Ft Worth IEEE-PES
Arc-Flash Hazard Mitigation &
Selectivity

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Electric Shock*
Approximately 30,000 nonfatal shock accidents occur each year. The National Safety Council estimates that about 1,000 fatalities each year are due to electrocution, more than half of them while servicing energized systems of less than 600 volts.

Arc Flash*
When an electric current passes through air between ungrounded conductors, or between ungrounded conductors and grounded conductors, the temperatures can reach 35,000°F. Exposure to these extreme temperatures burns the skin directly and causes ignition of clothing, which adds to the burn injury. The majority of hospital admissions due to electrical accidents are from arc-flash burns, not from shocks. Each year more than 2,000 people are admitted to burn centers with severe arc-flash burns. Arc-flashes can and do kill at distances of 10ft (3m).

Arc Blast*
The tremendous temperatures of the arc cause the explosive expansion of both the surrounding air and the metal in the arc path. For example, copper expands by a factor of 67,000 times when it turns from a solid to a vapor. The danger associated with this expansion is one of high pressures, sound, and shrapnel. The high pressures can easily exceed hundreds or even thousands of pounds per square foot, knocking workers off ladders, rupturing ear drums, and collapsing lungs. The sounds associated with these pressures can exceed 160dB. Finally, material and molten metal is expelled away from the arc at speeds exceeding 700 mph (1600 km/hr), fast enough for shrapnel to completely penetrate the human body.

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.

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.

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Example of an Arc Flash Event

635V/65kA 12 Cycle event, door open
33 cal/cm²
BOTTOM LINE:

A blast over 40 cal/cm² 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 scope¹

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
- Available short circuit current
- Working distance
- Arc gap
- Arcing fault clearing time (not short circuit clearing time)
- Sensitivity of Breaker/Trip Unit
- Fixed
- Based on system design and source
- Arms are only so long
- Determined by equipment type
- 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: 
  \textit{Gap, Voltage \& $I_{bf}$}

The variables include:

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

![Graph showing arcing current variability]
Arc flash protection – PPE vs. cal/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

<12cal/cm²  >12cal/cm²
Incident energy dependant on event time

- Low level of incident energy requires fast mitigation.
  - \( \sim \frac{1}{2} \) cycle interruption or less
  - At the proper current level molded case CB & fuses operate in this range
- Large switchgear CB do not

![Graph showing incident energy vs. current level](image)

- 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

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</table>
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 troubleshoot 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

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) STI²T 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.

more precision in settings and tolerances
Examples of TU curve flexibility

1. Fuse & Thermal CB curve
2. Broad range of adjustment, even $I^2t$ slopes
3. Fine adjustment exact delay... No more... No less
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”

However

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

But not 24x7
GTU Curve, CB1 & CB2

**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.
TU selective settings based on the curve of the downstream current limiting molded case CB. Depends on the MCCB curve being defined correctly.
Larger motor circuit protector – 250A MCP

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

50 kA \( I_{bf} \) ~ 23 – 28 kA \( I_a \)
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?

- 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
LV system: $\leq 8\text{ Cal/CM}^2$ on a $100\text{KA} I_{BF} \ 480\text{V}$

- MV Switchgear
- LV Switchgear

- WFR - I
- ZSI - I

- MCC/Switchboard
- Any Size
- 400A – 1200A
- $< 600\text{A}$
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/cm²?

...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
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

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

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

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

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

- D/O mechanism like circuit breaker
- Stored Energy – health monitor
- Device Status / Activation Switch
- Containment Dome
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

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<th>Feeders Incident Energy</th>
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<td>Existing System</td>
<td>~200 cal</td>
<td>~170 cal</td>
</tr>
<tr>
<td>MV CB w/ F35 Relay</td>
<td>~10 cal, Good</td>
<td>~10 cal, Good</td>
</tr>
<tr>
<td>TU w/ iZSI</td>
<td>~200 cal, Good</td>
<td>~5 cal, Good</td>
</tr>
<tr>
<td>TU w/ iZSI &amp; MV CB</td>
<td>~10 cal, Better</td>
<td>~5 cal, Better</td>
</tr>
<tr>
<td>Arc Transfer with MV CB</td>
<td>~1 cal, Best</td>
<td>~1 cal, Best</td>
</tr>
</tbody>
</table>

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.