

AFCIs Come of Age

by Douglas Hansen

Arc-Fault Circuit-Interrupters were the new kid on the block when they first appeared in the 1999 National Electrical Code (NEC). Since then we have seen the technology advance to a new generation of devices, along with incremental expansion of the requirements for AFCIs in each new code edition. The next (2014) edition will continue in that direction.

Why AFCI's?

An arc results from an electrical current propagated through air. A common example of the discharge of electricity between electrodes is the spark plug in a car engine. Snap switches will sometimes cause an arc as the contacts make or break continuity, though those arcs are momentary and do not last long enough to be cause damage. A sustained arc can occur at a loose connection or between conductors that have damaged insulation. These electrical arcs can produce temperatures of several thousand degrees while still drawing less current than is necessary to trip a conventional breaker.

Approximately 13% of home fires are electrical in origin. The National Fire Protection Association (NFPA) estimates 46,500 residential electrical fires occurred in 2010, resulting in \$1.5 billion in property losses, 420 deaths, and 1,520 injuries. Of these fires, approximately half resulted from some type of arcing, whether in the structure's wiring system or in the connected equipment.

AFCIs attempt to prevent these fires by interrupting the current when an arc is detected. The impetus for their development is in a report developed by Underwriters Laboratories (UL) for the Consumer Product Safety Commission (CPSC) in 1995. The report, *Technology for Detecting and Monitoring Conditions that could Cause Electrical Wiring System Failures*, recommended the development of AFCI technology as a means of reducing home electrical fires. One of the challenges in development of AFCIs was to develop a product that detected and interrupted current when a dangerous arc occurred, and that did not "nuisance trip" on an arc that was not dangerous, such as the one that occurs frequently at snap switches. AFCIs accomplish this by looking at the electronic "signature" of an electrical arc (figure 1), which includes a sequence of current spikes and voltage drops.

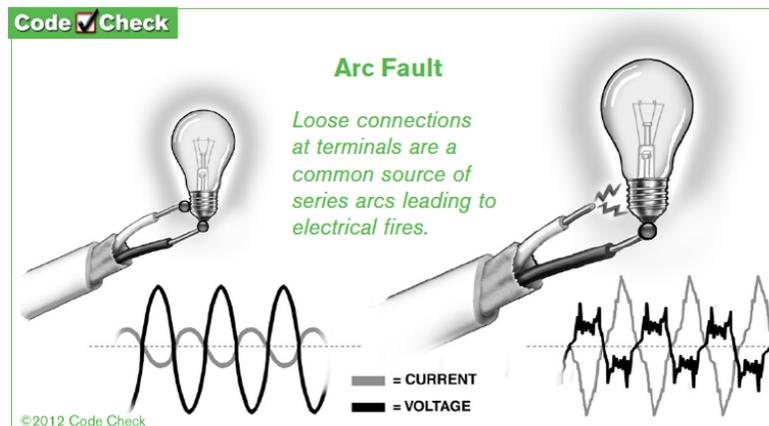


Figure 1 –Voltage and Current Arcing Signature

Types and Limitations of AFCIs

UL 1699 recognizes six categories of AFCIs. These UL categories are:

1. Branch/feeder types (AVZQ)
2. Combination types (AWAH)
3. Cord types (AWAY)
4. Outlet circuit types (AWCG)
5. Outlet branch circuit types (AWBZ) , and
6. Portable types (AWDO)

For practical purposes of inspecting what we see in the field (or will see in the near future) the three types we are concerned with are the branch/feeder, combination, and outlet branch-circuit type.

Branch/feeder AFCIs were the first generation of protection. They were listed by UL as circuit breakers, and also “classified” by UL as branch feeder AFCIs (figure 2). This type is no longer permitted by the NEC. The limitations of the branch/feeder type are the inability to detect series arcs with no equipment grounding conductor present, and the relatively high levels of available fault current necessary to active the device (table 1). If a dead short at the outlet had sufficient resistance that it could not produce at least 75 amps of current, the device would not trip. The main value of branch/feeder AFCIs was protection against relatively uncommon parallel arcs involving the hot and neutral of the circuit. The second generation of AFCIs is the combination type (figure 3). The term is derived from their ability to detect a greater range or combination of potential arcing conditions. It does not have anything to do with also having a ground-fault protection function (more on that later). Since January 1, 2008, all AFCI breakers are required to be combination types. The third type is the outlet branch-circuit type. These are similar in appearance to GFCI receptacles, and have essentially the same performance characteristics as the combination type.

