Ft Worth IEEE-PES

Arc-Flash Hazard Mitigation & Selectivity

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imagination at work

Electrical hazards

Today's power system engineer must not only assure that the facility receives all the power it needs efficiently and reliably, it is also important to make sure it is done as safely as possible without loss of reliability and under tight budgetary constraints.

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Being near live electrical equipment is dangerous, whether shock or arc flash hazard, solutions exist to reduce hazard risk levels in a wide range of conditions and needs.

Example of an Arc Flash Event

635V/65kA 12 Cycle event, door open
33 cal/cm^2

BOTTOM LINE:

A blast over 40 cal/cm^2 is not survivable due to the crushing effects of the pressure wave and shrapnel.

Arc-Flash Injury Potential

Potential Health Impacts – Burns, Lacerations, Concussions, Broken Bones, Vision Impairment, Fatality

- 5 to 10 arc-flash injuries occur daily in the U.S. requiring hospitalization
- Arc-plasma temperatures may reach 35,000°F (~ 4 x hotter than the sun's surface)
- 80% of all electrical injuries are burns from electric arc-flash and ignition of employees' clothing

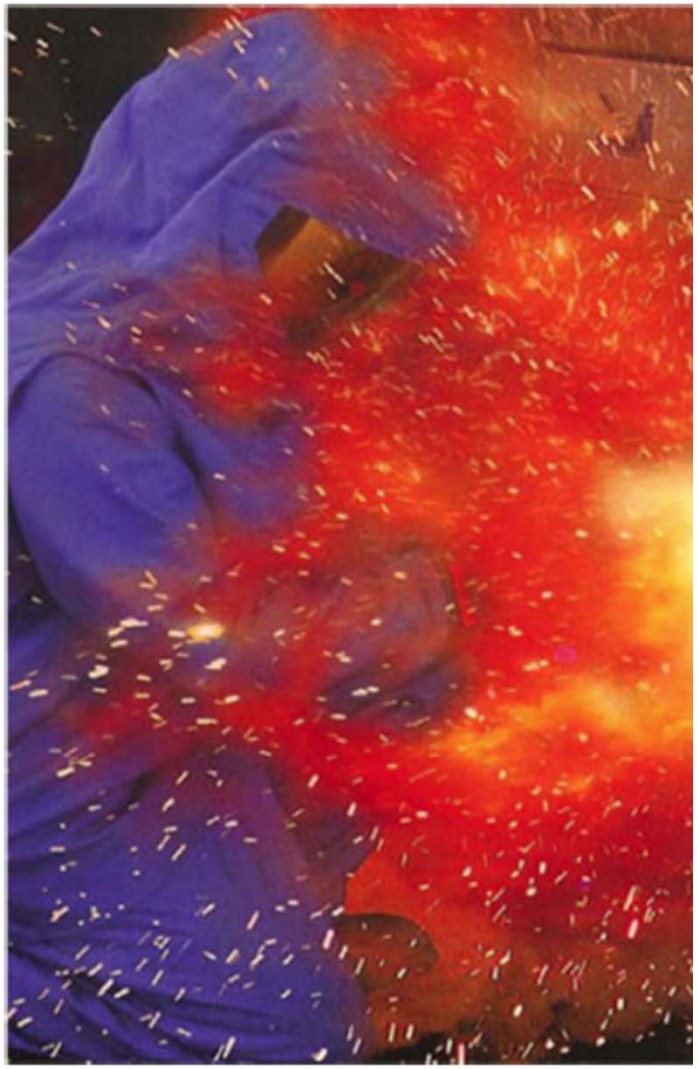


Photo courtesy of Salisbury by Honeywell

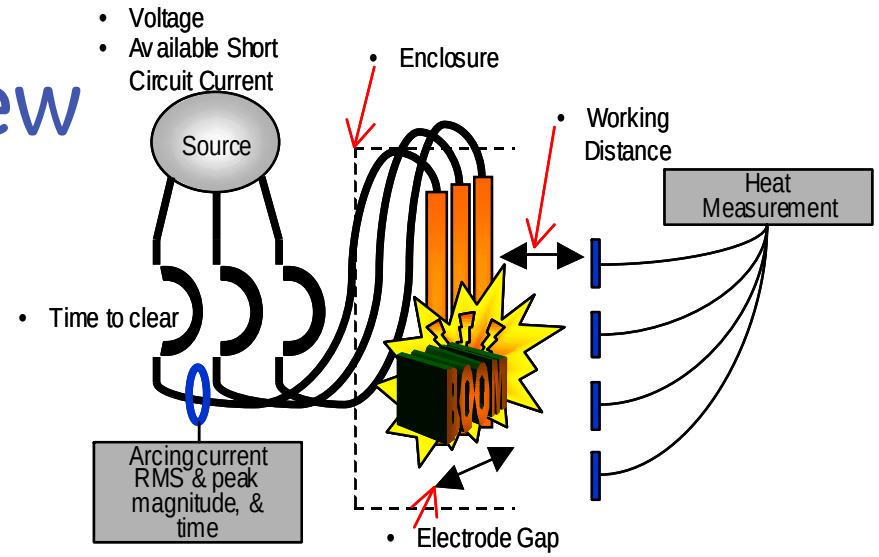
Problem scope[1]

8	Arc flash explosions per day
1 - 2	Deaths per day related to arc flash incidents
$16M	Average costs for each arc flash incident

At this cost, why take chances?

1. U.S. statistic cited by CapSchell, Inc. in a study for the Electric Power Research Institute, 1999

Arc Flash Hazard Overview



Arc Flash energy is a function of:

- Voltage → Fixed
- Available short circuit current → Based on system design and source
- Working distance → Arms are only so long
- Arc gap → Determined by equipment type
- Arcing fault clearing time (not short circuit clearing time)
- Sensitivity of Breaker/Trip Unit

→ A function of the protective device acting upon the arcing current

Clearing time is the only parameter than can be modified **after the power system design is set.** Therefore....

Arcing fault clearing TIME becomes the critical factor

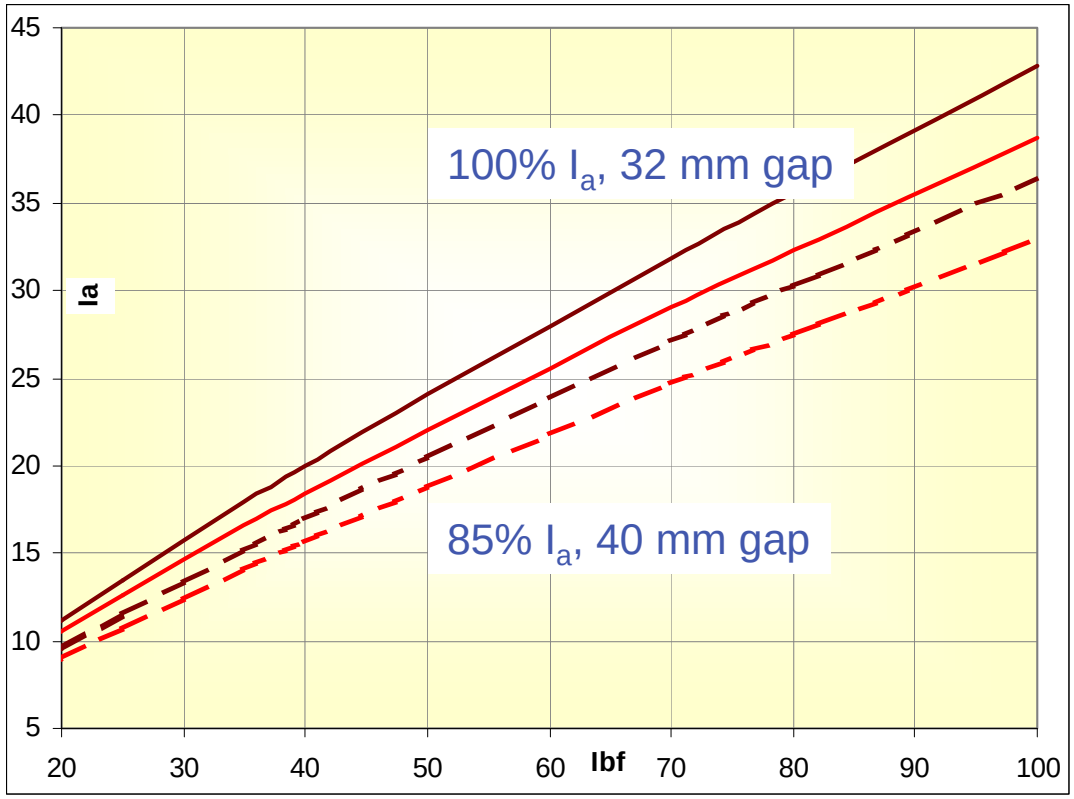
Arcing current (I_a) variability

- IEEE 1584 & NFPA 70E provide good guidelines…
- But real world variability may not be fully considered
- Tripping device response is dependent on arcing current
- Arcing current is dependent on:

Gap, Voltage & I_{bf}

The variables include:

Utility information (worst case v installed), cable length, temperature, joint & device Z, transformer Z, etc.



Arc flash protection – PPE vs. cal/cm2

<12cal/cm2

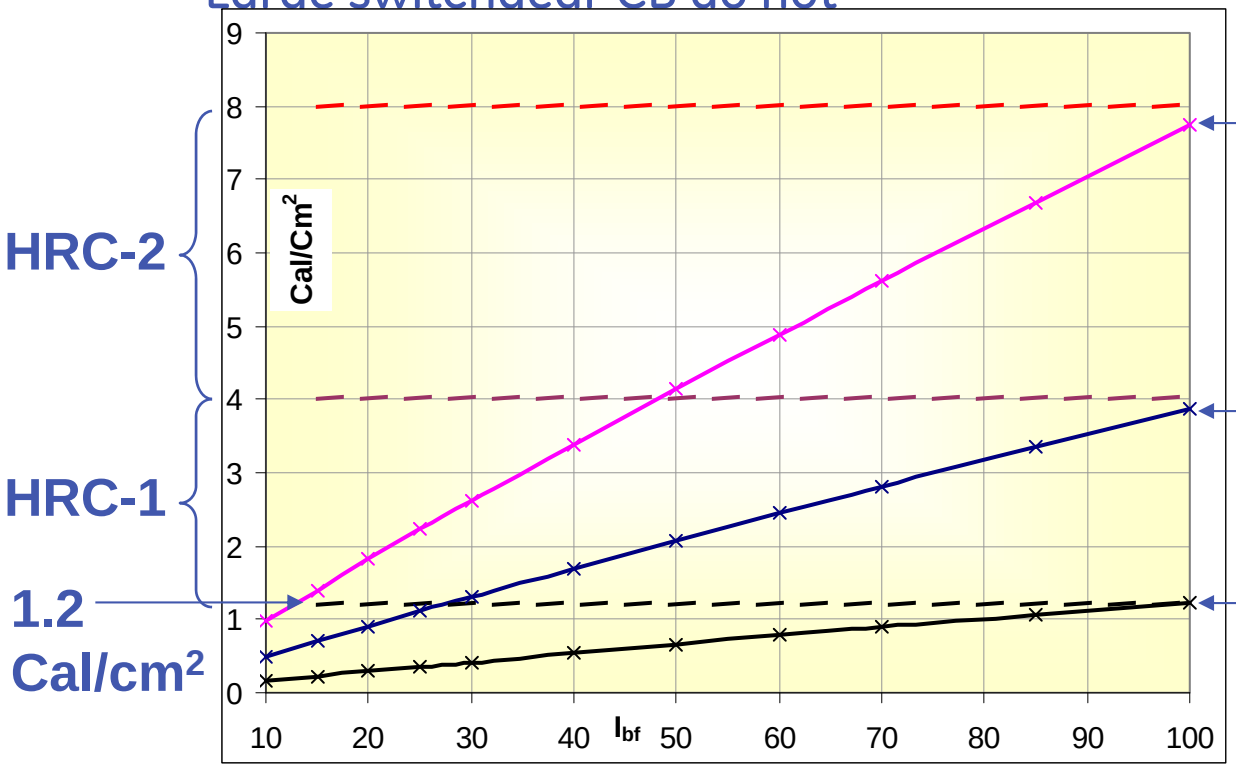
>12cal/cm2

Many systems are > 12 cal/cm2:

- Generally uncomfortable and may impair dexterity
- Wearing “suit” could possibly cause accidents
- Getting the system <12 cal/cm2 can eliminate cumbersome PPE

Incident energy dependant on event time

- Low level of incident energy requires fast mitigation.
  - ~ ½ cycle interruption or less
  - At the proper current level molded case CB & fuses operate in this range
  - Large switchgear CB do not



HRC-2

HRC-1

1.2 Cal/cm²

3 cycle (large CB) clearing time (~50ms)

1.5 cycle 600-1200A (MCCB) clearing time (~25ms)

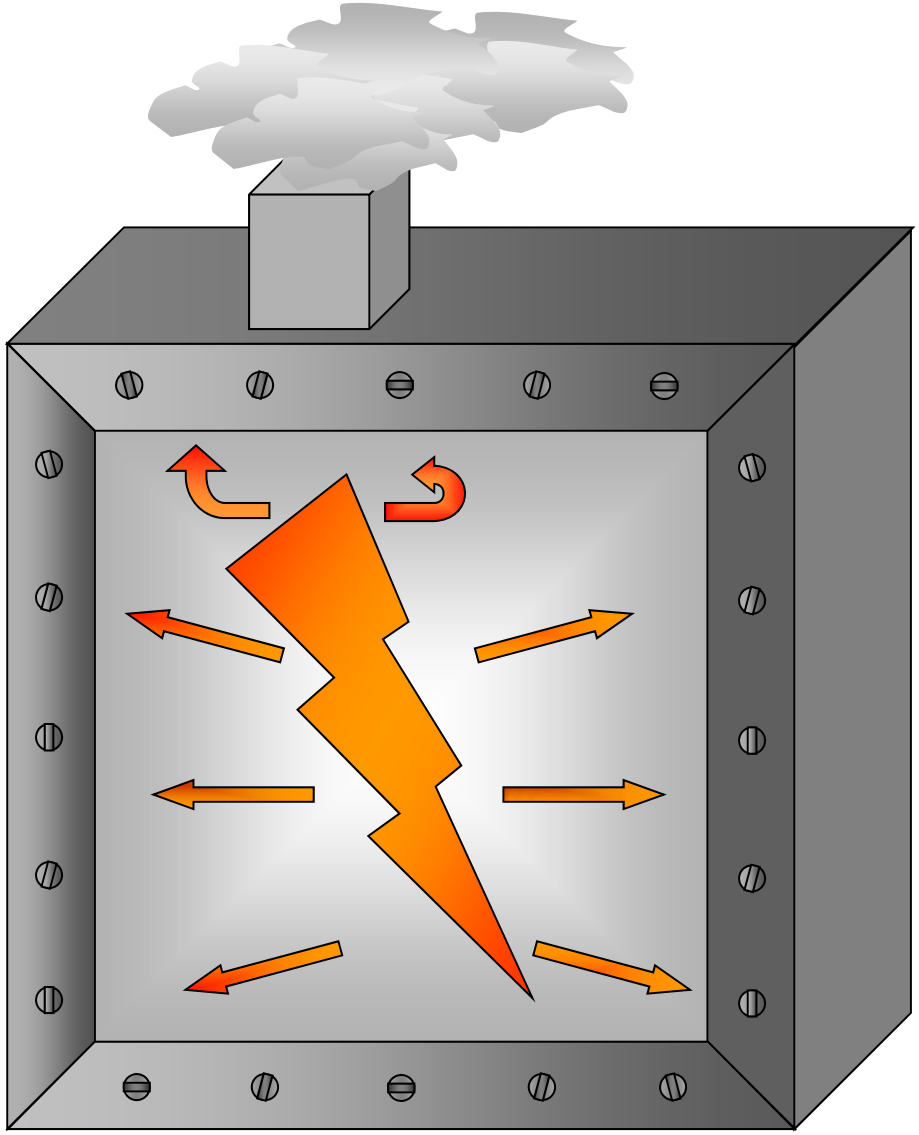
0.5 cycle clearing time, or less, (~<8ms)

Multiple approaches for arc flash safety and downtime

Approach	Key Limitations	Keep incident energy low	Preventive maintenance activity protection	Minimize event equipment damage	Shield personnel / add distance
Arc Transfer Protection System	Some extra footprint considerations, LV only	●	●	●	●
Fast Grounding "Crowbar" System	Potential equipment damage due to high fault current	●	●		●
Temporary Maint. Settings -RELT	Unplanned exposures if not enabled	●	●	●	
Arc Resistant Equipment	Retrofit, effluent vents, footprint considerations				●
Current Limiting (CL) Circuit Breakers	Fault current variability	●		●	
Fast (CL) Fuses	Large bus protection can increase arc flash energy	●		●	
Faster/More Sensitive Circuit Breakers	System reliability/ selectivity	●		●	
Remote Operation	Costs & complexity				●
Personnel Protective Equipment (PPE)	Comfort & dexterity				●

Some Present Approaches

Containment method – arc resistant



- Common in MV systems
- Moving into LV systems
- Contains arc inside structure
- Barrier between person & arc
- Must be fully assembled
- Plenum needed to exhaust

May be solution for operators, but not for maintenance

Testing for Arc Resistance Conformance

- Testing (IEEE C37.20.7) performed with covers & doors secured
  - **Arc resistance rating based on door & covers being properly secured**
- Testing done at prescribed voltage & current levels and presumes limited arc duration (0.5 sec recommended) but no standard set.
- Specified flammable cotton indicators are positioned to detect the escape of hazardous gases, plasma, etc.
- Pass/Fail Criteria
  - Door, covers, etc. do not open. Bowing/distortion is permitted except in panel used for relays, meters, etc.
  - No parts are ejected into the vertical plane defined by accessibility type
  - No openings caused by direct contact with an arc
  - No indicators ignite due to escaping gases or particles
  - All grounding connections remain effective

Other characteristics and alternatives

- Heavier sheet metal
- Double wall construction
- Space dedicated to internal flues to channel gasses
- External flue to channel gasses to outside environment
- Potential impact of overall size
- Potential impact on density of devices

Arc resistant gear does not address the ability to operate switches, inspect meters and trouble shoot the equipment.

Most of those same benefits may be achieved via remote controls, remote instrumentation and judicious use of digital communication and modern electronics.

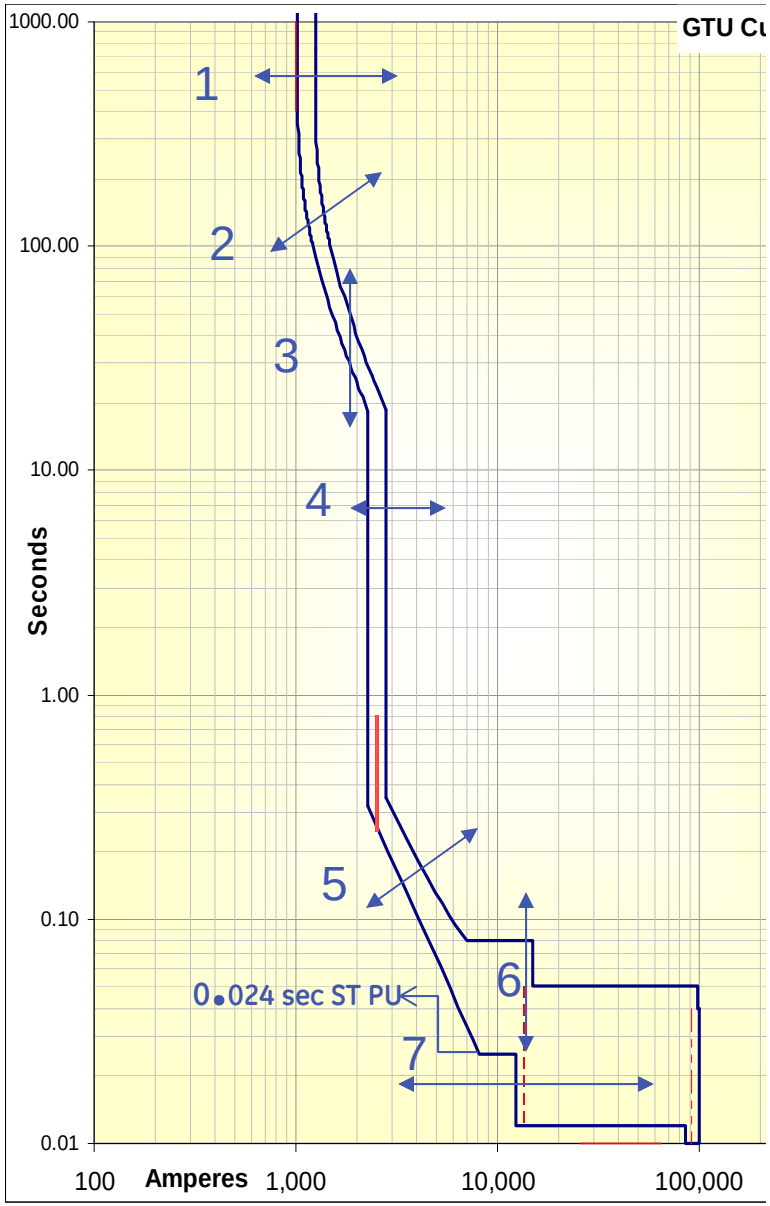
Modern Circuit Breaker Technology

- *"Reduced Energy Let – Thru" or "Maintenance Switch"*
- *Flexible Time Current Curves to "fit" all your needs*
- *Advanced Instantaneous Algorithm*
- *ZSI (Zone Selective Interlock) – now has Instantaneous*

Enables….

