Ground Fault Breakers and Arc Fault Circuit Interrupters (AFCI)

Kevin J. Lippert
Manager, Codes & Standards
Eaton Corporation
Agenda

- History of Circuit Protection
- Thermal Magnetic Breakers
- Ground Fault Breakers
- Arc Fault Circuit Interrupters
- Resources
Agenda

• History of Circuit Protection
• Thermal Magnetic Breakers
• Ground Fault Breakers
• Arc Fault Circuit Interrupters
• Resources
We Have Come A Long Way
In Electrical Safety

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>Knob &amp; Tube Primary Wiring</td>
</tr>
<tr>
<td>1930</td>
<td>2-Conductor BX Replacing Knob &amp; Tube</td>
</tr>
<tr>
<td>1950</td>
<td>Aluminum Bonding Strip Required On BX</td>
</tr>
<tr>
<td>1970</td>
<td>Aluminum Armored BX Cable &amp; NM-B Primary Wiring</td>
</tr>
<tr>
<td>1990</td>
<td>Ground Fault Protection Begins In the 70's On Swimming Pools (Electrocutions ~ 1100/ year) '70s: Bathroom, Garage, And near pools '80s: Whirlpools, Tubs, Kitchen Sinks '90s: Basements, Crawl Spaces, Wet Bars, Kitchens '00s: Outside and Other Locations (Electrocutions ~ 400/year)</td>
</tr>
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<td>2000</td>
<td>Ground Fault Protection Begins In the 70's On Swimming Pools (Electrocutions ~ 1100/ year) '70s: Bathroom, Garage, And near pools '80s: Whirlpools, Tubs, Kitchen Sinks '90s: Basements, Crawl Spaces, Wet Bars, Kitchens '00s: Outside and Other Locations (Electrocutions ~ 400/year)</td>
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Residential Homes Are Safer Because Of Codes and Standards Yet We Still Have Needless Deaths And Injuries
Overcurrent Protective Device Milestones

• 1918 Need Arises
• 1927 Westinghouse introduces a circuit breaker can interrupt a fault current of 5,000A at 120V
• 1973 Introduction of electronic trip units
Evolution Of Circuit Protection

- The Electrical industry is continuing to make steps to improve electrical safety
- Electrical Safety Requires Industry Advancements In Product & Installation Practices
Agenda

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What Is A Circuit Breaker?

Definition:

- A device designed to open and close a circuit by non-automatic means and to open the circuit automatically on a predetermined overcurrent, without damage to itself when properly applied within its rating.

Ref: NFPA 70-2008
Introducing…
Thermal Magnetic Circuit Breakers

• In the 1930’s Westinghouse introduced the “No-Fuze Load Center” featuring circuit breakers.
• The basic design and concept of the thermal magnetic breaker has not changed since its initial release.
• Thermal magnetic breakers protect the homes wiring from damage due to overcurrents (overloads & short circuits)
Thermal Magnetic Circuit Breaker

- Designed to protect conductors and their insulation from damage.
Overload Protection

• Overload protection is provided by bi-metal

• The bi-metal is made of two different metals which expand at different rates when heated.

• An overload event causes heating in the bimetal which bends and allows the trip mechanism to release
Short Circuit Protection

- Short Circuit protection is provided by a magnetic mechanism
- Per Ampere’s law, the strength of a magnetic field formed around an electrical current is proportional to the amount of current
- When a short circuit event occurs, a large amount of current flows creating a strong magnetic field. The armature is pulled down by the magnetic field, releasing the tripping mechanism
Time Current Curves

- Time current curves detail the response of a breaker to overcurrent events
- Shows both the thermal (overload) and magnetic (short circuit) responses
UL 489
Molded Case Circuit Breakers

• Calibration
  • 100% - No Tripping
  • 135% - Trip within 1 hr for ratings less than 50A
  • 200%
    • 2 min – 0-30A
    • 4 min – 31-50A

• Endurance (below 100A)
  • 6,000 operations w/ current
  • 4,000 operations w/o current

