Arc Flash Fault
Cause, Effect & Mitigation Strategies
Joe Xavier, Technical Manager – West Region
Arc Flash Fault - Agenda

What is an Arc Flash?
Why and when does Arc Flash occur?
Characteristics and effects of internal Arc Flash
Mitigation strategies
Arc Flash Fault

What is an Arc Flash?

- The result of a rapid release of energy due to an arcing fault between phases, neutral or a ground

- Air is the conductor
Arc Flash Fault
Staged Arc Flash Event
Arc Flash Fault
Impact of internal arc fault

- Rapid temperature rise (up to 20,000°C)
  - Rapid pressure rise
  - Release of material fragments and hot gases
  - Burning and vaporization of metal and insulation material

- Heavy damages possible inside of the switchgear, for the integrated devices and for the building
- Heavy injuries of the personnel possible for switchgear systems without internal arc classification
Arc Flash Fault
Impact of internal arc fault

- Electric arcs produce the highest temperatures on earth – up to 35,000 degrees Fahrenheit 4 times temp of the sun.
- The intense heat from arc causes the sudden expansion of air that results in a blast with very strong air pressure.
- All known materials are vaporized at this temperature, Copper expands 67,000 times; Water 1,670 times.

9941°F
Arc Flash Fault
Impact of internal arc fault

- Circuit-breaker compartment after internal arc impact
- Cable connection compartment after internal arc impact
- Contact terminal after internal arc impact
Arc Flash Fault
When is it likely to happen?

- Without operator, 25%
- With operator in front of a closed door, 10%
- With operator working in the switchgear, 65%
Arcing Incidents Happen

“One large utility has discovered an average of 1 arc-flash injury every 18 months for the past 54 years.”

--IEEE Std 1584 – 2002, 10.3
Arcing Incidents Happen
Evolution of standards

1982 - Ralph Lee's Paper, *The Other Electrical Hazard: Electric Arc Blast Burns*
- Brought attention to arc flash hazards
- Until then, focus was on shock hazards. Arc flash concerns were for equipment.

1991 - OSHA acknowledges the hazard

1995 - First included in a standard (NFPA 70E)
Arcing Incidents Happen
Since 2015…

- Arc Flash analysis
- Arc Flash deadlines
- Arc Flash hazards
- Arc Flash consultants
- Arc Flash software
- Arc Flash relays and relay schemes
- Arc Flash PPE
- Arc Flash standards and regulations
Characteristics and Effects of Arc Flash

Key Equations

Determination of Arcing Current

➢ For voltages below 1 kV

\[ \lg I_a = K + 0.662 \lg I_{bf} + 0.0966V + 0.000526G + 0.5588V(\lg I_{bf}) - 0.00304(\lg I_{bf}) \]

➢ For voltages above 1 kV

\[ \lg I_a = 0.00402 + 0.983 \lg I_{bf} \]

\[ I_a = 10^{\lg(I_a)} \]

where...

\( \lg = \log_{10} \)

\( I_a = \) arcing current (kA)

\( K = \) configuration constant

- 0.153 for open configurations
- 0.097 for box configurations

\( I_{bf} = \) available bolted three-phase fault current (RMS, kA)

\( V = \) system voltage

\( G = \) gap between conductors (mm)
Characteristics and Effects of Arc Flash

Key Equations

**Determination of Normalized Incident Energy**

\[ \lg E_n = K_1 + K_2 + 1.081 \lg I_a + 0.0011G \]

\[ E_n = 10^{\lg E_n} \]

where...

- \( E_n \) = incident energy (cal/cm\(^2\)) normalized for time and distance
- \( K_1 \) = configuration constant
  - -0.792 for open configurations
  - -0.555 for box configurations
- \( G \) = the gap between conductors (mm)
- \( E \) = incident energy (cal/cm\(^2\))
- \( C_f \) = calculation factor
  - 1.0 for voltages above 1kV
  - 1.5 for voltages at or below 1kV
- \( D \) = distance from the possible arc point to the person (mm)
- \( x \) = equipment specific distance exponent factor
- \( I_{bf} \) = available three-phase bolted fault current (RMS, kA)
- \( V \) = system line-line voltage
Characteristics and Effects of Arc Flash

Key Equations

\[ E = C_f E_n \left( \frac{t}{0.2} \right) \left( \frac{610^x}{D^x} \right) \]

where...

