Active Arc Flash Quenching for IEEE C37.20.7 Compliance

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IEEE Presentation Agenda

Engineered Solutions for Arc Flash Mitigation

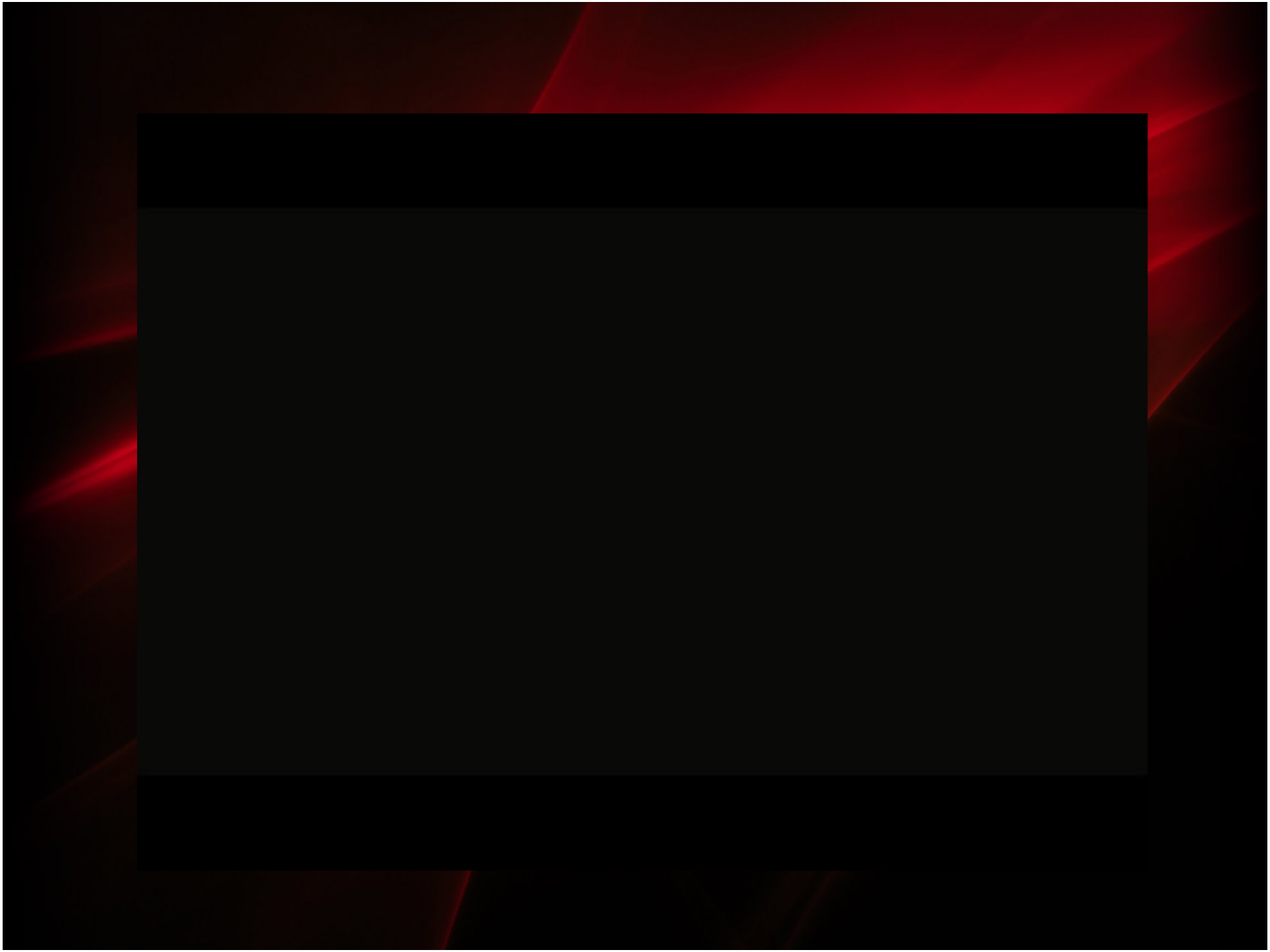
- *Introduction*
- *Arc Flash Mitigation Options – Advantages & Disadvantages*
- *Arc Quenching Definition – What is an "active" Arc-Quenching System?*
- *Standards that Reference Arc Quenching*
- *Arc Quenching Decision – Practical Applications*
- *Arc Quenching Benefit Summary*
- *Typical components of an Arc Quenching System*
- *Arc Quenching System Design – How Does the System Work?*
- *Testing an Arc Quenching System*
- *Arc-Quenching vs. Mechanical Arc Resistant ("Arc Venting")*
- *Arc Quenching System Stress Test Data (only if we have time!)*

Real-world Arc Quenching Application Examples

Question & Answer Session

Introduction

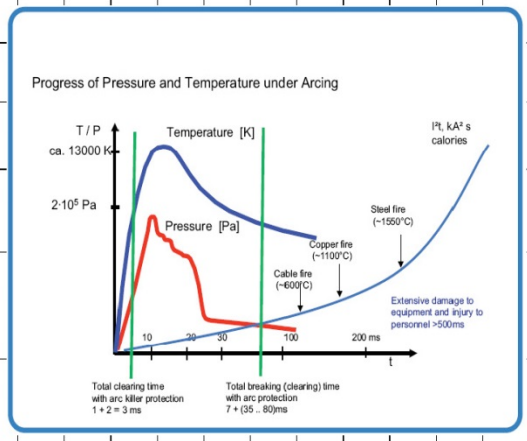
- History of Active Arc Quenching
- Technical Handouts (note the # !)
- Q&A



Arc Flash Mitigation Options (#1)

Tech4 Engineering: Arc-Flash Detection, Reduction and Protection through Superior Design

