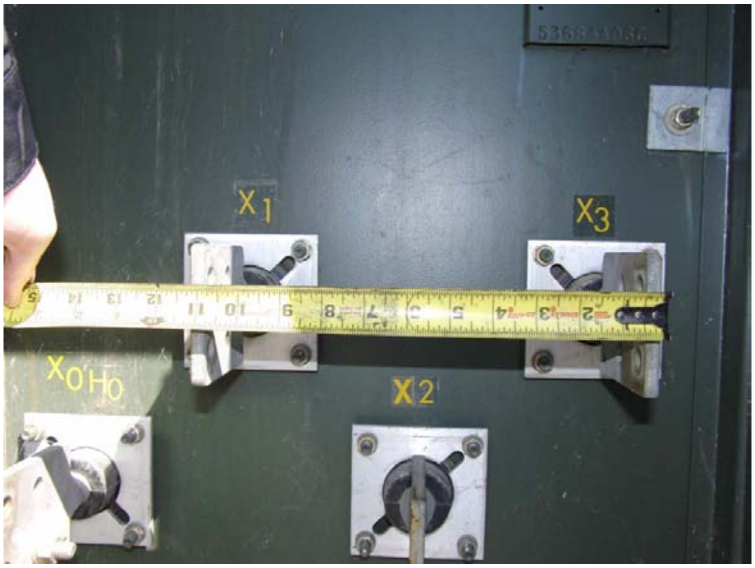


Figure 2-2
Test Unit

Test Results

Out of 35 tests, there were no cases of sustained arcing. Most arcs self-extinguished in less than 2.5 cycles with a maximum of 12 cycles. Incident energies were mostly less than 1 cal/cm^2 with the highest at 4.0 cal/cm^2.

Figure 2-3 shows a typical fault test initiated with a pair of vice grips laid across phases. The phase spacing in this configuration is approximately 2.75 in. This phase gap was progressively shortened by adding plates to see if tighter spacings would cause the arc to sustain.

Figure 2-4 shows a progression of high-speed video frames taken. The event lasted less than two cycles as shown in Figure 2-5. Note that the event progressed from a line-to-line fault to a three-phase fault in less than a quarter cycle.

Event 288

Figure 2-3
Vice Grip Test

Event 288

Figure 2-4
1200-fps Camera Snapshots through an Infrared-Passing Filter

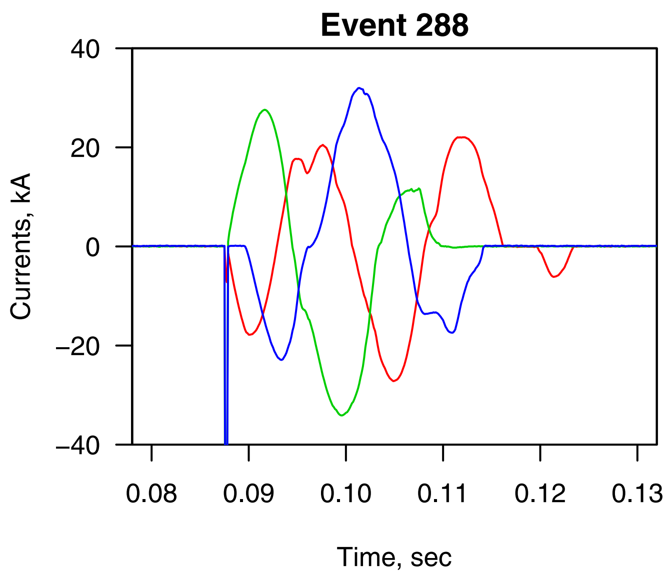


Figure 2-5
Current Waveforms for a Wrench Event

Figure 2-6 shows several fault initiations that were tested. Both phase-to-ground and phase-to-phase faults were attempted. Some common observations include:

- *Fault progression* – Faults generally became three-phase faults within a half cycle (with the exception of event 289 where the main point of arc initiation was well away from other phases).
- *Gap length* – Even to distances as close as two inches, faults could not sustain. The arcs grow into the open space around the electrodes until they cannot sustain. Arcs were first initiated at a distance of 3.7 in and reduced to 2 in.
- *Fault current* – This did not seem to change fault clearing characteristics. Bolted fault currents of 13, 28, and 53 kA were tested.
- *Blanket coverings* – One reason that the arcs clear quickly in the secondary compartment is that there is open space. To see if covering would restrict the arc and lead to sustained arcing, we initiated a phase-to-phase fault under a blanket, either with a #12 fuse wire or a wrench. See event 305 in Figure 2-6 for one example. In three such tests, arcs did not sustain any longer.