- \( E_n \) is the incident energy (cal/cm²) normalized for a specific time and distance from the arc
- \( E \) is the incident energy (cal/cm²)
- \( C_f \) is a calculation factor
  - 1.0 for voltages above 1 kV
  - 1.5 for voltages at or below 1kV
- \( t \) is the arcing time (seconds)
- \( D \) is the distance from the possible arc point to the person (mm)
- \( x \) is the equipment specific distance exponent
- \( I_{bf} \) is the bolted fault current for three-phase faults
- \( V \) is the system voltage
Arc Flash Mitigation
Most Common Mitigation Strategies

- **Reduce t (arcing time)**
  - “Maintenance switch” (temporary setting group changes)
  - Communication assisted (GOOSE) protection schemes
  - Optical arc flash relays with sound pressure supervision
  - Optical arc flash relays with current supervision

- **Increase D (working distance)**
  - Extended racking tools
  - Remote racking

- **Deflection of arc energy**
  - Arc resistant switchgear

- **Reduce Ibf (available bolted fault current)**
  - Electronically triggered fault current limiter (ET-FCL)

\[
E = C_j E_n \left( \frac{t}{0.2} \right) \left( \frac{610^x}{D^x} \right)
\]
### Arc Flash Mitigation

**Effect of Time – Reducing Arc Duration**

<table>
<thead>
<tr>
<th>Color</th>
<th>Hazard Category</th>
<th>Hazard Range cal/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>Above 4</td>
<td>Greater than 40</td>
</tr>
<tr>
<td>Orange</td>
<td>3</td>
<td>25 to 40</td>
</tr>
<tr>
<td>Yellow</td>
<td>2</td>
<td>8 to 25</td>
</tr>
<tr>
<td>Green</td>
<td>1</td>
<td>4 to 8</td>
</tr>
<tr>
<td>Light Green</td>
<td>0</td>
<td>1.2 to 4</td>
</tr>
<tr>
<td>Brown</td>
<td>0</td>
<td>Less than 1.2</td>
</tr>
</tbody>
</table>

#### Incident Energy Comparisons

<table>
<thead>
<tr>
<th>Bolted Fault Current (kA)</th>
<th>Arcing Current (kA)</th>
<th>Incident Energy (cal/cm²)</th>
<th>Clearing Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.10</td>
<td>0.20</td>
<td>0.30</td>
</tr>
<tr>
<td>10.0</td>
<td>1.25</td>
<td>2.50</td>
<td>3.75</td>
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<td>20.0</td>
<td>2.61</td>
<td>5.23</td>
<td>7.84</td>
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<tr>
<td>30.0</td>
<td>4.02</td>
<td>8.04</td>
<td>12.06</td>
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<td>40.0</td>
<td>5.46</td>
<td>10.91</td>
<td>16.37</td>
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<tr>
<td>50.0</td>
<td>6.92</td>
<td>13.84</td>
<td>20.75</td>
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<td>60.0</td>
<td>8.40</td>
<td>16.79</td>
<td>25.19</td>
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<td>70.0</td>
<td>9.89</td>
<td>19.78</td>
<td>29.67</td>
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<td>80.0</td>
<td>11.40</td>
<td>22.80</td>
<td>34.20</td>
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<tr>
<td>90.0</td>
<td>12.92</td>
<td>25.84</td>
<td>38.76</td>
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<tr>
<td>100.0</td>
<td>14.45</td>
<td>28.90</td>
<td>43.35</td>
</tr>
</tbody>
</table>

Arc Flash Mitigation
Typical PPE Suit Requirements

1

2

3

4
Arc Flash Mitigation
Maintenance Switch – Temporary Setting Group

- Maintenance settings are intentionally very sensitive. Normal coordination of protection is abandoned. The entire bus will be cleared for a feeder fault. Relay time is about 25 ms.

- The primary danger is forgetting to return the relay settings to normal after the maintenance work is complete.
Arc Flash Mitigation

GOOSE Blocking Scheme (Generic Object Oriented Substation Event)

- Blocking signals are sent to all upstream relays that might see the fault.
- If a blocking signal is not received, the relay is allowed to trip.
- All faults between A and C relays can be properly detected in about 20 ms.
- Conventional time coordination can take several tenths of seconds...a huge difference!
- Several tenths of seconds improvement can reduce arc flash hazards by several categories.
Arc Flash Mitigation
GOOSE Blocking Scheme (Generic Object Oriented Substation Event)

Arc Flash Mitigation
Optical Arc Flash Protection – Light and Sound

- Relay sensing time is about 2-4 ms*
- Sensor placement is critical*
- Testing issues?

Light and sound pressure sensor with fiber connection to a common relay

Reference: “A Novel Approach for Arc-Flash Detection and Mitigation: At the Speed of Light and Sound”, 2013 Texas A&M Relay Conference
Arc Flash Mitigation
Optical Arc Flash Protection – Light and Current

- Continuous fiber light sensor

- Relay operating time <2.5 ms
- Can also operate in “light only” mode
- Generally less expensive to install
- Current and light tests are easily done
## Arc Flash Mitigation

### Effects of Distance – Moving Away from the Arc

**Reference:** IEEE Std 1584 "IEEE Guide for Performing Arc-Flash Hazard Calculations"

<table>
<thead>
<tr>
<th>Color</th>
<th>Hazard Category</th>
<th>Hazard Range (cal/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 4</td>
<td>4</td>
<td>25 to 40</td>
</tr>
<tr>
<td>3</td>
<td>8 to 25</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4 to 8</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1.2 to 4</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Less than 1.2</td>
<td></td>
</tr>
</tbody>
</table>