• Overload
  • Must break 600 percent of its rated current

<table>
<thead>
<tr>
<th>Current rating (Iw) in Amperes</th>
<th>Maximum tripping time in minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 20</td>
<td>2</td>
</tr>
<tr>
<td>31 – 50</td>
<td>4</td>
</tr>
<tr>
<td>51 – 100</td>
<td>8</td>
</tr>
<tr>
<td>101 – 150</td>
<td>10</td>
</tr>
<tr>
<td>151 – 225</td>
<td>151 – 225</td>
</tr>
<tr>
<td>226 – 400</td>
<td>12</td>
</tr>
<tr>
<td>401 – 600</td>
<td>14</td>
</tr>
<tr>
<td>601 – 800</td>
<td>18</td>
</tr>
<tr>
<td>801 – 1000</td>
<td>20</td>
</tr>
<tr>
<td>1001 – 1200</td>
<td>24</td>
</tr>
<tr>
<td>1201 – 1600</td>
<td>20</td>
</tr>
<tr>
<td>1601 – 2000</td>
<td>28</td>
</tr>
<tr>
<td>Over 2000</td>
<td>30</td>
</tr>
</tbody>
</table>

* For circuit breaker frames rated more than 250 V, the maximum tripping time may be 3 minutes.
Agenda

- History of Circuit Protection
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- Ground Fault Breakers
- Arc Fault Circuit Interrupters
- Resources
UL 943
Ground Fault Circuit Interrupters, GFCI

UL 943

• Provides “people protection” from electric shock
  • Leakage < 6 mA
  • Trip time ~15 mS
Ground Fault Circuit Interrupters, GFCI

- GFCI monitors the difference in the current leaving the breaker, versus the current returning to the breaker.
UL 1053
Ground-Fault Sensing and Relaying Equipment

UL 1053

• Provides “equipment protection” from low level faults to ground

• Leakage within 10% of level defined by manufacturer
National Electrical Code, NEC

- NFPA 70, contains “installation” rules
- 2008 Edition has 882 Pages
- Created by 19 NEC Code-Making Panels (CMP)
  - Balanced Representation (Manufacturers, Electricians, Inspectors, UL, etc.)
  - Represent Groups/Associations (Directed Votes)
  - K. Lippert – Alternate NEMA Rep. On CMP 10
- 3-year revision cycle
- Mentions “Listed” products
  - References “product” Standards (Annex A)
NEC Ground Fault Origins

- **1968** GFCI required for swimming pool underwater lights
- **1971** GFCI expanded to Construction sites, Swimming pool receptacles, outdoors of dwellings
- **1971** GF protection of equipment required where Services >150V to ground and Service Disconnect >1200A
NEC Ground Fault Expands

• 1975  GFCI for dwelling bathrooms
• 1978  GFCI for dwelling garages,
Recreational vehicle parks;
  2nd Level of equipment GF for health care
facilities
• 1981  …
• 1987  GFCI for Kitchens (near sink)
• 1990  …

Every new Code edition seems to continue to expand
Ground Fault requirements.
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Need for Further Enhanced Fire Prevention

Annual Fire Statistics

- > 70,000 Residential Electrical Fires
- > 500 Deaths
- > 2000 Burn Injuries
- > $1 Billion Direct Property Damage
• 1980, 1984 and 1985 -- CPSC sponsored studies to investigate the causes of electrical distribution fires.

• The electrical arc was determined to be a major source of electrical fires (>80%).

• The electrical industry was challenged to provide an engineered solution.

• Advances in electronics made possible the development of arc fault detection technology
Arcing Faults

- Unintentional Arcing Condition
- Temperatures In Excess Of 10,000 degrees Fahrenheit
- Not persistent enough to heat the bimetal in Thermal Magnetic Breakers
Classifying An Arc Fault

- Operational Arcs - occur in a properly functioning electrical system
  - Switching loads on/off
  - Contact closure/opening

- Non-Operational Arcs - potential fire hazards
  - Damaged insulation in fixed wiring and appliance cords
  - Loose connections
Operational Arcs

- Some examples of operational arcs:
Hazardous Arcs

- Some examples of non-operational arcs:
Types Of Arcing Faults

High Current Level Arc
“Parallel Arc”
- An Arc Fault That Occurs at 75Amps and higher
- An Arc Fault That Occurs Line-Line or Line-Neutral