Equipment Type or Procedure	Arc-Flash Detection	Mechanism	Benefit	Approximate Clearing Time	Drawbacks
Forbid Energized Electrical Maintenance	None	De-energized equipment with lockout tagout (LOTO)	- Eliminates all arc-flash hazards with limited investment (education)	N/A	- Many electrical testing, troubleshooting and calibration tasks must be performed on energized assets.
Fuses as protective devices	Electrical current	Relies on current-limiting interruption	- Fastest interruption if Ia > current-limiting threshold. Long history of reliable industry usage	Fast if Ia > current limiting threshold. Slow if Ia < current limiting threshold.	- Large fuses have high CL thresholds > arcing current & may be slow to react. Concerns over fuse replacement & lack of other capabilities offered by circuit breakers
Current-limiting circuit breakers	Electrical current	Relies on current-limiting interruption	- Fast current interruption similar to fuses if Ia > current-limiting threshold, expands standard AIC ratings of breakers to values as high as 200KAIC	Fast if Ia > current limiting threshold. Slow if Ia < current limiting threshold.	- Limited in availability relative to fuses and subject to similar limitations. May require replacement after limited number of operations. Not easily available in a broad range of sizes
Circuit breaker with arc flash-initiated instantaneous trips	Electrical current which may be combined with light detection	Relies on fast fault interruption	- Provides moderately fast current interruption. Possibility for expanding selective coordination capabilities.	60ms - 70ms	- Not as fast as current-limiting fuses or circuit breakers. Use of the instantaneous at arcing current levels may negatively affect selectivity. Requires adjustable-trip circuit breakers
Overcurrect protection relays (instantaneous overcurrent relays, ANSI-50)	Overcurrent 1-2 cycles	Relay based system	- Fast elimination of contributing fault sources. Basic overcurrent protection; instantaneous trip stage of a standard over-current relay cannot be set low enough.	32ms + circuit breaker mechanical latency time	- Slow MV breaker operation speed
Bus differential protection (ANSI-87B)	Current differential 1-2 cycles	Relay based system	- Fast elimination of all contributing fault sources. Very long history of reliable industry usage. Relied upon in many process industries.	32ms + circuit breaker mechanical latency time	- Breaker operation speed. 87B protection usually requires dedicated set of CT's for every breaker and detecated Bus Diff Relays for each bus segment (including Tie CB if any). Expensive
Zone selective interlocking (ANSI-68)	Current with restraint signal 3-10 cycles	Trip unit or relay based	- Speeds up interruption of ST and/or GF and/or Inst protective functions. Maintains full-time selective coordination settings. Inexpensive.	166ms	- Breaker operation speed. Requires specific capable trip/relay system and wiring.
Instantaneous zone selective interlocking (I-ZSI) - ANSI-68	Current restraint within the circuit breaker's instantaneous trip region	Trip unit based; currently only available on GE low-voltage circuit breakers	An improved implementation of ZSI, which frequently improves protective device coordination; useful in critical power applications.	Variable and dependent on the amount of available fault current	Only works with newjer General Eletric circuit breakers; has all the same implementation requirements as standard short-time ZSI.
Remote operation 1- Remote operating station 2- Remote Electrical (Automation), or Mechnical racking	None	Operator outside arc flash boundary	- No impact on system selectivity. Some remote racking devices can be used on existing equipment.	N/A	- Does not improve downstream or equipment protection. May be costly and difficult to retrofit into existing installations. Does not allow for energized testing, troubleshooting, or calibration at a safe incident energy level.
Traditional arc-resistant switchgear (NEMA 2, 2b, and 2bc switchgear) which meets IEEE C37.20.7. This traditional "venting" technology has been superceded by Arc Quenching solutions.	None	Enclose entire enclosure volume and "vent" (redirect) arc flash to the top of the equipment	- Protects ground-level of the switchgear from arc flash and blast energy. Mechanical/Structural solution.	High (same as standard switchgear). For MV breakers, 83ms plus protective relay response time.	- The most drawbacks of any solution. Enclosure integrity must be maintained (doors closed) for protection to work. Blast energy must be exhausted, resulting in a complex, expensive installation. Does not improve equipment protection nor can it be added to existing equipment. Does not allow for energized testing, troubleshooting, or calibration. Few benefits for an expensive solution.
Arc Flash Relays, used to shunt-trip or open an LV or MV Circuit Breaker	Current & Light or Current & Light & Pressure	Protective Relay, used to assert (open) an upstream circuit breaker	Provides superior arc flash mitigation vs. relying solely on ciruict breakers or fuses. Typoical examples are Arcteq AQ-110P, SEL-751A & ABB REB, and Schneider Electric "VAMP" products.	Relay latency time (between 1ms and 7ms is typical) PLUS circuit breaker latency time; LV breakers are typically 60ms, while MV breakers are fixed at 83ms (5 cycles).	Frequently too slow to get the available arc flash incident energy below 4 calories per cm^2.
MV Arc Quencher System	Protective relay with light and current detection	Ultra-fast protection from arc blast and flash	- Eliminates arc flash and blast energy. Can also be configured to provide equal protection to downstream assets. Comprehensive real-time protection of people and assets.	Less than 7ms (less than 1/2 cycle)	None.
Temporarily reduced overcurrent protection settings ("maintenance switch")	Current measurement (O/C Protection Relay with more than one group) (Change group setting)	Reduces instantaneous trip setting by sacrificing the selective coordination which is mandated by the National Electric Code (NFPA 70)	- Temporarily reduces incident energy under specific conditions. Very inexpensive.	Varies - a power system study is always required.	- Requires specific capable trip systems and does not provide protection if the event does not occur during planned activity. Maintenance switch may accidentally be left in an "on" state.
Arc Quencher, either low-voltage or medium-voltage	Light detection with current; slower pressure detection is optional	Creates a upstream bolted short-circuit on all three phases.	- Provides lowest incident energy even with doors open - Protects personnel and reduces equipment damage - Applicable for both new and retrofit applications Provides lowest incident energy in downstream assets with sensors and 51ARC protective relay system.	> Clears MV arc flash events in 6.0ms > Clears LV arc flash events in 5.0ms	- None. Provides the safest practical solution for mitigating arc flash risks in both low-voltage and medium-voltage assets. Assures safety of personnel and continuity of equipment assets.



Arc Resistant Switchgear

There are two choices for IEEE C37.20.7 compliance

Mechanical Venting
(Arc Redirection)

Arc Quenching

Active Arc Flash Mitigation Definition

Any of the methods listed by the NEC, Article 240.87.

Arc Quenching Definition

"A fast-acting low-impedance arc flash mitigation system which has a total clearing time from arc flash initiation to complete extinguishing of the arc flash event in less than .006 seconds (6ms)." - Draft Standard EN 50110.

Arc Quenching Standards

NEC Article 240.87:

> History

> Requirements

> NEC arc flash mitigation methods:

1. ZSI
2. Differential Relaying
3. Maintenance switch w/local status indication
4. Energy reducing active arc flash mitigation system
5. Approved equivalent means by the AHJ

Arc Quenching Standards

UL 2748 - Maximum (peak) fault current and short-time fault-current withstand. Modern 3rd-generation arc quenching devices typically have a peak current rating of 162.5kA and a minimum short-time fault-current withstand of 100kA for 200ms.

IEC 60947-9-1 – The IEC standard defines the maximum voltage drop across the Arc Quenching Device (AQD) as 34 volts peak; this essentially precludes the addition of significant impedance between the AQD and ground.

Arc Quenching Standards

NFPA 70E (2018 Ed.) – Annex O.2.4(1):

(1) Energy-reducing active arc flash mitigation system. This system can reduce the arcing duration by creating a low impedance current path, located within a controlled compartment, to cause the arcing fault to transfer to the new current path, while the upstream breaker clears the circuit. The system works without compromising existing selective coordination in the electrical distribution system.

