PDHonline Course E228 (2 PDH)

The Proper Use of Arc Fault Circuit Interrupters (AFCI)

Instructor: Kevin A. Mussmacher, PE

2020

PDH Online | PDH Center

5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

An Approved Continuing Education Provider

The Proper Use of Arc Fault Circuit Interrupters (AFCI)

Kevin A. Mussmacher, P.E.

Section 1 - What is an AFCI?

An **arc fault circuit interrupter (AFCI)** is a circuit breaker designed to prevent fires by detecting non-working electrical arcs and disconnect power before the arc starts a fire. Advanced electronics inside an AFCI breaker detect sudden bursts of electrical current in milliseconds, long before they would trip a regular overcurrent circuit breaker or fuse. The AFCI should distinguish between a working arc that may occur in the brushes of a vacuum sweeper, light switch, or other household devices and a non-working arc that can occur, for instance, in a lamp cord that has a broken conductor in the cord from overuse. Arc faults in a home are one of the leading causes for household fires.[1]

The AFCI (Arc Fault Circuit Interrupter) breaker (See photos below) will shut off a circuit in a fraction of a second if arcing develops. The current inside of an arc is not always high enough to trip a regular breaker. You must have noticed a cut or worn piece of a cord or a loose connection in a junction box or receptacle arcing and burnt without tripping the regular breaker. As you can guess this is a major cause of fires in a dwelling.

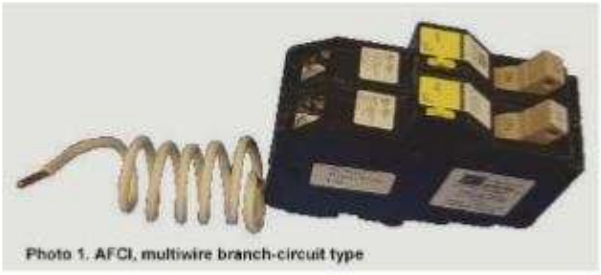


Photo 1. AFCI, multiwire branch-circuit type

Photo 2. AFCI, single circuit breaker type

There is a difference between AFCIs and GFCIs. AFCIs are intended to reduce the likelihood of fire caused by electrical arcing faults; whereas, GFCIs are personnel protection intended to reduce the likelihood of electric shock hazard. Don't misunderstand, GFCIs are still needed and save a lot of lives.

Combination devices that include both AFCI and GFCI protection in one unit will become available soon. AFCIs can be installed in any 15 or 20-ampere branch circuit in homes today and are currently available as circuit breakers with built-in AFCI features. In the near future, other types of devices with AFCI protection will be available. [2]

If a GFCI receptacle is installed on the load side of an AFCI it is possible for both the AFCI and the GFCI to trip on a fault if the current exceeds the limit for both devices. It is also possible for the AFCI to trip and the GFCI to not trip since the two devices could race each other. However, in no case is safety compromised.

AFCIs resemble a GFCI/RCD (Ground-Fault Circuit Interrupt/Residual-Current Device) in that they both have a test button, though it is important to distinguish between the two. GFCIs are designed to protect against electrical shock, while AFCIs are primarily designed to protect against fire.

Figure 1 – Arc Fault Circuit Interrupter (AFCI)

Section 2 - Why Do We Need AFCIs?

Electrical fires happen every day in the United States because of electrical shorts that produce intensely hot arcs. An arc fault circuit interrupter senses these arcs and stops them, making them smarter than traditional circuit breakers.

Approximately 115 electrical fires happen each day in the USA. These fires cause hundreds of millions of dollars in damage, injure thousands of people and are responsible for the deaths of hundreds of people each year. Ask any firefighter and he will tell you that electrical fires are non-discriminatory. They can strike anywhere and at any time.

The electrical shorts that cause these fires produce arcs. These miniature fireworks create sparks and temperatures that approach 10,000°F. This intense heat can rapidly ignite plastic insulation, wood, carpeting or any other combustible material in the vicinity of the arcing wires. Arcs happen frequently in appliance electrical cords where insulation has become brittle or is cracked. Hidden wires behind walls nicked by nails or pinched by fasteners can also be sources of sinister arcing. Loose connections where wires are attached to switches and outlets are often arc hot spots.

The traditional household circuit breakers did not prevent the fire for a simple reason. They are not designed to sense arc faults. Traditional circuit breakers are actually designed to protect just the wire behind the walls and the switches and outlets that they are connected to. The circuit breakers are designed to trip when they sense a short that causes an avalanche of electricity coursing through a circuit. They also will trip when a constant massive amount of electricity passing through the circuit causes a heat buildup within the breaker. Traditional breakers are not designed to protect lightweight appliance wires and extension cords that are plugged into wall outlets.

Fire producing arcs can occur in wiring before traditional breakers react. Electrical manufacturers recognized this problem and decided to attempt to stop as many of these electrical fires as possible. The result of the hard work of many is a new arc fault circuit interrupter breaker. These devices work and act like a traditional circuit breaker except that they are smarter. Many of these new devices contain small filters and logic devices that allow them to sense an arc just as it is about to produce the sparks and intense heat. If arcing conditions are present, then the breaker trips instantaneously. The following video demonstrates the difference between not having and having AFCI protection.

AFCI Video (from Texas Instruments).

Do not confuse these devices with the personal protection ground fault circuit interrupters (GFCI) that have been around for over 30 years. The GFCI circuit breakers, at the present time, do not have the capability to sense arcs.

Arc fault circuit breakers were identified in section 210-12 of the 1999 edition of the National Electric Code. Beginning January 1, 2002, they were required to protect branch circuits that serve residential bedrooms. These areas of the house have been identified

as the source of many electrical arc related fires. See Section 3 for the extensive requirement updates in the 2017 National Electrical Code.