Low Current Level Arc
“Series Arc”
- An arc fault at low levels down to 5 Amps
- An arc fault at a break or gap in a single conductor in series with a connected load
Introducing AFCI
UL 1699 – AFCI Standard

- UL 1699 details the required testing
- Extensive “detection” testing required

Table 34.2
Arc fault detection tests table
Table 34.2 revised August 29, 2006

<table>
<thead>
<tr>
<th>Tests</th>
<th>Branch/feeder AFCI</th>
<th>Combination AFCI</th>
<th>Outlet circuit AFCI</th>
<th>Portable AFCI</th>
<th>Cord AFCI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>With feed</td>
<td>Without feed</td>
<td>AFCI</td>
</tr>
<tr>
<td>40.2</td>
<td>Carbonized path arc ignition test</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
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<tr>
<td>40.3</td>
<td>Carbonized path arc interruption test</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.4</td>
<td>Carbonized path arc clearing time test</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40.5</td>
<td>Point contact arc test</td>
<td>X</td>
<td>X</td>
<td></td>
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<tr>
<td>41.2</td>
<td>Load condition I – Inrush current</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>41.3</td>
<td>Load condition II – normal operation arcing conditions a – c</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>41.4</td>
<td>Load condition III – non-sinusoidal waveform</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>41.5</td>
<td>Load condition IV – cross talk</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>41.6</td>
<td>Load condition V – multiple load</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>41.7</td>
<td>Load condition VI – lamp burnout</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>42</td>
<td>Operation Inhibition</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>42.2</td>
<td>Masking</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>42.3</td>
<td>EMI filter</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>42.4</td>
<td>Line impedance</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

NOTE - All SPT-2 wire specimens shall have insulation rated 60°C.
# Circuit Breaker - Levels of Protection

<table>
<thead>
<tr>
<th>Device</th>
<th>Protection</th>
<th>Method</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Magnetic Breaker</td>
<td>▪ Thermal Overload</td>
<td>Current flow heats a bi-metal device within the breaker which bends and trips breaker</td>
<td>Overloaded Circuit</td>
</tr>
<tr>
<td></td>
<td>▪ Over Current Condition</td>
<td>Flowing current creates a magnetic field which trips breaker</td>
<td>Short Circuit</td>
</tr>
<tr>
<td>Branch Feeder Arc Fault Circuit Interrupter</td>
<td>▪ Thermal Overload</td>
<td>Same the thermal magnetic plus electronic circuitry monitors parallel arcing current signature</td>
<td>Any line to neutral or line to ground arc such as a drywall screw or nail which penetrates electrical wiring</td>
</tr>
<tr>
<td></td>
<td>▪ Over Current Protection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ High Current Arcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Low Current Arcing in Installed Wiring</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Combination Arc Fault Circuit Interrupter</td>
<td>▪ Thermal Overload</td>
<td>Same as the thermal magnetic breaker and the branch feeder plus electronic circuitry monitors series arcing current signature</td>
<td>A broken wire or poor connection in connected appliance cords or permanent house wiring</td>
</tr>
<tr>
<td></td>
<td>▪ Over Current Protection</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ High Current Arcing</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Low Current Arcing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Eaton’s AFCI Protection

Branch AFCI

Arcing Fault Protection
≥ 5 Amps
≥ 75 Amps

Earth Leakage Protection
≥ 30 mA

Combo AFCI

Arcing Fault Protection
≥ 5 Amps

Earth Leakage Protection
≥ 30 mA
National Electrical Code (NEC)

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999 NEC</td>
<td>Introduction of <strong>Branch Feeder</strong> AFCI to the National Electrical Code. Protection of branch circuits supplying bedroom receptacle outlets as of January 1, 2002.</td>
</tr>
<tr>
<td>2002 NEC</td>
<td>Listed <strong>Branch Feeder</strong> AFCI protection of branch circuits supplying bedroom outlets.</td>
</tr>
<tr>
<td>2005 NEC</td>
<td>Branch circuits supplying outlets installed in dwelling unit bedrooms shall be protected by a listed arc-fault circuit interrupter, <strong>Combination type</strong>, installed to provide protection of the branch circuit.</td>
</tr>
<tr>
<td></td>
<td>Branch feeder AFCI's permitted to be used until January 1, 2008. Location of the of AFCI is permitted to be within 6’ of the origin of the branch circuit via a metal raceway or a cable with a metallic sheath.</td>
</tr>
<tr>
<td>2008 NEC</td>
<td><strong>Combination-Type</strong> AFCI required on Bedroom, Family Rooms, Living Rooms, Parlors, Libraries, Dens, Sun Rooms, Recreation Rooms, or Similar Rooms. It shall be permitted to install a combination AFCI at the first outlet. RMC, IMC or EMT or steel armored cable, Type AC, meeting the requirements of 250.118, using metal outlet or junction boxes must be installed between the origin of the Branch Feeder and the first outlet.</td>
</tr>
</tbody>
</table>
NEC Article 210.12