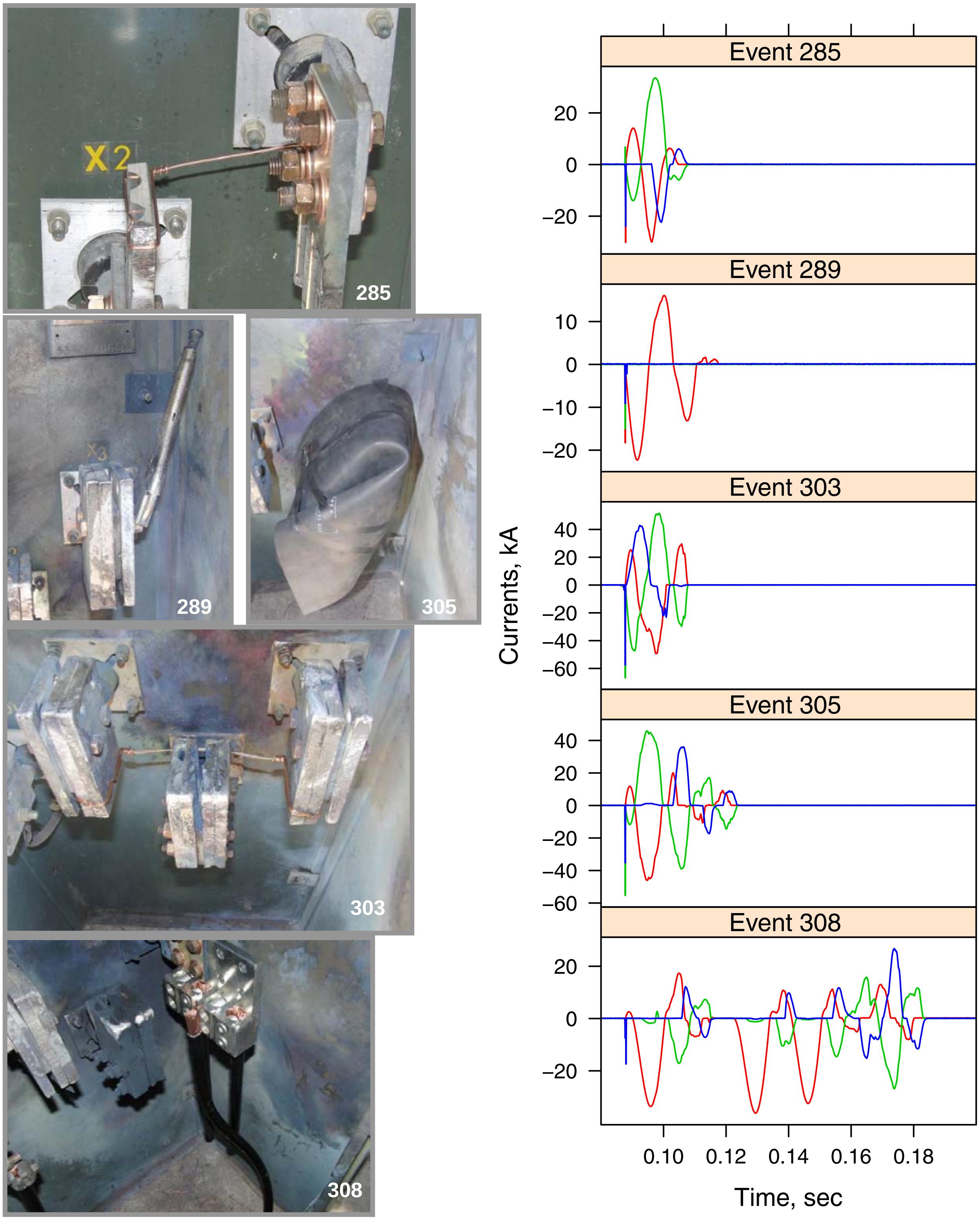