Section 3

The National Electrical Code Requirements for AFCIs

The National Electrical Code (NEC), or NFPA 70, is a U.S. standard for the safe installation of electrical wiring and equipment. It is part of the National Fire Codes series published by the National Fire Protection Association (NFPA). "National Electrical Code" and "NEC" are registered trademarks of the NFPA. While the NEC is not itself a U.S. law, NEC use is commonly mandated by state or local law, as well as in many jurisdictions outside of the United States. The NEC codifies the requirements for safe electrical installations into a single, standardized source.

The following are the actual paragraphs from the 2017 National Electrical Code defining the requirements for the use of Arc Fault Circuit Interrupters. After this section is an article listing AFCI requirement changes in the 2017 National electrical Code, which took effect January 2017. More stringent requirements for using AFCI outlets, as well as, circuit breakers are clearly described.

210.12 Arc-Fault Circuit-Interrupter Protection. Arc-fault circuit-interrupter protection shall be provided as required in 210.12(A), (B), (C), and (D). The arc-fault circuit interrupter shall be installed in a readily accessible location.

(A) Dwelling Units. All 120-volt, single-phase, 15- and 20-ampere branch circuits supplying outlets or devices installed in dwelling unit kitchens, family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets, hallways, laundry areas, or similar rooms or areas shall be protected by any of the means described in 210.12(A)(1) through (6):

(1) A listed combination-type arc-fault circuit interrupter, installed to provide protection of the entire branch circuit.

(2) A listed branch/feeder-type AFCI installed at the origin of the branch-circuit in combination with a listed outlet branch-circuit type arc-fault circuit interrupter installed at the first outlet box on the branch circuit. The first outlet box in the branch circuit shall be marked to indicate that it is the first outlet of the circuit.

(3) A listed supplemental arc protection circuit breaker installed at the origin of the branch circuit in combination with a listed outlet branch-circuit type arc-fault circuit interrupter installed at the first outlet box on the branch circuit where all of the following conditions are met:

a. The branch-circuit wiring shall be continuous from the branch-circuit overcurrent device to the outlet branch-circuit arc-fault circuit interrupter.

b. The maximum length of the branch-circuit wiring from the branch-circuit overcurrent device to the first outlet shall not exceed 15.2 m (50 ft) for a 14 AWG conductor or 21.3 m (70 ft) for a 12 AWG conductor.

c. The first outlet box in the branch circuit shall be marked to indicate that it is the first outlet of the circuit.

(4) A listed outlet branch-circuit type arc-fault circuit interrupter installed at the first outlet on the branch circuit in combination with a listed branch-circuit overcurrent protective device where all of the following conditions are met:

a. The branch-circuit wiring shall be continuous from the branch-circuit overcurrent device to the outlet branch-circuit arc-fault circuit interrupter.

b. The maximum length of the branch-circuit wiring from the branch-circuit overcurrent device to the first outlet shall not exceed 15.2 m (50 ft) for a 14 AWG conductor or 21.3 m (70 ft) for a 12 AWG conductor.

c. The first outlet box in the branch circuit shall be marked to indicate that it is the first outlet of the circuit.

d. The combination of the branch-circuit overcurrent device and outlet branch-circuit AFCI shall be identified as meeting the requirements for a system combination–type AFCI and shall be listed as such.

(5) If RMC, IMC, EMT, Type MC, or steel-armored Type AC cables meeting the requirements of 250.118, metal wireways, metal auxiliary gutters, and metal outlet and junction boxes are installed for the portion of the branch circuit between the branch-circuit overcurrent device and the first outlet, it shall be permitted to install a listed outlet branch-circuit type AFCI at the first outlet to provide protection for the remaining portion of the branch circuit.

(6) Where a listed metal or nonmetallic conduit or tubing or Type MC cable is encased in not less than 50 mm (2 in.) of concrete for the portion of the branch circuit between the branch-circuit overcurrent device and the first outlet, it shall be permitted to install a listed outlet branch-circuit type AFCI at the first outlet to provide protection for the remaining portion of the branch circuit.

Exception: Where an individual branch circuit to a fire alarm system installed in accordance with 760.41(B) or 760.121(B) is installed in RMC, IMC, EMT, or steel-sheathed cable, Type AC or Type MC, meeting the requirements of 250.118, with metal outlet and junction boxes, AFCI protection shall be permitted to be omitted.

Informational Note No. 1: For information on combination-type and branch/feeder-type arc-fault circuit interrupters, see UL 1699-2011, *Standard for Arc-Fault Circuit Interrupters*. For information on outlet branch-circuit type arc-fault circuit interrupters, see UL Subject 1699A, *Outline of Investigation for Outlet Branch Circuit Arc-Fault Circuit-Interrupters*. For information on system combination AFCIs, see UL Subject 1699C, *Outline of Investigation for System Combination Arc-Fault Circuit Interrupters*.

Informational Note No. 2: See 29.6.3(5) of *NFPA 72 -2013, National Fire Alarm and Signaling Code*, for information related to secondary power-supply requirements for smoke alarms installed in dwelling units.

Informational Note No. 3: See 760.41(B) and 760.121(B) for power-supply requirements for fire alarm systems.

(B) Dormitory Units. All 120-volt, single-phase, 15- and 20-ampere branch circuits supplying outlets and devices installed in dormitory unit bedrooms, living rooms, hallways, closets, bathrooms, and similar rooms shall be protected by any of the means described in 210.12(A)(1) through (6).

N **(C) Guest Rooms and Guest Suites.** All 120-volt, single-phase, 15- and 20-ampere branch circuits supplying outlets and devices installed in guest rooms and guest suites of hotels and motels shall be protected by any of the means described in 210.12(A)(1) through (6).