Table 1 – AFCI Arc Detection Capabilities (and currents necessary to activate the AFCI protection)			
Arc Condition	Branch/Feeder	Combination	Outlet Branch Circuit
Line-to-Neutral	Yes (min. 75 amps)	Yes (5 amps)	Yes (5 amps)
Line-to-Ground ¹	Yes (0.050 amps)	Yes (0.050 amps)	Yes (0.050 amps)
Series with Ground ²	Yes (5 amps)	Yes (5 amps)	Yes (5 amps)
Series without Ground ³	No	Yes (5 amps)	Yes (5 amps)
1. The 50 milliamp ground-fault detection of AFCIs is voluntary and not part of the UL standard. 2. These tests are with a series arc to the equipment grounding conductor. 3. These tests are with no equipment grounding conductor in the circuit.			

The ability to detect a series arc without involvement of the equipment grounding conductor is the critical factor. A loose connection, such as an improperly tightened terminal on a receptacle, or a loose wire nut, is a much more likely source of an arc than a line-to-neutral arc, which must involve both current –carrying conductors of the circuit. We see that both the combination and outlet branch circuit types are capable of detecting these much more common arcs.

AFCIs cannot detect a “glowing” arc. A high-resistance connection through a conductor can sometimes reach conditions that will ignite adjacent combustible material, and AFCIs will not prevent this. UL states that AFCIs will mitigate the potential effects of electrical arcs, not that it will eliminate them.



Figures 2 & 3 – Labels Indicating Branch/Feeder and Combination Type AFCIs

Outlet Branch Circuit Types

An outlet branch circuit type AFCI (figure 4) is a device with feed-through connections and an integral receptacle. In those regards, they look very similar to the more familiar GFCI receptacles. They are intended as the first outlet on a branch circuit that otherwise does not have combination AFCI protection. Under the present (2011) NEC, they are permitted when the wiring between an ordinary circuit breaker and the first outlet of the circuit is rigid metal conduit, intermediate metal conduit, electrical metallic tubing, MC cable, or steel type AC cable.



Figure 4 – Outlet Branch Circuit Type AFCI

Since these are permitted by the code in some circumstances, you might wonder why you haven't seen one yet. Though the manufacturers have patented these, the current restrictions in the code severely limit the market for these devices. It simply wouldn't be cost-effective to produce them yet. That may change in 2014. The 2011 edition of the NEC requires that all replacement receptacles in areas presently requiring AFCI protection be either provided with AFCI protection upstream (such as at the breaker) or be replaced with outlet branch circuit type AFCIs. That requirement goes into effect January 1, 2014.

Ground Fault Detection

AFCI circuit breakers look just like GFCI breakers when you first see them. They have the familiar coiled wire that connects to the neutral bus in the panelboard, and they have a very similar test button. The neutral conductor of the AFCI-protected branch circuit connects to the breaker, not to the neutral bar, just as it does with a GFCI breaker. In fact, most AFCIs do also have ground-fault detection built into them, though not at the same level as to qualify as Class A GFCI protection. The type of Class A GFCI we are accustomed to in our homes is required to trip when a current imbalance of 6 milliamps exists between the hot and neutral conductors. That is well below the level at which a person being shocked would reach the “let go” threshold of involuntary muscle contraction, or the level of ventricular fibrillation (electrocution). The ground fault detection of AFCIs is voluntary on the part of the manufacturers, and is generally set at 30 milliamps. This does not qualify as a replacement for a Class A GFCI.

There are some types of equipment which require GFPE – Ground Fault Protection of Equipment. Outdoor receptacles on a branch circuit dedicated solely to electric snow melting or de-icing equipment are exempt from GFCI requirements, though the equipment does require GFPE. In some jurisdictions, an AFCI breaker might be deemed acceptable for this protection, though it would be a matter of interpretation by the local jurisdiction, since AFCIs are not listed as GFPEs.

