Arc Flash Mitigation Techniques and Considerations for Systems Design

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Chief Engineer
Eaton

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Arc Flash

An Arc Flash - An electrical arc due to either a phase to ground or phase to phase fault.

- 80 percent of all electrical injuries are burns that result from the electric arc flash
- Arc flashes cause electrical equipment to explode, resulting in an arc-plasma fireball
- Solid copper vaporizes, expands to 67,000 times its original volume
- Temperatures exceed 35,000 degrees F
- Detected sound levels of 141.5 decibels
- Pressure levels of 2,160 pounds per square foot

Arc Flash Mitigation

Pre Arcing | Arcing

Passive

Arc Prevention
- Training -Safe Work Practices
- Maintenance
- Good Design
- Remote Racking

Arc Containment
- Arc Resistant / Explosion Proof Enclosures: Panelboards, Switchboards, Motor Control Centers and Switchgear
- Personal Protective Equipment (PPE)

Active

Arc Prediction - Monitoring
- Partial Discharge
- Smoke
- Temperature
- Acoustic

Arc Detection
- Current / Voltage signal analysis
- Ground Fault
- Light sensing

Arc Elimination
- Shorting Bar – Arc Mitigator
- Create a Parallel Arc

Arc Flash Reduction
- Differential Protection
- Zone Selective Interlocking
- Maintenance Switch

Original Source: IEC SC17B

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Arc Prevention

- De-energize equipment if at all possible
- Label Equipment & Train Personnel
- Minimize Risk with Good Safety Practices
- Move People Further Away
- Closing and tightening door latches or door bolts before operating a switch
- Design the Hazard Out (Safety by Design)
  - Reduce Available Fault Current
  - Faster Clearing Times

Training
Minimize Risks with Good Safety Practices

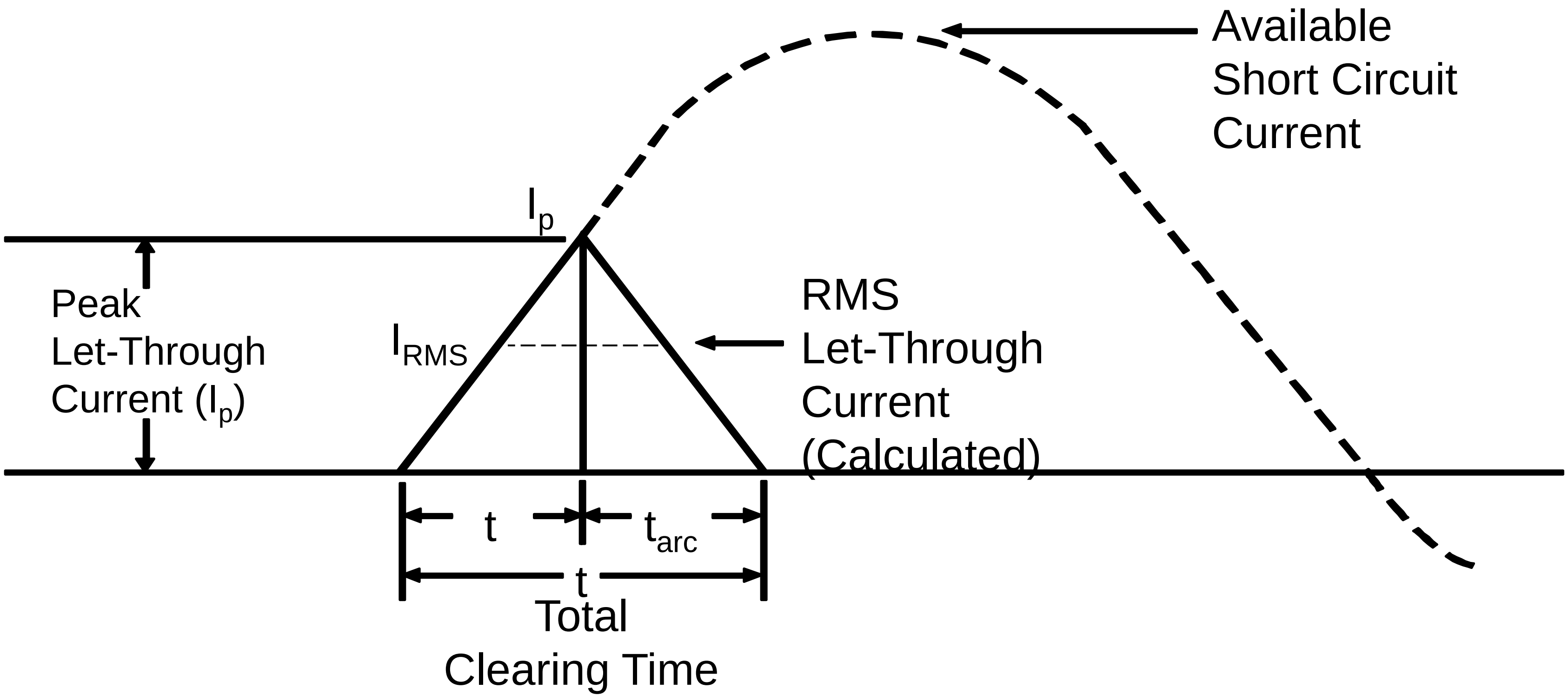
Bad – Exposed Back of Neck

Good – All of Body Protected Toward the Arc Flash Area

National Fire Protection Association NFPA 70E®

- Addresses electrical safety-related work practices
- Developed in cooperation with OSHA
- Assumes an NEC compliant installation.
- 1979: First published,
- 1995: Added Flash Protection Boundary
- 2000: Focused on personal protective equipment (PPE).
- 2004: Emphasizes safe work practices.
- 2009: Energized work permits, Harmonized with CSA Z462

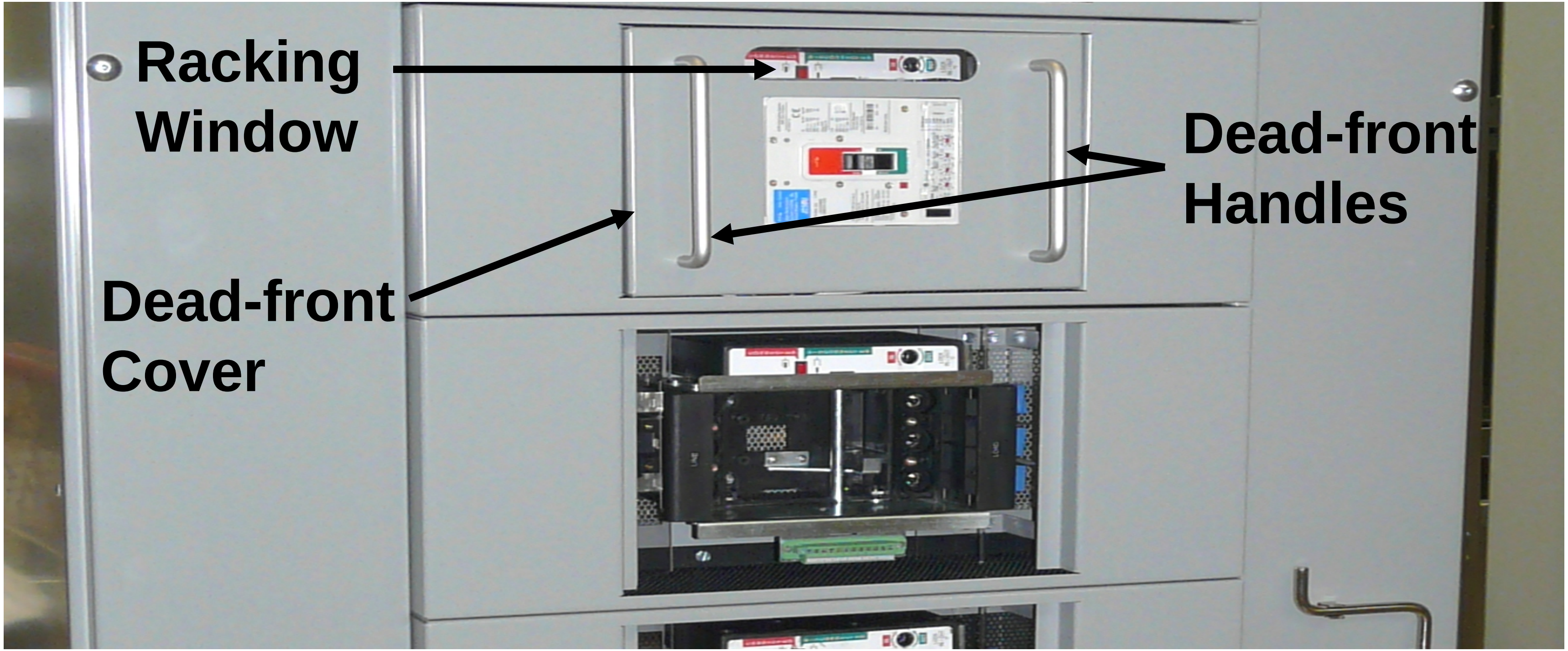
Good Design Practices
Current Limiting – Circuit Breakers and Fuses



Good Design
Remote Racking and Robots

VS.

Racking MCCB Breakers



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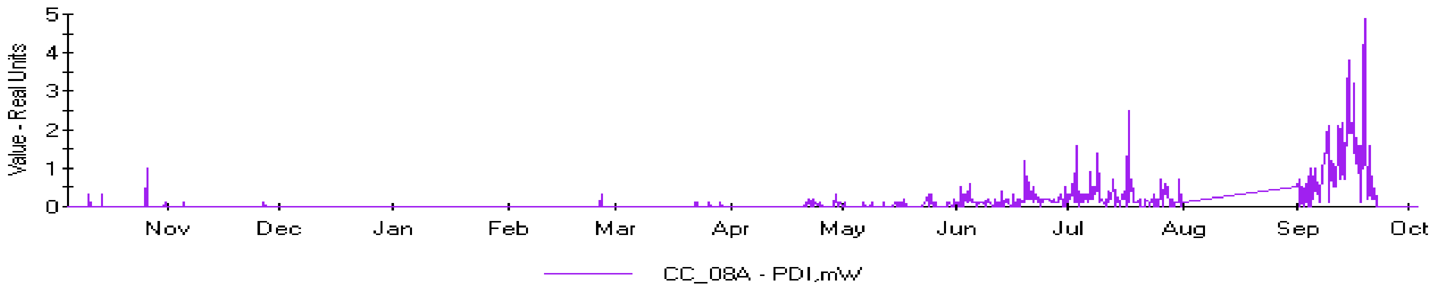
Predictive Monitoring

- Partial Discharge Monitoring
  - Insulation Integrity
    - Switchgear
    - Generators
    - Motors
  - Transformer Bushings

Stop Switchgear Failures



Thermography – View Ports

- Traditional Infrared Thermograph survey using IR Windows or Viewports
- Visual Inspections
- Scheduled regularly for intervals between shutdown maintenance
- “snapshot” of temperature at the time of the viewing.
  - Thermographer wears appropriate PPE while in the flash boundary

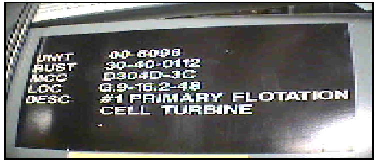
Thermal Scan - Example

- IR scan identified 149.4ºF hot spot temperature
- Temperature above the IEEE 1458 Standard of 130ºF.
- Removed from service and returned for further analysis

[redacted]

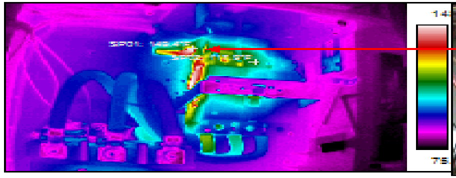
ELECTRICAL INSPECTION

LOCATION	D-1
EQUIPMENT	
TIME OF IMAGE	11:09:24 AM
DATE OF IMAGE	1/22/2008
DATE OF REPORT	1/22/2008
THERMOGRAPHER	RODGER LEAK



THERMAL IMAGE

F:\D-1\



VISUAL IMAGE

HOT SPOT	149.4°F
REFERENCE TEMP.	117.9°F
DELTA-T	31.5
MAX RATED AMP LOAD	
ACTUAL AMP LOAD	
COMMENTS	CHECK CONNECTION A-PHASE TOP OF BREAKER
REPAIR / DATE	
REPAIRED BY	
COMMENTS	

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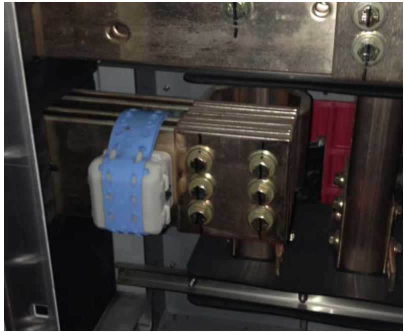
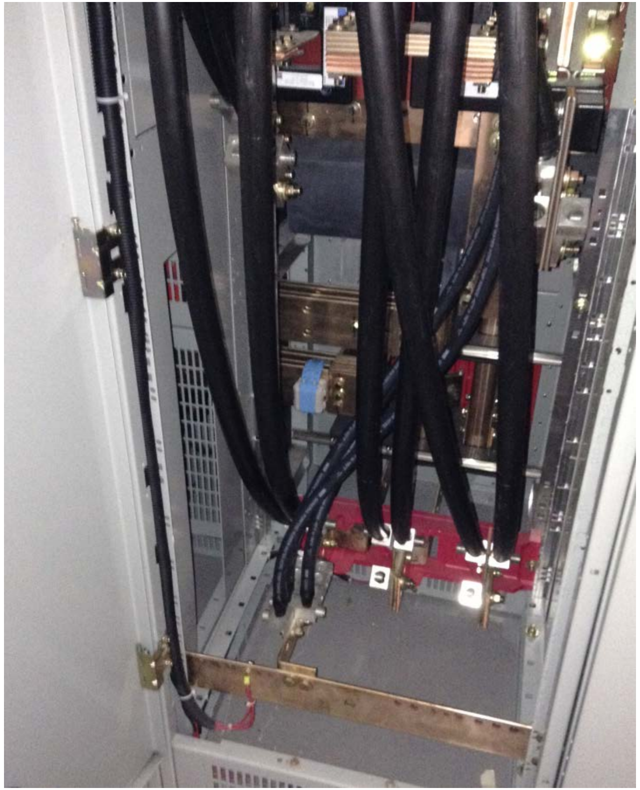
Acoustic Arc Detection

- New technology that detects acoustic signature of micro-arcing of loose connections before they become dangerous.