Arc Flash Protection and Selectivity at the Same Time

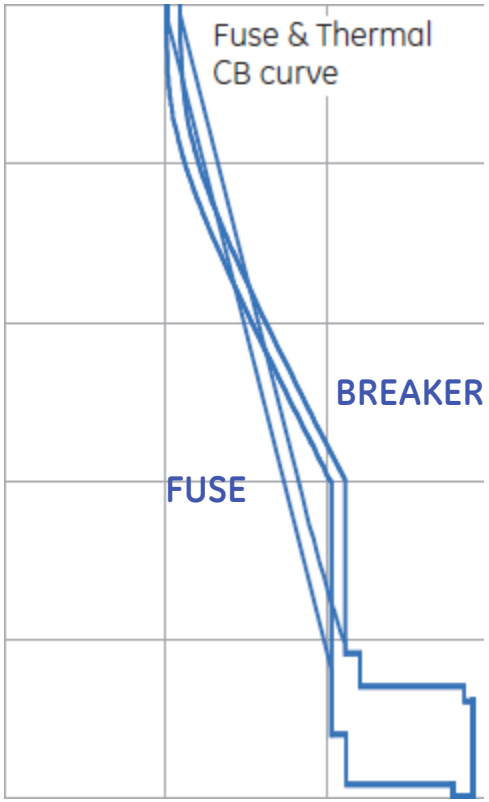
Flexible Time Curves

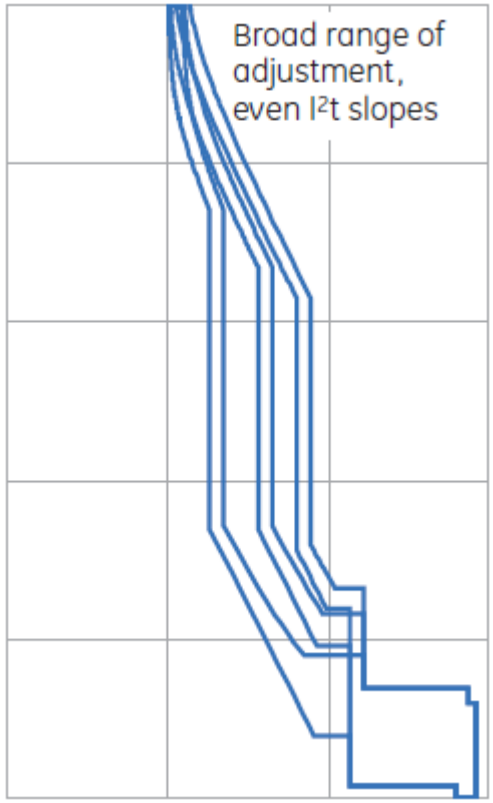


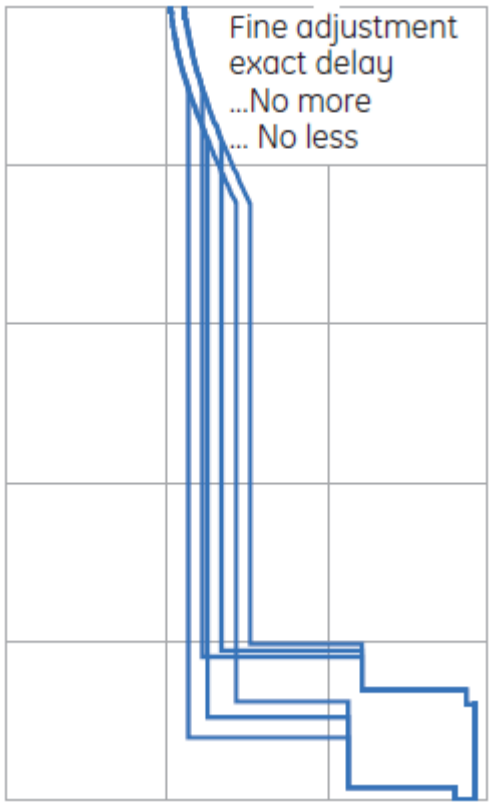
more precision in settings and tolerances

1) Plugs: 37.5-100% sensor. LTPU 50-100% Plug – Universal Rating Plugs
2) CB & Fuse Shaped LT Bands
3) 22 LT delays in both CB & Fuse shapes, 44 total
4) STPU:1.5-12X LTPU, (0.05 increments)
5) STI^{2}T slope: 3 different slopes
6) ST TB: As fast as 1.5 Cycles, 11 different bands, in 55ms increments
7) Instantaneous pickup 2X-15X standard, optional 1.5-30X.

Examples of TU curve flexibility

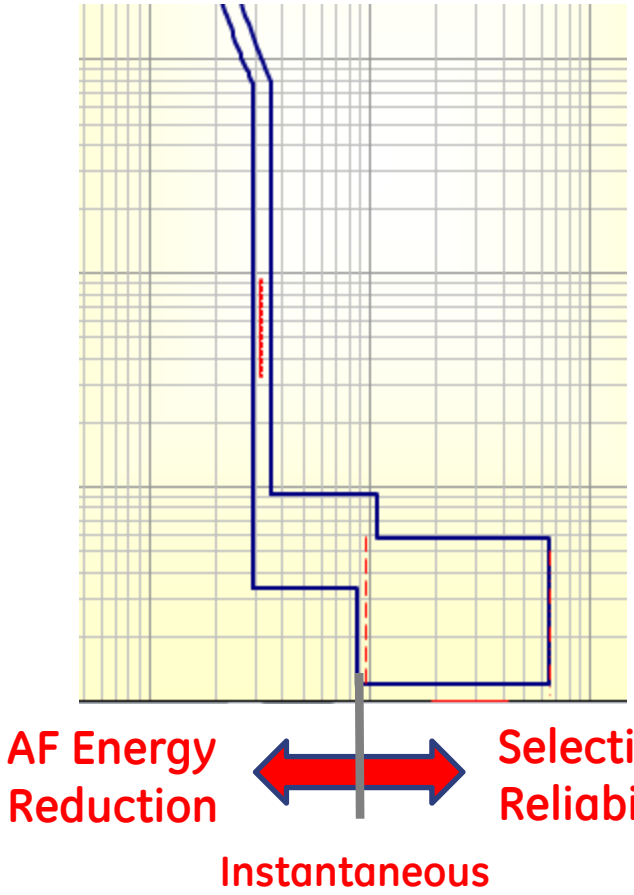






The Dilemma?

Arcing Current is typically below traditional Selective/Coordinated Instantaneous Pickup



What's more Important?

- Reliability/Selectivity
- Reduced Arc Flash Energy

Why Not Both?

Example Arc Flash Current Level

Arc Flash is typically 35-55% of the Bolted Fault Level…

- 42KAIC Available fault current = ~18kA to 21kA Arc Flash Current (based on IEEE 1584)
- 3000A Breaker with Instantaneous set to 7X or Above won't see the fault and will be tripping on Short Time or maybe even Long time.

Why not set the Instantaneous to 4X or 5X?

- Selectivity compromised.
- Loose coordination with downstream equipment. Don't want the upstream device to trip if the fault is below a downstream device.

A Popular Approach

"RELT"
"Arc Flash"
"Maintenance"
"Safety"
"Many other names"

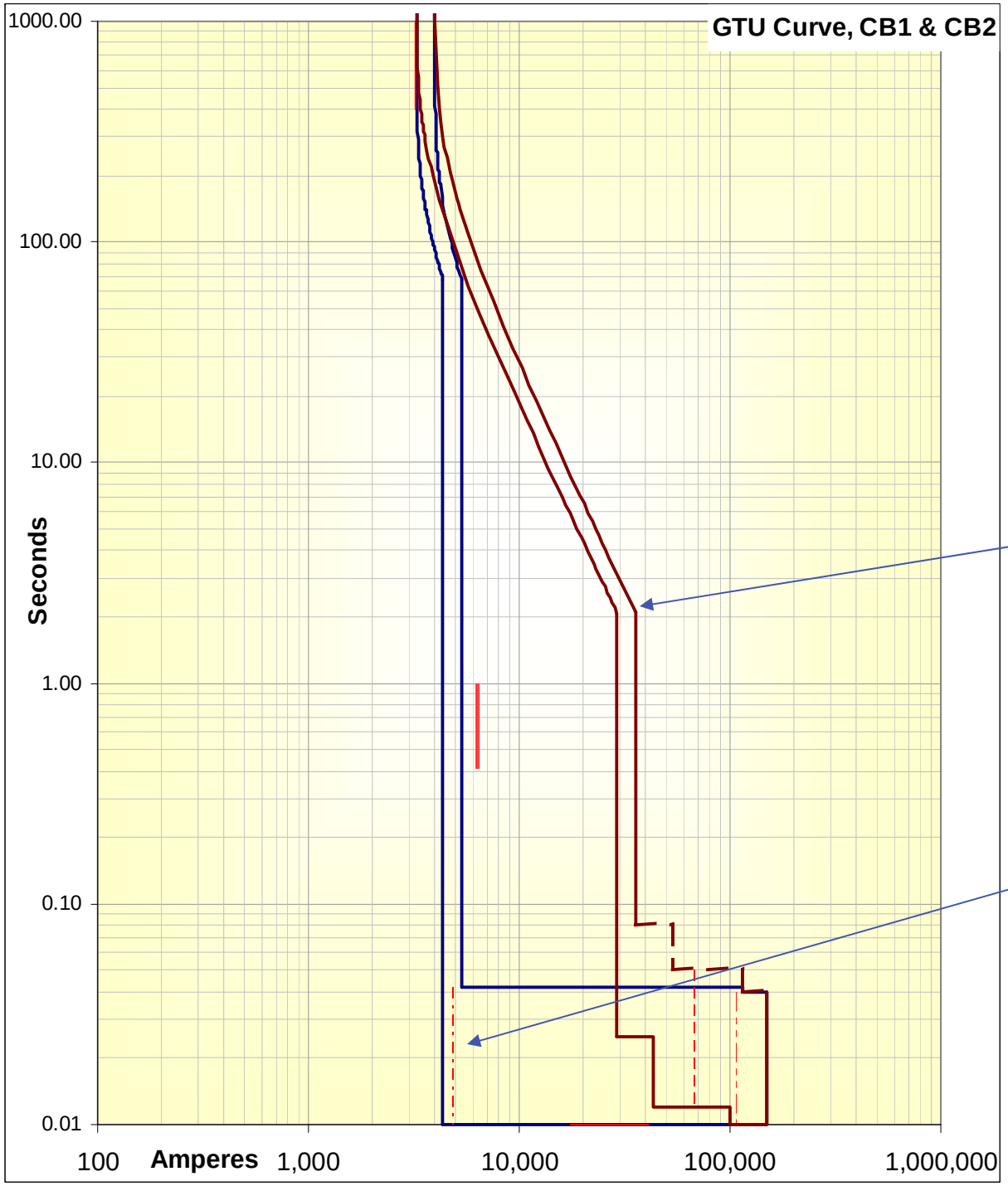
} **Switch**

EntelliGuard® TU's RELT Switch With Positive Indication
(Available on MCCB and ACB)

However

1. Remember to turn **ON** and LOTO
2. Turn it **OFF**: Uptime/Reliability is at stake

But not 24x7



RELT TCC

RELT OFF
I-PU=45KAIC

RELT ON
I-PU=4.5KAIC

Now you can have Both, 24x7

Without the need for an ON/OFF Switch, Without sacrificing Reliability

- Trip unit algorithms monitor the current waveform to provide discriminant tripping
- Breaker to breaker communications

HOW?