Arc Quenching Decision

Three Practical Application Questions:

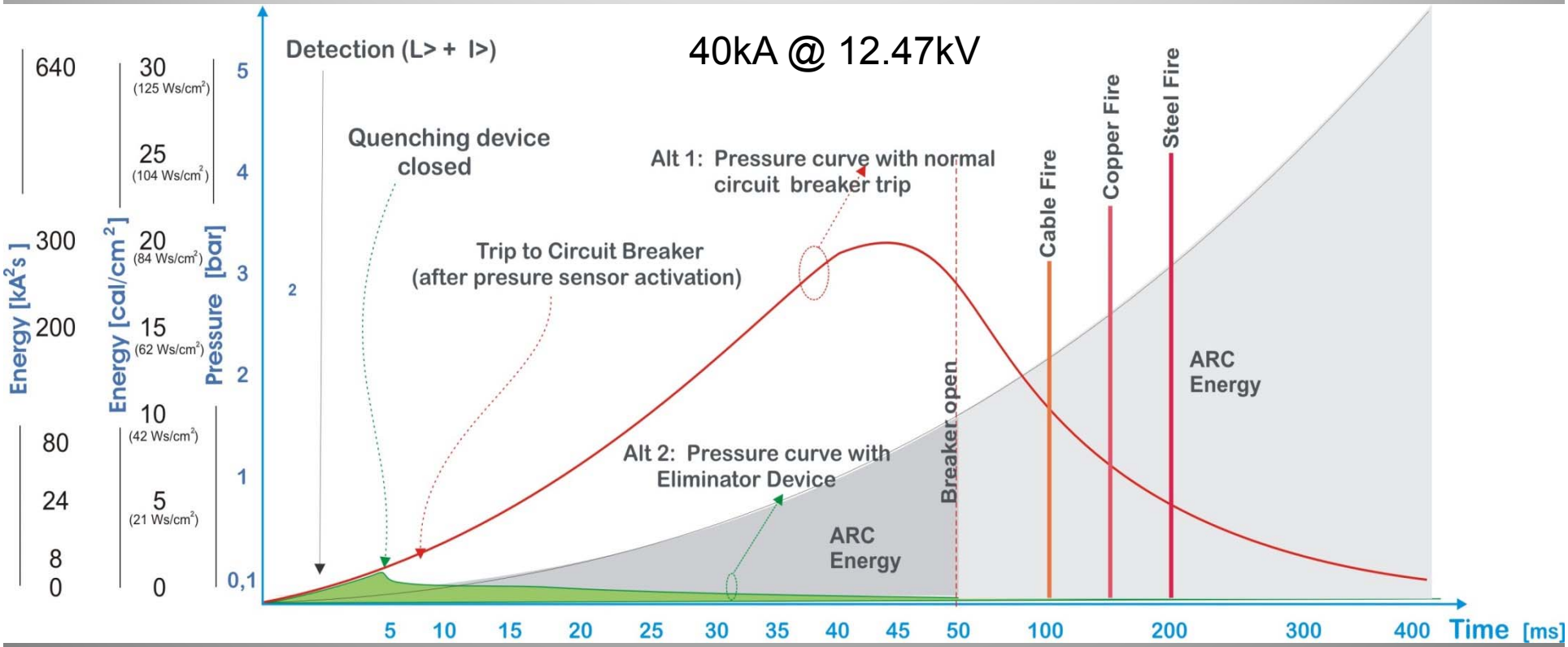
1. How important is uptime and power system continuity?

2. How important is reducing arc flash hazards? (Lowering the arc flash thermal incident energy to < 1.2 calories per cm^2 at the Working Distance)

3. Are there benefits associated with eliminating the need for arc-rated PPE clothing?

The Four Primary Arc Quenching Benefits (#2)

- Minimize arc flash incident energy
- Maximize personnel / Qualified Person safety
- Minimize downtime and equipment damage
- Eliminate the need for arc-rated PPE clothing



Arc Quenching Benefits Summary

- Eliminates the need for arc-rated (“AR”) clothing PPE
- Achieves an incident energy less than 1.2 calories per cm^2 at the Working Distance
  - Formerly referenced as “Category 0” by NFPA 70E
- Protects VFD enclosures, Motor Control Centers (MCCs) and control cabinets
- Extends the useful life of old switchgear utilizing air-break circuit breakers
- Easily applied in new equipment & retrofit applications, both LV & MV up through 15kV
- Protects equipment in environments where unexpected downtime is not an option
- Eliminate all permanently-debilitating and life-threatening arc flash risks (personnel safety)