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- Arc Resistant / Explosion Proof Enclosures: Panelboards, Switchboards, Motor Control Centers and Switchgear
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Arc Resistant

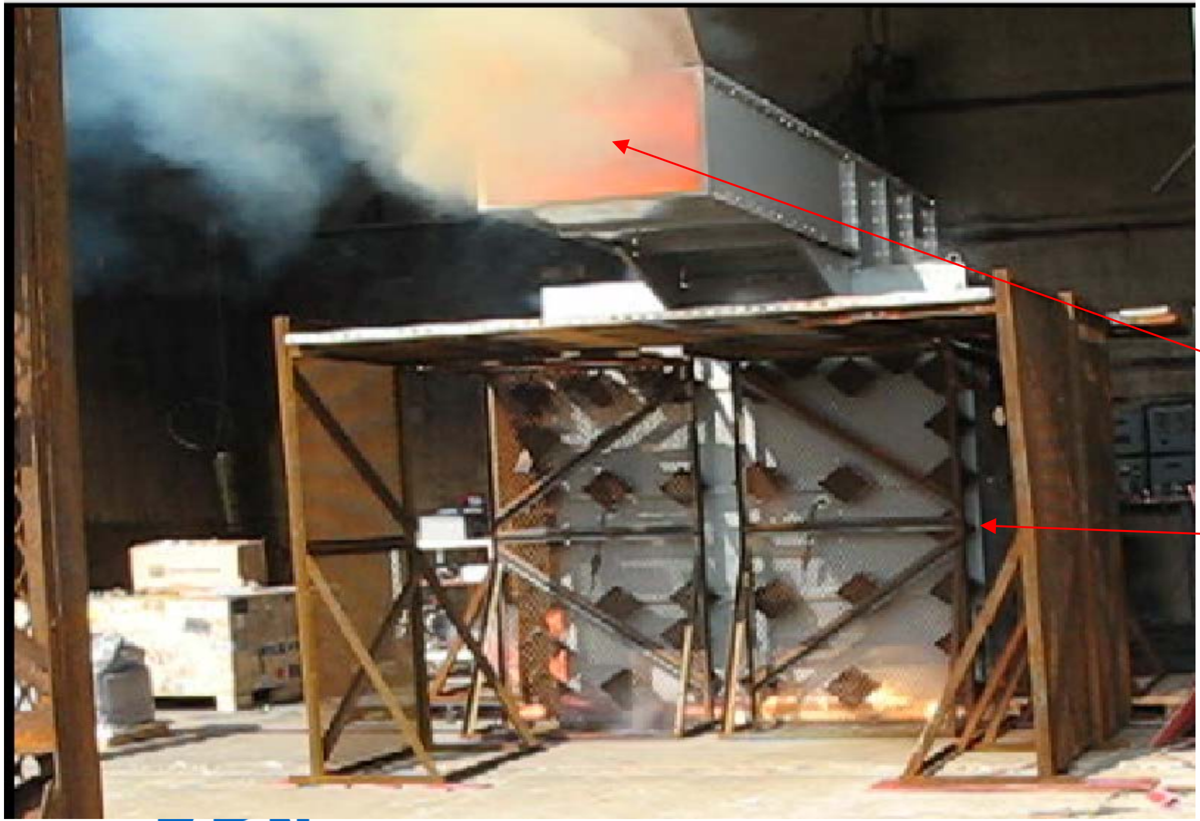
- Enclosures
  - Provide for maximum strength during an arcing fault event.




ARC Resistant - Testing

- Test is successful if:
  - No indicators are burned
  - Doors do not open
  - No projectiles come from equipment
  - No holes are burned in the enclosure

Arc Safety– Arc Resistant Gear



65kA / 508V

Arc initiated in breaker compartment

Plenum Design

Arc projected out of plenum

No arc flash out of the front of the gear

PPE Clothing

Hazard Risk Category	Clothing Description (Number of clothing layers given in parenthesis)	Total Weight oz./yd^2	Minimum Arc Thermal Performance Exposure Value (ATPV)* or Breakopen Threshold Energy (E_{bt})* Rating of PPE cal/cm^2
0	Untreated Cotton (1)	4.7 - 7	1.2
1	FR Shirt and FR Pants (1)	4.5 – 8	4
2	Cotton Underware plus FR Shirt and FR Pants	9 – 12	8
3	Cotton Underwear plus FR Shirt and FR Pants plus FR Coverall (3)	16 – 20	25
4	Cotton Underwear plus FR Shirt and FR Pants plus Double Layer Switching Coat and Pants (4)	24 -40	40

Category 4 PPE

Extracted from NFPA 70E-2004

Based upon maximum energy for a 2nd degree burn (1.2 cal/cm^2)

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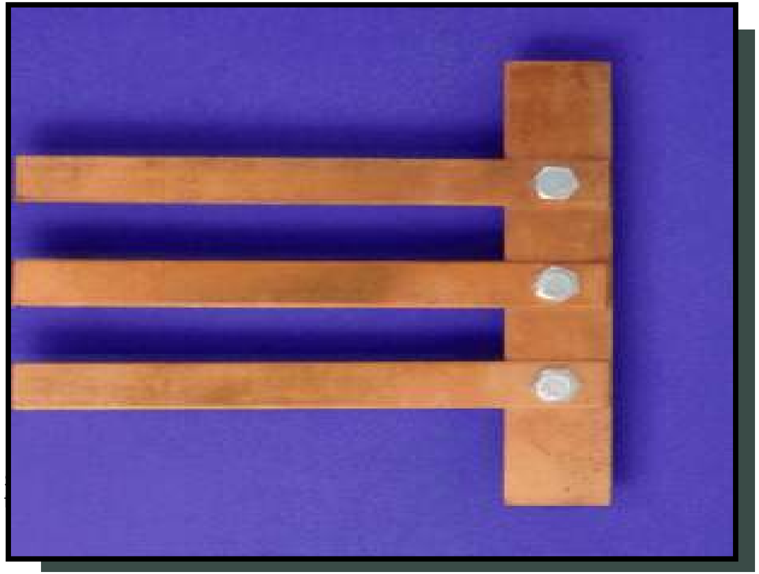
Line-to-Line-to-Line Fault

Bolted Fault

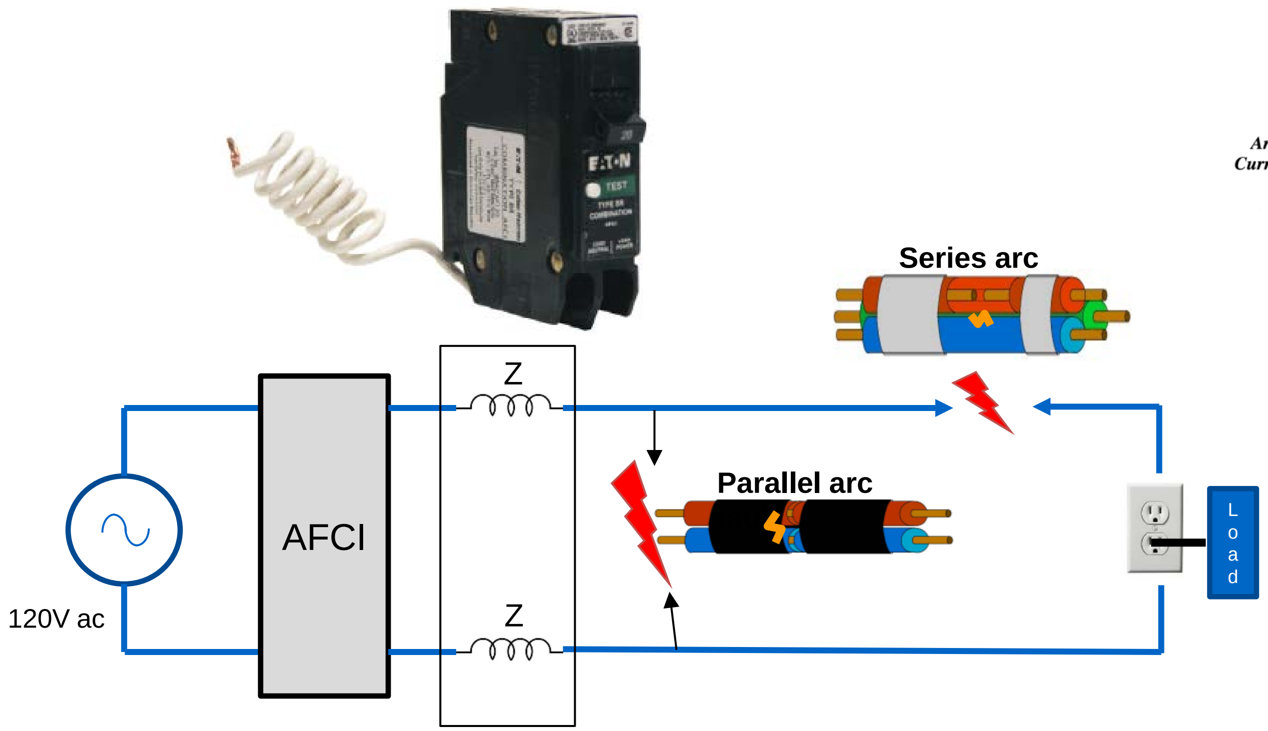


Arcing Fault

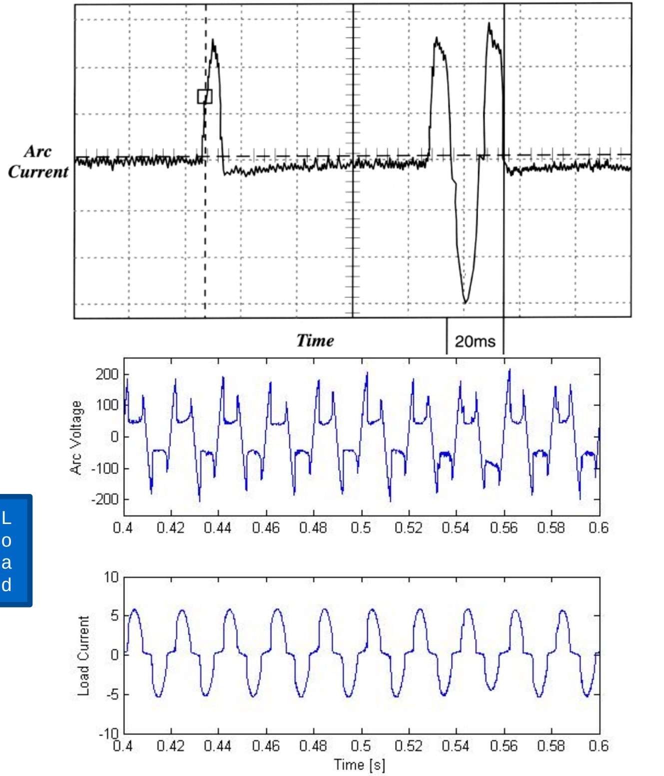
Arc Detection - AFCI

- Arc Fault Circuit Interrupter
  - UL 1699 standard – Residential
  - Standard thermal-magnetic (overload-short circuit protection) circuit breaker with AF technology.
  - Some designs contain 20mA GF protection although the standard does not require it.

Arc Detection - AFCI



Sputtering parallel arc waveform



Arc Detection - AFCI

Standard overcurrent protection does not detect if:

- Parallel Arc Faults are sputtering – will not trip on overload because there is not enough RMS heating current.
- Parallel Arc Faults that are limited due to wiring impedances – Below the breaker’s instantaneous value.
- Algorithms for Parallel arc fault protection looking at the slope of the rise of the fault current.
- Series Arc Faults that look like load current – Ok arcs (light switch, bi-metal on a skillet or coffee pot)
- Complex Algorithms for series arc faults to detect the signature of good vs. bad arcs.

Arc Detection - Ground Fault Sensing

- Different levels of protection:
  - Machinery Equipment Protection
    - 30mA Sensitivity = Equipment Protection
  - Personnel Protection
    - NEC Code says less than 6mA sensitivity required to protect people
    - IEC standard says less than 30mA sensitivity should be used.
- High Resistance Grounding
  - Reduces the level of current in arcing faults to ground

Arc Flash Light Detection Relays

- Speed, no intentional delays (2ms operate time – 52ms Trip Time)
- Sensitive, adjustable phase and ground fault current set-points from sensitive to above load
- Selectivity, trip only affected feeder(s)
- Secure, dual-sensing option (current and light) prevents false trips
- Full self-supervision

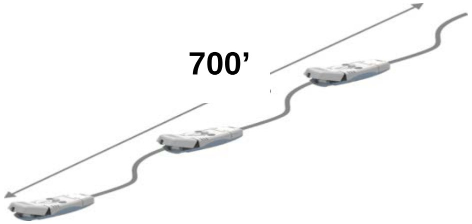
Arc Light Detection - Sensors

EAFR-06 – Arc light plastic fiber sensor

EAFR-07 – Arc light glass fiber sensor

Arc Light Detection - Point Light Sensor

- Wired connections provides simple installation and allows full factory testing even with shipping splits
- Current signaling based information (2mA, 20mA)
- Maximum 3 sensors in line (up to 700feet)
- Snap-in cable connector for quick installation
- Shielded cable connection
- Three styles of different light intensity (8000, 25000, or 50000 Lux)
- 180 degrees of visibility.



Options for Arc Flash Relay Modules

Features	EAFR-110F	EAFR-110P	EAFR-102	EAFR-101/D
3 Phase Current Detection	Yes	Yes	No	No
Ground Current Detection	Yes	Yes	No	No
Maximum Point Sensors	0	12	0	12
Maximum Fiber Loop Sensors	3	0	3	0
High Speed Outputs (2ms)	2	2	0	0
Trip Relays (7ms)	4	4	4	4