Multiwire circuits

One of the limitations of AFCIs is brought about by their ground-fault detection. A multiwire circuit in residential wiring is a pair of 120-volt circuits sharing a common neutral conductor. When these circuits are wired with NM cable, they are readily identifiable by having a black, red, and white wire. Multiwire circuits have been used in house wiring since the days of Thomas Edison. To this day they are still called Edison circuits by some electricians. They actually provide greater efficiency. Because the neutral conductor only carries the imbalanced load difference between the two hot conductors, the voltage drop is lower than it would be with individual neutrals.

If ordinary AFCI breakers are installed on a multiwire circuit, they trip as soon as loads are applied. The amount of current on the neutrals will not match the amount of current on the hot conductors. We have seen this problem a number of times on renovations and panel upgrades to existing houses. At times, the contractors don't seem to know this because they haven't yet applied a load to the circuit, and don't realize that the breakers will trip as soon as someone does plug in a light or appliance.

Only four large manufacturers remain in the United States market, and each has their own strategy for AFCIs on multiwire circuits. **General Electric** has a line of breakers that will work with multiwire circuits, and does so by disabling the ground-fault function of the breaker. The breakers that are suitable for this application have a **MOD 3** suffix on the breaker, rather than the usual **MOD 2**. GE instructs that a handle tie be applied first (something required now for all multiwire branch circuits formed from individual single-pole breakers) and that both of the pigtail neutrals be connected to the neutral bus. The branch circuit neutral is then connected to one of the breakers, not to both. It doesn't matter which one. GE also cautions that the breakers are not an internal trip. The handle tie enables the two breakers to be simultaneously disconnected, though if one breaker trips from a fault it might not automatically trip the other breaker unless the handle moved sufficiently.

Eaton, the parent company of Cutler Hammer, sells a 2-pole combination breaker suitable for multiwire circuits for both their BR (1-inch wide) line as well as the CH models (3/4 inch wide). Unfortunately, they continued to sell their branch-feeder 2-pole breakers well past the time when they were no longer permitted under the NEC. **Square D** has so far not manufactured a 2-pole AFCI for either their QO or Homeline series. **Siemens** makes a 2-pole AFCI that includes indicator lights that will tell you if it has tripped from an arc fault or a ground fault, as well as test buttons for each pole (figure 5).



Figure 5 – Siemens 2-pole AFCI

Code Issues – Locations Requiring AFCI Protection

The NEC provides an ever-expanding list of the circuits and devices which require AFCI protection. Not all states and cities adopt these portions of the NEC. Pressure from builders groups and others have left many areas lagging behind the NEC, and it is always best to learn the rules that apply in your local area.

Section 210.12(A) of the 2011 NEC requires that all 15 and 20 amp branch circuits have protection for the entire branch circuit when that circuit has outlets in dwelling family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets, hallways, or similar rooms or areas. What doesn't that cover? For the most part, the areas left off that list (garages, exteriors, kitchens, and laundries) have requirements for GFCI protection, though not for 100% of the outlets in those rooms. Remember that the term "outlet" as used in the NEC means more than just receptacle outlets. An outlet can be a lighting outlet or another point on the circuit where electrical equipment is supplied with current. Hard-wired smoke alarms are outlets, and require AFCI protection. To some, that seems counterintuitive (potentially disabling the circuit that powers a warning device). However, there have been fires in attics caused by the smoke alarm circuits, and smoke alarms today have battery backups in addition to drawing power from the house electrical system.

The protection required for the locations listed above is required to be combination type, not from branch feeder AFCIs. The exception is the previously mentioned allowance for an outlet branch-circuit type AFCI at the first outlet with a metal-clad wiring system between it and the panel. Since those devices have not yet been manufactured, that exception is moot.

Another exception allows an individual branch circuit for a fire alarm system. This exception is for central-station fire alarms, where the branch circuit breaker is accessible only to qualified persons per sections 750.41(B) and 760.121(B) and where the wiring is also protected by a metal system.

Extensions, modifications, or replacement of existing branch circuits in the areas requiring protection triggers a need for AFCI protection either by a combination type breaker at the origin of the branch circuit, or an outlet branch-circuit type AFCI at the first outlet of the circuit (210.12(B)).

Replacement receptacles (section 406.4(D)(4) in areas that are listed above will require AFCI protection beginning January 1, 2014. The protection can be provided either by a combination AFCI breaker, or by an upstream outlet branch-circuit AFCI, or by an outlet branch-circuit AFCI receptacle.