- Waveform Recognition **Instantaneous**
- Zone Selective Interlocking **Instantaneous**

No Longer Depend on Short Time

Now you can have Both, 24x7

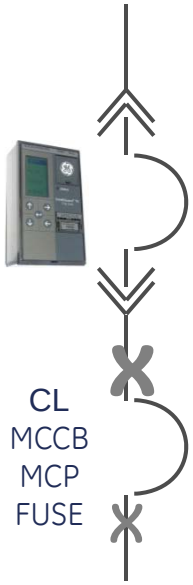
Without the need for an ON/OFF Switch, Without sacrificing Reliability

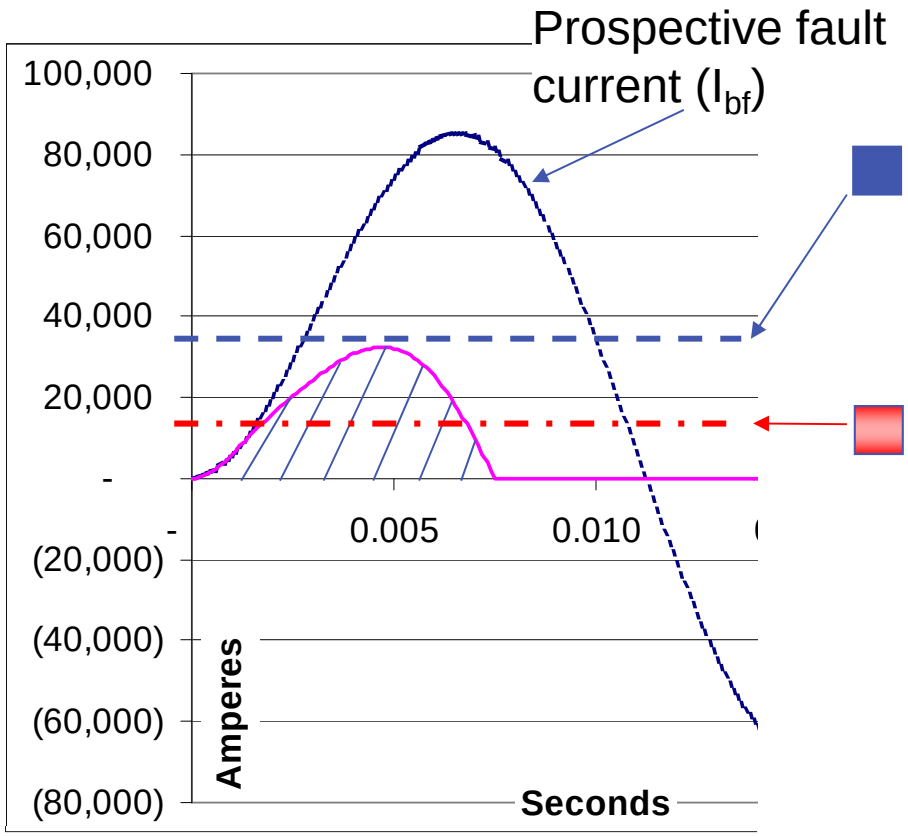
HOW? OPTIMIZED INSTANTANEOUS SETTINGS

- Waveform Recognition **Instantaneous**
- Trip unit algorithms monitor the current waveform to provide discriminant tripping
- Zone Selective Interlocking **Instantaneous**
- Breaker to breaker communications

No Longer Depend on Short Time

Waveform Recognition (WFR) Instantaneous





Without WFR Instantaneous set above max peak let thru of downstream device (peak sensing)

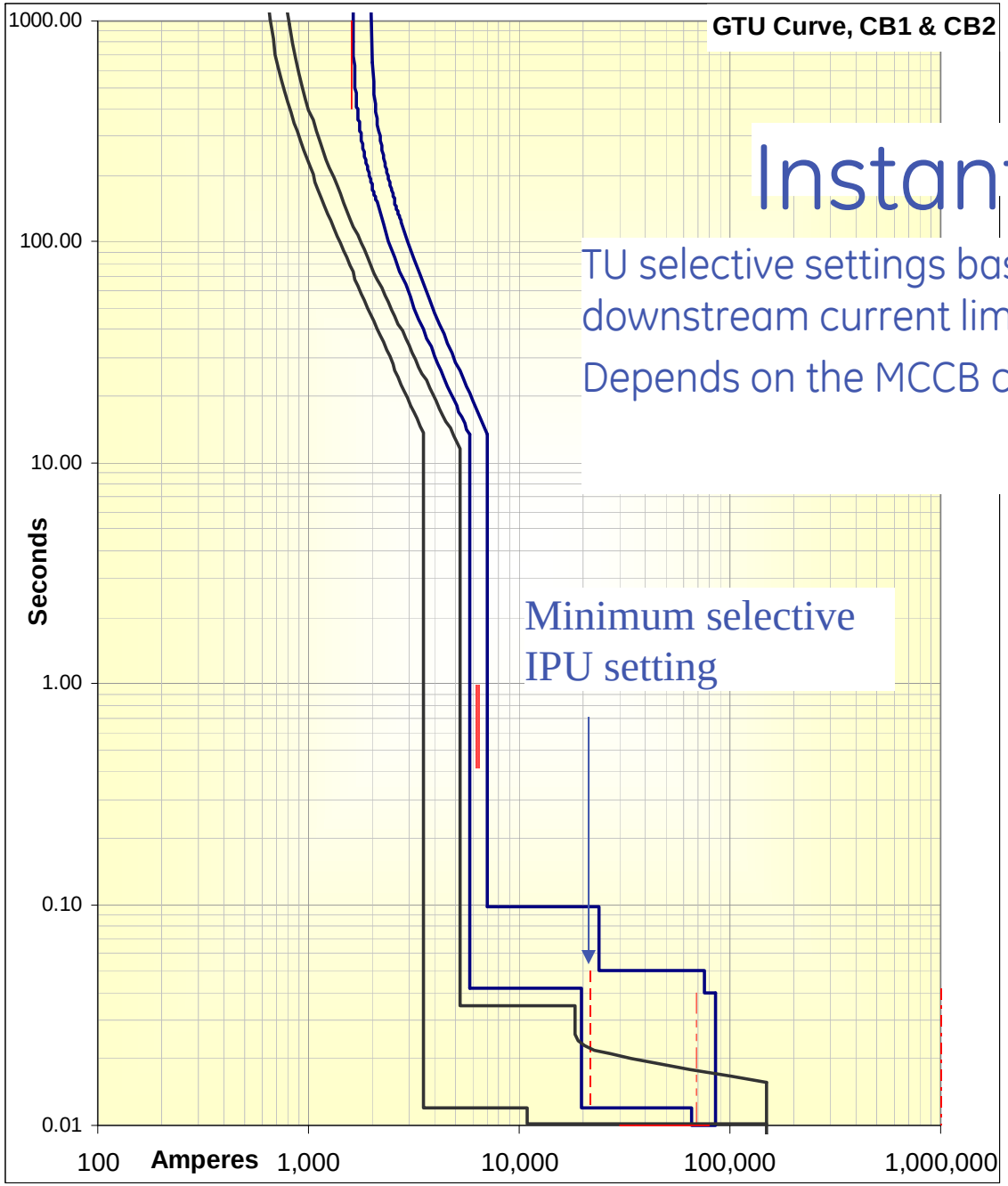
TU Set below Current Limiting peak let thru

Instantaneous set below Arcing Current while maintaining selectivity.

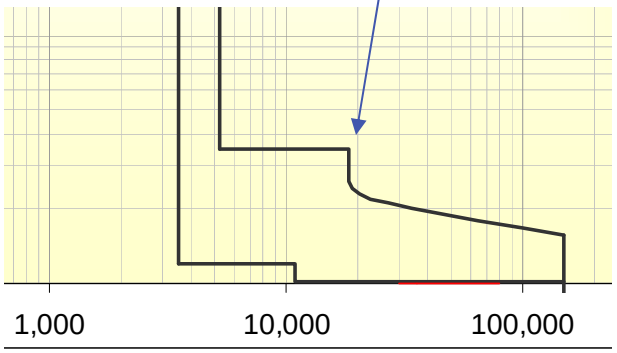
Instantaneous

TU selective settings based on the curve of the downstream current limiting molded case CB.