EAFR-110

EAFR-101/102

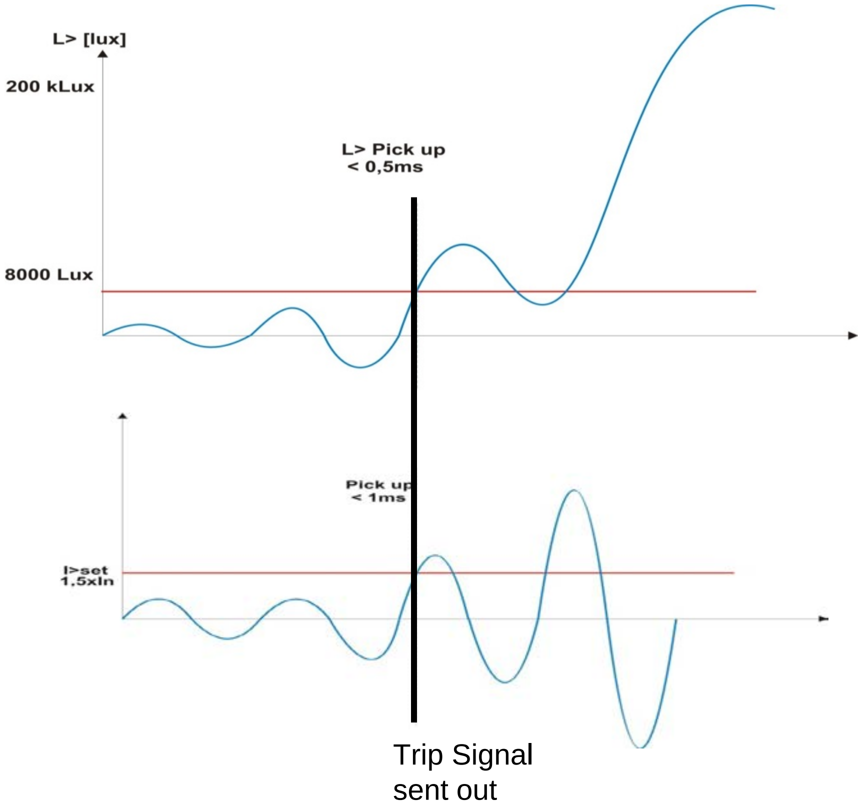
EAFR-101D

Arc Detection – Light / Current

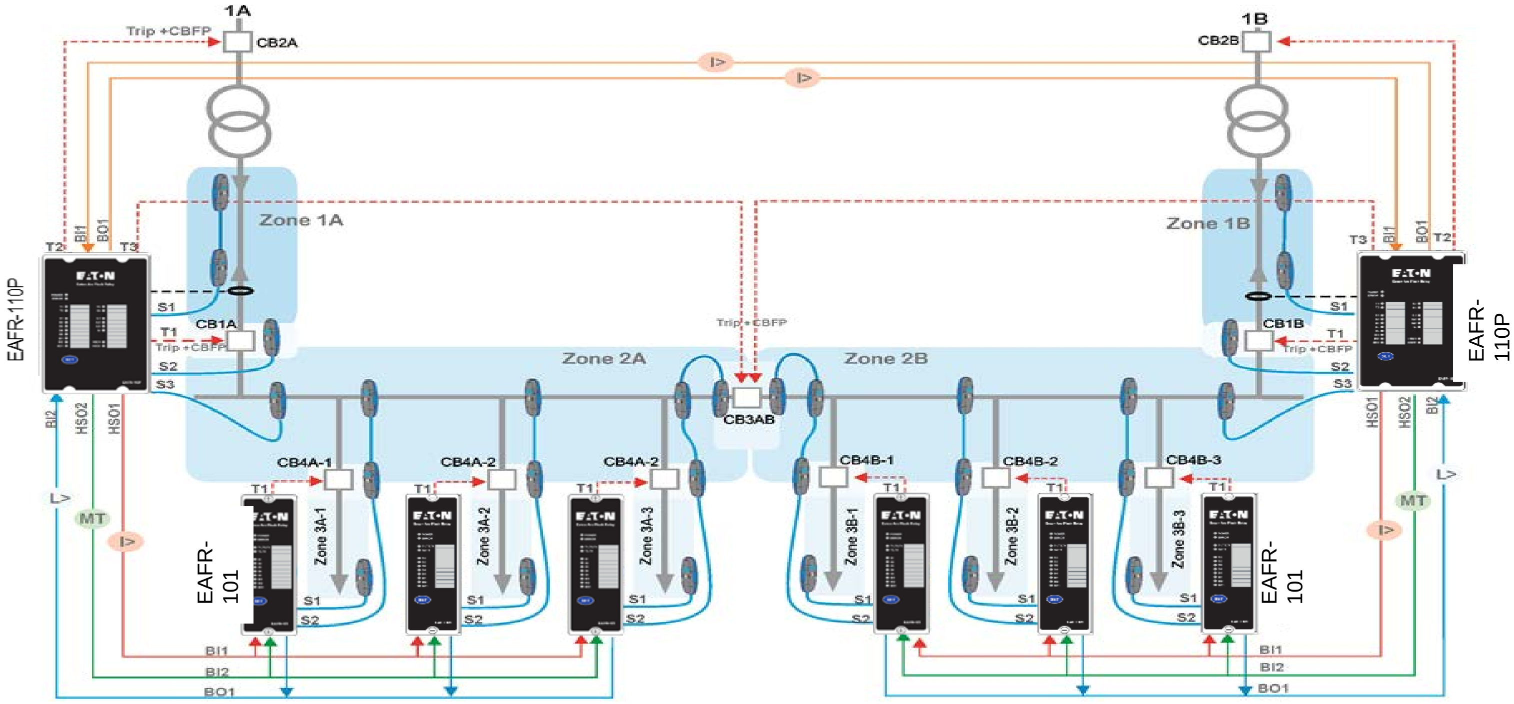
- Detect (sputtering) low power phase to ground arc faults

  - Optimal sensor sensitivity for quick detection before fault escalates.

  - Current pickup setting for high resistance sputtering fault current condition on phase or ground.

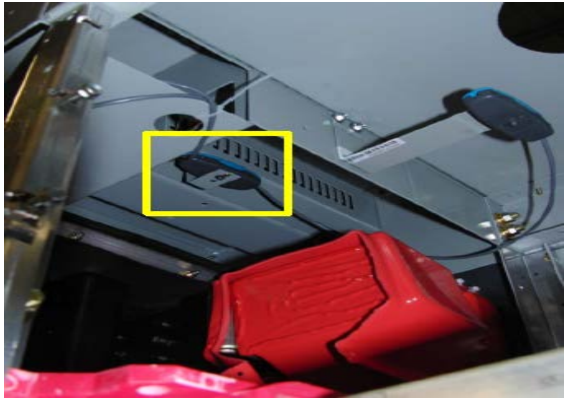


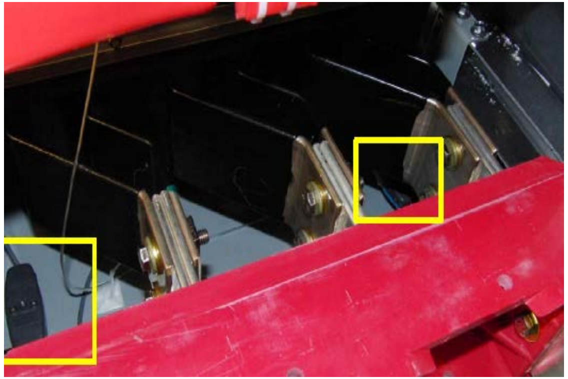
Arc Detection – Light Selectivity



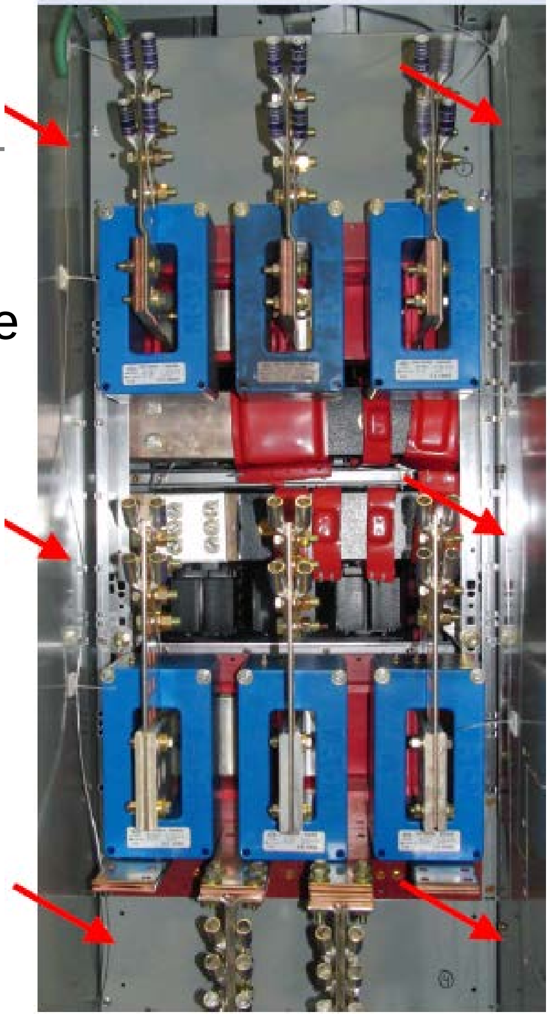
Sensor Locations

- Point Sensors

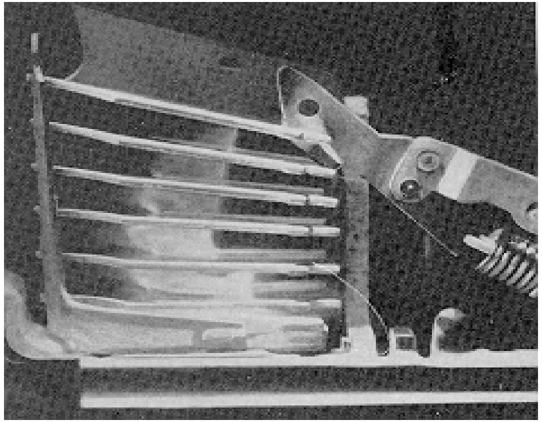




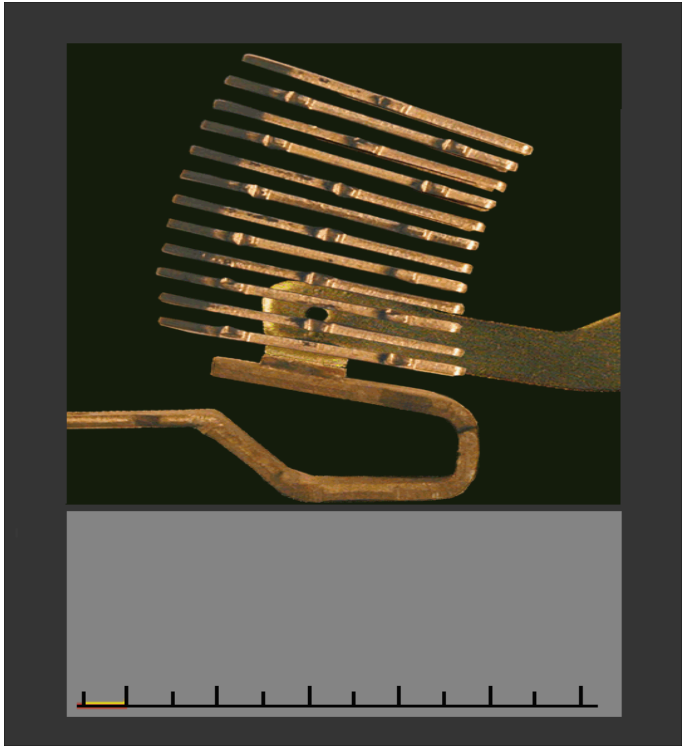
- Arrows Point to the Fiber Loop



Arc Detection - Light Sensing



- Contact parting creates arc
- Magnetic field pulls arc into arc extinguisher
- Arc divided and cooled by steel plates
- Arc extinguishes, opening circuit



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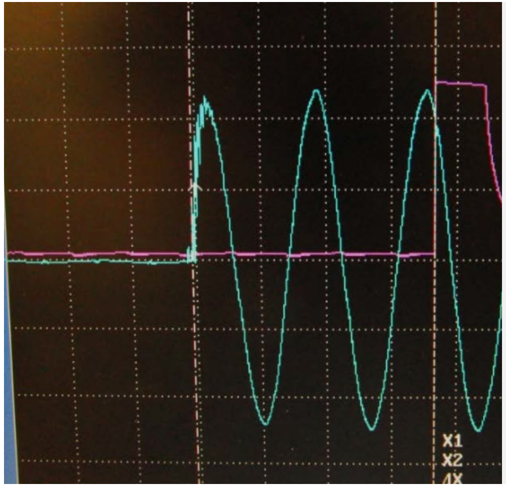
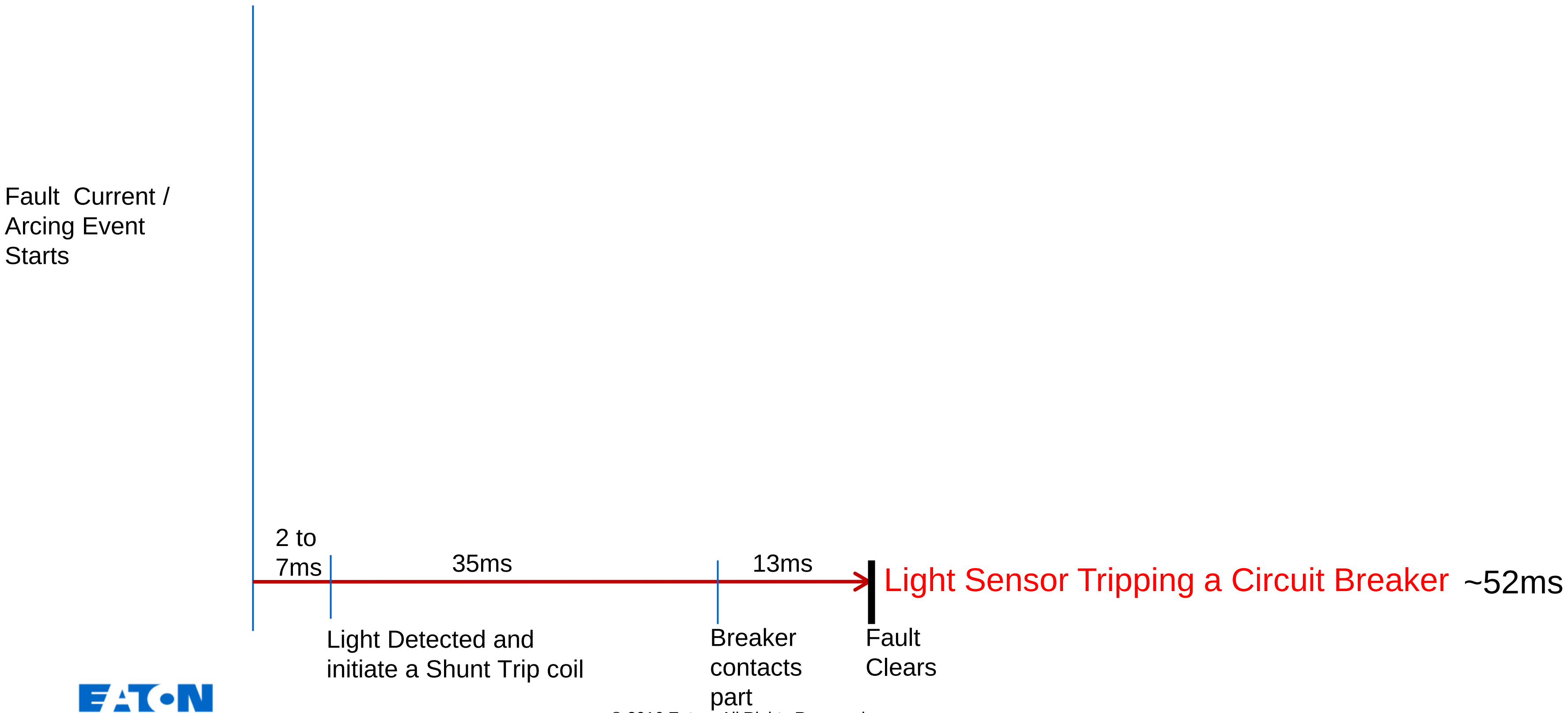
Arc Detection - Light Sensing

- Low Voltage Circuit Breakers create arc flash light when they interrupt.
- Do not want to trip the upstream circuit breaker on the light produced by the circuit breaker that is closest to the fault and is interrupting to clear the fault.
- There are light sensing relays with restrain signals to prevent nuisance trip on circuit breaker arc flash.