4ms

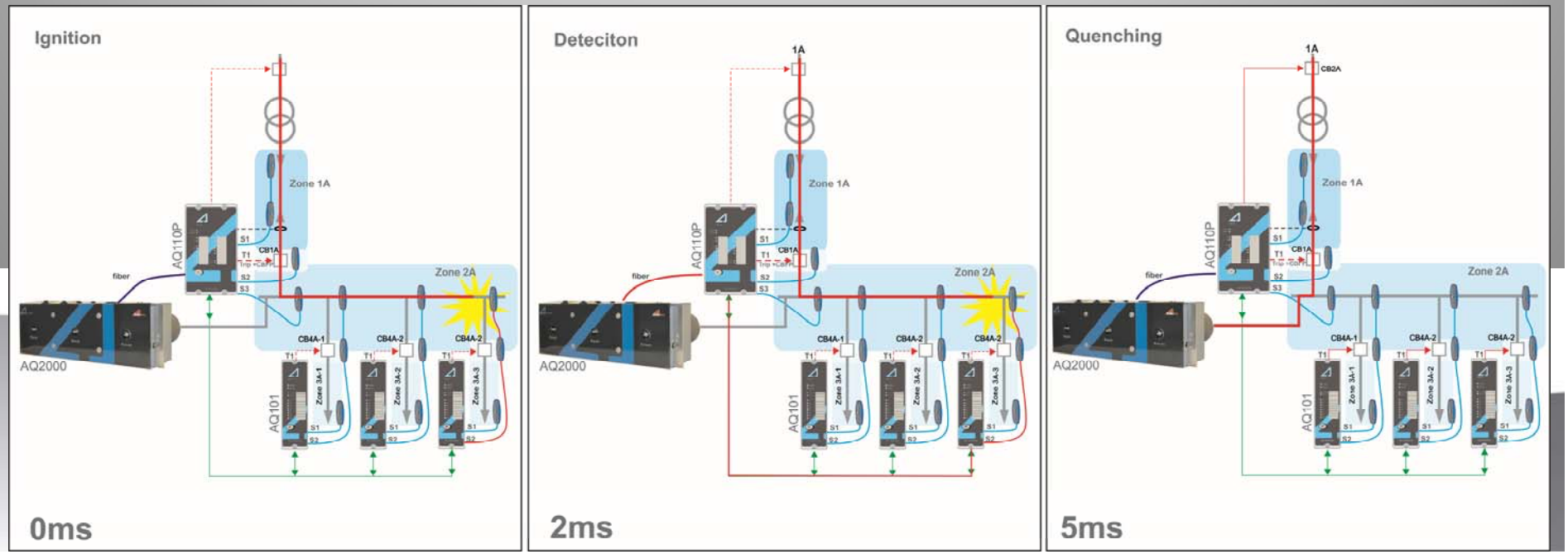
50ms

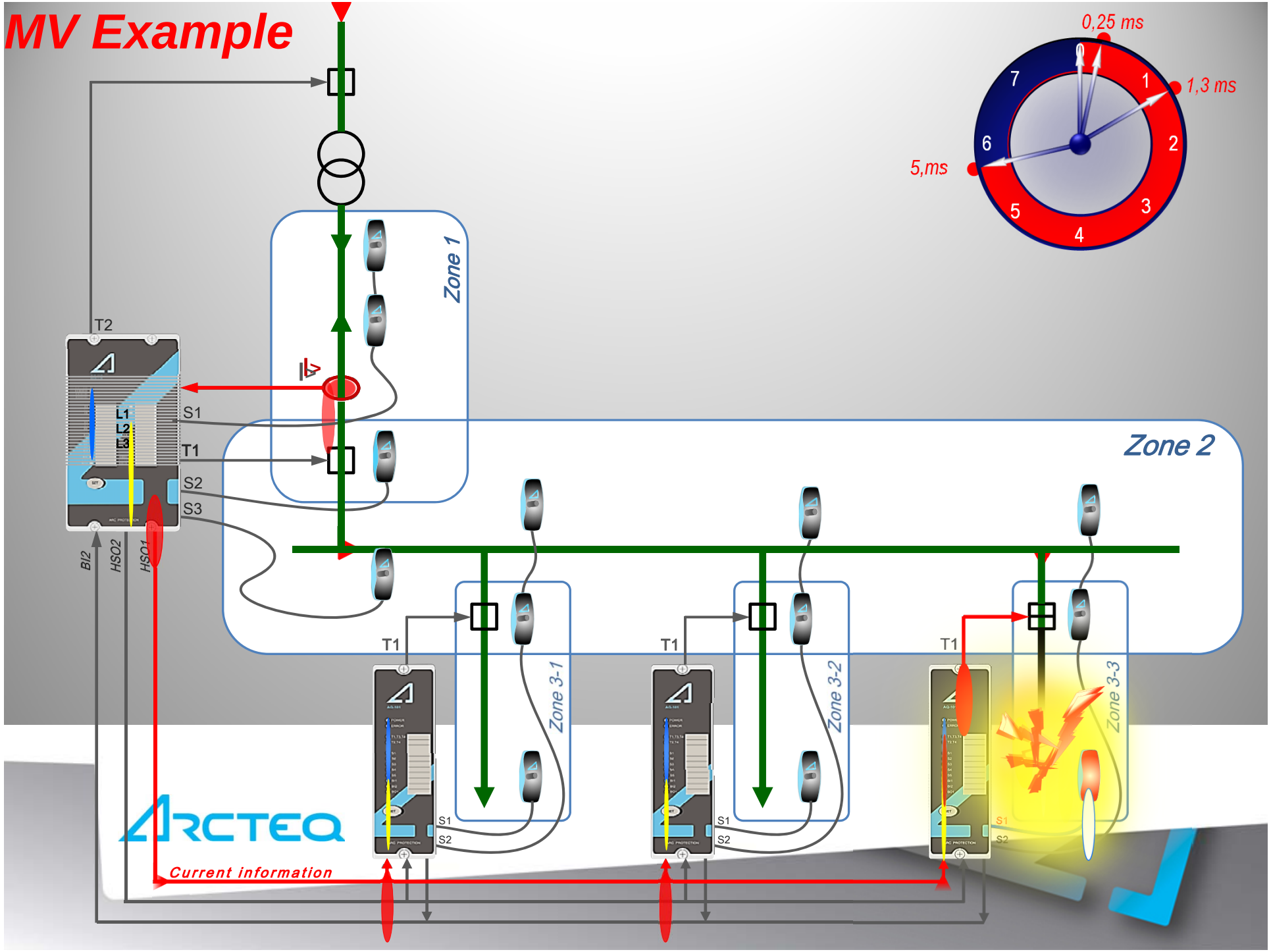
300ms

Typical Components of an Arc Quenching System

Fast detecting + Quenching

- Arc Flash Protective Relay (detection + assertion time < 2ms)
- Current Transformers
- Light Sensors (point-light and fiber-optic)
- Quenching Device (“crowbar”) generating a low impedance path
- Upstream Circuit Breaker
- Uninterruptible Control Power Source
- Annunciation System
- 50MHz Waveform Capture SOE / Meter

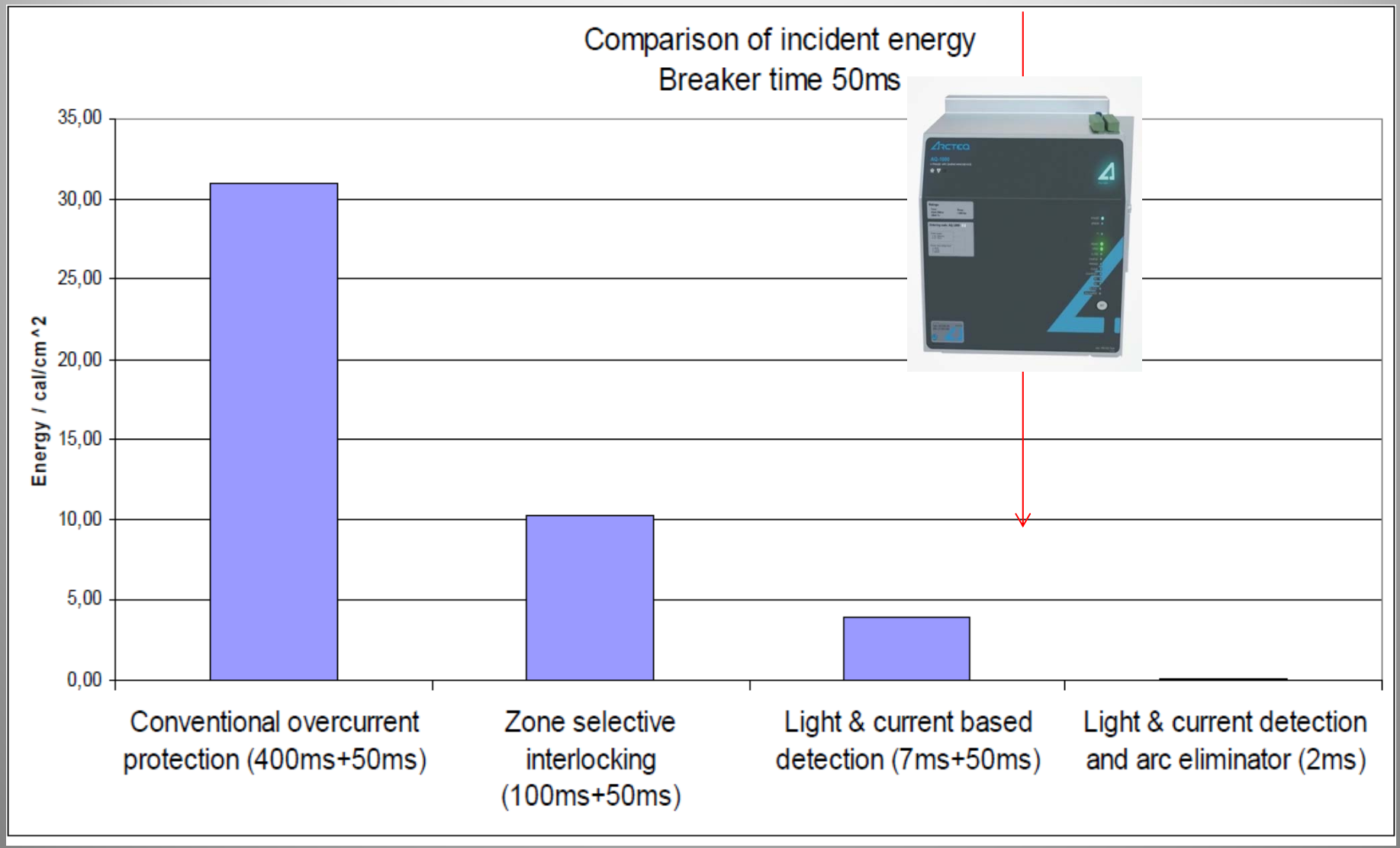



MV Example
0,25 ms
1,3 ms
5,ms
1
2
3
4
5
6
7
Zone 1
Zone 2
Zone 3-1
Zone 3-2
Zone 3-3
T2
T1
L1
L2
L3
S1
S2
S3
BI2
HSO2
HSO1
Current information
ARCTEQ