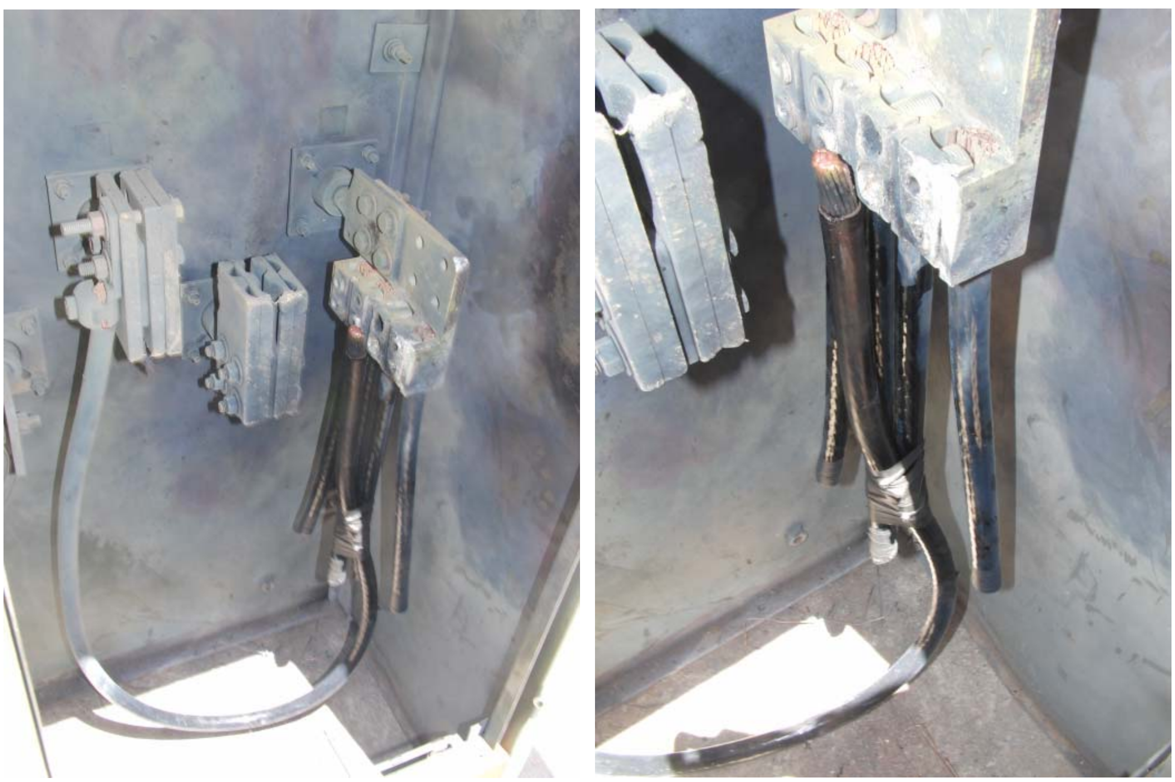