Fault/Arc Clearing Timing



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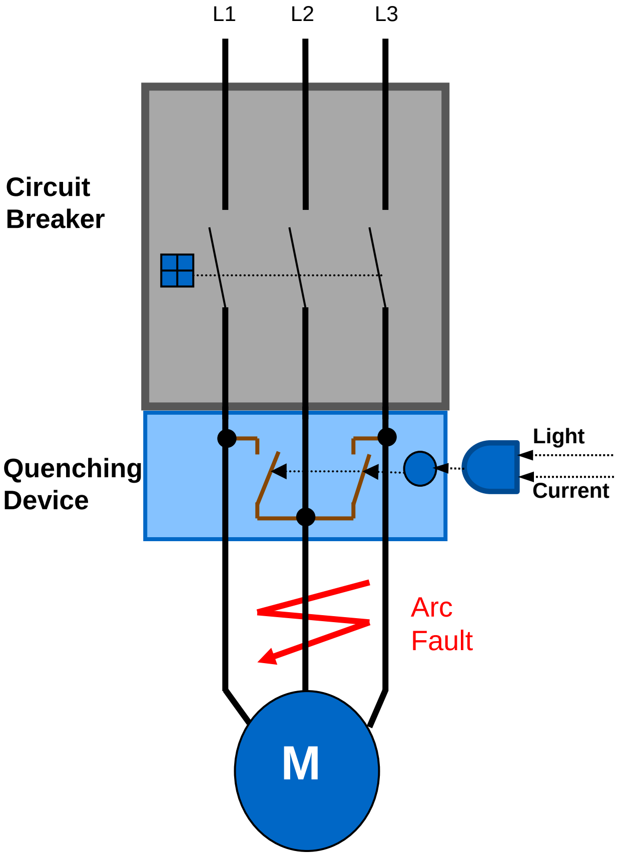
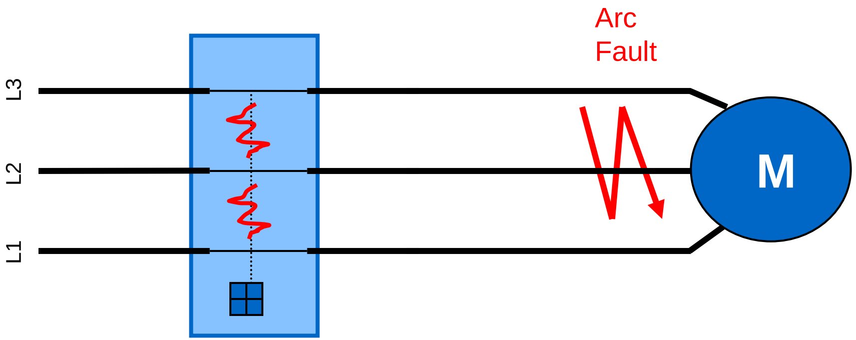
Arc Quenching Devices – Shorting Bar

- Shorting bar – eliminates current flow to fault (load)
- Maximum fault current is created.
- Large stress on upstream breaker and transformer
- Dangerous arc fault is cleared in less than 7ms
- Created fault is cleared 1 to 2 cycles later by the upstream circuit breaker



Quench the Arc with another Arc
Create an Arc In Parallel

- Higher impedance fault then the Shorting Bar (quenching device).
- Less stress on the upstream circuit breaker and transformer



Arcing Quenching Device

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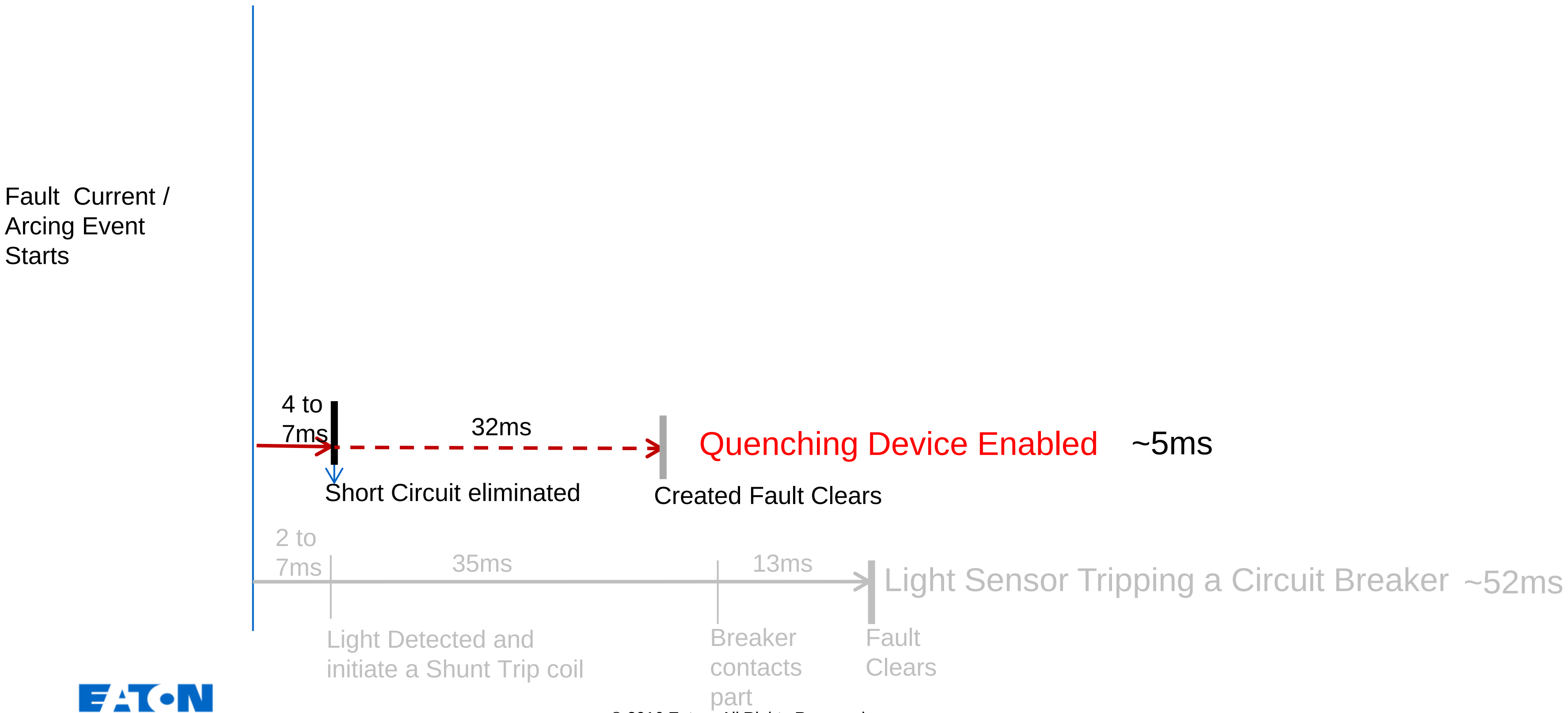

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NEC 2014’s Section 240.87

(B) Method to Reduce Clearing Time. One of the following or approved equivalent means shall be provided:

(1) Zone-selective interlocking or

(2) Differential relaying or

(3) Energy-reducing maintenance switching with local status indicator or

(4) Energy-reducing active arc flash mitigation system or

(5) An approved equivalent means

(1) Zone Selective Interlocking

Important Clearing Time Information

Circuit Breaker Time/Current Curves (Phase Curre

Magnum, Magnum DS and Magnum SB Circuit Breakers

Response: Long Delay (I^2T) & Short Delay Trip (FLAT & I^2T)

This curve is for 50Hz or 60Hz applications.

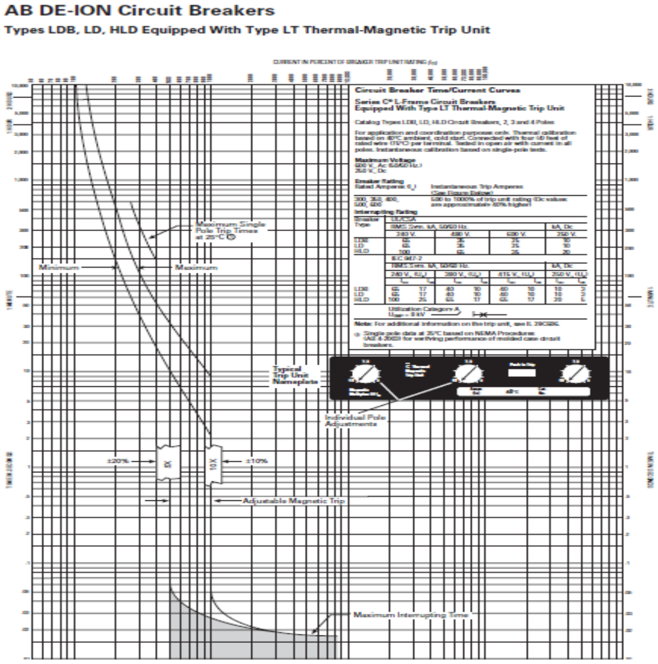
Notes:

1. If Long delay memory is enabled, trip times may be shorter than indicated on th
2. This curve shown as a multiple of the LONG PU Setting (I_r). The actual Pickup p rapid flashing of Unit Status LED on the product) occurs at 110% of the I_r, curre

   LongTIME Curve Equation: Trip = LongTIME *36/ I^2, where I is a multiple of I_r. T Function and the LongTIME function act independently and the entire set of Lor continue to be active even after the curves intersect.
3. With Zone Selective Interlocking enabled, max trip times w/o aux power are as f

	3-phase fault
60 Hz	75ms
50 Hz	85ms

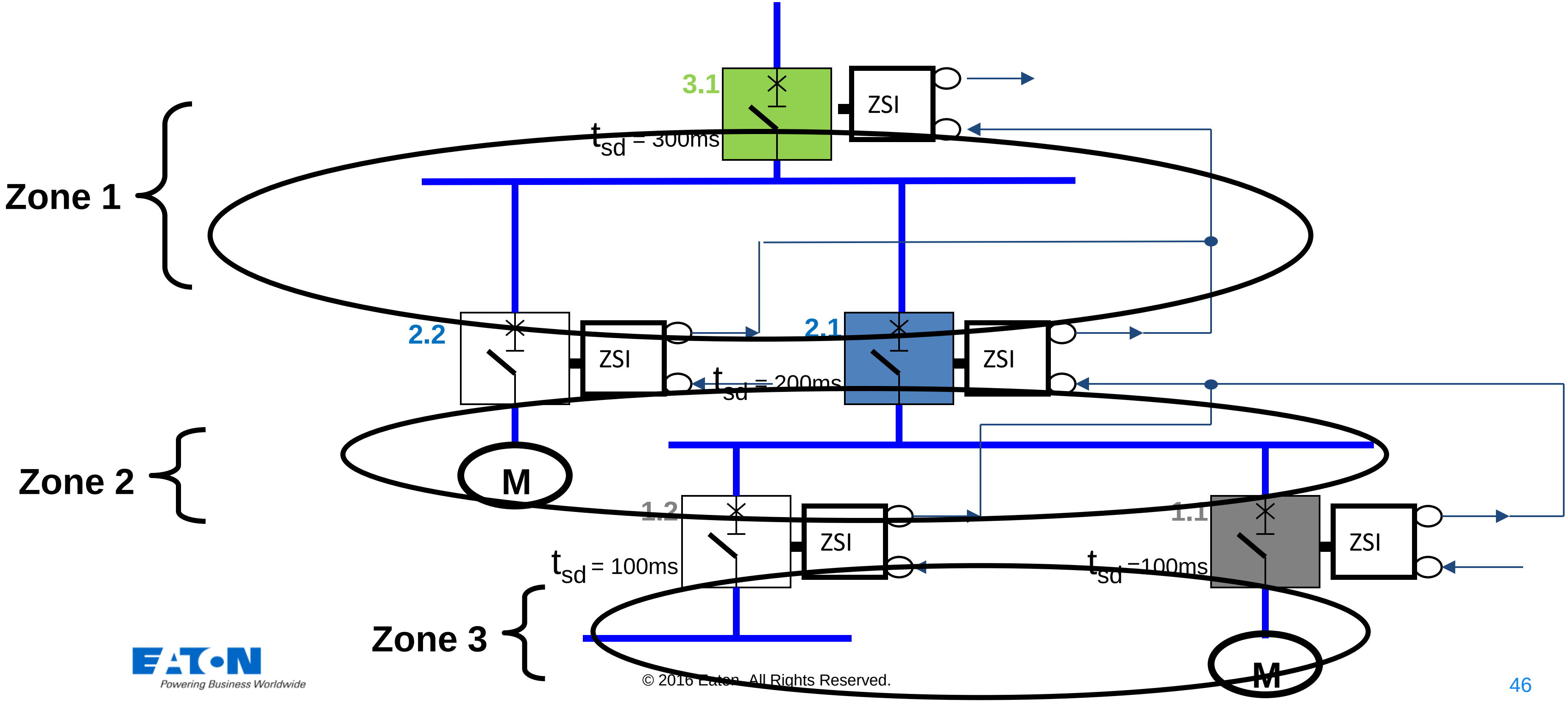
When only one pole is carrying current and a fault occurs, trip times increase t 95ms at 50 Hz, however with Aux power these times would be reduced by 10%



ZSI

- **zone selective interlock (ZSI):** A system feature designed to reduce thermal and mechanical stress on electrical distribution equipment during short-circuit or ground-fault events. ZSI permits the nearest upstream circuit breaker to a short-circuit or ground-fault to clear the fault without intentional delay, while maintaining system coordination, see NEMA PB 2.2. Per NEMA AB3-2013