Several proposals for the 2014 NEC call for the upstream outlet branch feeder AFCI to be in an accessible location. It also appears likely that AFCI protection will be required in 2014 for all 120-volt circuits that have any outlet in a laundry room or kitchen.

Code History

1999: The first mention of AFCIs is in the 1999 NEC. Section 210-12 required them for protection of branch circuits having bedroom receptacle outlets. The requirement did not become effective until January 1, 2002. This small first step gave manufacturers and builders a chance to get ready to implement AFCI protection.

2002: Section 210.12(B) required AFCI protection for circuits with any outlet in a bedroom, not just receptacle outlets.

2005: Section 210.12(B) required that the AFCI be a combination type, while allowing branch/feeder types to still be used until January 1, 2008. By then, the recession had begun, and manufacturers had years of backlogged stock of old branch/feeder types. Despite the code, they remained on the market well into 2010. The 2005 NEC also was the first to start acknowledging the possibility of the AFCI protection being at other than the origin of the branch circuit, allowing it to be 6 feet from the panel without specifying what kind of device could possibly comply. Section 760.41 introduced a prohibition on installing AFCI protection for fire alarm circuits within the scope of article 760.

2008: Section 210.12(B) expands the required areas of AFCI protection to include circuits with outlets in dwelling family rooms, dining rooms, living rooms, parlors, libraries, dens, bedrooms, sunrooms, recreation rooms, closets, hallways, or similar rooms or areas. Branch/feeder AFCIs are no longer allowed. The requirements prohibiting AFCIs on fire alarm circuits are included in 210.12(B) Exception 2 and are harmonized with article 760. The distance limitations are removed for situations where the AFCI protection is not at the panelboard, and the list of metal-clad wiring methods is created for those situations. The NEC still calls for all protection to be combination type, so outlet branch-circuit types are still not recognized.

2011: The types of rooms for which the circuits require protection does not change. Section 210.12(B) is renumbered as 210.12(A), and a new section (B) deals with branch circuit extensions and modifications. Outlet branch-circuit types of AFCIs are recognized in both 210.12(A) and in Article 406 – Receptacles. Section 406.4(D)(4) requires replacement receptacle outlets to comply with the AFCI requirements for their locations, and this can be achieved with outlet branch-circuit types.

2014: We anticipate that AFCI protection will be required for all 120-volt circuits having outlets in kitchens and laundries, and that AFCI devices will be required to be readily accessible.

What Could Go Wrong?

When Code-Making Panel 2 decided to endorse the idea of AFCI protection for bedroom receptacle outlets in the development of the 1999 NEC, they were clear that it was only a small step towards an inevitable expansion of the rules for AFCIs. Their analogy was that it was much the same as mandating seat belts, and that they had to start somewhere. Therefore, the first generation of AFCIs was a learning opportunity both for the manufacturers and for installers. The great expansion of required areas of AFCI protection did not come about until the second generation of AFCIs had come into being, and they are a much improved product.

One of the issues found with the first-generation AFCIs was an increase in the amount of heat given off by the breaker. Since these devices are monitoring the circuit and include electronic circuitry that is constantly energized, some residual heat is expected. According to the manufacturers, this has not been so extensive as to cause any performance issues, and they claim that the combination AFCIs do not have this issue to the same extent as the first generation AFCIs.

In November, 2004, Square D announced a recall of 700,000 of their AFCIs. The issue with them was that the test button had a malfunction that could cause the AFCI circuitry to not work. The breakers could act like nothing more than (much cheaper) non-AFCI breakers. The breakers which were recalled had a blue test button. Square D changed the color of the test button in subsequent breakers. The breakers in the recall were branch-feeder types which do not meet present code.

Many contractors reported nuisance tripping issues with AFCIs. This problem seemed to be more widespread after the 2002 NEC expanded the application of AFCIs to include lighting circuits. One cause of this problem could be the electrician's fault. If the neutrals of more than one circuit are joined together in a box, current will have more than one path to return to the panelboard, and the ground-fault sensing of the AFCI will cause the breaker to trip. Neutrals should not be joined with those of other circuits except inside panelboards, yet many electricians have been lazy about this issue when wiring up multi-gang switch boxes. It is essentially another version of the problem with using AFCIs on multiwire circuits.