(D) Branch Circuit Extensions or Modifications — Dwelling Units and Dormitory Units. In any of the areas specified in 210.12(A) or (B), where branch-circuit wiring is modified, replaced, or extended, the branch circuit shall be protected by one of the following:

(1) A listed combination-type AFCI located at the origin of the branch circuit

(2) A listed outlet branch-circuit-type AFCI located at the first receptacle outlet of the existing branch circuit

Exception: AFCI protection shall not be required where the extension of the existing conductors is not more than 1.8 m (6 ft) and does not include any additional outlets or devices.

Arc-Fault Circuit Interrupters (2017 NEC Update)

The 2017 NEC Update has increased the requirements for arc fault circuit interrupters (AFCIs). Before 2008, AFCIs were only required to protect bedrooms. As of 2017, AFCI requirements have greatly expanded. So where are arc fault breakers required for 2017? Keep reading to find out.

The following section has been excerpted from **Mike Holt** article originally published in EC&M magazine on November 18, 2016 addressing changes in the 2017 National Electrical Code (NEC).

Section 210.12 (Arc-Fault Circuit-Interrupter Protection)

The AFCI requirements have been greatly expanded.

Arc-fault circuit-interrupter protection must be provided in accordance with Sec. 210.12(A), (B), and (C). AFCI devices must be installed in readily accessible locations.

(A) Required Locations. A listed combination AFCI breaker is required for all 15A or 20A, 120V branch circuits in dwelling units supplying outlets or devices in kitchens, family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets, hallways, laundry areas, or similar rooms or areas.

(B) Dormitory Units. A listed combination AFCI breaker is required for all 15A or 20A, 120V branch circuits for outlets and devices in dormitory unit bedrooms, living rooms, hallways, closets, bathrooms, and similar rooms in accordance with 210.12(A).

(C) Guest Rooms and Guest Suites. A listed combination AFCI breaker is required for all 15A or 20A, 120V branch circuits supplying outlets and devices in guest rooms and guest suites of hotels and motels (**Fig. 5**).

Fig. 5.

(D) Branch-Circuit Extensions or Modifications in Dwelling Units and Dormitory Units. Where 15A or 20A, 120V branch-circuit wiring is modified, replaced, or extended in a dwelling unit or dormitory where AFCI protection is required [210.12(A)], the modified, replaced, or extended branch-circuit wiring must be AFCI protected by one of the following methods:

(1) A listed combination AFCI circuit breaker.

(2) A listed AFCI receptacle located at the first receptacle outlet of the branch circuit.

Exception: AFCI protection isn't required for extension wiring that's less than 6 ft in length if no outlets or devices are added.

Analysis:

AFCI protection is now required for guest rooms and suites of hotels and motels. This seems to be the progression of Code rules, such as the tamper-resistant receptacles required in Sec. 406.12. Because these areas are very similar in their use to dwelling units, this new rule was accepted.

The requirement for updating the electrical system when adding or modifying wiring was extended to dormitories. The NEC is often three years behind in making new allowances, and this will be the case as long as humans are responsible for the Code. Considering that there are typically 3,000 to 5,000 proposals (now called "public input") to change the NEC, things are going to slip through the cracks. Why not require the same rules and the same exception to all areas requiring AFCI protection?

End excerpt from MikeHolt.com

In addition, several minor changes concerning AFCI use have been added to the NEC:

406.4 - General Installation AFCI Requirements

Clarification was added about the rule that requires AFCI protection for replacement receptacles.

550.25 - Mobile Homes

AFCI protection for mobile homes mirror the AFCI requirements for dwellings in 210.12.

AFCIs provide protection against electrical fires. Make sure they are working properly by testing them every month.

Article showing new AFCI usage requirements in the 2014 National Electrical Code.

(Provides good background to changes to 2017 NEC).

New Electrical Safety Requirement: AFCI Protection for Replacement Outlets

By Reuben Saltzman In AFCI Devices on January 7, 2014

The 2011 National Electric Code has an important little note at the end of section 406.4(D)(4) which just took effect January 1st, 2014. The exact text from this section is shown below:

(4) Arc-Fault Circuit-Interrupter Protection. Where a receptacle outlet is supplied by a branch circuit that requires arc-fault circuit interrupter protection as specified elsewhere in this Code, a replacement receptacle at this outlet shall be one of the following:

1. A listed outlet branch circuit type arc-fault circuit interrupter receptacle.
2. A receptacle protected by a listed outlet branch circuit type arc-fault circuit interrupter type receptacle. 3. A receptacle protected by a listed combination type arc-fault circuit interrupter type circuit breaker.

This requirement becomes effective January 1, 2014.

This section requires that all replacement receptacles be arc-fault circuit interrupter (AFCI) protected. This means that if you're replacing an old outlet in an old home in a location that needs AFCI protection in a new home, the replacement outlet needs to be AFCI protected.

What's an AFCI device? In short, it's an electrical safety device designed to prevent fires. It looks and acts a lot like a GFCI device in that it has a test button and a reset method, but GFCI devices are designed to prevent people from getting electrocuted, not prevent fires. For an excellent document explaining the functionality of AFCIs as well as the history of these devices, click here: AFCIs Come of Age.

To paraphrase the exact code text, there are three ways to achieve compliance with this new requirement:

1. Replace the outlet with an AFCI outlet. AFCI outlets look almost identical to GFCI outlets.

2. Install an AFCI outlet upstream from the new outlet. AFCI outlets can protect outlets wired downstream from them.

3. Add AFCI protection to the entire circuit, using an AFCI circuit breaker. This is fairly easy to do in modern electric panels, but it's not possible with fuse panels and many older circuit breaker panels.