Zone Selective Interlocking Example



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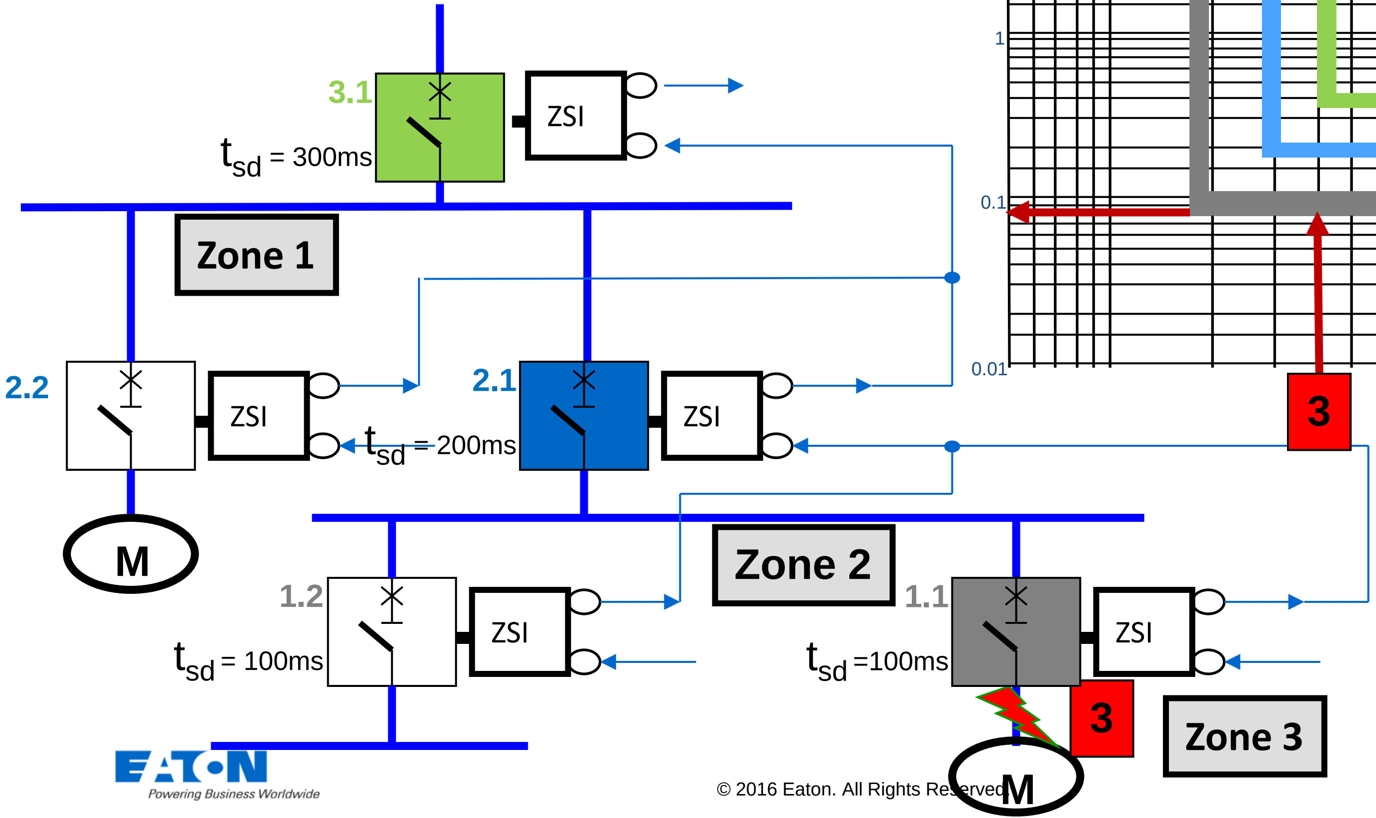
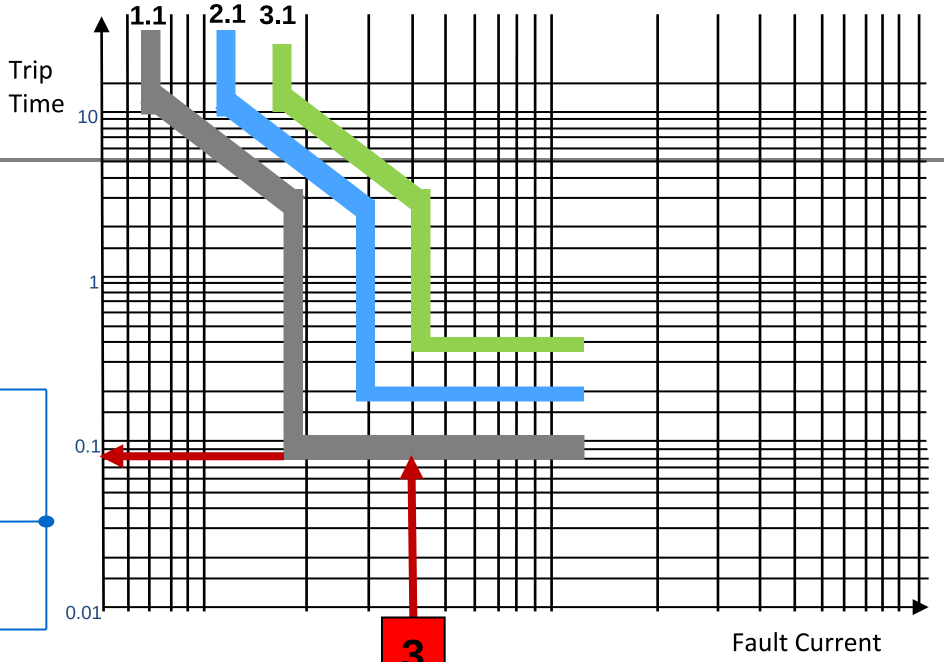
Zone Selective Interlocking





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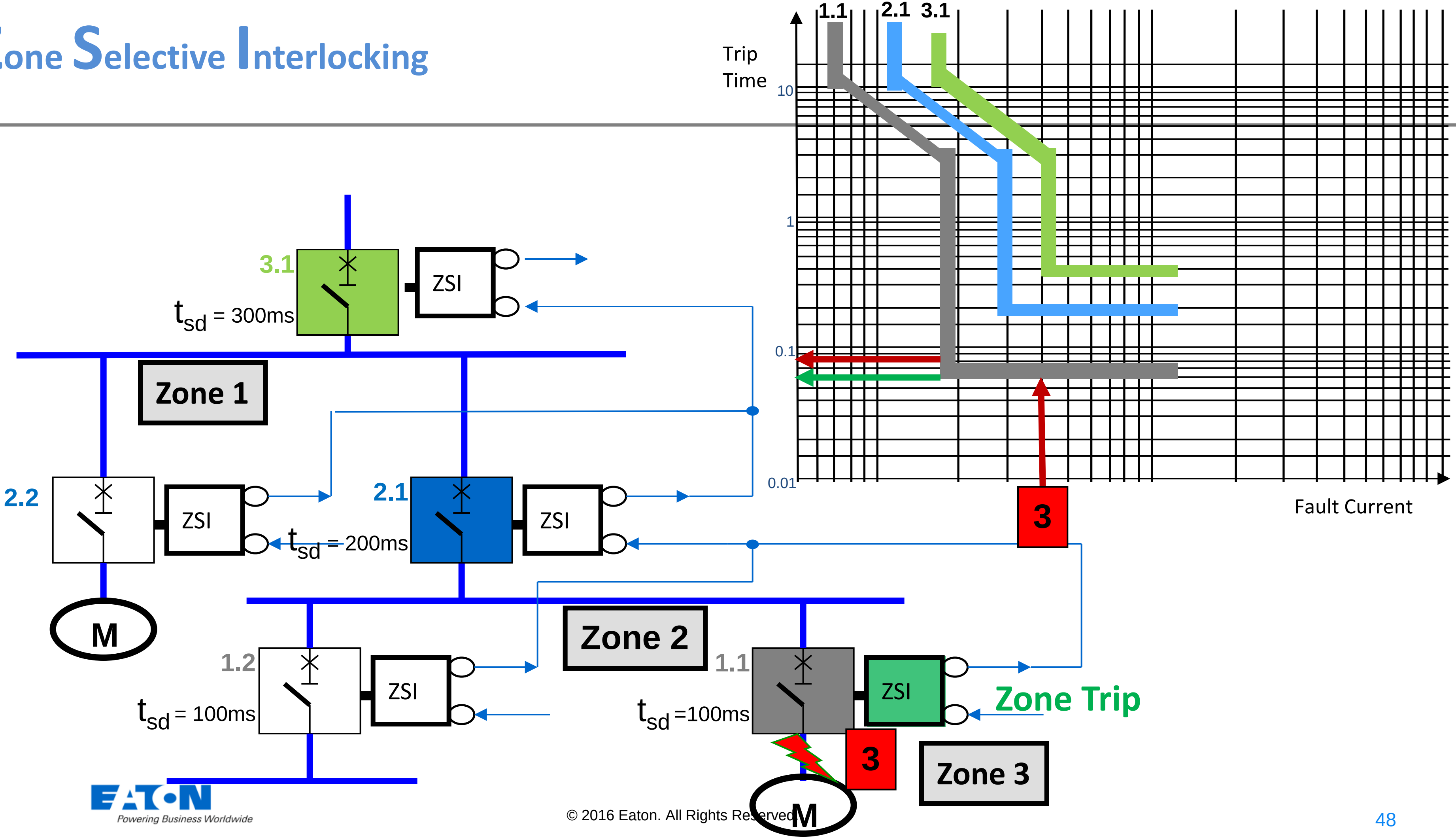

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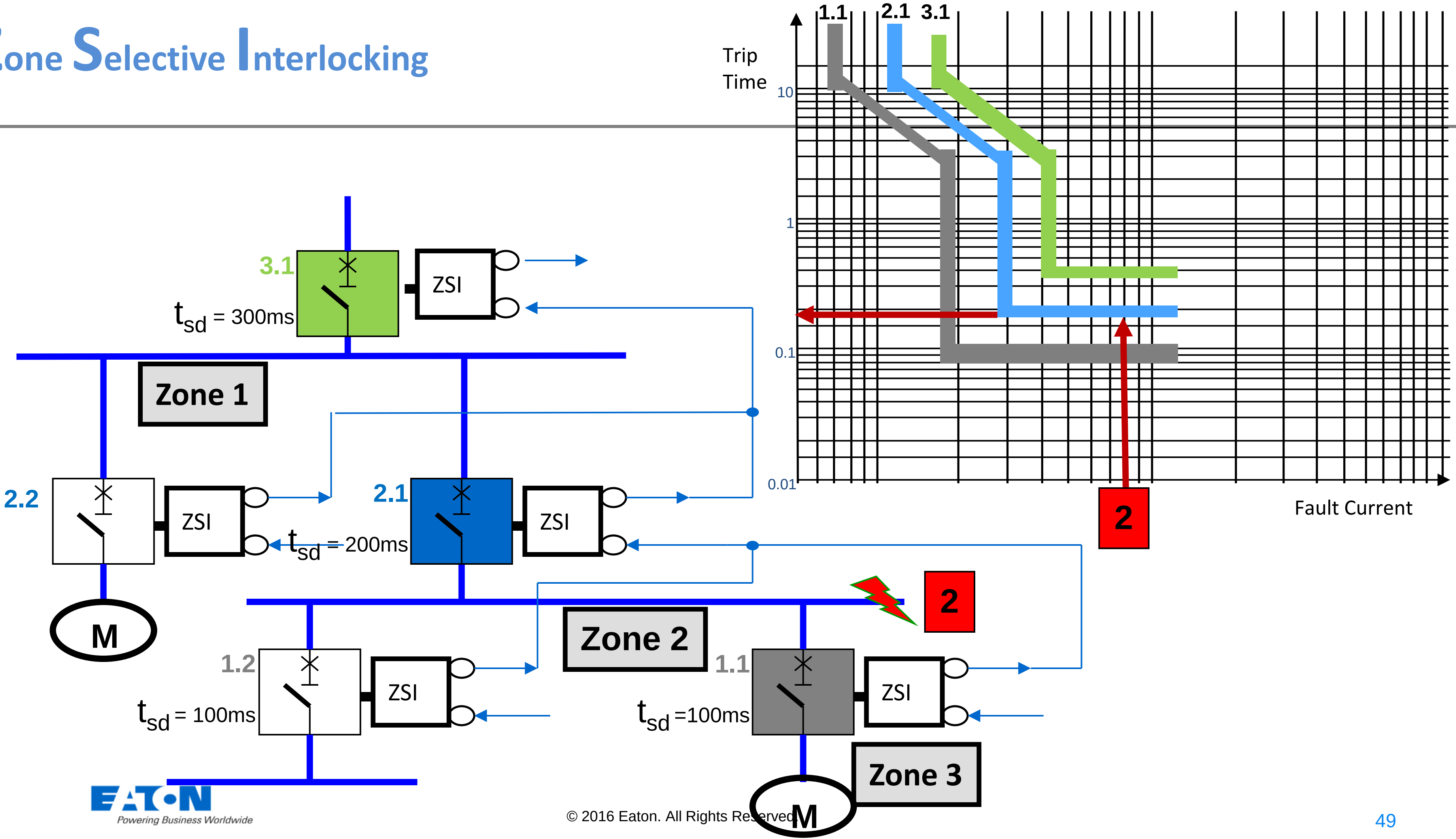

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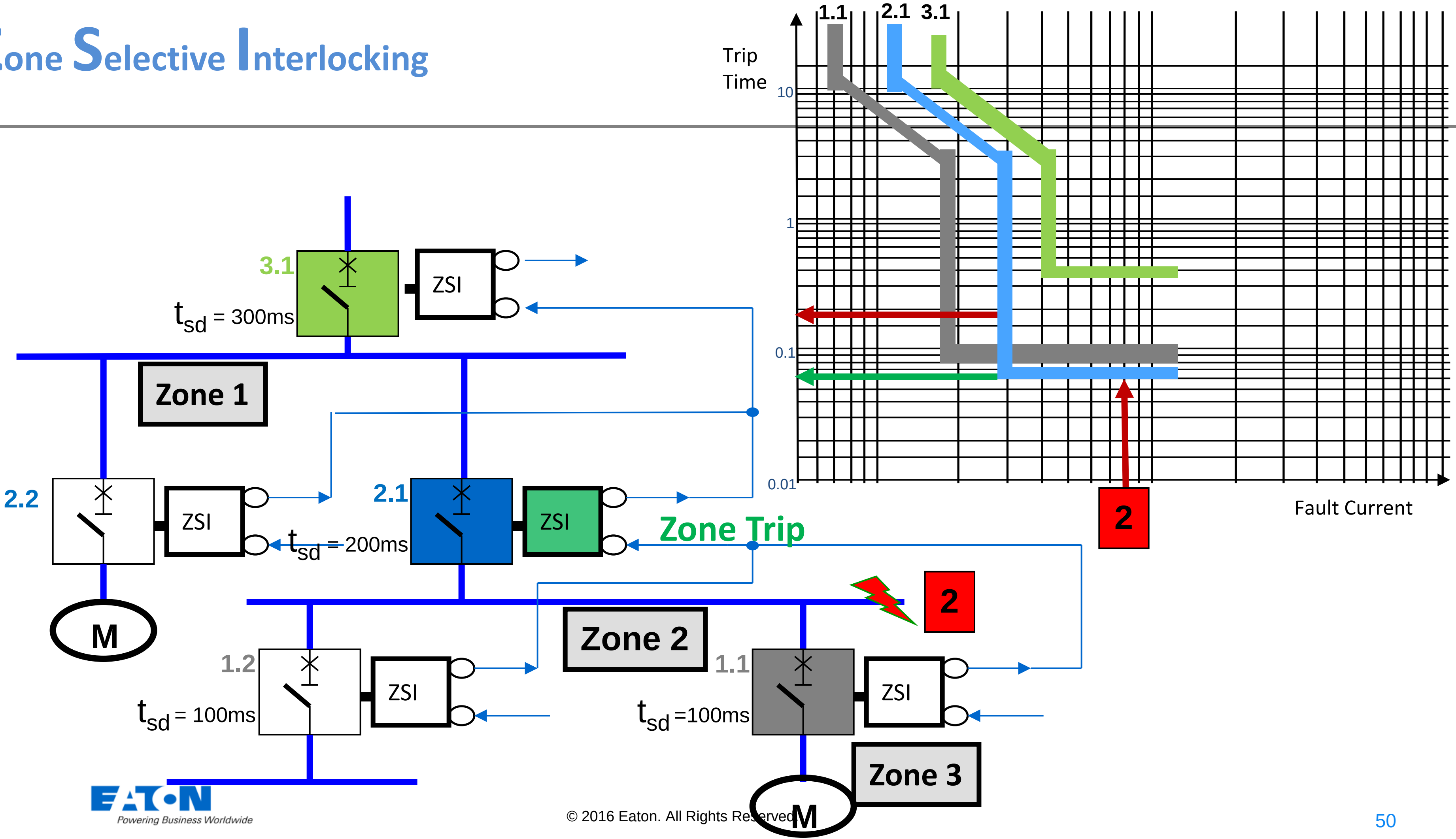