Figure 2-6
Fault Variations Tried

The longest-duration arcing occurred for a configuration where we used a 500-kcmil conductor from either the phase or the ground and looped it around and touched it to a Homac terminal block. This is to replicate the condition in the field where a worker accidentally touches a conductor to the wrong phase, and that conductor is either energized or grounded at the other end. See event 308 in Figure 2-6 for an example where the conductor is solidly grounded to the neutral bushing and then touched to the Homac connector. In this case, the fault lasts longer than the fuse wire or wrench tests, but it still clears quickly.

Figure 2-7 shows a test for a phase-to-phase connection. This test was made more severe by taping the incoming cable to adjacent conductor stubs to prevent cable movement. This event cleared in less than 12 cycles. From the damage observed after the event (Figure 2-8), we see that the cable and aluminum alloy connector both burned away, apparently until the gap was large enough for the arc to self clear. As this was the most severe event found so far, this fault scenario was tried at other spacings and fault currents. Figure 2-9 shows an example tested at a spacing of less than two inches. Faults still cleared within 12 cycles. Figure 2-10 shows waveforms for some of the longer-duration events.



Event 310

Figure 2-7
Cable Jumpering Phase to Phase with the Fault-Point Taped and Wire-Tied on the Right

Figure 2-8
Results after Test 310

Figure 2-9
Test 317

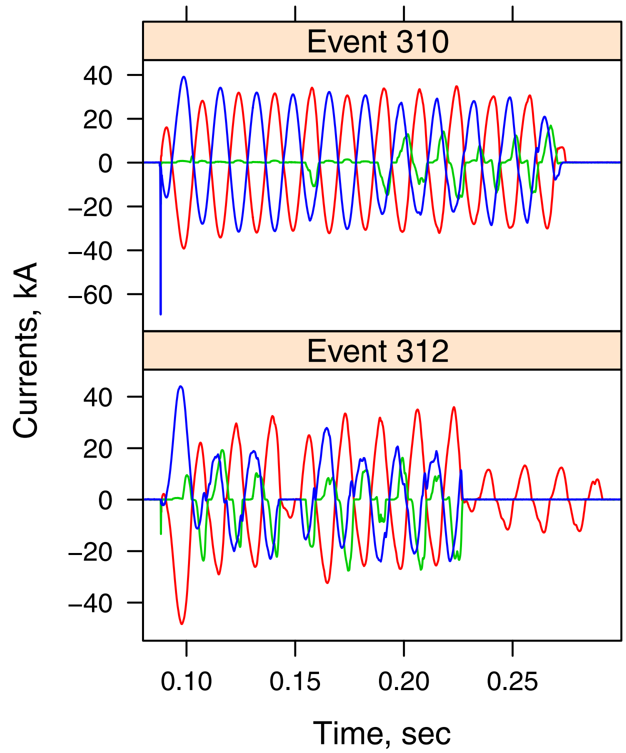


Figure 2-10
Waveforms from the Longer-Duration Events

Data Summary

Figure 2-11 summarizes the fault durations observed from the 35 tests with fault type shown by color. The "miswired cable" indicates the tests with the 500-kcmil conductor jumpering ground to phase or phase to phase, either tied down to adjacent stubs or free.

Figure 2-12 shows distributions of incident energies measured at 21 inches from the fault location. This is longer than the 18 inches used for most of the PG&E 480-V tests.