AFCI protection is currently required for all 15 and 20-amp branch circuits providing power to outlets* in residential family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets, hallways, and similar rooms or areas. Once the

2014 NEC is adopted, both outlets and devices in these locations will need AFCI protection, and list will be expanded to include kitchens and laundry areas.

* An "outlet" is defined in the NEC as "A point on the wiring system at which current is taken to supply utilization equipment." This might mean a light, a smoke alarm, or a 'receptacle'. A receptacle is what normal people call an outlet.

With this new requirement now in effect, I'm guessing the demand for AFCI outlets is going to skyrocket. Home Depot sells AFCI outlets for under $30, but they currently only have white. For more info on AFCI outlets from Leviton, visit their website.

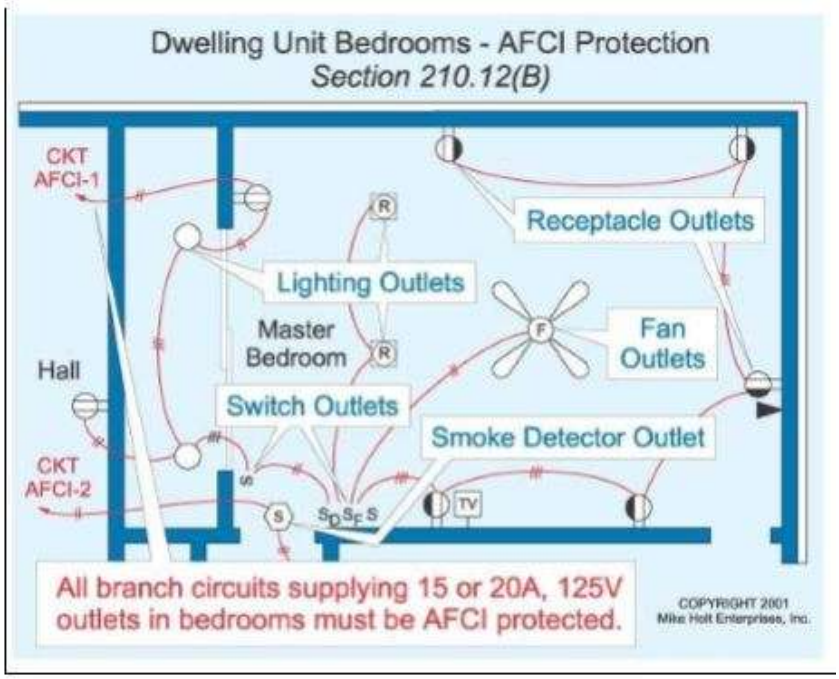
END ARTICLE

The following (from MikeHolt.com and is copyrighted to Mike Holt Enterprises, Inc.) are changes from the NEC 2005 to the NEC 2008. It provides a good description of AFCIs.

210.12 Arc-Fault Circuit-Interrupter (AFCI) Protection

Revised text to require, after January 1, 2008, that all dwelling unit, bedroom branch circuit, AFCI protection devices must be listed as a "Combination Type AFCI." And new exception permits AFCI protection by a device that isn't a circuit breaker (such as a receptacle), but only if it meets stringent requirements.

(A) AFCI Definition. An AFCI protection device provides protection from an arcing fault by recognizing the characteristics unique to an arcing fault and by functioning to deenergize the circuit when an arc fault is detected. (B) Dwelling Unit Bedrooms. All branch circuits supplying 15 or 20A, single-phase, 125V outlets installed in dwelling unit bedrooms must be AFCI protected by a listed device that protects the entire branch circuit. See figure below:



Author's Comment: This applies to all outlets, including smoke detectors.

See 2017 NEC for current requirements.

Intent: The change extends AFCI protection to all branch circuit conductors that supply 125V outlets in dwelling unit bedrooms, whereas the 1999 NEC only required AFCI protection for all branch circuit conductors that supply 15 or 20A, single-phase, 125V receptacle outlets in dwelling unit bedrooms. Currently there are three types of AFCI protection devices.

AFCI Branch/Feeder Type (AVZQ) – This protection device typically has the AFCI protection integral with a circuit breaker. It is designed to protect the branch circuit wiring against the unwanted effects of arcing, with limited protection to power supply cords connected to the receptacle.

AFCI Outlet Branch Circuit Type (UL – AWBZ) – This AFCI protection device is typically a receptacle with integral AFCI protection that is intended to protect both the power supply cords connected to the receptacle and the upstream branch circuit wiring.

AFCI Outlet Type (UL – AWCG and AWBZ) – This device is likely to be a receptacle with integral protection that is designed to protected cord sets plug into it, not the upstream branch circuit wiring.

Author's Comment: At the time a dwelling unit is wired, it is hard to tell from looking at the bare walls whether a room will be used as a home office or a bedroom. Also, if you are looking at an efficiency apartment, a room may well be furnished with a foldout couch that is used for sleeping on every night, making it look as much like a bedroom as a living room.

If you wire bedroom branch circuits with one circuit for lighting and receptacles, this change will have little effect. But the practice of separating the lighting from the receptacle circuits in dwelling unit bedrooms will now require two AFCI circuit breakers. The 125V limitation to the requirement means that AFCI protection would not be required for a 240V baseboard heater or room air conditioner.