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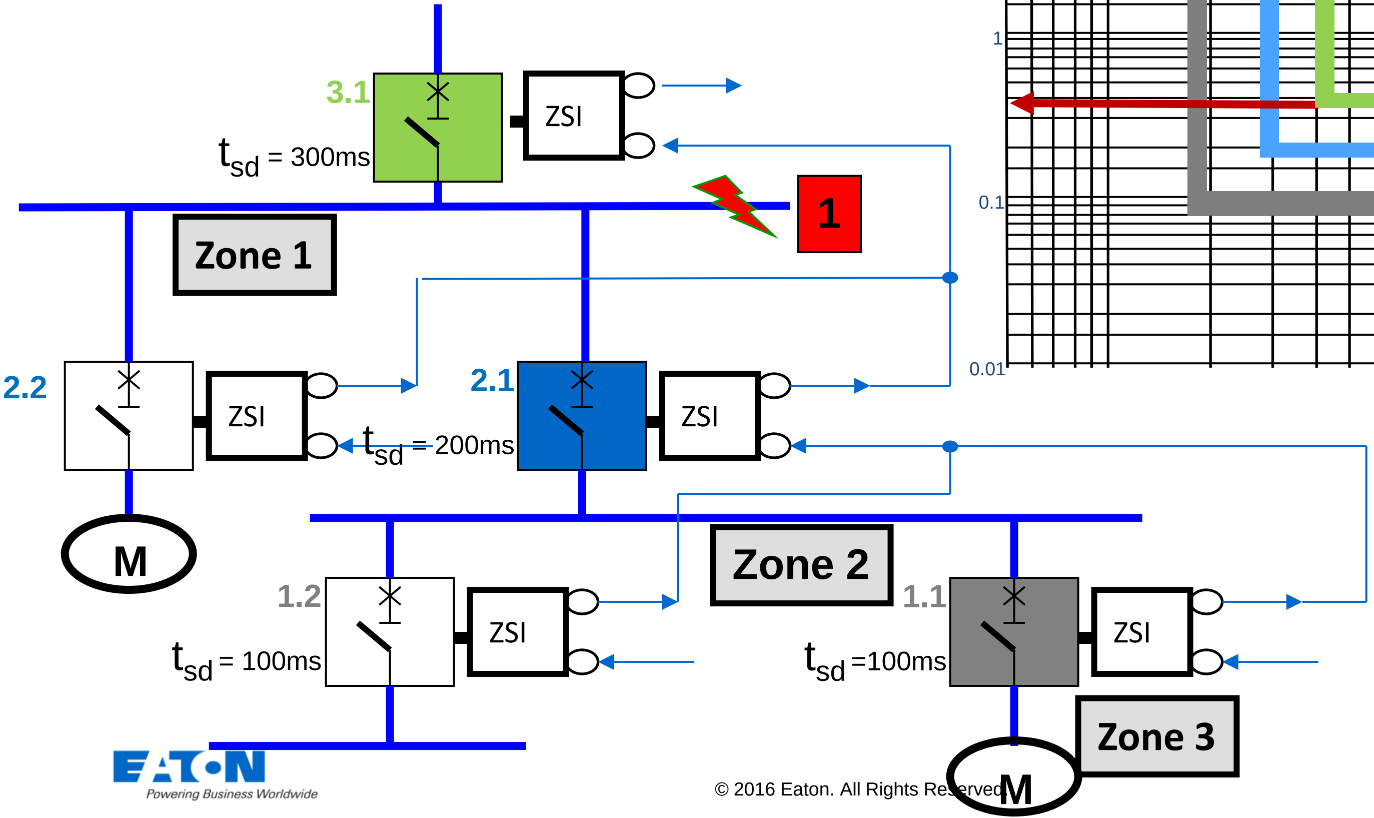

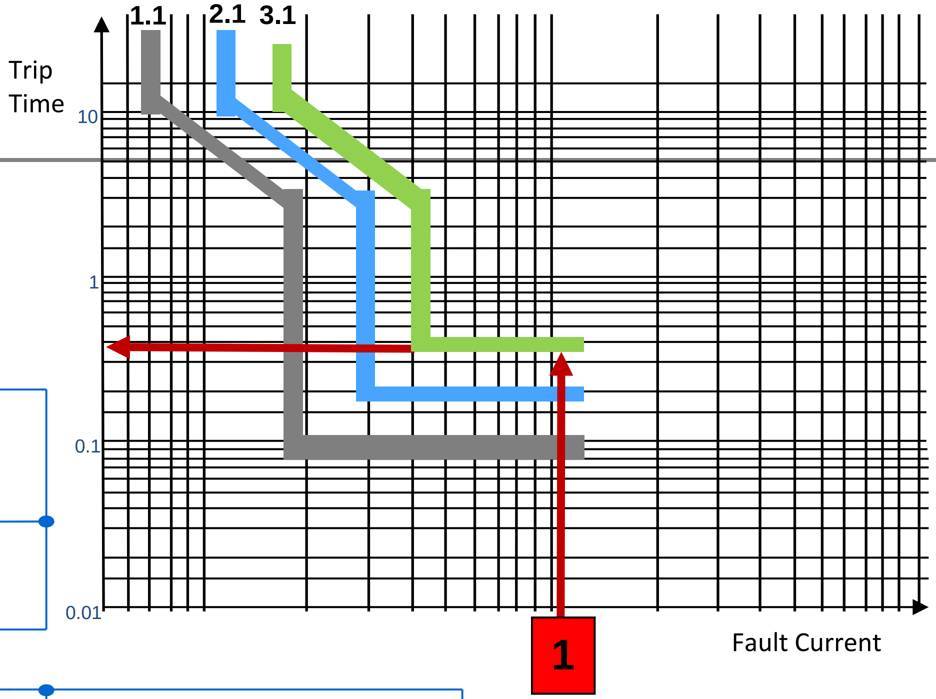

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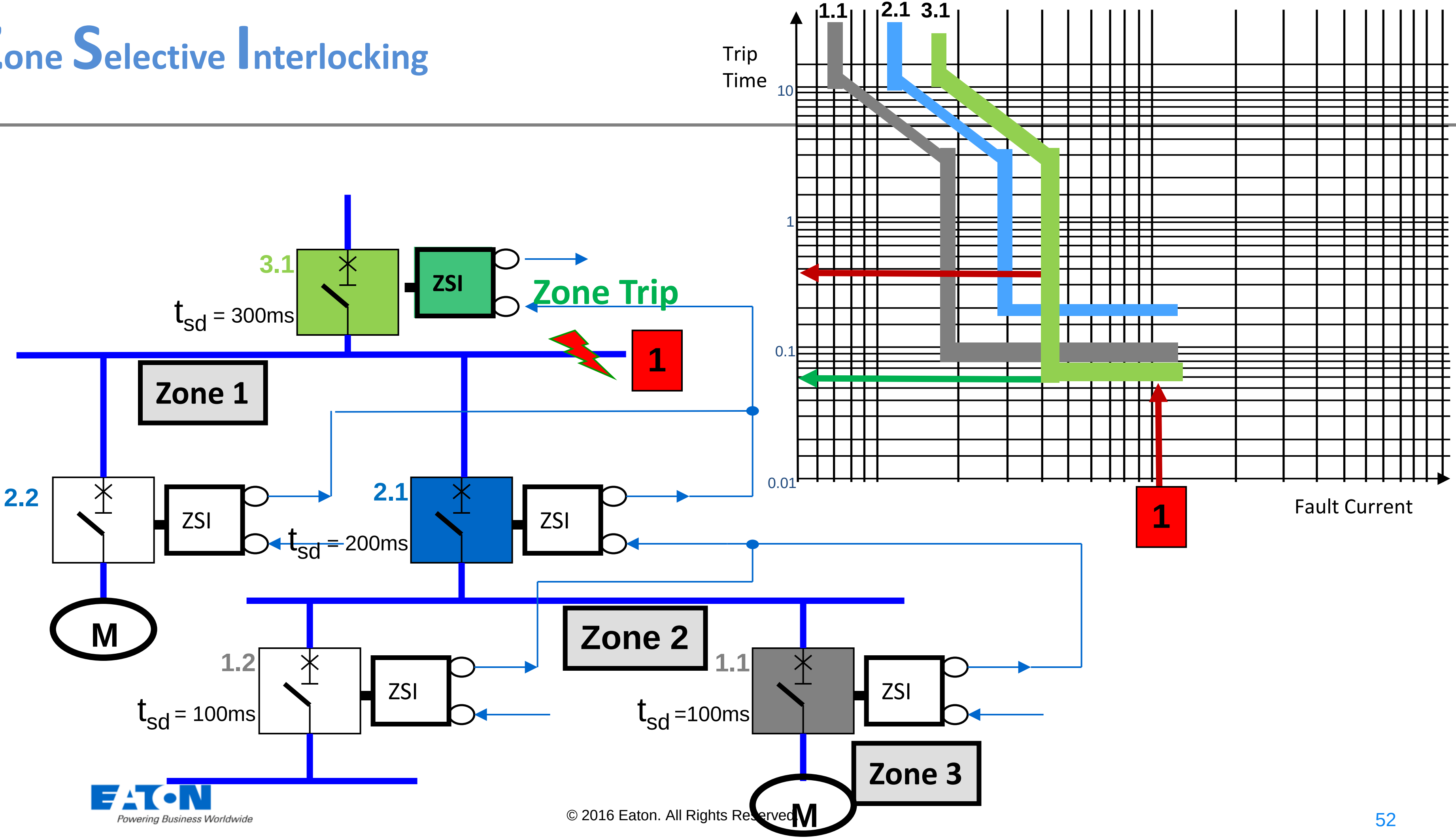
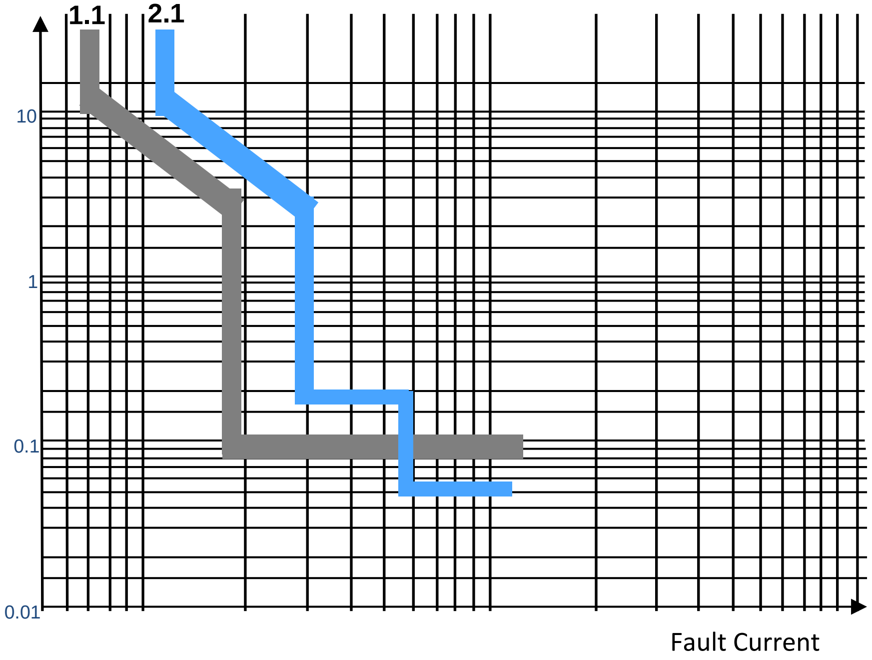


ZSI – Design Considerations

- Number of devices
- Auxiliary Power – requirement
- Length of each run
- Compatibility with other protective devices – MV

ZSI – Terminology

- ZSI on Instantaneous?
  - Definition of Instantaneous: short circuit protection without an intentional time delay.
  - Actually it is a second short delay function with ZSI because it has a restraining signal.



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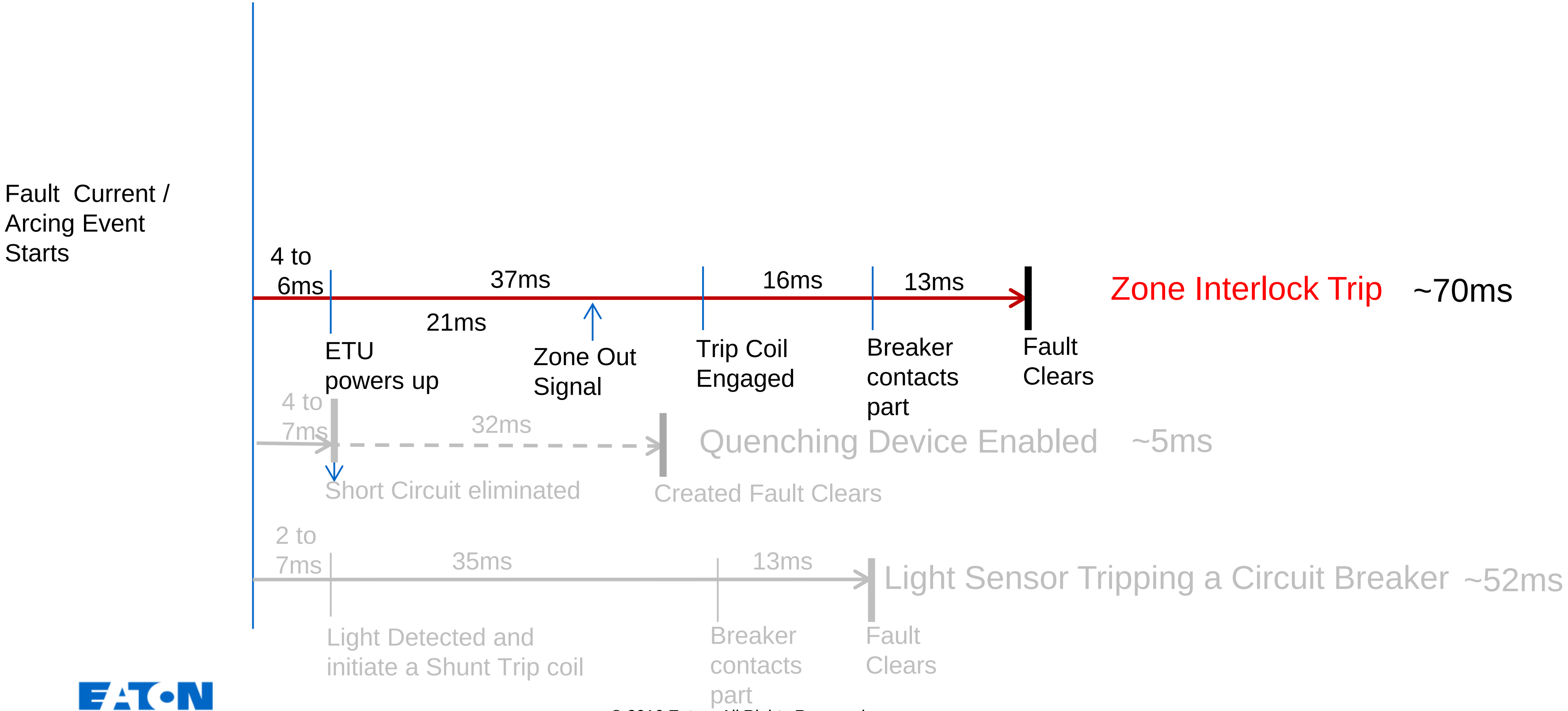
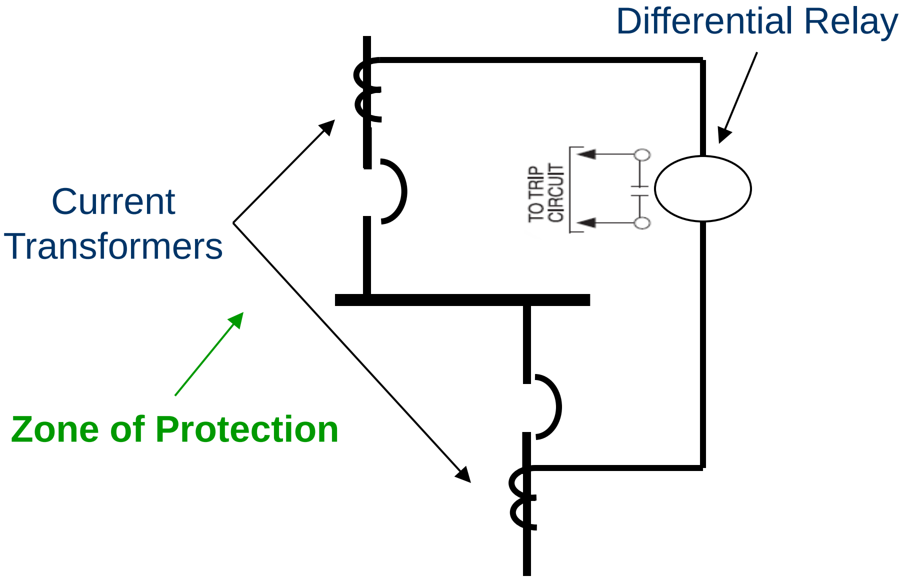