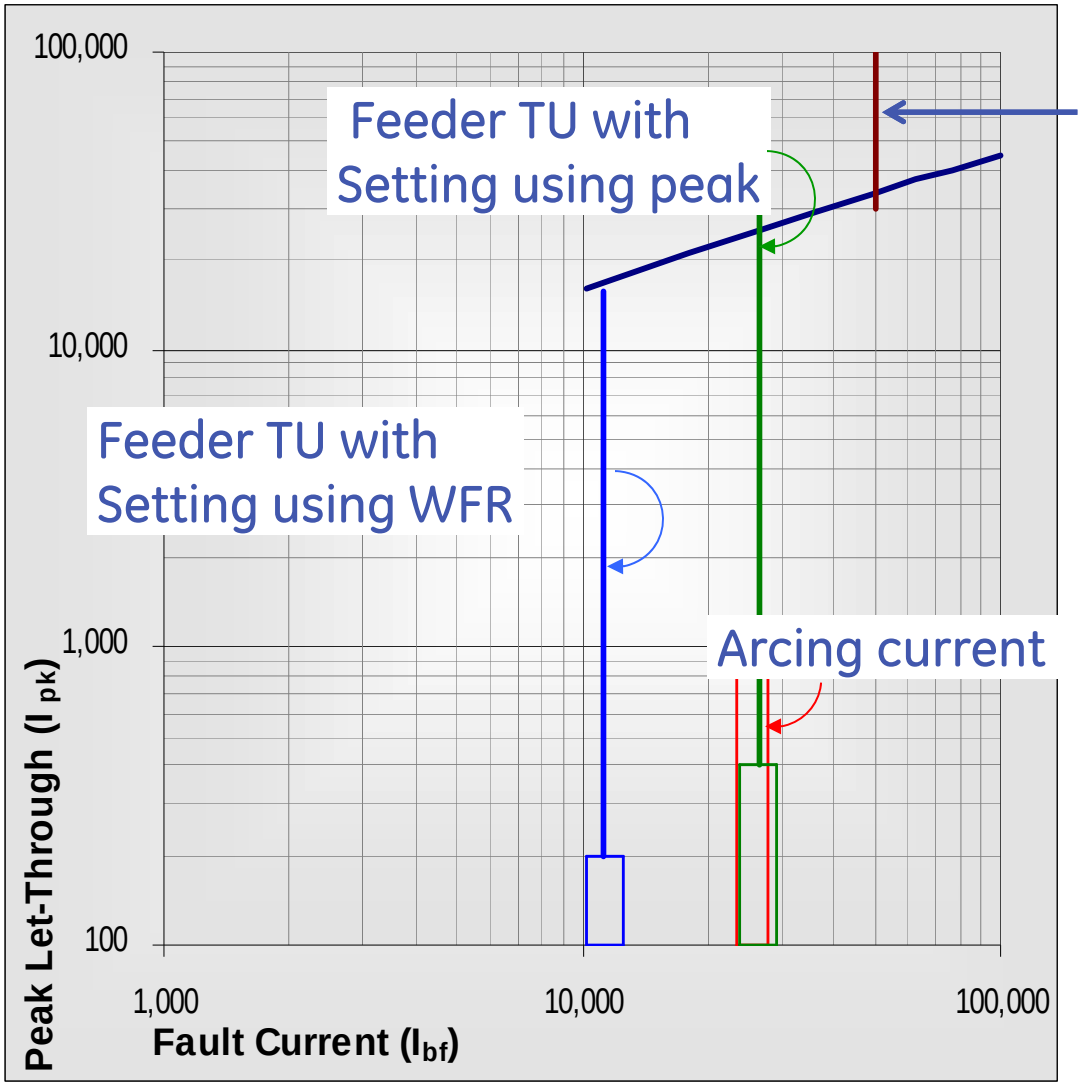
Depends on the MCCB curve being defined correctly.



Transition



Larger motor circuit protector – 250A MCP

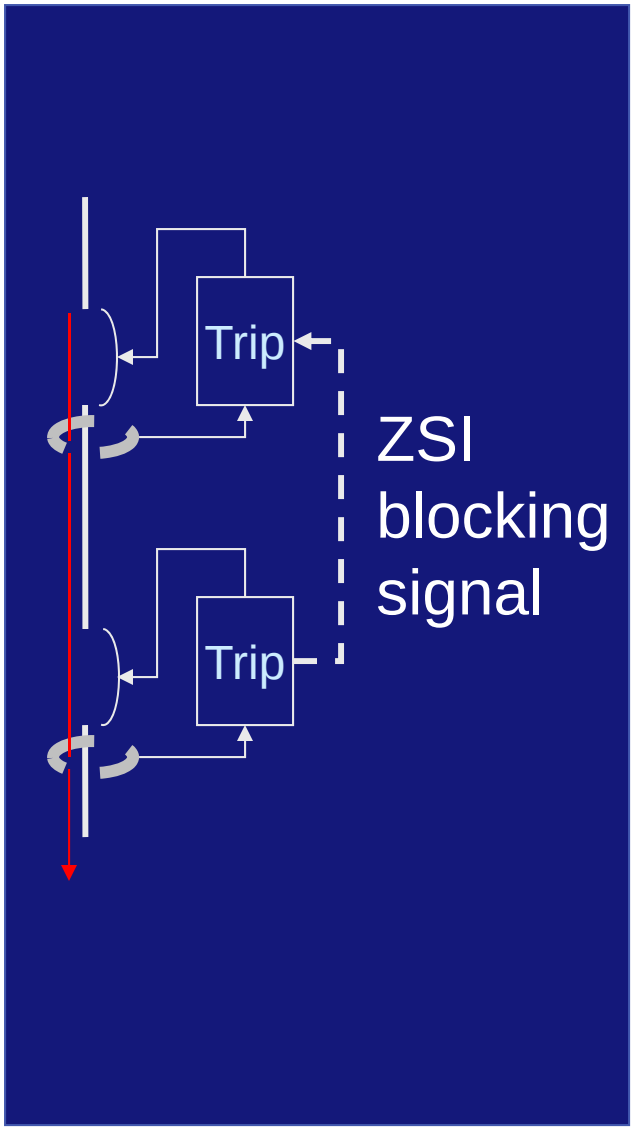


50 kA I_{bf} ~ 23 – 28 kA I_a

Feeding a 250A MCP or CB in MCC with:

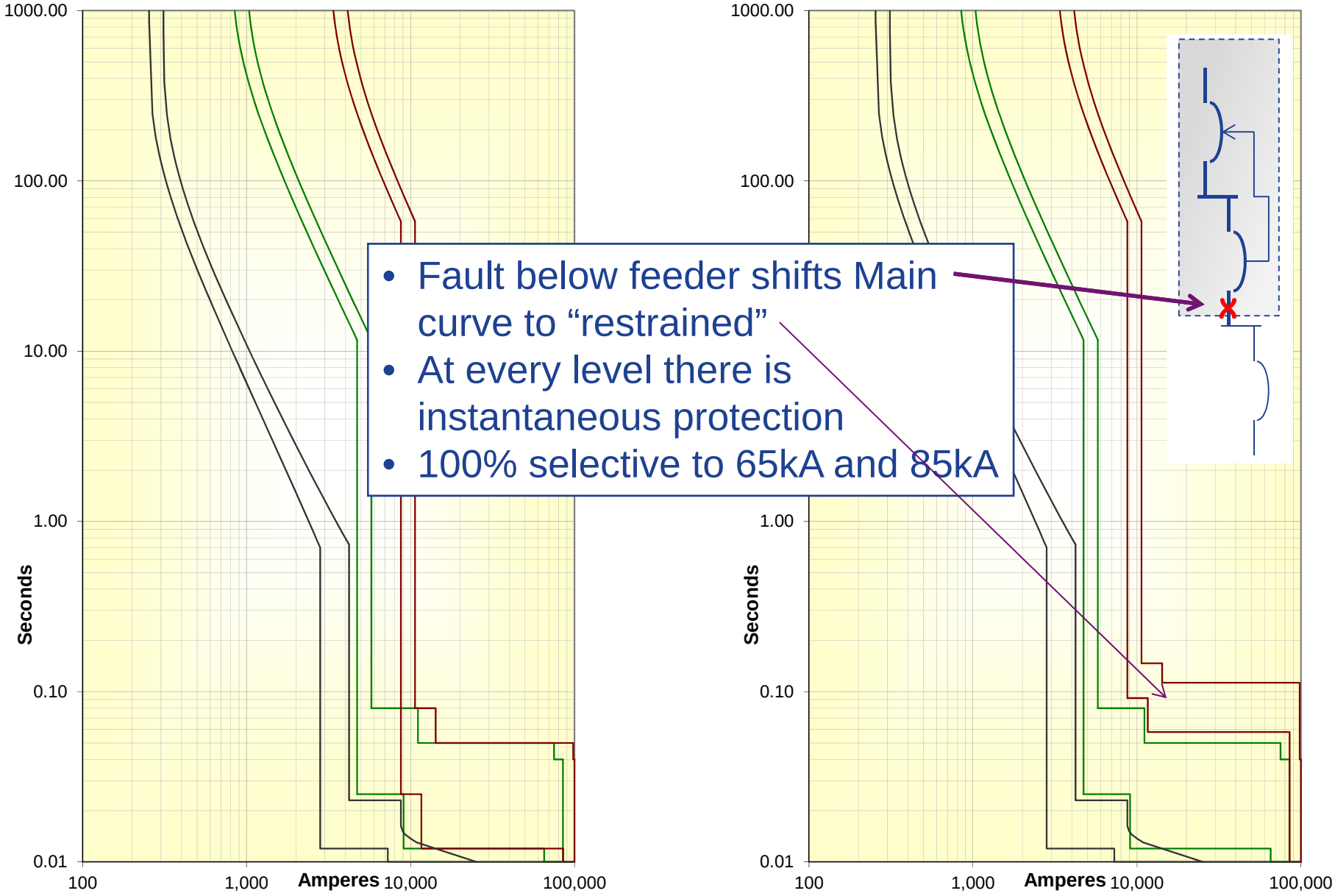
- peak sensing trip, pickup overlaps arcing current so setting does not provide reliable instantaneous arcing fault protection
- waveform recognition (WFR) capability, provides selectivity & instantaneous arcing fault protection with ~10kA of margin

Zone Selective Interlocking (ZSI)



- Zone Selective Interlocking used to force upstream CB to be selective with downstream CB
- When upstream CB receives signal that CB below is interrupting fault it operates at a “restrained” slower speed allowing downstream CB to clear
- All manufacturers offer ST & G
- Can only be applied when using LVPCB upstream.
- 1000 ft. Max signal cable length.