[Low Voltage Arc Quencher Video]

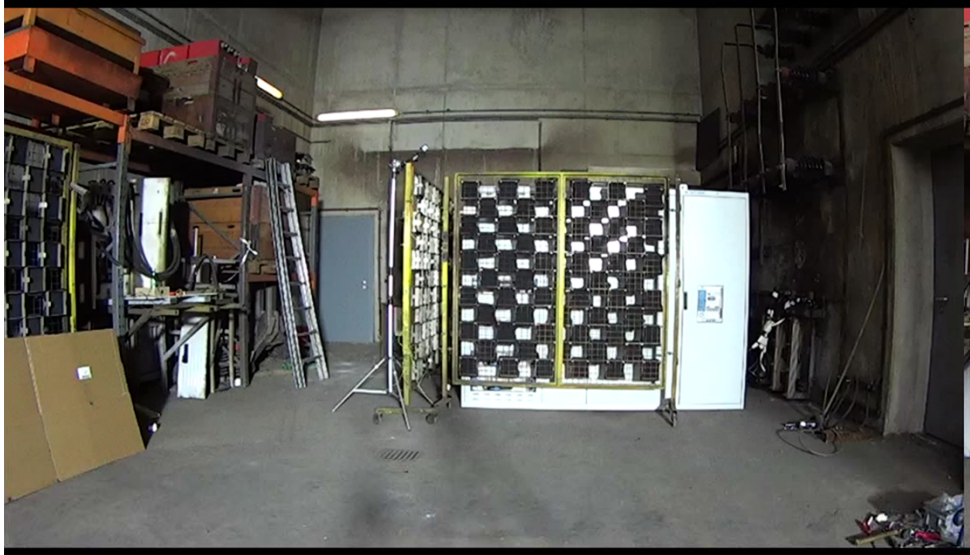
Arc Flash Energy Comparison

With the Arc Quencher, the arc never gets large enough to require arc-rated PPE clothing.

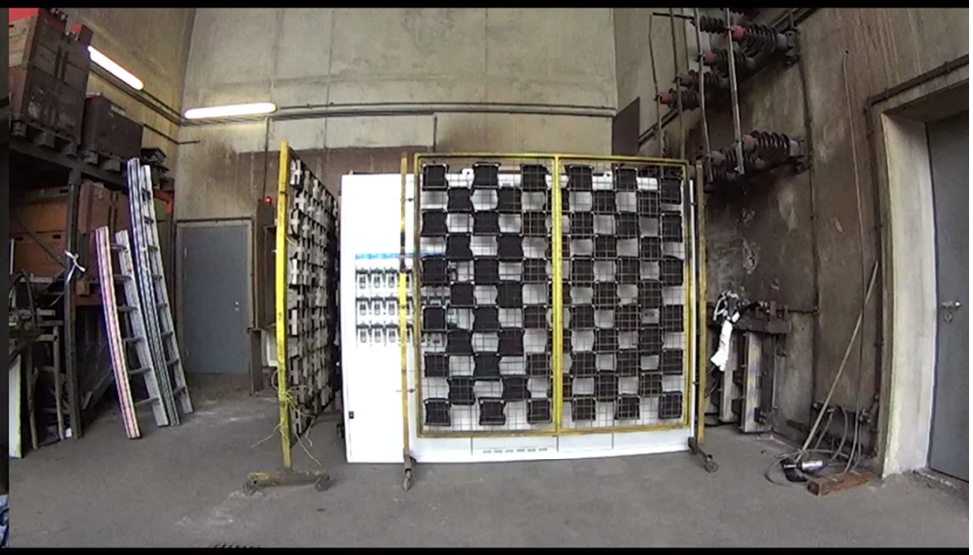


65 kA / 480V arc test, peak transient 163kA

Quenching time 4ms

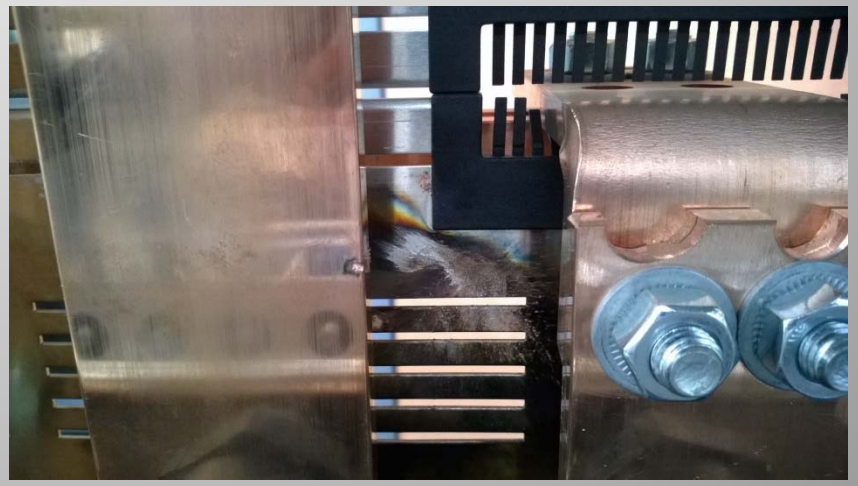


Tripping time 50ms



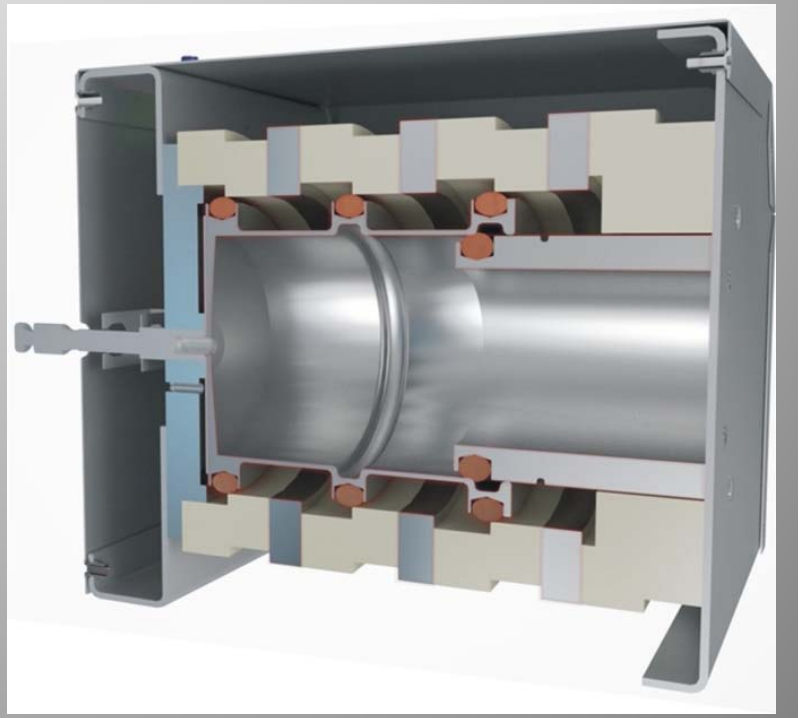
65 kA / 480V arc flash test (peak transient current 163kA)