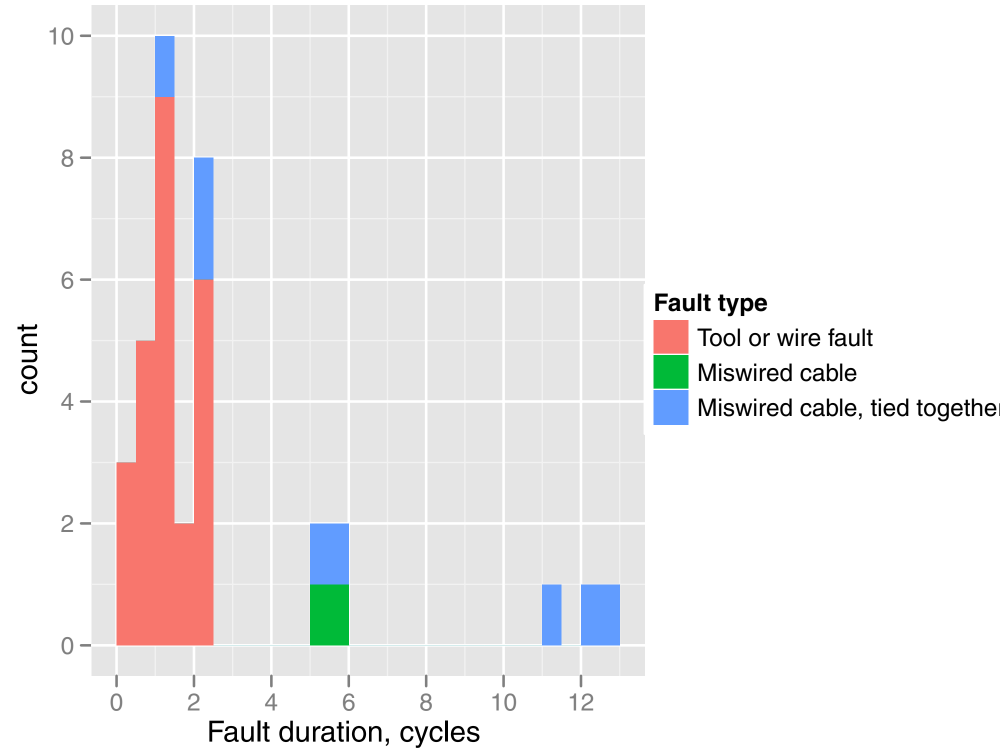


Figure 2-11
Fault Duration Histogram

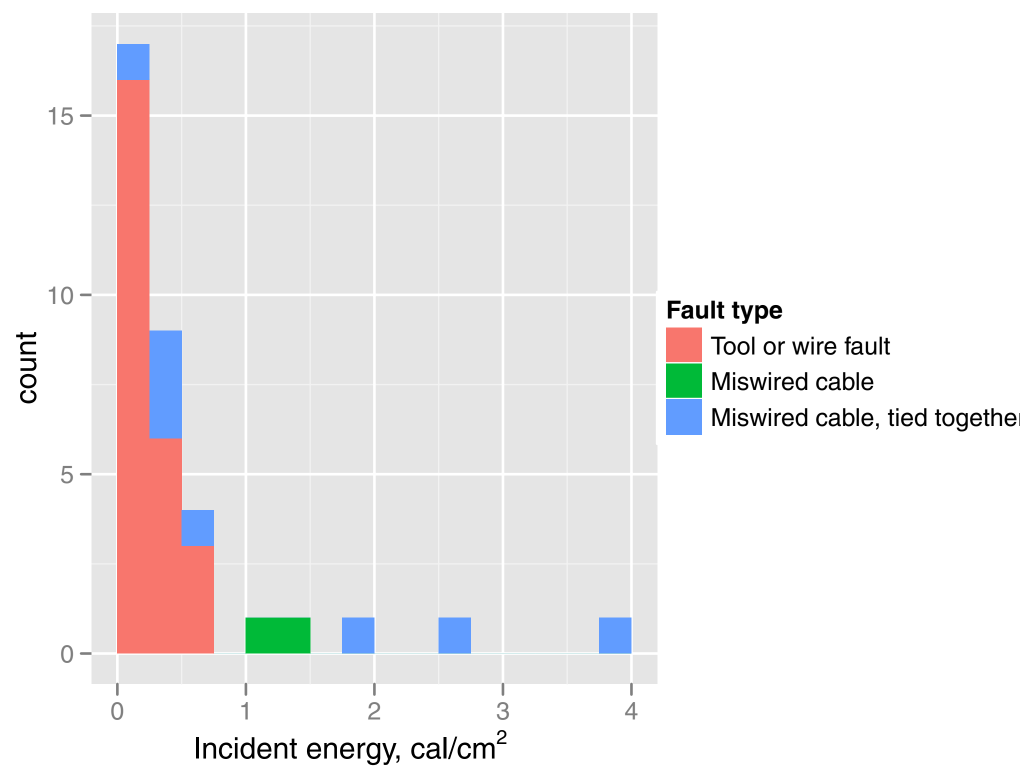


Figure 2-12
Incident Energy Histogram

The durations show that the arcs cannot sustain long in secondary compartments with typical or even tighter-than-normal conductor spacings. Because the duration is short, incident energies are low, much lower than the 20 cal/cm^2 cited in the consensus change proposal drafted for the 2012 NESC.

3
FABRIC TESTS

At part of the network protector testing and padmounted transformer testing, flame-resistant (FR) fabric samples were placed in front of two calorimeters as shown in Figure 3-1. The padmounted transformer tests had so few events with significant incident energy that we only show the results from the network protector tests. Four calorimeters were clustered in front of the network protector as shown in Figure 3-2.

Figure 3-1
Clothing Test Result Example

Figure 3-2
Test Setup

Figure 3-3 summarizes the fabric results by number of layers and rated Arc Thermal Performance Value (ATPV). The results fell out cleanly by number of layers in the fabric. The number of layers is a statistically significant parameter, while the ATPV rating is not a statistically significant indicator as shown in the analysis of variance in Table 3-1. The R^2 value for this linear regression is 0.65.