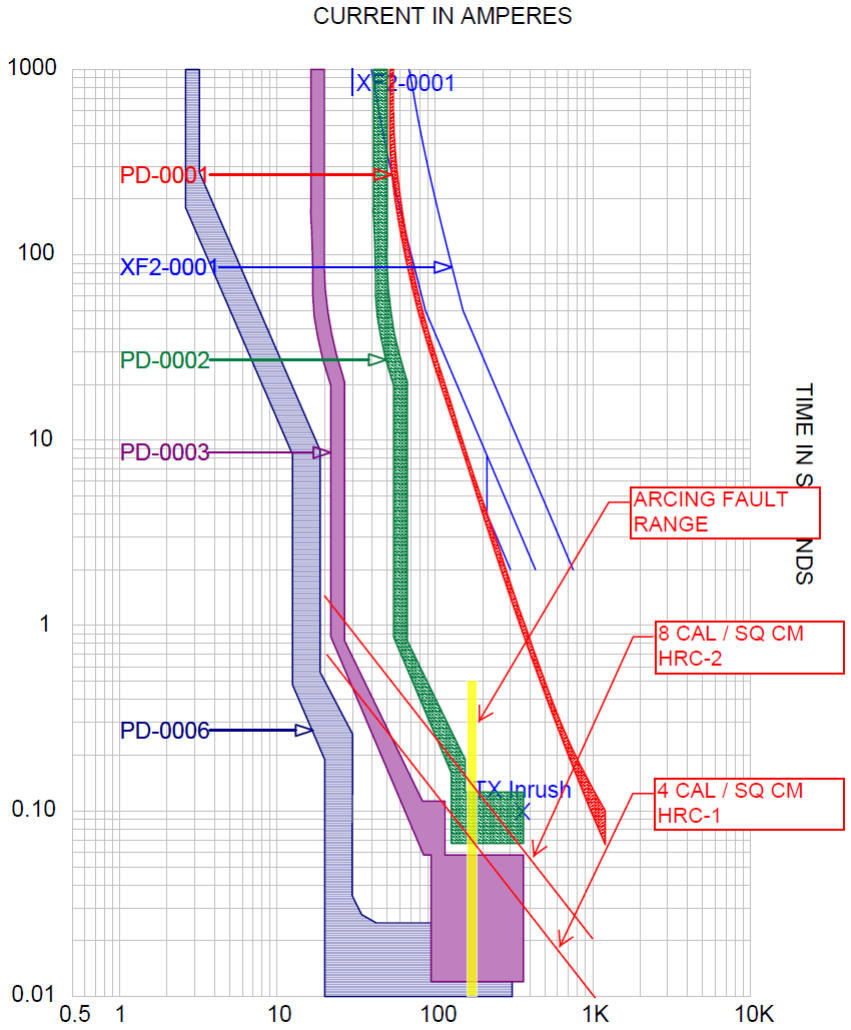
What about next level up? I-ZSI



- Fault below feeder shifts Main curve to “restrained”
- At every level there is instantaneous protection
- 100% selective to 65kA and 85kA

Feeder Fault using Waveform Recognition and Instantaneous ZSI

HRC 1

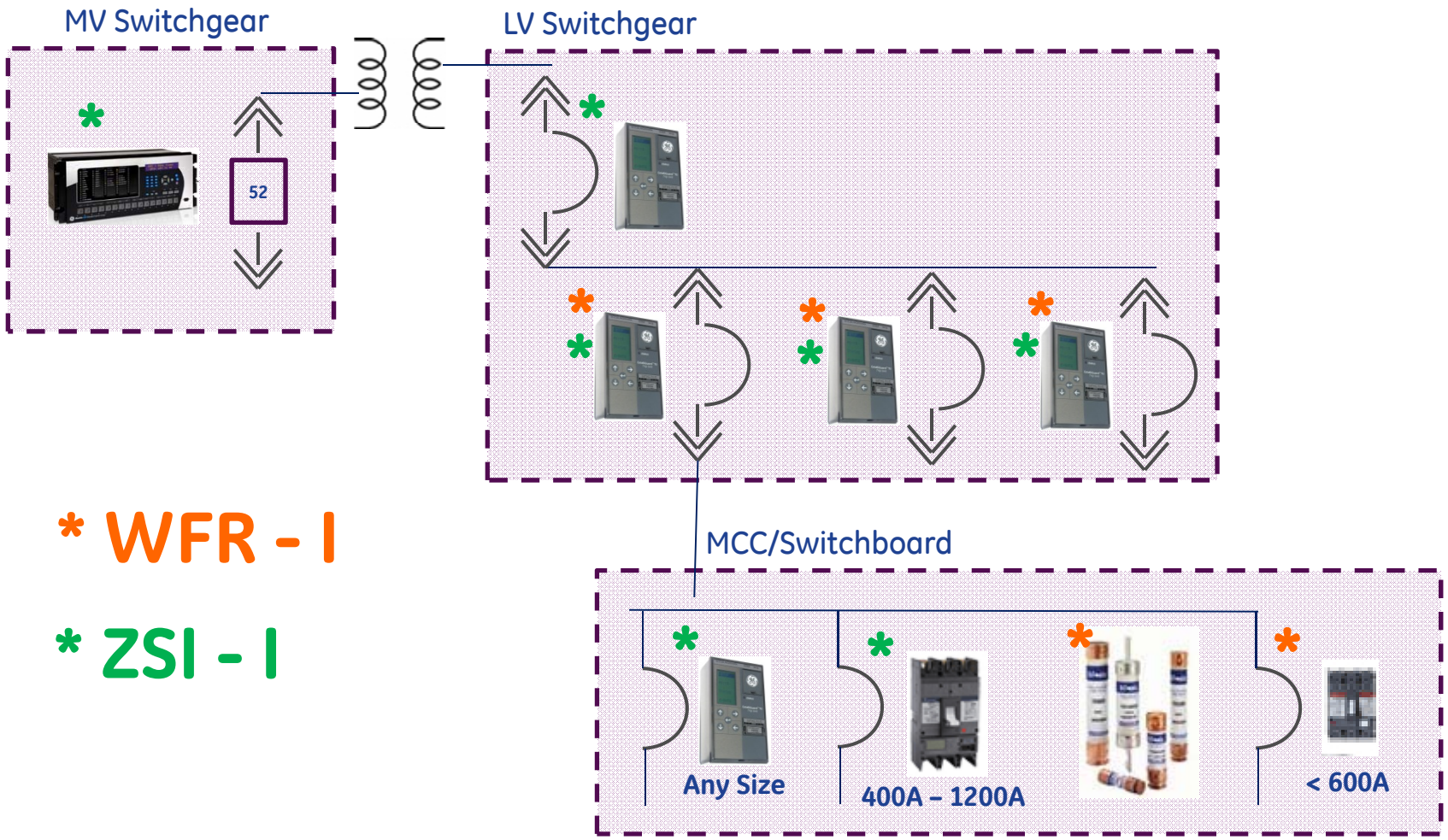


PRE ETU.tcc Ref. Voltage: 480V Current in Amps x 100

HRC 2

imagination at work

LV system: <= 8 Cal/CM^2 on a 100KA I_{BF} 480V



* WFR - I

* ZSI - I

A new approach

What if...

...a product could contain an arc fault in less than 8ms?

...a product could limit incident energy to 1.2 cal/cm^2?

...this could be done with equipment doors open?

...this could be done without adding additional bolted-fault type stress to the system?

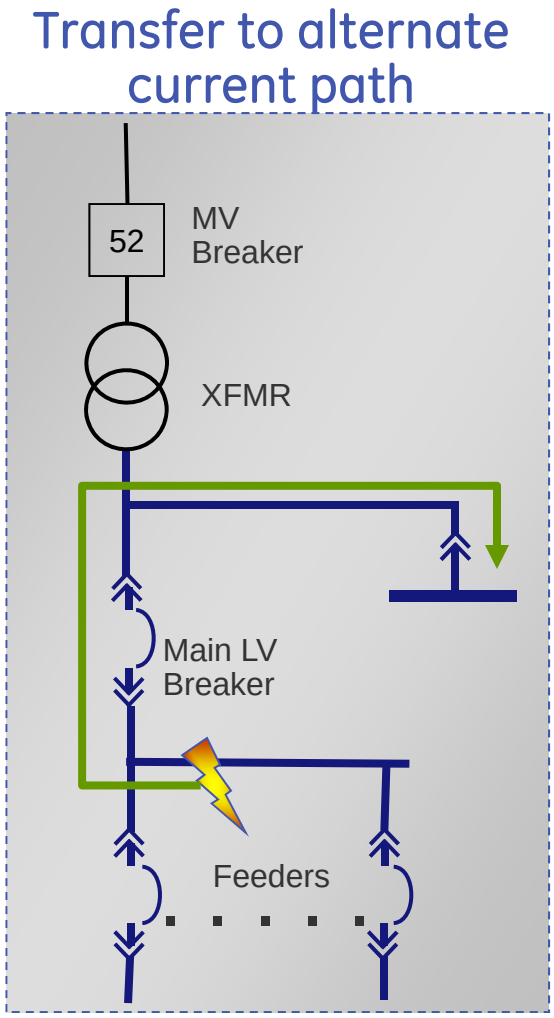
...the product could be retrofit onto existing equipment?

Overview of arc containment method – Arc Vault™

How it works

imagination at work

Alternative to Arc Resistance via containment - diversion



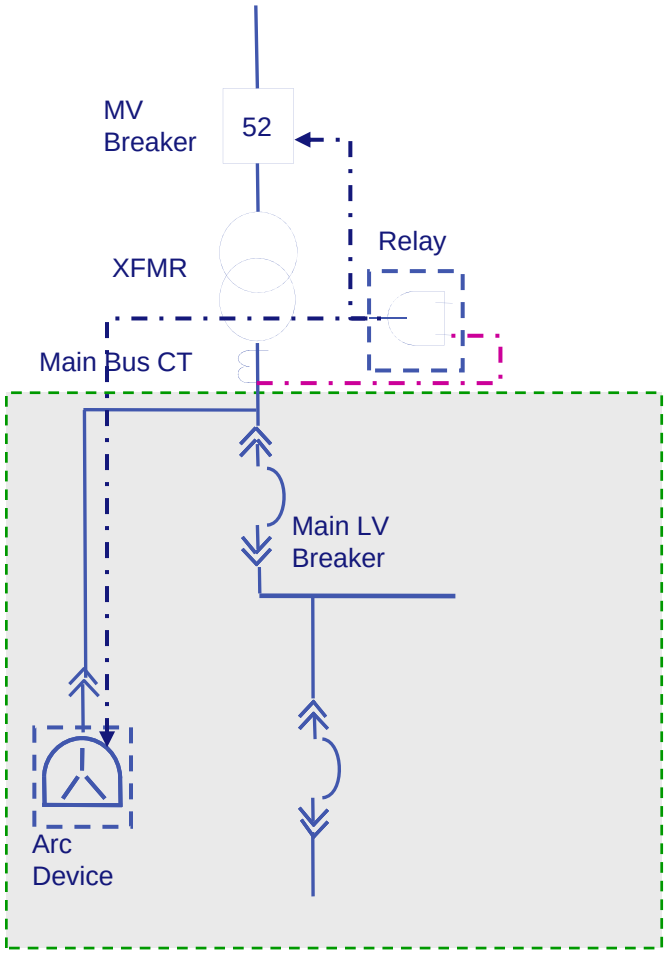
Present Technology - Crowbar

- Remove arcing fault via bolted fault
- Maximum bolted fault current
- Electrical equipment damage

New Technology – Arc Containment

- Arc-to-arc transfer keeps energy low & allows fast mitigation
- Other equipment not damaged
- Fault eliminated in < ½ cycle
- No moving parts
- And, in new gear, meet the same Arc Resistance standard

Detection – upstream controllable device



- Entire switchgear line-up protected
- Incoming bus, main breaker, main bus, feeders
- Consider CT sensor placement
- Reasonable close-coupling
- Retrofit or new construction