Another aspect of nuisance tripping occurred with some early AFCIs that also had GFCIs on the same circuit. That issue too appears to have been resolved with the combination type AFCIs. Part of the UL testing of an AFCI breaker includes placing GFCIs on the same circuit.

AFCI breakers are always full width. Many panels have provisions for installing either a tandem breaker or a single breaker on a single bus stab. Tandem breakers allow two circuit breakers in the same space that would otherwise be occupied by one breaker. Some panels have a specified number of bus spaces where tandem breakers are allowed, and other bus spaces that accept only full-size breakers. You might see a 150 amp panel that is rated to have 30 branch circuit breaker poles, yet has only 20 bus stabs. In that case, the label will state that 10 of them are designed for full-sized breakers and include a feature that will reject tandem breakers, and 10 of them allow tandem breakers. 30 breakers are therefore possible on such a panel, 20 tandems and 10 full size breakers. What happens when the electrician pulls all of their circuits back to that panel, and then discovers that he must use AFCIs where he had planned on using tandem breakers? Since the AFCIs are always full size, he may find that the panel is no longer large enough for all these circuits, as it only has room for 20 full size breakers.

With some brands and models, AFCIs take up not only a full breaker slot; they also take up some of the gutter space in the panel. Square D and Eaton AFCI circuit breakers are almost twice the length of their ordinary breakers. The result is that the neutral bar cannot be seen unless the breaker is removed, and the wiring space of the panels becomes much more crowded (figures 6 & 7).



Figure 6 – Square D AFCIs



Figure 7 – Eaton AFCIs

Testing AFCIs

Just as with GFCIs, there is no shortage of instrument makers willing to provide external “testers” for these devices. UL emphatically denies that these instruments are testers, even when the instrument carries a UL listing. UL evaluates outlet testers for safety, not for performance, so the UL insignia has nothing to do with whether it can accurately test an AFCI. The AFCI testing performed by UL in their laboratories is a whole different matter. They do this under conditions that actually do create (not just simulate) an arc, and AFCIs must pass those UL tests to gain their listing. The built-in test button on an AFCI tests whether the circuitry is functional, and it is the only valid field test. An inspector who finds an AFCI that is non-responsive to their hand-held tester has not necessarily found a defective AFCI. What matters is whether the built-in test button tripped it, and whether it properly reset after it was tripped. With most AFCIs, you need to turn them the rest of the way to the “off” position, then back to “on.”

AFCIs and Older Homes

AFCIs are not available for many of the older panel types, such as Federal Pacific, Zinsco, or the many regional products and old designs that are still in use. While it might be possible to partially retrofit such systems with outlet branch-circuit AFCIs, a more efficient approach is to replace the panel with one of the modern types that are available. Some panelboard makers (e.g., Eaton) make replacement panelboards that can fit inside the enclosure of an old Federal Pacific that is the full width of a stud bay.

AFCIs might seem like an ideal product to recommend for houses with knob and tube wiring, or with old-technology aluminum wire (1964 – 1973). It is possible that these systems would benefit from the added safety of AFCIs, although we caution against thinking of these as a magic bullet or an excuse to avoid repairing any obviously hazardous situations. If there are problems with aluminum wire terminations, or with deteriorated knob and tube wiring, the known issues should be repaired first. In some cases, AFCIs can then be added to older homes, though remember that most knob and tube systems use multiwire circuits, which create another set of limited options for compatibility with AFCIs.

Conclusions

AFCIs are here to stay. From their origins in the UL report to CPSC, back in 1995, we have seen improved product development and increased code acceptance to the point where we expect to someday see all the 120-volt circuits in a home requiring AFCI protection. Yet the report back in 1995 did not make the development of this technology its primary recommendation. In fact, that was number three on their list. Number one was to promote the electrical inspection of older dwellings to identify flagrant hazards in need of correction. Number two was to stimulate the repair and correction of those hazards. The chances of an electrical fire rise dramatically with the age of the home, and the best prevention is by competent inspection and repair of electrical hazards.

This article is dedicated to James W. Carpenter. Among the numerous contributions he has made to the electrical industry, he was chairman of Code Panel 2 during the 1999 NEC cycle, and the first requirements for AFCIs were a result of his vigorous leadership.

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