End excerpt from MikeHolt.com

NOTE: A "Branch Circuit" is defined as a portion of a wiring system that extends beyond the final, automatic overcurrent protective device (i.e., fuse or breaker) which qualifies for use as branch-circuit protection, and terminates at the utilization device or outlet (such as a lighting fixture, motor, or heater). [3]

Section 4 – Arc Fault Theory

From **Arc-Fault Circuit Interrupter Technology** by Walter Smittle III from IAEI Magazine, July/August 2004

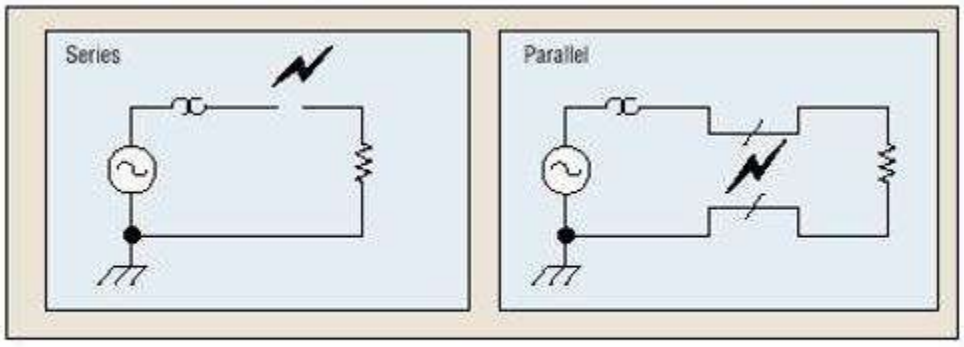
Arcing

UL defines "arcing as a luminous discharge of electricity across an insulating medium. The electrical discharge of an arc can involve temperatures on the order of several thousand degrees Celsius. In general, arcing can be divided into two categories: (1) non-contact arcing and (2) contact arcing.

"Non-contact arcing is arcing that does not require direct physical contact between the conductors where the arcing is taking place. With arcing between conductors separated by insulation, the mechanism of initiating an arc between stationary conductors separated by insulation will depend on the type and geometry of the conductors and insulation between them. Contact arcing is arcing that involves direct or indirect physical contact between the conductors or 'electrodes' where the arcing is taking place, such as arcing between closing or parting conductors making or breaking a circuit." [1]

Types of arcing faults

"Arcing faults can occur in one of two ways, series arcing faults or parallel arcing faults. A series arcing fault can occur when one of the current-carrying paths (e.g., a single wire) in series with the load is unintentionally broken. For example, extreme flexing in an appliance power supply cord can cause one of the conductors to open and arc when flexed. Series arcing faults are limited in the circuit. Parallel arcing faults occur when there is an unintentional conducting path between two conductors of opposite polarity, such as between a black and a white conductor or between a line conductor and ground. Parallel arcing faults generally involve high currents, as they are limited only by the available fault current of the circuit."[2]



From Power Electronics Technology, November 2004 – Controller Guard Against Arc Faults by Kevin A Mussmacher, PE and William Froeb

Series arcing occurs when a light switch is opened or closed or when an appliance cord is pulled from an outlet. These are common occurrences in the electrical circuitry of the home. Parallel arcing is the most dangerous; it generates high temperatures and ignites available combustibles. These parallel arcs have been observed in fire scene investigations where a positive conductor comes in contact with a neutral or ground conductor. The fire service has for years referred to this as a "direct electrical short."

An AFCI is designed to detect arcing by continuously monitoring the current flow by discriminating between normal and unwanted arcing conditions. "Once an unwanted arcing condition is detected, the control circuitry in the AFCI trips the internal contacts, thus de-energizing the circuit and reducing the potential for a fire to occur. An AFCI should not trip during normal arcing conditions, which can occur when a switch is opened, or a plug is pulled from a receptacle."[3]

Causes of arcing faults

Common causes of arc-faults, as reported by the national fire service and insurance organizations, include: pinched or pierced insulation on construction wire or cords nipped by a nail or screw or a chair leg setting on an extension cord; cracked insulation on wire or cords from age, heat, chemical erosion or bending stress; overheated wire or cords; loose or improper connections, such as electrical wires to outlets and switches; frayed or ruptured extension or appliance cords; electrical appliances in which support or insulation for energized electrical parts is damaged; moisture or contaminants between conductors of different voltage and electrical wire insulation chewed by rodents. The AFCI can detect these arcs from the normal current flow by the electronic circuitry within the AFCI.

Aluminum Wiring

Aluminum wiring is sometimes associated with arcing and house fires. The wire itself is not the direct cause. The interface between aluminum wire and copper or brass terminals is the real issue. These dissimilar metals expand and contract at different rates over temperature. This can cause connections to loosen over time creating conditions conducive to an arc. As long as connections are checked for tightness, there should be no issues. AFCIs in these systems would be added protection.

Cost

The cost to install AFCIs in a new home was previously approximately $100. This cost estimate is based on replacing two or three conventional circuit breakers with AFCIs. With the increased requirements, this cost could approach $750 to $1000. According to a cost study analysis by the U.S. Consumer Product Safety Commission in March 2003, if an AFCI is installed in homes 10 years old, homeowners could expect a cost-effectiveness benefit of $530 for each $175 spent to retrofit or install the AFCIs. To review this report goes to the CPSC website previously mentioned.

Author Comment: It's a lot cheaper than replacing your burned down house.

Availability

AFCIs are available at Lowe's, Home Depot, and other home improvement centers as well as numerous online sources. There are approximately 6 to 7 million AFCIs installed throughout America.

Misinformation

Individuals and organizations are circulating misinformation regarding the effectiveness of AFCIs. NASFM Science Advisory Committee has reviewed and researched each comment and provides the following response.

1. Claim: AFCIs are not needed, based on current fire losses.

Finding: The data in support of AFCIs are compelling, notwithstanding the introduction of this article regarding the information reported by the National Fire Protection Association on

electrical fires. NASFM recently conducted a study from ten state fire marshal fire investigation divisions where electrical fires caused the loss of life. The results of this study clearly indicated the causes of the fires were electrical arc-faults that resulted in the loss of lives (adults and children) and property; this is appalling.