• The National Electrical Code requires AFCIs
• 2008 NEC expands AFCI requirements from Bedroom circuits only, to many other circuits of a home
• Combination-Type AFCI is the new technology required by the 2008 NEC
2005 NEC Branch Feeder Coverage

- Green Highlighted Rooms Are Those Required To Be Protected By AFCI
- Red Highlighted Rooms Are Those Not Required To Be Protected By AFCI
- Outside Receptacles Also Do Not Require AFCI Protection
“(B) Dwelling Units. All 120-volt, single-phase, 15- and 20-ampere branch circuits supplying outlets installed in dwelling unit family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sun rooms, closets, recreation rooms, hallways, or similar rooms or areas shall be protected by a listed arc fault circuit interrupter, combination-type, installed to provide protection of the branch circuit”
2008 NEC Combination AFCI Coverage

- **Green Highlighted Rooms Are Those Required To Be Protected By AFCI**
- **Red Highlighted Rooms Are Those Not Required To Be Protected By AFCI**
- **Outside Receptacles Also Do Not Require AFCI Protection**
AFCI Supporters
Agenda

• History of Circuit Protection
• Thermal Magnetic Breakers
• Ground Fault Breakers
• Arc Fault Circuit Interrupters
• Resources
Eaton’s Resources Available

- Combination AFCI Brochure
  Publication # BR00402001E

- CH Plug-on Neutral Brochure
  Publication # BR00301005E

- UL Classified Replacement Circuit Breakers
  Publication # SA00304001E

- Residential Warranty Folder
  Publication # SA00305001E

- Application Documents
  - FAQs
  - “How an AFCI Works”
  - Preventative Maintenance
  - Troubleshooting Guides
Additional Eaton Resources

✓ FAQs
✓ “How an AFCI Works”
✓ Preventative Maintenance
✓ Homeowner Troubleshooting Guide
Eaton’s Residential Applications Team

Phone: 1.800.326.9513

Option 1: Technical Support
  Option 1: Arc Fault Circuit Interrupter
  Option 2: Ground Fault Circuit Interrupter

Email: resiapps@eaton.com

24/7/365 Support
Eaton’s application technicians are available around the clock to support any issue.

US Based Support Staff
Eaton’s support staff is located in the United States and is trained in US and Canadian electrical codes and standard wiring practices.

Real World Experience
Eaton’s support staff is comprised of degreed engineers with industry experience as well as accredited electricians, each familiar with real world field issues and solutions.
Questions And Comments

Thank You
“EXTRA” Material

• The following slides are “extra” … to be used only if physical demonstration samples are not available

• Additional “Case Study” slides can be used…time permitting
Arc Detection / Fire Prevention

• AFCI versus Thermal Magnetic Demo’s

- High Energy Arcing
  - Thermal Magnetic

- Low Energy Arcing
  - Thermal Magnetic

- High Energy Arcing
  - AFCI

- Low Energy Arcing
  - AFCI
Case Study

Location: Fort Mill, SC
Age of Home: Home Built in 2005
Background: An arc fault breaker began tripping intermittently on a bedroom lighting circuit when turning on fan or lights.
Case Study

- Electrician initially replaced AFCI but new breaker tripped as well

- Inspection of the homerun showed wires were pulled through a truss connector plate
Case Study

- Wire was siliconed and taped to prevent grounding
- Breaker continued to trip intermittently
- Homeowner requested the homerun be replaced
When removing the homerun, evidence of an arcing condition was found on the wire which was in the wall. Note the carbonization on the neutral indicating arcing.