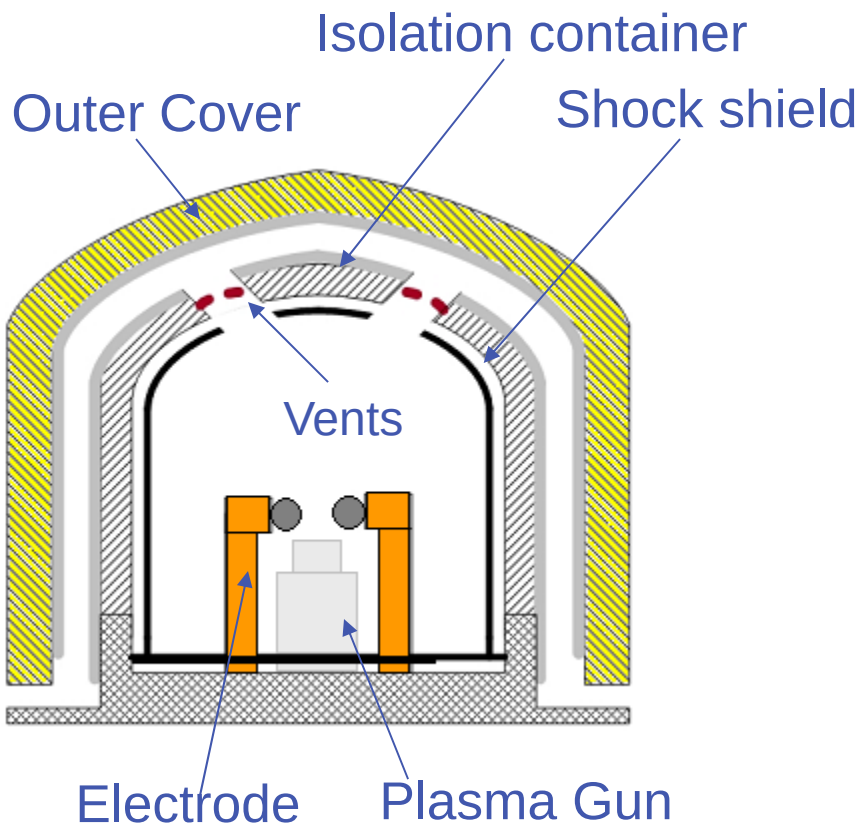
Using transfer tripping & other techniques upstream protectors may be added as back up

Arc containment system

Principle follows crowbar concept but..

- Suppresses arc-flash with lower contained arc impedance
- Easier circuit interruption
- 63% less energy than a bolted fault
- Less impact on other components in electrical system
- Faster, simplified triggering method
- Fast transfer
- No moving parts
- Multiple use
- Maintenance tests

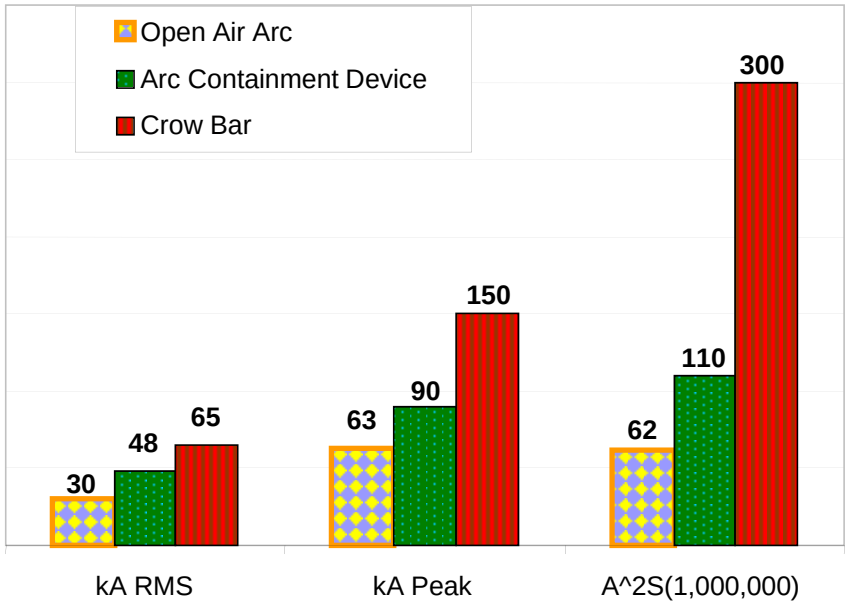
Arc containment device



- Arc created in interior chamber
- Device has 3 functions
  - Containment
  - Isolation
  - Dissipation
- Size = 2000A CB
- Minimal venting
- Energy is dissipated/absorbed

Stress on power delivery system minimized

$$I = \frac{V_{sys}}{Z_{sys} + Z_{capture}} \left[\sin(wt + \theta - \varphi) - e^{-\frac{Rt}{L}} \sin(\theta - \varphi) \right]$$



Arc impedance is key

- Not "0" ohms
- Resistive – reduces DC offset

I peak related to mechanical damage

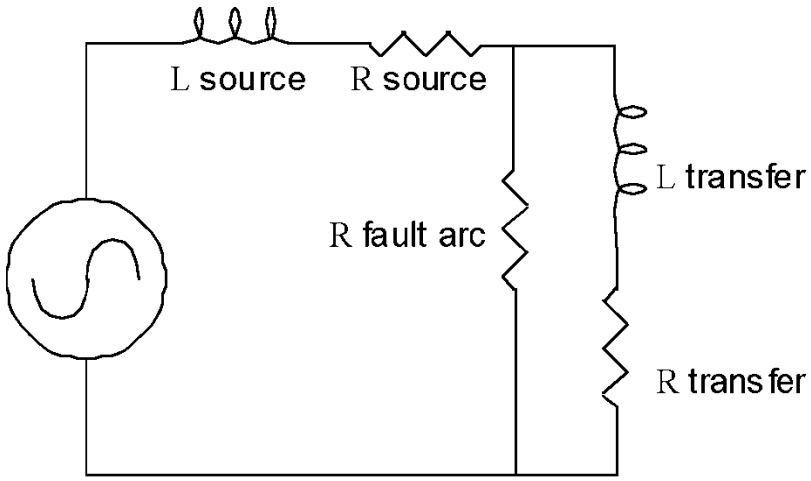
- 40% less than bolted

I^2t related to thermal damage

- 63% less than bolted

Arc transfer principles

$$V_{capture} = V_{sys}\left(\frac{Z_{arc}}{Z_{arc} + Z_{source}}\right)$$

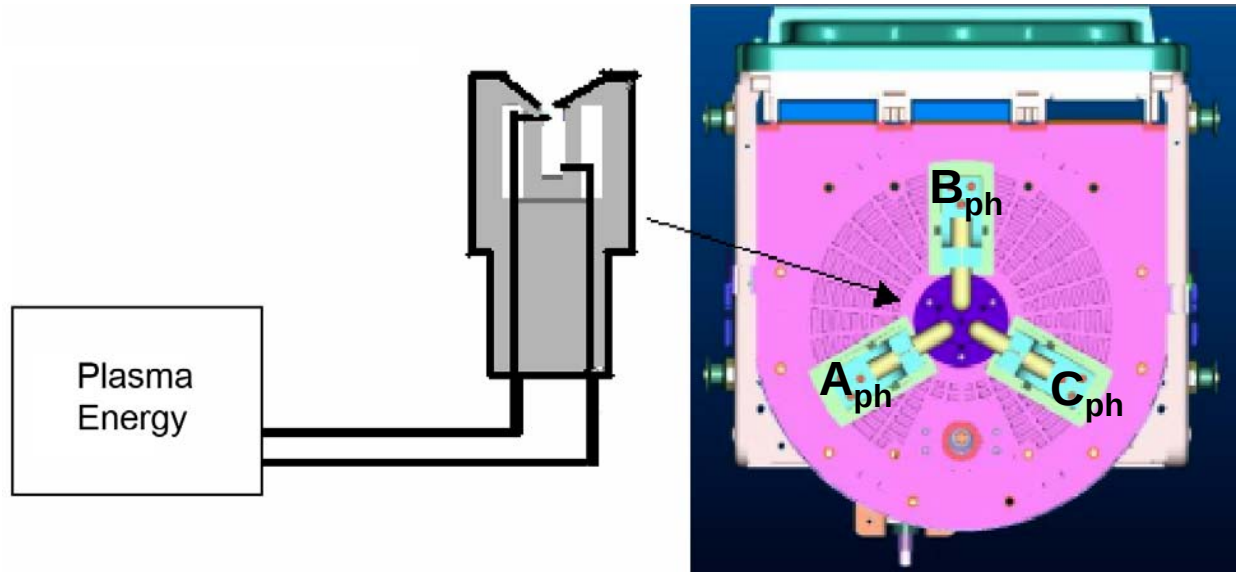


Path of least impedance…

- Impedance of new arc lower than fault arc being removed
- But **NOT** zero impedance
- Introduced arc must be stable & divert current long enough for upstream CB to interrupt
- Pressure & heat must be predictable & controllable

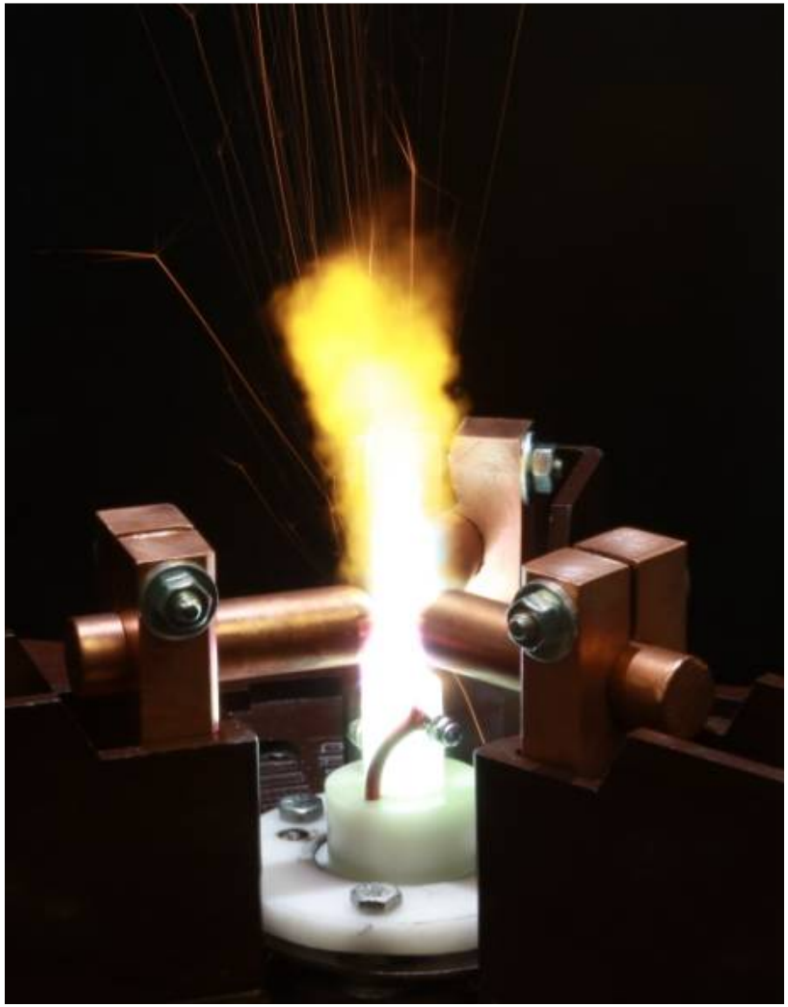
Triggering

Dielectric reduction with plasma



- Plasma gun breaks down air allowing current to flow between electrodes
- <200 microsecond pulse is required
- Spacing & electrode geometry prevent breakdown during normal operation
- Limited wear allows testing & triggering system reuse