2. Claim: AFCIs cost in excess of $125 per unit.

Finding: NASFM's survey on June 14, 2002, of two of the largest retailers in nine U.S. cities revealed the retail price ranged from $34.97 to $39.97 for both 20- and 15-amp units. Today that cost has come down and ranges from $24.95 to $34.95 per unit.

3. Claim: AFCIs are not reliable or effective.

Finding: A CPSC fact sheet on AFCIs states, "Several years ago, a CPSC study identified arc fault detection as a promising new technology. Since then, CPSC electrical engineers have tested the AFCIs on the market and found these products to be effective. Also, according to an article entitled "Arc-Fault Circuit Interrupters," by UL Senior Research Engineer David Dini, "The AFCI functions by recognizing characteristics unique to arcing and de-energizing the circuit when an arc-fault is detected. By doing so, this device will safeguard persons and property by mitigating the unwanted effects of arcing, which can result in a fire."

4. Claim: AFCIs do not protect against ground faults, high-resistance contacts and glowing contacts.

Finding: AFCIs on the market do protect against ground faults. While these AFCIs may not directly detect some electrical arcing and glowing that can occur at high-resistance contacts and other connection points, the devices respond to secondary arcing and leakage currents to the ground that result from degraded insulation between conductors in proximity to the incipient fault condition.

5. Claim: AFCIs have a history of nuisance tripping.

Finding: UL 1699, Standard for Safety for Arc-Fault Circuit Interrupters, addresses nuisance tripping and is far in excess of practical requirements. If the AFCI trips when installed, it will indicate if the wiring is not properly installed or an appliance connected to the circuitry is causing severe arcing. One manufacturer reported that an AFCI detected a faulty garage door opener. Upon examination of the unit it was found the garage door motor had severe arcing and when replaced the current flow was normal.

6. Claim: AFCIs currently on the market fail to protect against all arcing faults.

Finding: Branch/feeder type AFCIs protect against all unwanted arcs to ground at any point in the circuit, and unwanted arcing in parallel with the load throughout the circuit including the branch-circuit extension wiring. Branch/feeder AFCIs do not detect series arcs in two conductor extension wiring. These arcs are less hazardous than parallel arcs since they are typically low current and short duration. These arcs are essentially indistinguishable from switching arcs.

7. Claim: AFCIs will not work on a shared neutral.

Finding: Typical branch/feeder AFCIs will not work on a shared neutral. However, some manufacturers have an AFCI that will work on a shared neutral.

8. Claim: AFCIs will not work on a two-wire system.

Finding: AFCIs will work on a two-wire system for protection from parallel arcing.

9. Claim: Smoke detectors will cause nuisance tripping.

Finding: Smoke detectors do not cause nuisance tripping. Furthermore, smoke detector wiring should be on the AFCI circuitry. The NEC committee has rejected a proposal to exclude smoke detectors from the AFCI circuitry.

10. Claim: There is no way to test the AFCI that it is protecting the circuit.

Finding: The AFCI has a test button and should be tested monthly by pushing the button. Furthermore, there are testers available to the electrician that will test both the AFCI circuit and the GFCI and identify if the wiring is installed correctly.

References

1,2 Arc-Fault Circuit Interrupters, Underwriters Laboratory (UL), 2002

3 AFCI Fact Sheet, NASFM Science Advisory, AFCI Inquiry and Report, August 1, 2002

Walter Smittle III is West Virginia state fire marshal (retired), IFMA past president and NASFM, special representative.

Section 5 -Arc Fault Circuit Interrupters (AFCIs) Type and Performance

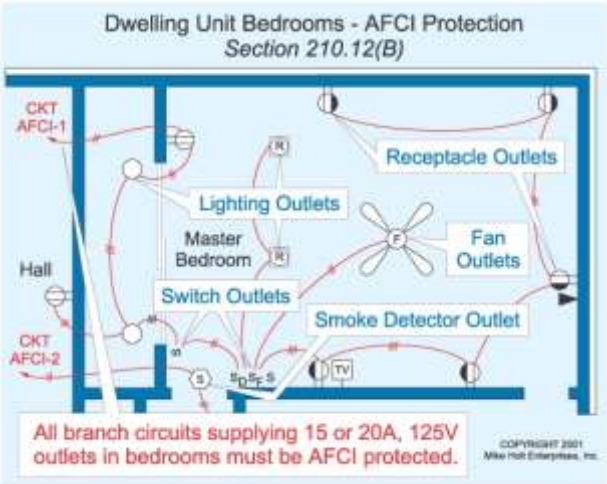
Underwriters Laboratories (UL) has written an excellent white paper on types and performance of AFCI. Please review this document contained below.

Arc-Fault Circuit Interrupters (AFCIs) -Type and Performance Considerations

In February of 1999, UL published the First Edition of the Standard for Arc-Fault Circuit-Interrupters (AFCIs), UL1699. According to the National Electrical Code (NEC), an AFCI is defined as a device intended to provide protection from the effects of arc faults by recognizing characteristics unique to arcing and by functioning to de-energize the circuit when an arc fault is detected. The 2002 NEC will require all branch circuits that supply 125volt, single-phase, 15- and 20-ampere outlets installed in dwelling unit bedrooms to be protected by an AFCI listed to provide protection to the entire branch circuit.

Branch Circuits

A branch circuit is defined in Article 100 of the NEC as the circuit conductors between the final overcurrent device protecting the circuit and the outlet(s). The length of a ranch circuit can vary from several feet to several hundred feet and include from one to several outlets. Figure 1 shows a pictorial representation of a typical branch circuit that could be associated with a



dwelling unit bedroom.