Table 3-1
Analysis of Variance Table

	Df	Sum Sq	Mean Sq	F value	Pr(> F)
Incident energy	1	28.20	28.20	53.68	0.0000
Layers	2	27.18	13.59	25.87	0.0000
ATPV rating	1	0.42	0.42	0.80	0.3744
Residuals	57	29.94	0.53		

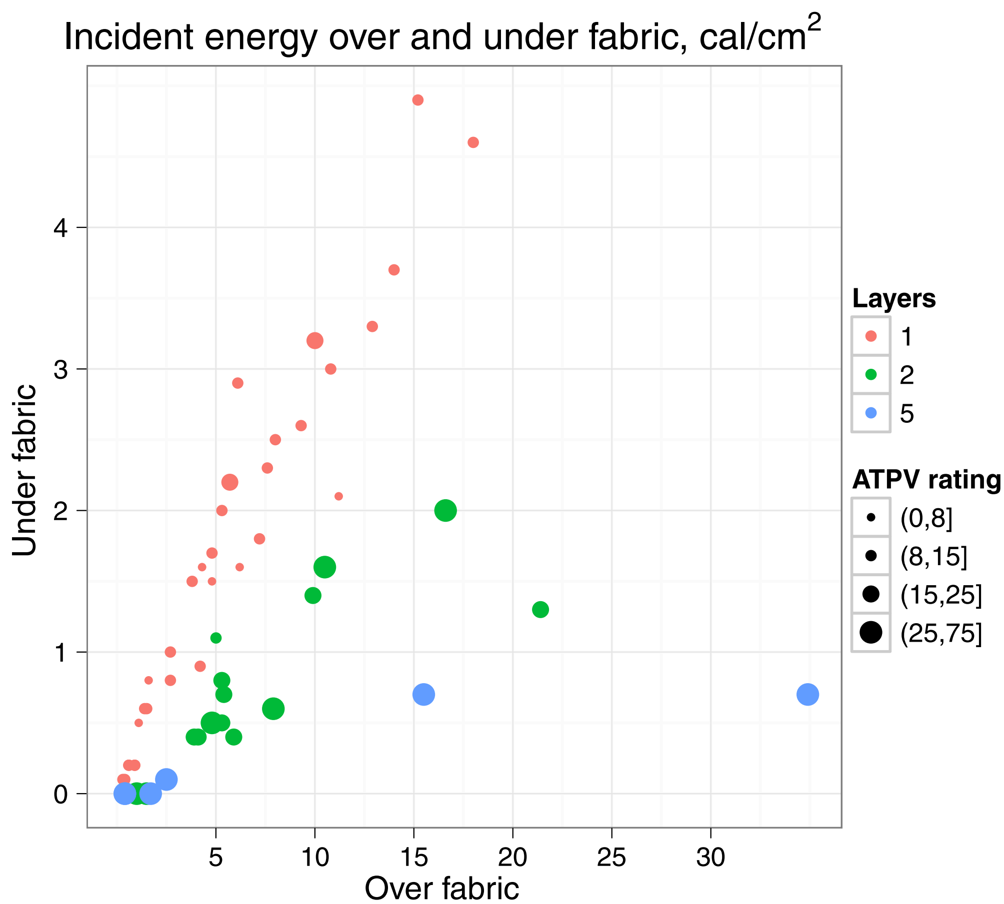


Figure 3-3
Clothing Test Results

Table 3-2 and Table 3-3 show the raw data from the test results. Note that we did not have published ATPV ratings for all of the sample fabrics, so estimates were used.

Many of the fabrics under-performed relative to their ATPV rating. Of the 20 tests where the fabric was subjected to between 30% and 100% of its ATPV rating, 75% let through more than 1.2 cal/cm^2, the value NFPA 70E cites as the threshold for a second-degree burn.