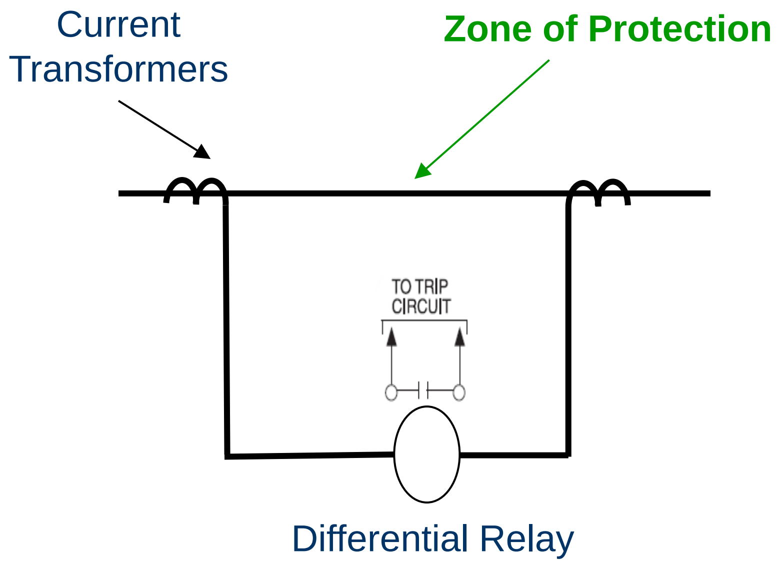
(2) Differential Relaying

- Similar To Zone Selective Interlocking
- Recognizes Faults Within The Zone Of Protection
- Acts To Reduce Arc Flash

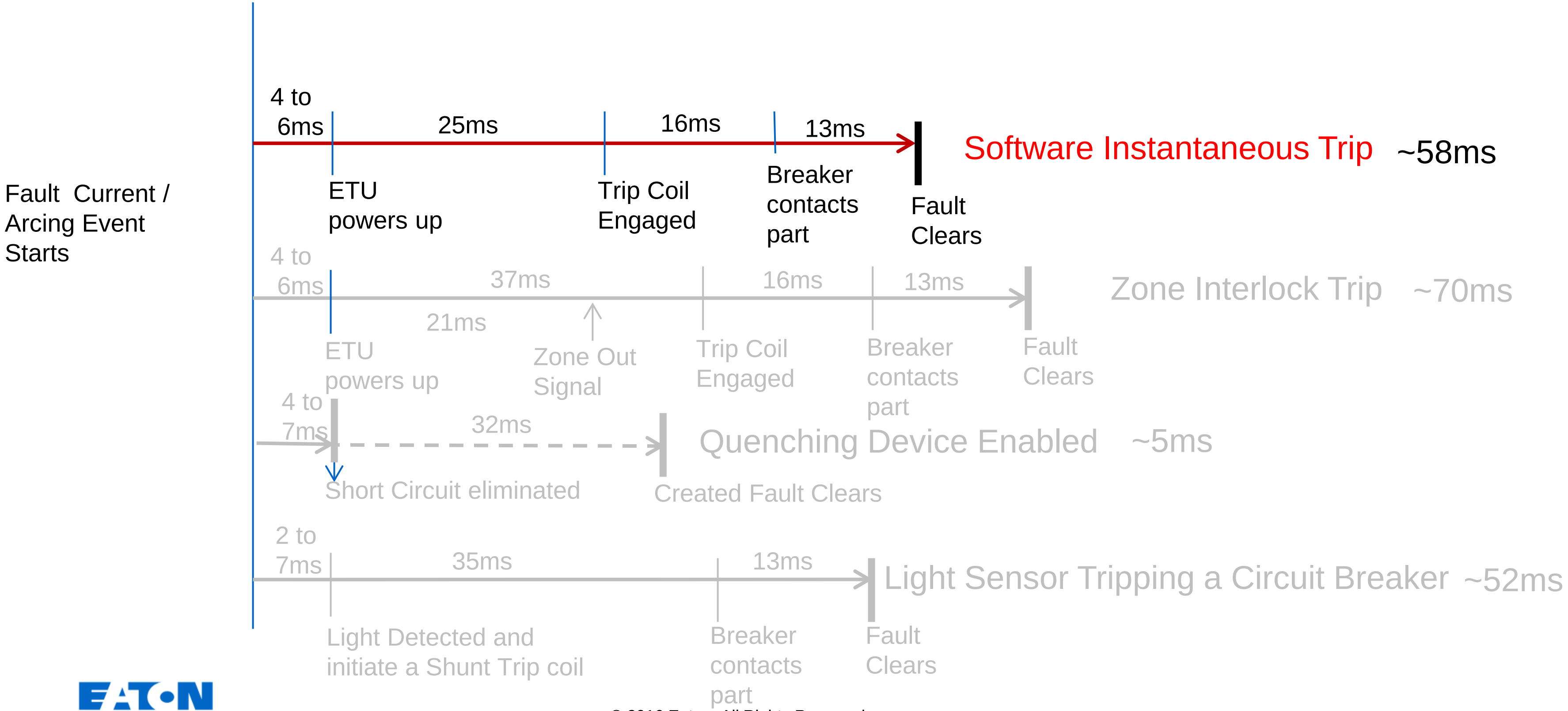


Differential Relaying

- Recognizes Faults Within The Zone Of Protection
- Current into and out of the zone must equal.
- If current is not balanced it is going into Acts To Reduce Arc Flash



Fault/Arc Clearing Timing



(3) Energy-reducing maintenance switching with local status indicator

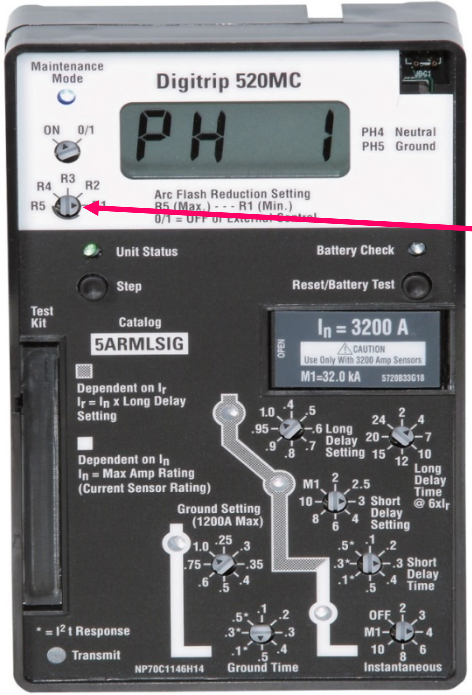
Indicating Light

Lockout

Tag out

Switch

Arc Flash Reduction Maintenance Switch



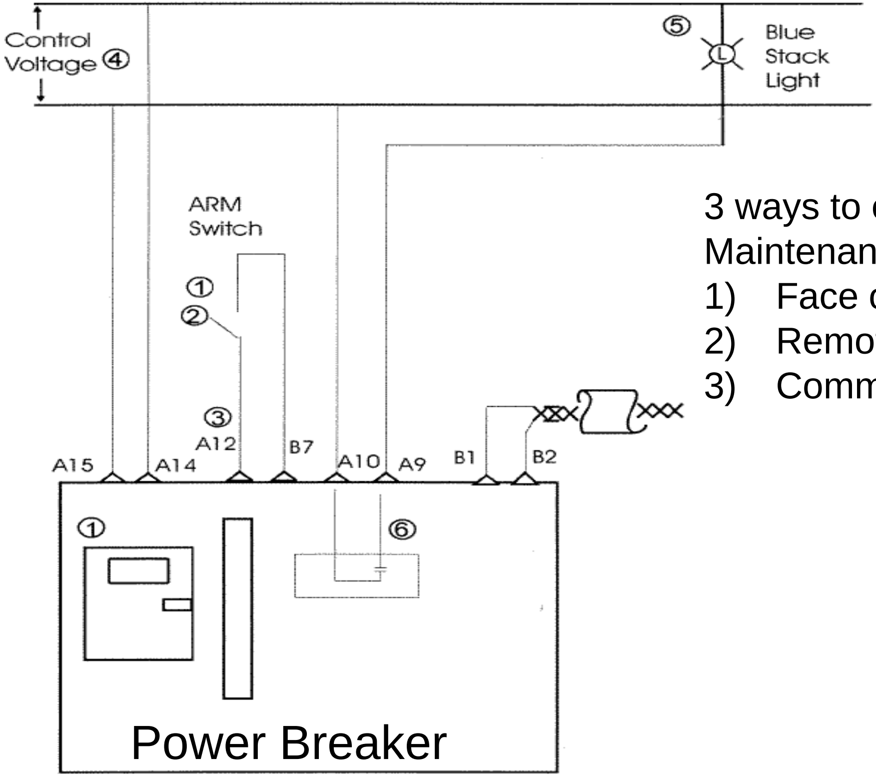
- ARMS uses a separate bypass path that is strictly analog, bypassing all issues such as microprocessor boot up time, A/D conversion rate or code execution time saving a couple of milliseconds (and therefore calories) over something that "just" uses the instantaneous trip.

- Blue LED “Maintenance Mode” lit indicates that it is engaged.

5 Position Arc Flash Reduction Setting:
From R5 (10x trip rating) …. To R1 (2.5x trip rating) Reduction

- **Remote Indication:**
  - **Power Relay Module Maintenance Mode Contact**
- **Remote Enable: via communications**
- **Lock-out/Tag-out**

Arc Reduction – Maintenance Mode Switch

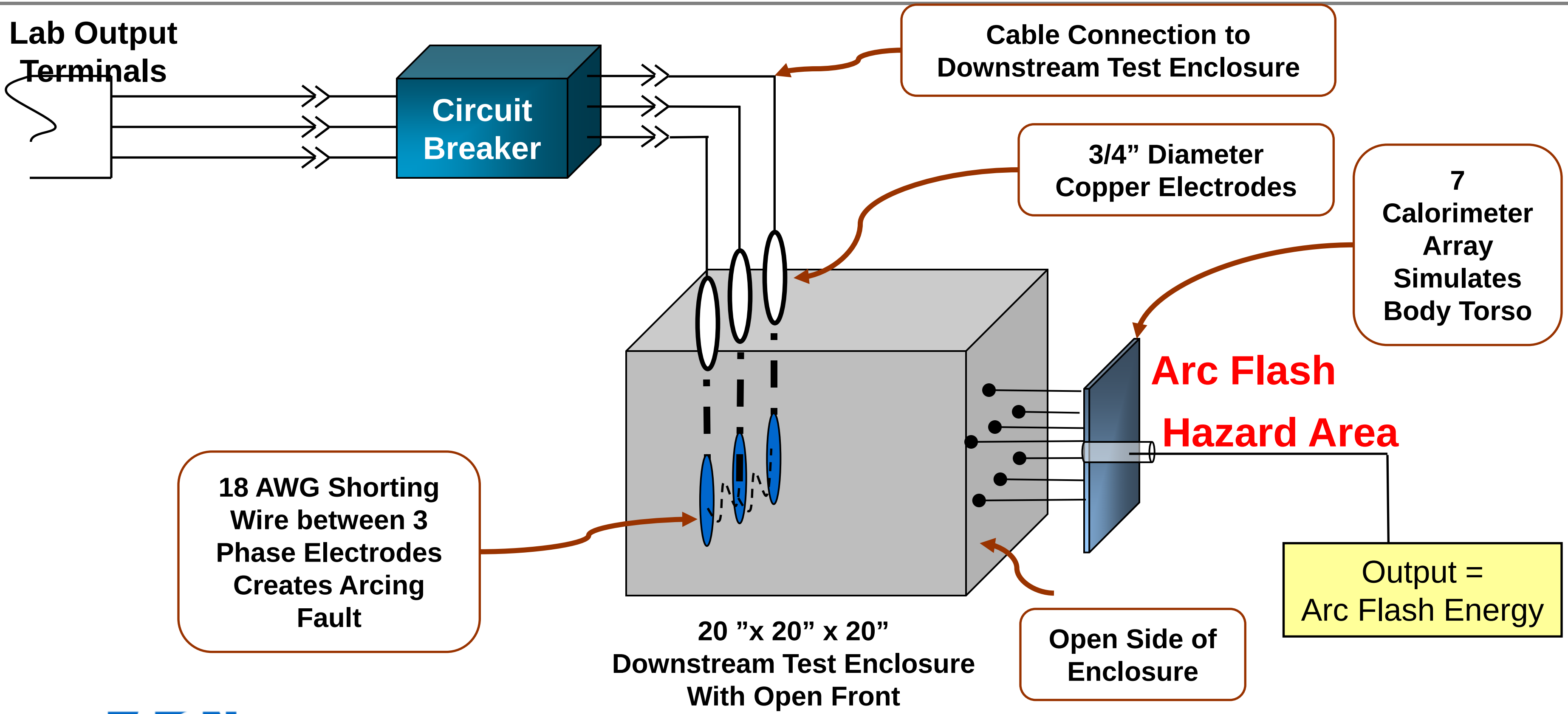


3 ways to enable the Maintenance Switch

1) Face of the trip unit
2) Remote Switch
3) Communications

Arc Flash Testing

IEEE 1584 Test Setup for Power Circuit Breakers



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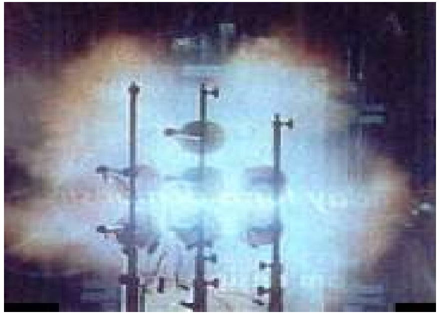
Magnum DS Arc Flash Test Program