Figure 1 Typical Branch Circuit in Bedroom

The branch circuit overcurrent protection is provided by a fuse or circuit breaker usually located in a centralized panel board that is served with power by the local utility. As the name implies, overcurrent protection protects the branch circuit against any currents that are in excess of the

rated current or ampacity of the branch circuit conductors. Over currents can be the result of overloads, short circuits, or ground faults. Overcurrent protection is provided to open the circuit if the current reaches a value that will cause an excessive or dangerous temperature in the branch circuit conductors or conductor insulation.

The branch circuit conductors are normally contained within a non-metallic cable (NM-B), armored cable (AC), or a metal or non-metallic raceway such as conduit or tubing. Nonmetallic cables and raceway systems contain a separate conductor for equipment grounding purposes. Metal armor cables and raceways may contain an equipment grounding conductor, but in most cases the metal itself is permitted to serve as the equipment grounding path.

The branch circuit conductors extend throughout the building to outlets, which may be a receptacle outlet for connecting to cord- and plug-connected appliances, or to fixed equipment, such as a lighting outlet for a wall or ceiling mounted lighting fixture (luminaire). Receptacle outlets in the branch circuit provide for the connection of cord connected appliances, which in a bedroom may include appliances such as portable lamps, clock-radios, and portable air heaters. The cords attached to these appliances are generally referred to as power supply cords, as they supply the power from the branch circuit to the cord-connected appliance. In some cases, a power supply cord is not long enough to reach from the intended location of the appliance to the nearest receptacle outlet. In these situations, a cord set, often referred to as an extension cord, is used to extend the length of the appliance power supply cord to the electrical outlet.

Cord sets and power supply cords are made from flexible cords that have designations such as SPT-2 which is often used on portable lamps and light duty extension cords. Although flexible cords are not a substitute for fixed branch circuit wiring, they are tested for mechanical impact and flexural strength properties that are suitable for their intended application. Flexible cords may or may not be provided with an equipment grounding conductor depending on the application or appliance involved. Cord sets and power supply cords are not part of the branch circuit wiring, but since they extend power beyond the branch circuit, they can be subjected to the same overloads, short circuits, and ground faults as would the branch circuit wiring.

Branch Circuit Protection

The branch circuit overcurrent protective device (OCPD), (i.e. a fuse or circuit breaker), is specifically designed to protect electrical circuits, including the branch circuit conductors and flexible cords, against the unwanted effects of over currents. For example, when too many products are plugged into the same electrical outlet, and the total load current exceeds the rating of the branch circuit (i.e. 15 or 20 amps), the OCPD will open the circuit before damage to equipment or a fire occurs. However, an OCPD is not designed to protect the circuit against arcing faults. Because of the time-current characteristics of the OCPD necessary to provide effective protection against over currents, some arcing faults, including damaging arcing faults, may have time and/or current characteristics below the threshold levels necessary to open the OCPD.

Arcing Faults

"Arcing" is defined as a luminous discharge of electricity across an insulating medium. The electrical discharge of an arc can involve temperatures on the order of several thousand degrees Celsius. In general, arcing can be divided into two categories: (1) non-contact arcing and (2) contact arcing. "Non-contact arcing" is arcing that does not require direct physical contact between the conductors where the arcing is taking place. With arcing between conductors separated by insulation, the mechanism of initiating an arc between stationary conductors separated by insulation will depend on the type and geometry of the conductors and insulation between them. "Contact arcing" is arcing that involves direct or indirect physical contact between the conductors or "electrodes" where the arcing is taking place, such as arcing between closing or parting conductors making or breaking a circuit.

Arcing faults can occur in one of two ways, series arcing faults or parallel arcing faults. A series arcing fault can occur when one of the current-carrying paths (e.g. a single wire) in series with the load is unintentionally broken. For example, extreme flexing in an appliance power supply cord can cause one of the conductors to open and arc when flexed. Series arcing faults are limited in current to the load current of the connected appliance or appliances in that circuit. Parallel arcing faults occur when there is an unintentional conducting path between two conductors of opposite polarity, such as between black and white conductors, or between a line conductor and ground. Parallel arcing faults generally involve high currents, as they are limited only by the available fault current of the circuit.

AFCI Types

The UL1699 Standard addresses several types of AFCIs. Each type of AFCI is intended for different applications and/or protection of different aspects of the branch circuit and extension wiring. Three types of AFCIs for permanent connection to the branch circuit are identified in UL1699 as follows:

• **Branch/Feeder AFCI** – This device is installed at the origin of a branch circuit or feeder, such as at a panel board, to provide protection of the branch circuit wiring, feeder wiring, or both, against unwanted effects of arcing. This device also provides limited protection to branch circuit extension wiring (e.g. cord sets and power supply cords). These may be a circuit-breaker type device or a device in its own enclosure mounted at or near a panel board.

• **Outlet Circuit AFCI** – This device is installed at a branch circuit outlet, such as at an outlet box, to provide protection of cord sets and power-supply cords connected to it (when provided with receptacle outlets) against the unwanted effects of arcing. This device may provide feed-through protection of the cord sets and power-supply cords connected to downstream receptacles.

• **Combination AFCI** – This is an AFCI which complies with the requirements for both branch/feeder and outlet circuit AFCIs. It is intended to protect downstream branch circuit wiring, cord sets and power-supply cords.