Table 3-2
Clothing Results Measured at 18 Inches

Test	Fabric	Layers of fabric	ATPV rating, cal/cm^2	Measurements, cal/cm^2 Over fabric	Under fabric
241	Oberon I8	5	71	1.7	0
242	Oberon I8	5	71	0.4	0
243	Oberon I6	2	46	1	0
244	Drifire twill over silk weight	2	16*	0.3	0
245	Drifire twill over heavy weight	2	20*	4.1	0.4
247	Sentinel polyurethane with Mt Vernon Mills	2	25*	5.9	0.4
248	Oberon I1	1	8	4.8	1.5
249	Drifire heavy weight over silk weight	2	12*	0.2	0
250	Drifire heavy weight over silk weight	2	12*	0.2	0
251	Arclite sewn to Mt Vernon Mills	2	17*	5.4	0.7
252	MP3 over Mt Vernon Mills	2	15*	4.1	0.4
253	Oberon I3 very light denim	1	13	15.2	4.9
255	Drifire heavy weight over silk weight	2	12*	5.2	0.8
256	Drifire twill over heavy weight	2	20*	9.9	1.4
257	Drifire twill	1	12.4	7.6	2.3
258	Drifire heavyweight	1	8.6	8	2.5
262	Southern Mills 7 oz	1	8.4	0.9	0.2
263	Reused Southern Mills 7 oz	1	8.4	0.9	0.2
264	MP3	1	7.7	11.2	2.1
265	Oberon I3 904	1	13	14	3.7
266	Oberon I2 917	1	12	10.8	3
267	Oberon I7 navy twill 2 layer	2	42	10.5	1.6
268	Drifire heavyweight	1	8.6	12.9	3.3
269	Drifire twill	1	12.4	4.8	1.7
270	Mt Vernon Mills 7oz	1	8.4	0.4	0.1
271	Proterra	1	8.4	3.8	1.5
272	Oberon I8 on #1	5	71	34.9	0.7
276	Oberon I8 on #1	5	71	15.5	0.7
277	Ultrasoft style 451 twill	1	12.4	2.7	1
278	Drifire silk weight	1	4.4	1.6	0.8
279	Majestic c6 interlock single ply	1	22.6	10	3.2

* Estimated ATPV rating (not actual)

Table 3-3
Clothing Results Measured at 24 Inches.

Test	Fabric	Layers of fabric	ATPV rating, cal/cm^2	Measurements, cal/cm^2 Over fabric	Under fabric
241	Oberon I8	5	71	2.5	0.1
242	Oberon I8	5	71	0.4	0
243	Oberon I6	2	46	1.5	0
244	Drifire twill over silk weight	2	16*	0.3	0
245	Drifire twill over heavy weight	2	20*	3.9	0.4
247	Sentinel polyurethane with Mt Vernon Mills	2	25*	5.3	0.5
248	Oberon I1	1	8	4.3	1.6
249	Drifire heavy weight over silk weight	2	12*	0.2	0
250	Drifire heavy weight over silk weight	2	12*	0.2	0
251	Arclite sewn to Mt Vernon Mills	2	17*	5.3	0.8
252	MP3 over Mt Vernon Mills	2	15*	4.1	0.4
253	Oberon I3 very light denim	1	13	18	4.6
255	Drifire heavy weight over silk weight	2	12*	5	1.1
256	Drifire twill over heavy weight	2	20*	21.4	1.3
257	Drifire twill	1	12.4	5.3	2
258	Drifire heavyweight	1	8.6	4.2	0.9
262	Southern Mills 7 oz	1	8.4	0.6	0.2
263	Reused Southern Mills 7 oz	1	8.4	0.6	0.2
264	MP3	1	7.7	6.2	1.6
265	Oberon I3 904	1	13	9.3	2.6
266	Oberon I2 917	1	12	6.1	2.9
267	Oberon I7 navy twill 2 layer	2	42	4.8	0.5
268	Drifire heavyweight	1	8.6	7.2	1.8
269	Drifire twill	1	12.4	2.7	0.8
270	Mt Vernon Mills 7oz	1	8.4	0.3	0.1
271	Proterra	1	8.4	1.5	0.6
272	Oberon I6 on #6	2	46	16.6	2
276	Oberon I6 on #6	2	46	7.9	0.6
277	Ultrasoft style 451 twill	1	12.4	1.4	0.6
278	Drifire silk weight	1	4.4	1.1	0.5
279	Majestic c6 interlock single ply	1	22.6	5.7	2.2

* Estimated ATPV rating (not actual)

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