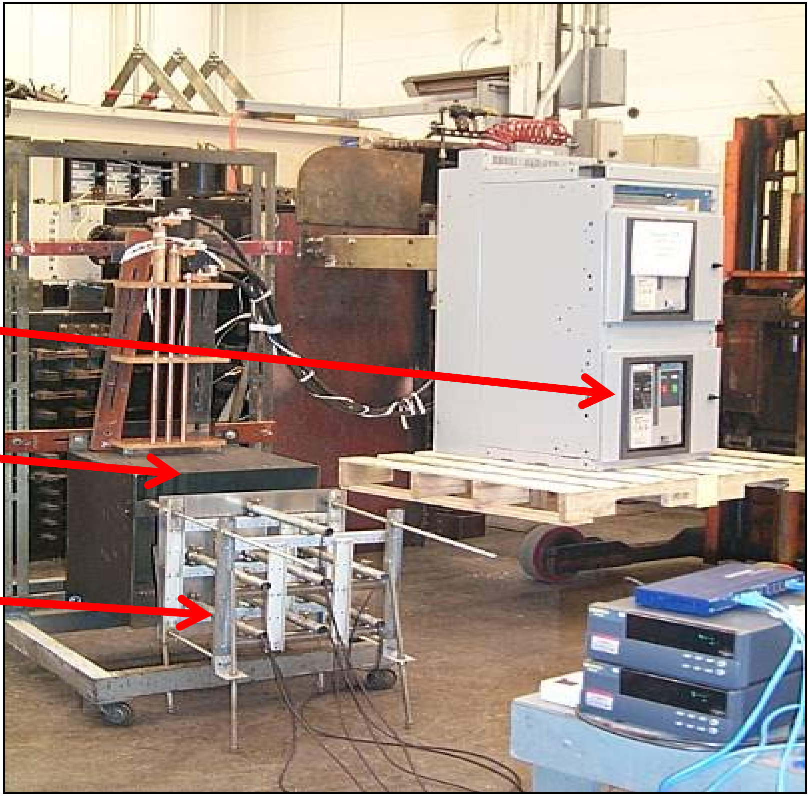
Eaton High Power Test Laboratory – Test configured per IEEE 1584



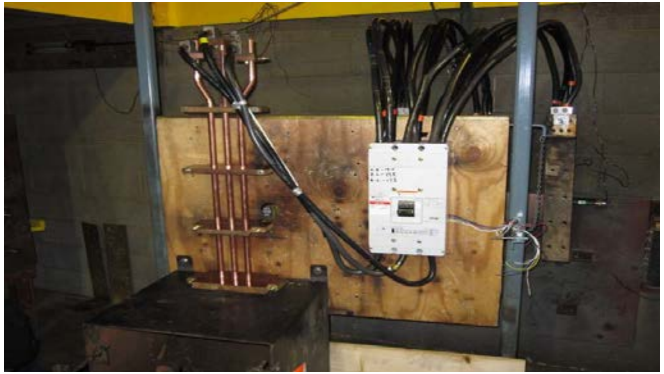
Circuit breaker
with ARMS enabled

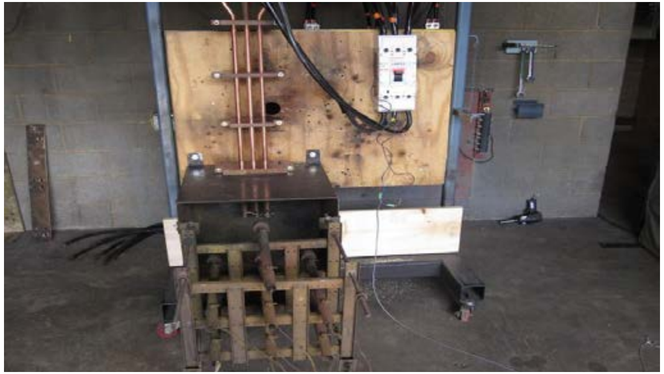
Enclosure
with internal 3 phase fault

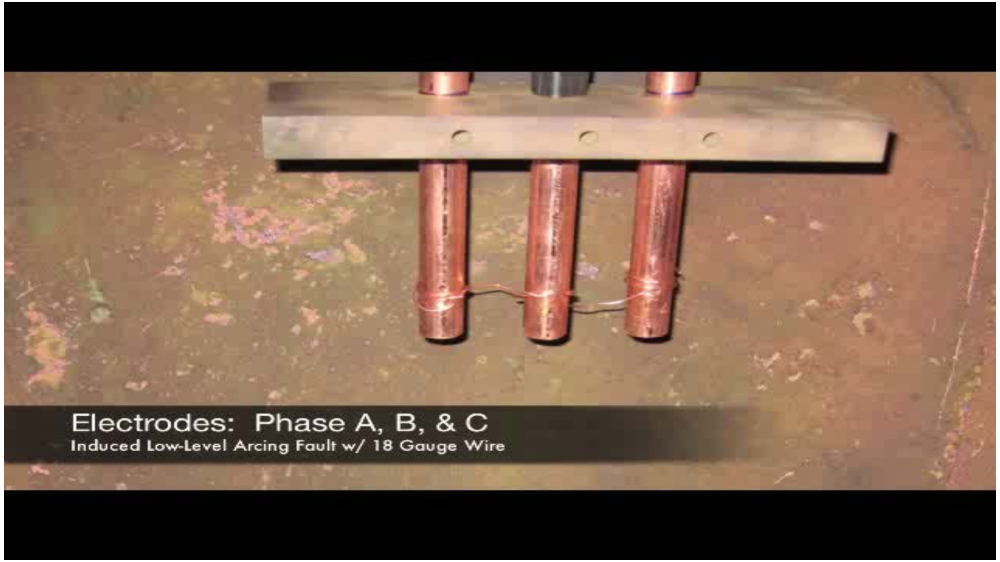
Calorimeter Array



Maintenance Mode Switch – MCCB Tests







Arc Flash Reduction Maintenance Switch (ARMS)

- ARMS uses a separate bypass path that is strictly analog, bypassing all issues such as microprocessor boot up time, A/D conversion rate or code execution time saving a couple of milliseconds (and therefore calories) over something that "just" uses the instantaneous trip.

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Arc Flash Reduction Maintenance Switch (ARMS)

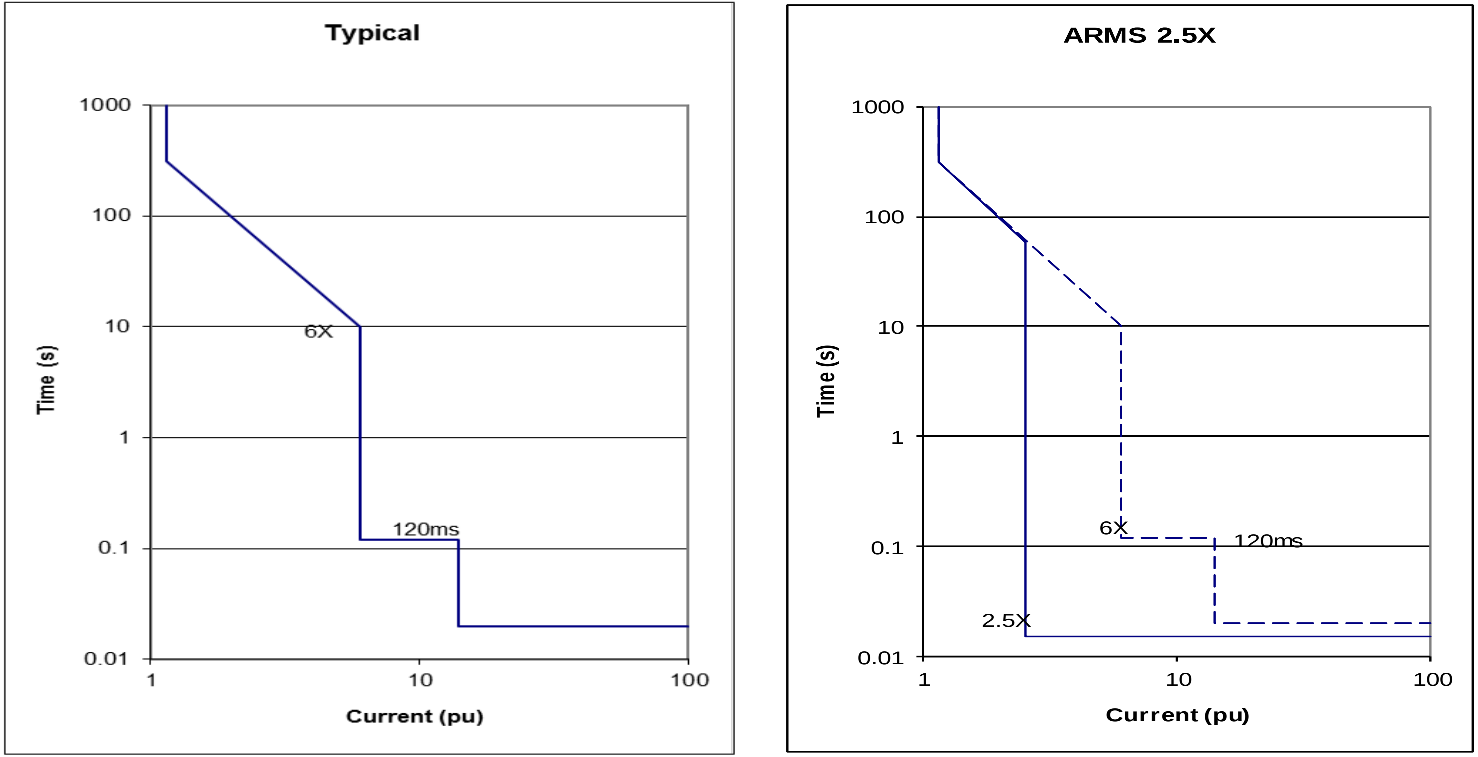
Upon completion of the maintenance, the lock is removed, the switch is manually opened, and all previous trip unit settings are again re-activated, without need for recalibration.

Maintenance Mode Now Available for Molded Case Circuit Breakers

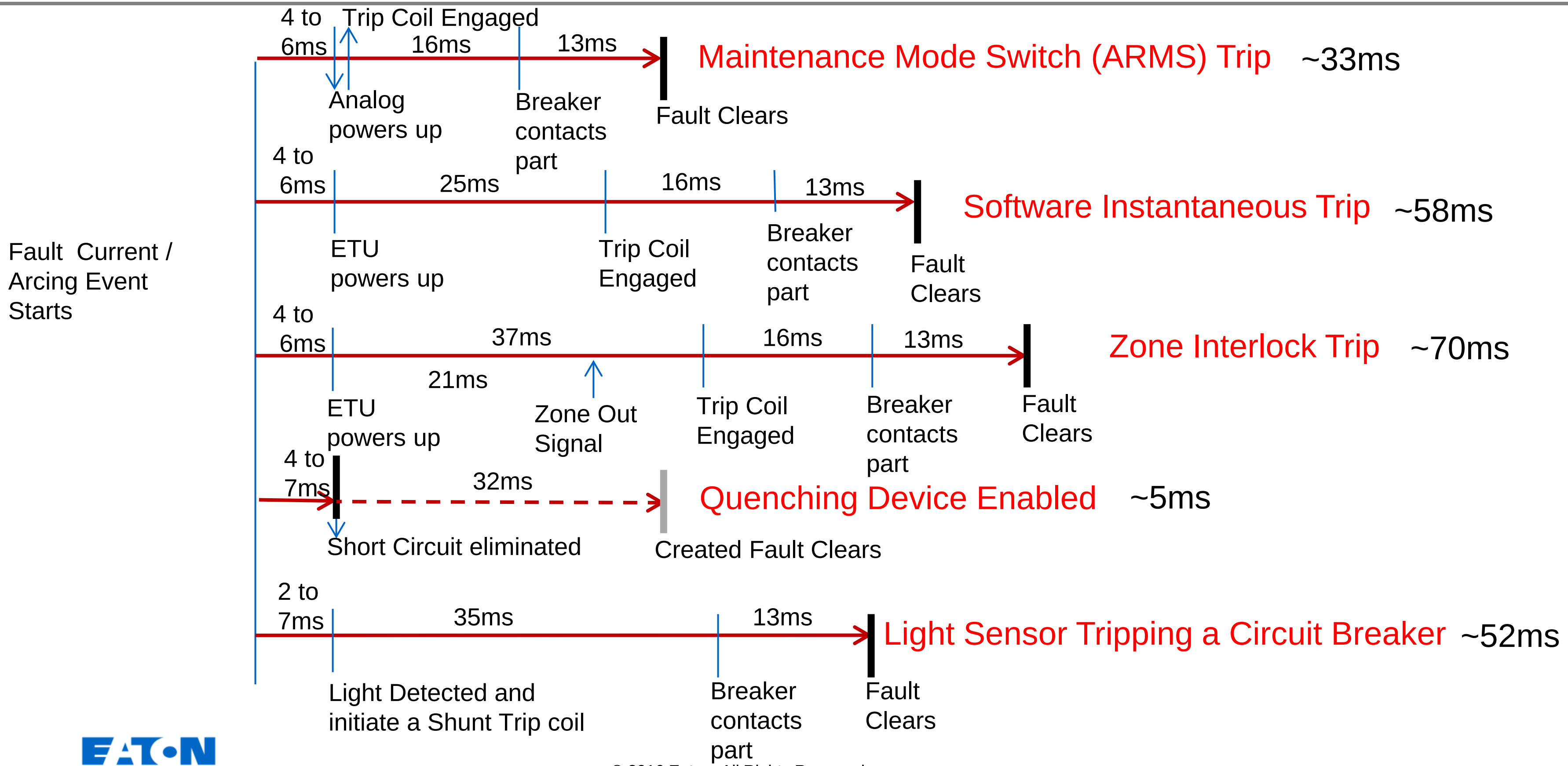
- •Two instantaneous Maintenance Mode Settings of 2.5 and 4x In
- •Five Instantaneous Normal Mode Settings of 6, 7, 8, 10 and 12 x In

MCCB Breaker with Maintenance Mode Equipped Trip Unit

Maintenance Mode Trip Curves



Fault/Arc Clearing Timing



Arc Flash Mitigation

Pre Arcing | Arcing

Passive

Arc Prevention
- Training -Safe Work Practices
- Maintenance
- Good Design
- Remote Racking

Arc Containment
- Arc Resistant / Explosion Proof Enclosures: Panelboards, Switchboards, Motor Control Centers and Switchgear
- Personal Protective Equipment (PPE)

Active

Arc Prediction - Monitoring
- Partial Discharge
- Smoke
- Temperature
- Acoustic

Arc Detection
- Current / Voltage signal analysis
- Ground Fault
- Light sensing

Arc Elimination
- Shorting Bar – Arc Mitigator
- Create a Parallel Arc

Arc Flash Reduction
- Differential Protection
- Zone Selective Interlocking
- Maintenance Switch