**Select Equipment Type:**
- Switchgear
- Panelboard or MCC (<1000V)

**Select Grounding Method:**
- Ungrounded or High Resistance Grounded System
- Grounded Systems

**Voltage (kV):** 13.8

<table>
<thead>
<tr>
<th>Bolted Fault Current (kA)</th>
<th>Arcing Current (kA)</th>
<th>0.40</th>
<th>Total Clearing Time (sec)</th>
<th>Min. Distance Hazard Level 0 (feet)</th>
<th>Min. Distance Hazard Level 1 (feet)</th>
<th>Min. Distance Hazard Level 2 (feet)</th>
<th>Min. Distance Hazard Level 3 (feet)</th>
<th>Min. Distance Hazard Level 4 (feet)</th>
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<td></td>
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<tr>
<td>20.0</td>
<td>19.2</td>
<td>10.45</td>
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<td>30.0</td>
<td>28.6</td>
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<tr>
<td>40.0</td>
<td>37.9</td>
<td>21.83</td>
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<td>50.0</td>
<td>47.2</td>
<td>27.67</td>
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<tr>
<td>60.0</td>
<td>56.5</td>
<td>33.59</td>
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<td>70.0</td>
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<tr>
<td>80.0</td>
<td>74.9</td>
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<td>90.0</td>
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<td>51.67</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100.0</td>
<td>93.3</td>
<td>57.80</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Arc Flash Mitigation
Increasing Distance – Extended Racking Tools

An extra 3 feet cuts the incident energy approximately in half
Arc Flash Mitigation
Increasing Distance – Remote Racking Device

Detachable remote controller

Detachable motor operator
Arc Flash Mitigation
Increasing Distance – Remote Operation of Breakers
Arc Flash Mitigation
Energy Deflection – Arc Resistant Switchgear

1 - Hinges and flaps designed for controlled venting of over-pressure
2 - Roof-mounted flaps vent excess pressure away from workers
3 - Self-aligning tulip connectors
Arc Flash Mitigation
Energy Deflection – Arc Resistant Switchgear

1 - Instrument compartment
2 - Reinforced PT, CPT and breaker doors
3 - Double sidewall construction to resist burn-through
4 - Breaker door window
5 - Closed-door racking
Arc Flash Mitigation
Energy Reduction – Electronically Triggered Fault Current Limiter

Low fault current but poor regulation

Good regulation but high fault current

Opens immediately, separating the two buses

Low fault current and good regulation

Lower fault current means lower arc flash hazard levels
Arc Flash Mitigation

Energy Reduction – High Speed Grounding Switch (HSGS)

HSGS eliminates arc fault well before the first peak of the fault current which means lower arc flash hazard levels.
# Arc Flash Mitigation

## Comparison of Mitigation Strategies

<table>
<thead>
<tr>
<th>Method</th>
<th>Pros</th>
<th>Cons</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Switch</td>
<td>Simple</td>
<td>Overtrip likely</td>
<td>15-25 ms</td>
</tr>
<tr>
<td></td>
<td>Very low cost</td>
<td>Requires manual activation/de-activation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relatively fast</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GOOSE Blocking</td>
<td>Passive</td>
<td>Requires IEC61850 compliant relays</td>
<td>15-25 ms</td>
</tr>
<tr>
<td></td>
<td>Low cost</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relatively fast</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can be expanded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optical w/ Sound</td>
<td>Passive</td>
<td>Sensor placement critical</td>
<td>2-4 ms</td>
</tr>
<tr>
<td></td>
<td>Very fast</td>
<td>Sound testing?</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can be expanded</td>
<td>Sensitivity?</td>
<td></td>
</tr>
<tr>
<td>Optical w/ Current</td>
<td>Passive</td>
<td>Requires care in installation</td>
<td>&lt;2.5 ms</td>
</tr>
<tr>
<td></td>
<td>Very fast</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Easily tested</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Can be expanded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extended racking tool</td>
<td>Simple</td>
<td>Only impacts racking in/out</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Very low cost</td>
<td>Limited improvement</td>
<td></td>
</tr>
<tr>
<td>Remote racking</td>
<td>Low cost</td>
<td>Only impacts racking in/out</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Large improvement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fault Current Limiter</td>
<td>Ultra fast</td>
<td>Relatively high cost</td>
<td>&lt;1 ms</td>
</tr>
<tr>
<td></td>
<td>Fault currents cleared in &lt; 0.5 cycle</td>
<td>Requires system study to establish settings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate coordination</td>
<td></td>
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</tr>
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</table>

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The occurrence of an arc fault is the most serious fault within a switchgear system. High incident energy levels can cause severe equipment damage, injury to operating personnel and could result in huge loss of revenue due to prolonged outages. Conducting an Arc flash study determines the incident energy level in the gear and safe operating distance. Implementing fast operating mitigation solution drastically reduces the risk associated with Arc Flash incidents for the equipment and operating personnel. It is better to be safe than sorry!
If you have further questions, please contact:

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