Quenching time 4ms

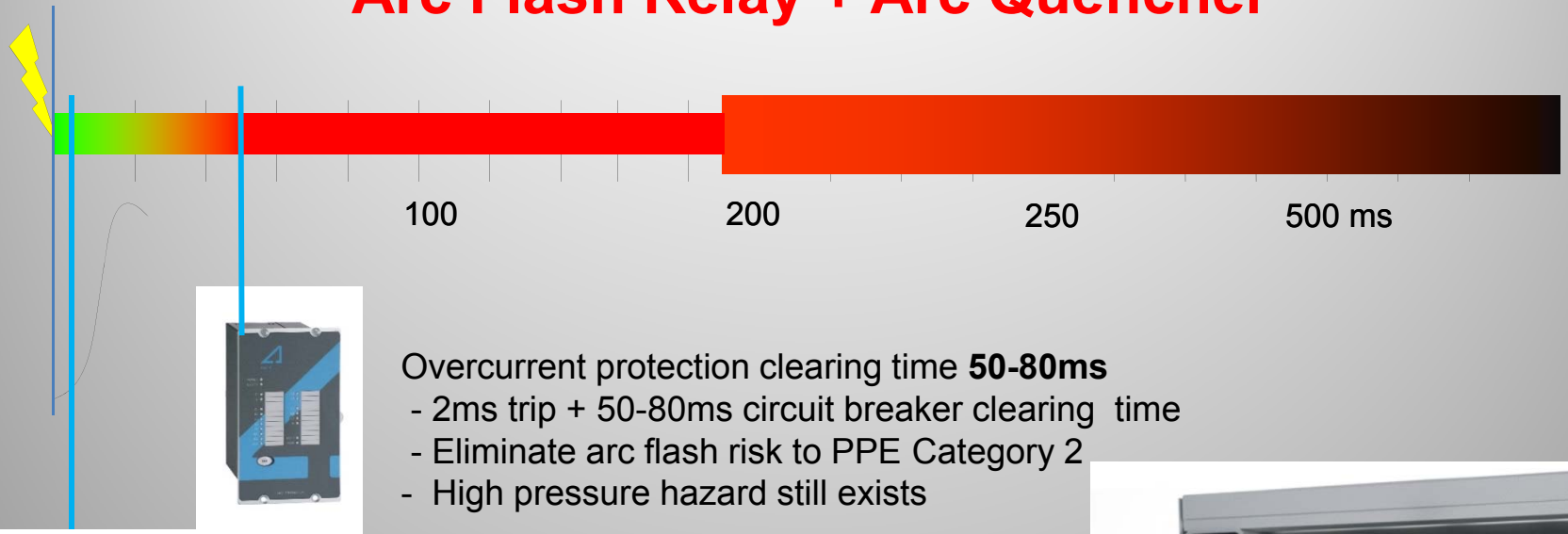


Arc Quenching Devices (#3)

- Pictured below is a Thompson coil (electromagnet) based system
- LV Total system clearing time < 5ms
- MV Total system clearing time < 6ms
- Required: On-line diagnostics and system annunciation
- UL-listed arc flash sensors & 50ARC relay system
- Tested and validated by 3rd-party test laboratory



Arc Flash Relay + Circuit Breaker
vs.
Arc Flash Relay + Arc Quencher



Overcurrent protection clearing time **50-80ms**
- 2ms trip + 50-80ms circuit breaker clearing time
- Eliminate arc flash risk to PPE Category 2
- High pressure hazard still exists

Worst-case arc quenching time 5**ms**
- 2ms trip + < 3ms quenching time
- Pressure hazard is eliminated
- Thermal (burn) hazard is so low that arc-rated PPE clothing is not required

Installation / Application Examples (#4 for drawings)

“Before” @ Kimberly-Clark

“After” @ Kimberly-Clark: 0.4 Calories per cm^2

Arc Flash PPE: Minimum Survival Requirements
Kimberly-Clark Application

Category 4 Flash Suit in the front of the switchgear. In the rear of the switchgear, even a Cat 4 suit would not guarantee survival when standing behind the switchgear (less than 36” Working Distance).

Marilyn Monroe - 1956

Guaranteed no life-threatening burns with an Arc Quencher

Green Bay Waste Water Treatment Plant (NEW Water) – Arc Quencher Front Panel

Land O'Lakes Fertilizer Plant
Caledonia, New York

Arc Quencher System Testing & Validation

- **Just like a circuit breaker, the Arc Quencher system is an electromechanical life-safety device. As such, it must be periodically tested to assure a compliant clearing-time.**

- **Factory testing**

- **Jobsite testing**

- **Recommended testing frequency**

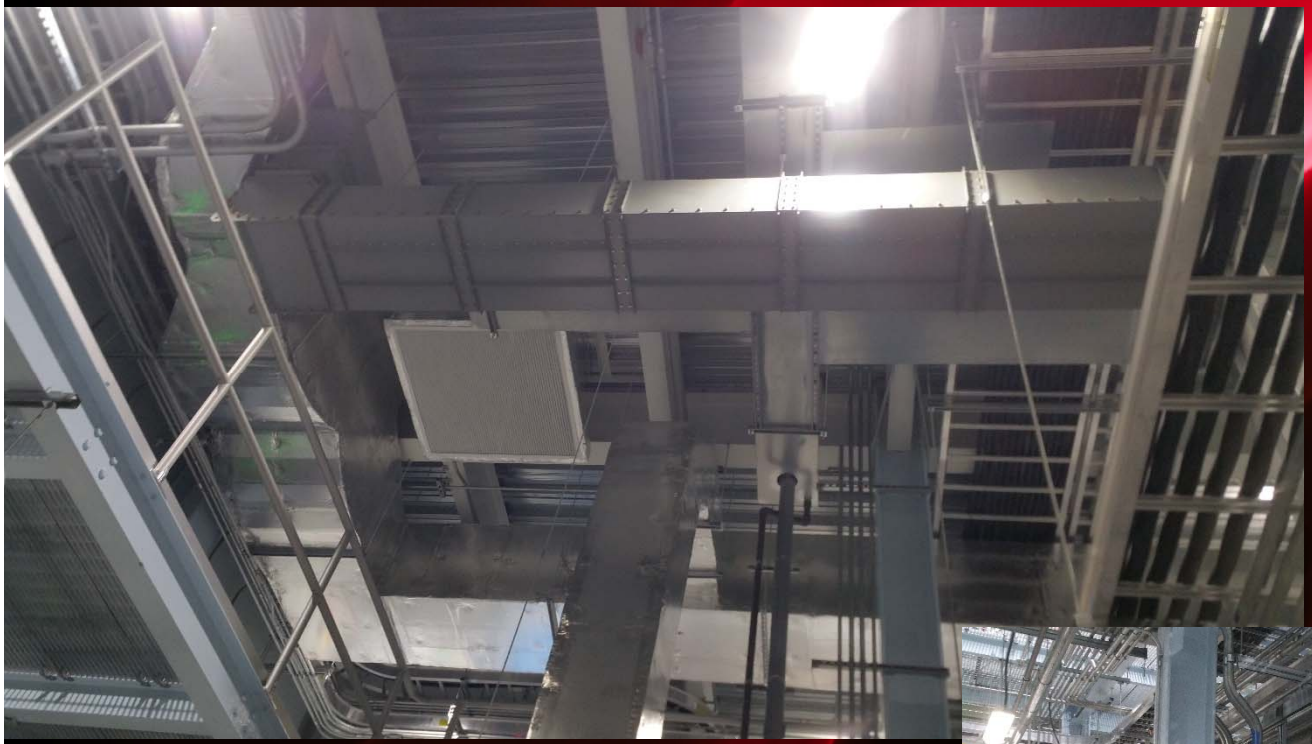
Traditional "Arc Resistant" Equipment:

Mechanically-Top-Vented and compliant with IEEE C37.20.7

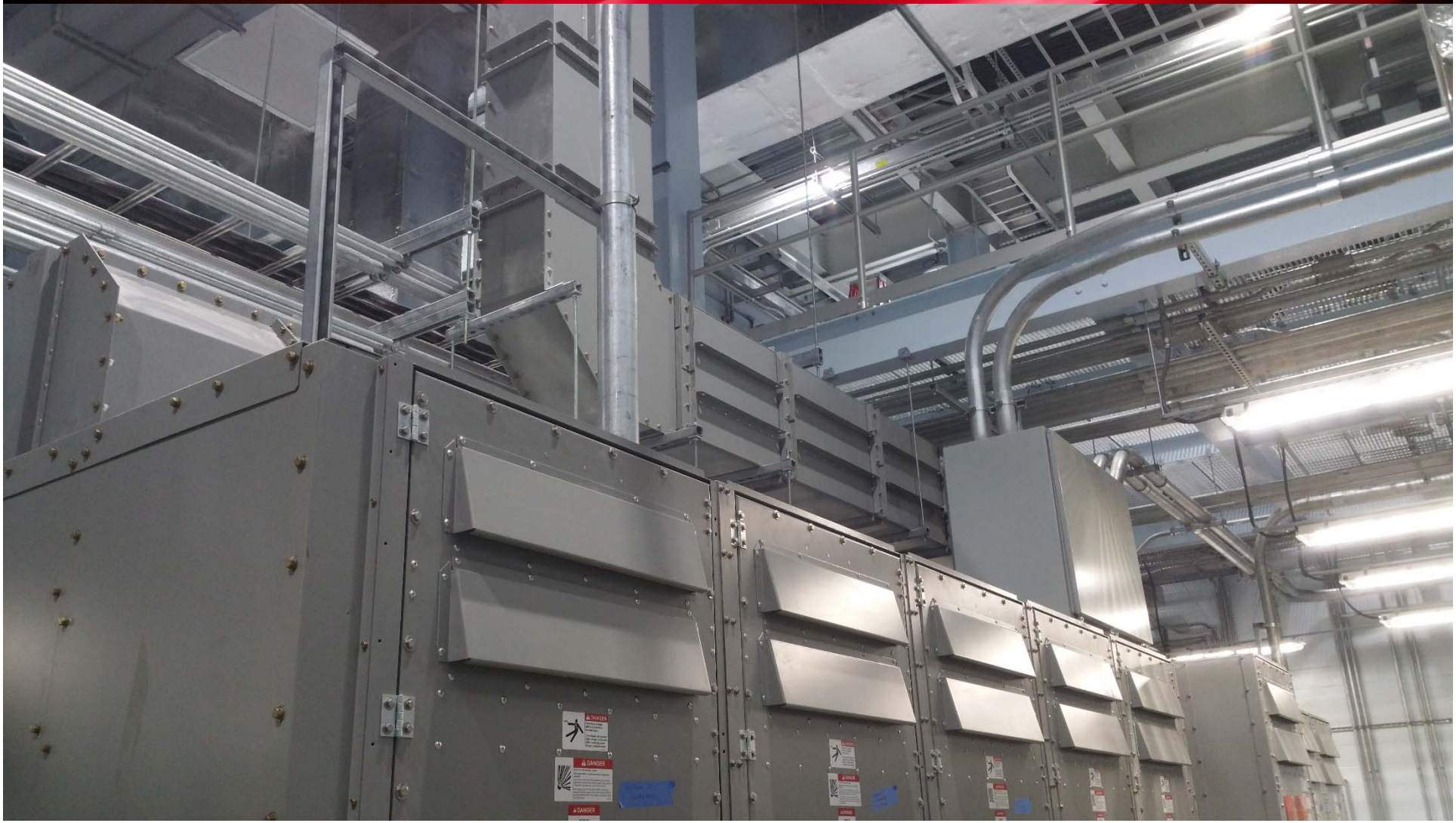
- **Popular because of the words "arc resistant"**
  - **This type of solution is referenced as"arc venting" or "arc redirection" equipment**
- **Does not reduce arc flash incident energy vs. standard equipment; therefore, it delivers no additional "exposed energized" protection from arc flash hazards**
- **Traditional Arc Resistant switchgear does not protect downstream assets (such as MCCs, VFDs, and control cabinets) any more than standard equipment**
- **Expensive to purchase and expensive to install**

Typical mechanically-vented IEEE C37.20.7-compliant switchgear

Typical mechanically-vented arc resistant switchgear exhaust plenums



Typical mechanically-vented arc resistant switchgear exhaust plenums



Typical mechanically-vented arc resistant switchgear exhaust plenum area

Mechanical Arc Resistant vs. Arc Quenching

- **Complies with all ANSI/IEEE C37.20.7-2007 "arc resistant switchgear" requirements**
- **The Arc Quencher solution does not "redirect" or "vent" the electrical arc: it *eliminates* the arc.**
- **The Arc Quencher solution is superior to traditional "arc resistant" switchgear in all respects:**
  - **Only the Arc Quencher protects both people *and* the physical equipment assets from the damaging effects of arc flash events, *even when exposed-energized***
  - **Only Arc Quencher systems may be configured and expanded to protect downstream assets**
  - **Only the Arc Quencher always guarantees what used to be referenced as PPE Category 0: no AR-rated PPE required by NFPA 70E (lower than 1.2 calories per cm^2)**

“I am concerned about Arc Quenching because it creates a low-impedance current path.”

Is system stress a legitimate argument against arc quenching?