The NEC and AFCIs

During the revision process for the 2002 NEC there were several proposals to revise Sec. 210-12 to require both a branch/feeder and outlet circuit AFCIs in branch circuits required to be protected (bedrooms). This would provide protection to both the branch circuit wiring, as well as cord sets and power supply cords that extend beyond the branch circuit. The Code Panel did not accept these proposals. There was also a proposal for the 2002 NEC to permit either a branch/feeder AFCI located at the origin of the branch circuit, or a new type of AFCI designated an "outlet branch circuit" type located at the first outlet receptacle. A proposed revision to UL1699 would include this new type of AFCI defined as follows:

• Outlet Branch Circuit AFCI – A device intended to be installed as the first outlet in a branch circuit. It is intended to provide protection to downstream branch circuit wiring, cord sets and power-supply cords against the unwanted effects of arcing. These devices also provide protection to upstream branch circuit wiring. The final language agreed upon by the Code Panel for the 2002 NEC for Sec. 210.12 will indicate the following: "All branch circuits that supply 125-volt, single phase, 15- and 20-ampere outlets installed in dwelling unit bedrooms shall be protected by an arc-fault circuit interrupter listed to provide protection to the entire branch circuit."

AFCI Tests

As the UL1699 Standard continues to develop and address different product types and technology enhancements, it is important to understand how each type of AFCI is suitable for protecting various regions of the entire circuit against arc faults, and the extent and conditions under which this protection will be provided.

Four different arc-fault tests are identified in UL1699 as shown in Figure 2.

Tests	Branch/ feeder AFCI	Combination AFCI	Outlet branch circuit AFCI
Carbonized path arc ignition test <series>			
NM-B insulation cut	X	X	X(+)
<new> NM-B w/o gnd insulation cut			X(+)
Carbonized path arc interruption test <parallel>			
SPT-2 insulation cut	X	X	X
NM-B insulation cut	X	X	X
Carbonized path arc clearing time test <series>			
SPT-2 insulation cut		X	X
<new> NM-B insulation cut			X(+)
Point contact arc test <parallel>			
SPT-2 insulation cut	X	X	X
NM-B insulation cut	X	X	X

(+) – also includes an upstream insulation cut

Figure 2 – AFCI Arc-Fault Tests

The Carbonized Path Arc Ignition Test is a non-contact arcing test conducted with NM-B cable with a series insulation cut. Tests are conducted with arcing currents of 5 A, 10 A, rated current, and 150% rated current. The Branch/Feeder, Combination, and Outlet Branch Circuit AFCIs are subjected to the Carbonized Path Arc Ignition Test. The Outlet Branch Circuit AFCI is subjected to the Carbonized Path Arc Ignition Test with the arcing occurring upstream, to represent series arcing in the branch circuit wiring between the origin of the branch circuit and the first outlet receptacle. The Outlet Branch Circuit AFCI is also subjected to the Carbonized Path Arc Ignition Test using NMB cable without a grounding conductor, as may be found in some older homes built over 40 years ago.

The Carbonized Path Arc Interruption Test is a non-contact arcing test conducted with NM-B cable and SPT-2 flexible cord with a parallel insulation cut. Tests are conducted with arcing currents of 75 A and 100 A. The Branch/Feeder, Combination, and Outlet Branch Circuit AFCIs are subjected to the Carbonized Path Arc Interruption Test, however, the Outlet Branch Circuit AFCI is not tested with this parallel arcing occurring upstream from the device.

The Carbonized Path Arc Clearing Time Test is a non-contact arcing test conducted with SPT-2 flexible cord with a series insulation cut. Tests are conducted with arcing currents of 5 A, 10 A, rated current, and 150% rated current. The Outlet Branch Circuit and Combination AFCIs are subjected to the Carbonized Path Arc Clearing Time Test. The Branch/Feeder AFCI is not subjected to this series arcing test with flexible cord as found in many cord sets and power supply cords. The Outlet Branch Circuit AFCI is subjected to the Carbonized Path Arc Clearing Time Test with NM-B cable and the arcing occurring upstream, to represent series arcing in the branch circuit wiring between the origin of the branch circuit and the first outlet receptacle.

The Point Contact Arcing Test is a contact arcing test conducted with NM-B cable and SPT-2 flexible cord with a parallel insulation cut. Tests are conducted with arcing currents of 75 A through 500 A. The Branch/Feeder, Combination, and Outlet Branch Circuit AFCIs are subjected to the Point Contact Arcing Test, however, the Outlet Branch Circuit AFCI is not tested with this parallel arcing occurring upstream from the device.

Further Information

For more information on AFCIs, see the Regulators Page on the UL Web site at: http://www.ul.com/regulators/afci/index.html Figure 1 – Pictorial Representation of a Typical Branch Circuit (Not to Scale)

Section 6 – REFERENCES

REFERENCES

1 From Wikipedia, the free encyclopedia

2 From Free Electrical Answers by MaRoSteph

3 www.electrical-knowhow.com/2011/12/nec-article-100-branch-circuit.htmNCES

OTHER REFERENCES

Arc-Fault Circuit Interrupter Technology by Walter Smittle III from IAEI Magazine, July/August 2004

Controllers Guard Against Arc Faults by Kevin A. Mussmacher, P.E. and William L. Froeb Power Electronics Technology magazine, November 2004

210.12 Arc-Fault Circuit-Interrupter (AFCI) Protection by Mike Holt, Mike Holt Enterprises, Inc., MikeHolt.com

Free Electrical Answers by MaRoSteph, MaRoSteph.com

National Electrical Code 2008 Edition, NFPA 70

National Electrical Code 2014 Edition, NFPA 70

National Electrical Code 2017 Edition, NFPA 70

New Electrical Safety Requirement: AFCI Protection for Replacement Outlets By Reuben Saltzman in AFCI Devices On January 7, 2014

AFCIs Come of Age by Douglas Hansen

END OF COURSE CONTENT