Trigger arc



No moving parts

Microsecond duration

Microsecond response

Multiple use

Low energy trigger source

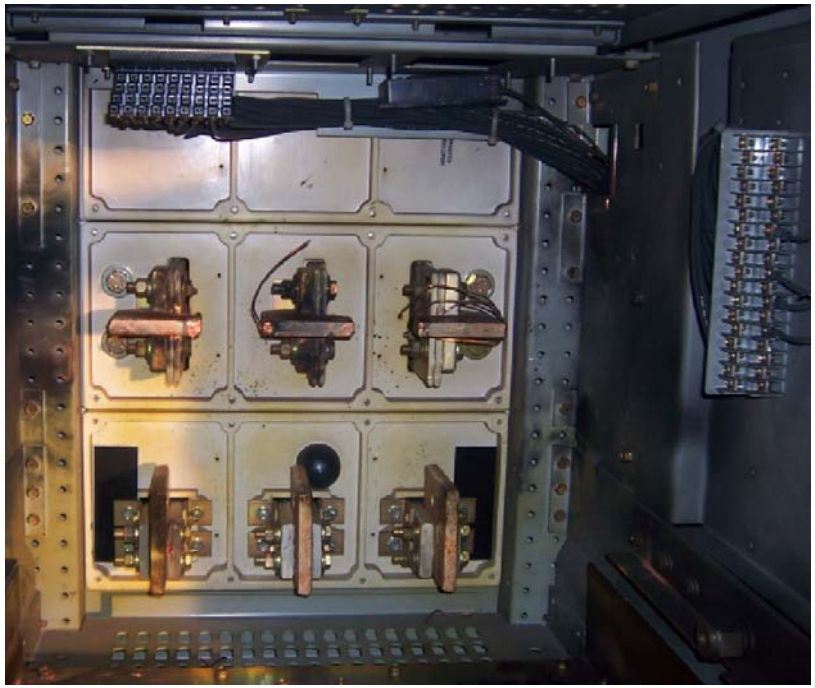
Field testable

Limit energy “and” protect equipment

Instead of containing arc flash event in the equipment; limit energy from arc flash event

Decreased arc energy and increased system reliability

3 cycle CB interruption



Arc Vault™ protection

Arc Vault components and indicators

Device Status / Activation Switch

D/O mechanism like circuit breaker

Stored Energy – health monitor

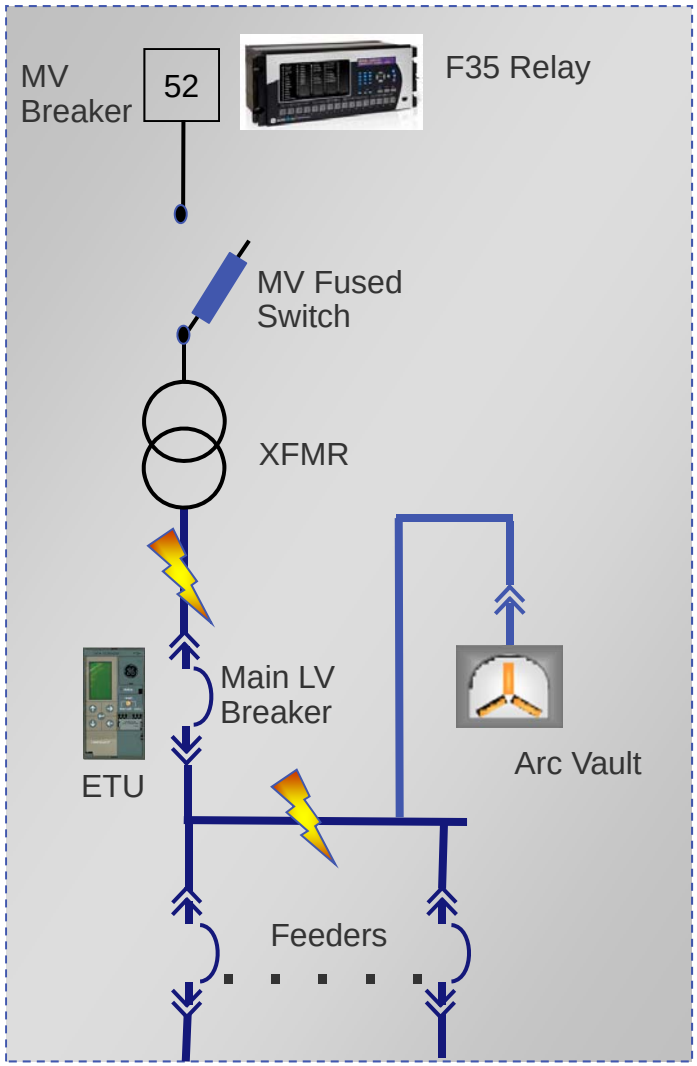
Containment Dome

D/O mechanism like circuit breaker

The Arc Transfer Protection System:

- ✓ Will contain an arc fault in less than 8ms, resulting in incident energy in accordance with IEEE 1584 at 18” from the arc event of less than 1.2 cal/cm², with the circuit breaker compartment doors open, in a 480V 65kAIC system.
- ✓ Can be retrofit onto existing LV equipment, including switchgear, switchboards, and MCCs
- ✓ Reduces building construction costs because it does not require exhaust chimneys or plenums
- ✓ Can be returned to service within a working day in the event of an arc flash incident, which improves overall system uptime
- ✓ Reduces energy released by 63%, compared to crow-bar type systems, which will lessen stresses on other system components, and improves overall system uptime

Summary of A-F Mitigation Alternates



	Mains		Feeders	
Technical Approach	**Incident Energy**		**Incident Energy**	
Existing System	~200 cal		~170 cal	
MV CB w/ F35 Relay	~10 cal	Good	~10 cal	Good
TU w/ iZSI	~200 cal		~5 cal	Good
TU w/ iZSI & MV CB	~10 cal	Better	~5 cal	Better
Arc Transfer with MV CB	~1 cal	Best	~1 cal	Best

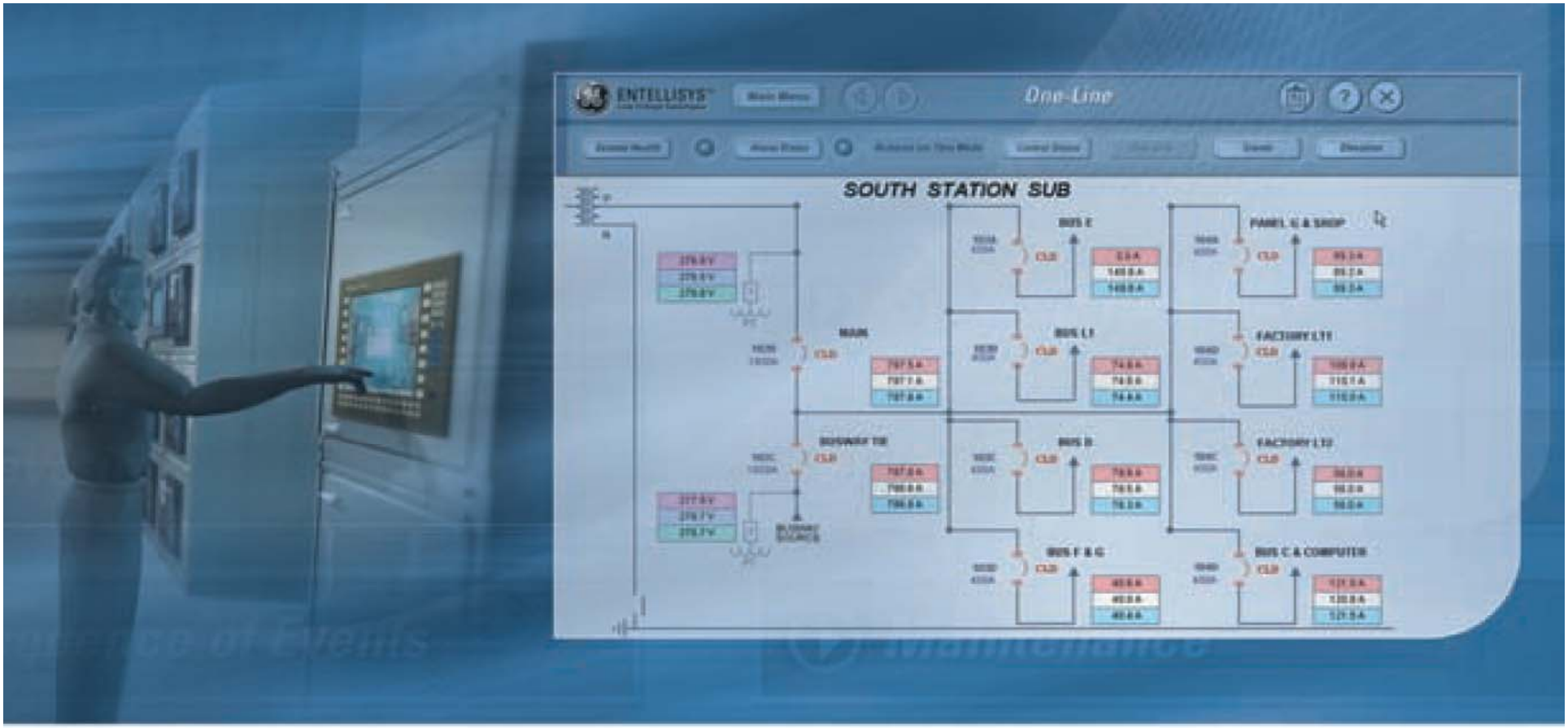
Values shown are for a typical 13.8kV to 480Volt Substation with 2500 kVA transformer, 65 KA.

Electrically Operated Remote Racking Device for Low Voltage Switchgear

The electrically operated racking device allows maintenance personnel the ability to be up to 30 feet away from a draw-out breaker during the racking operation.

REMOTE OPEN/CLOSE and MONITORING

- Near gear HMI in a stand-alone or wall mount unit can be placed well beyond the arc flash boundary.
- HMI interface installed on a remote desktop or laptop PC connected via a LAN or the Web.



Thank you.