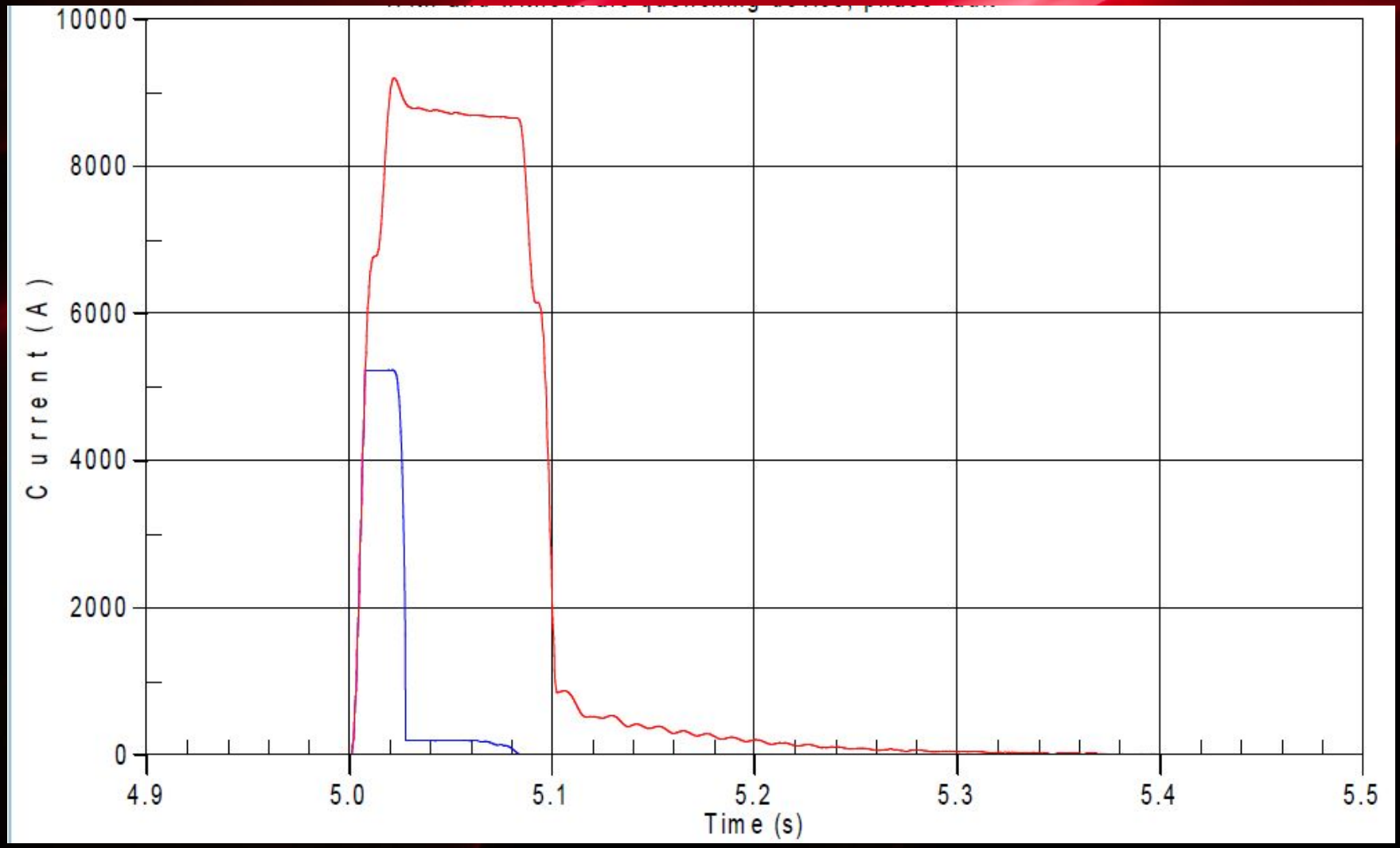
1. “Properly applied and installed” for the maximum available fault current.

2. Upstream and downstream transformers must be protected within their damage curves.

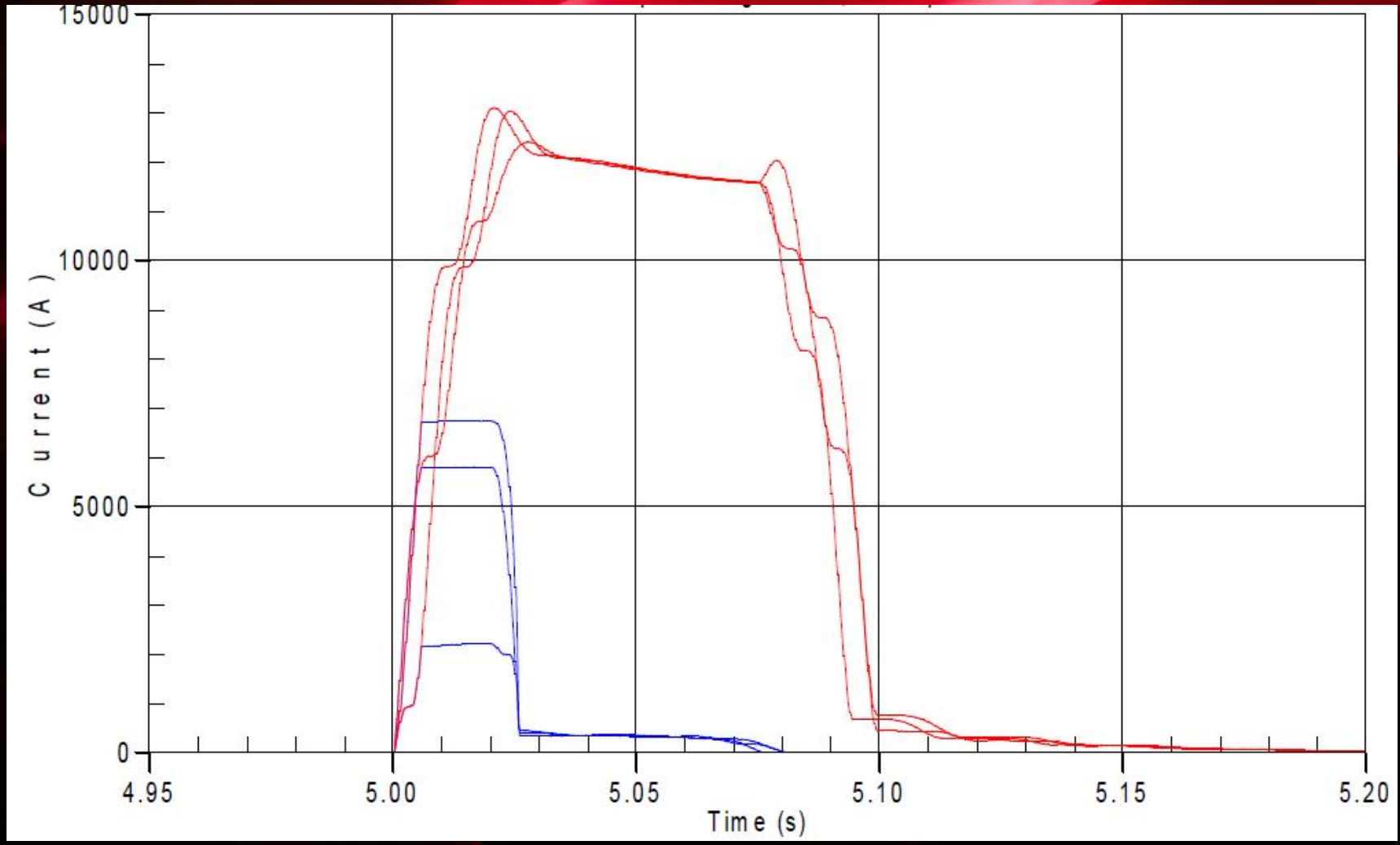
Arc Quenching System Stress Tests @ KEMA

We ran tests at various LV and MV voltages, comparing arcing faults using both arc quenchers and circuit breakers under identical fault conditions.

15kV Arc Fault Currents At The Fault Location With & Without an Arc Quenching Device Ground Fault



15kV Arc Fault Currents At The Fault Location With & Without an Arc Quenching Device Three-Phase Fault



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- **Thank you for your time!**