Data Bulletin

The Truth About AFCIs
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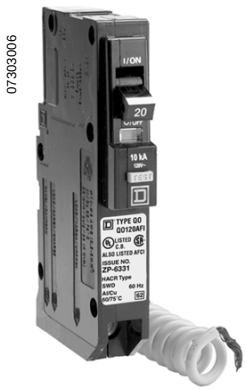
INTRODUCTION



Arc-Fault Circuit Interrupters (AFCIs) have recently become required for installation in residences under the National Electrical Code (NEC). Not surprisingly, questions have been raised regarding their application and even the need for them. There have been marketing pitches, technical opinions, and, quite frankly, intentional misinformation floating around various industry channels. Square D Company has always been truthful about what AFCIs are and what they are not. In addition, we have made it a point to discuss the how, when, and why of AFCIs to industry groups instead of simply take a “product sales” approach.

With that said, this data bulletin will directly address some of the questions and misinformation about AFCIs.

BACKGROUND

Contrary to popular belief, AFCIs are not new. They are certainly in their infancy relative to many products, but they are not new. Square D began research in this area in the late 1980s and early ‘90s when the Consumer Product Safety Commission (CPSC) identified a concern with residential fires of electrical origin. A large number of these fires were identified to be in the branch circuit wiring system.

AFCIs gained more momentum when the Electronic Industries Association (EIA) initiated a project and, ultimately, code proposals to the 1993 NEC to change the instantaneous trip levels of 15 A and 20 A circuit breakers. The EIA had studied the issue of arcing fires and determined that some level of additional protection against arcing faults would be beneficial. The EIA first attempted to do this by requiring that the instantaneous trip level of a circuit breaker be reduced to 85 A. However, it became clear that the lowering of those instantaneous levels below some of the minimums already on the market would result in nuisance operation of the circuit breaker due to inrush currents.

The CPSC study and the EIA efforts led to the first proposals requiring AFCIs that were included in the revision stage in the 1999 NEC creation.

Code-Making Panel 2 (CMP-2) of the NEC was presented with many proposals, ranging from protection of basically all 15 A and 20 A branch circuits in dwelling units to protection of living and sleeping areas. After listening to many presentations, reviewing large amounts of data, conducting extensive discussions, and giving much consideration to the issues, the CMP-2 concluded that AFCI protection should be required on branch circuits that supply receptacle outlets in bedrooms. The panel placed a date of January 1, 2002, for the requirement to become effective. This action was unanimously passed by CMP-2 members. The requirement was retained in the 2002 NEC with enhancements.

REAL QUESTIONS; REAL ANSWERS

AFCIs and the 2002 NEC

Do we really need AFCIs?

Just as we only need a smoke alarm or a circuit breaker when a problem occurs, we also only need AFCI protection when a problem occurs—then, we really need it. A fuse or circuit breaker cannot detect hazardous arcing current that is below its opening current. Arcing faults are frequently below this current, which in fact is lowered because arc impedence limits current. The data on fire origins show the need for this protection.

Aren't the problems AFCIs protect against found only in older homes?

The greatest problems are found in homes ten years old and older where changes have been made to electrical circuits and where insulation is deteriorating from age, use, and misuse. However, fires from electrical arcs have been recorded in residences of all ages. Besides, all homes become older homes. If the protection is not present before they age, they will remain unprotected as they age.

What changed in the 2002 NEC?

For the 2002 Edition, the CMP-2 retained with only minor revisions the requirement of the 1999 NEC that AFCI protection be required on branch circuits that supply receptacle outlets in bedrooms. One revision confirmed that the AFCI must protect the "entire" branch circuit. Another replaced the term "receptacle outlets" with simply "outlets" and required that all outlets—including those for lights, fans, and smoke alarms—be protected as well as receptacle outlets. These changes affirm that the CMP-2 intends that fixed wiring be protected and that all wiring associated with bedrooms be covered by the rule.

AFCI Types

Which AFCI types satisfy the 2002 NEC?

Section 210.12 (A) of the 2002 NEC requires protection for the entire branch circuit, and it requires that the circuit be de-energized when an arc fault is detected. The only devices covered by the UL 1699 Standard for AFCIs that also satisfy the NEC requirement are Branch/Feeder and Combination AFCIs, when they are installed at the source of the branch.

The Branch/Feeder AFCI is the circuit breaker type discussed since the AFCI was first proposed for the 1999 NEC. Branch/Feeder AFCIs are listed by at least four manufacturers and are readily available. A Combination Type AFCI has not yet appeared commercially.

Will there be a Receptacle AFCI?

This is a broad question. There may very well be a receptacle type AFCI marketed, but not necessarily one that will comply with the NEC requirements. The definition of an AFCI in NEC 210.12(a) states that an AFCI must protect by "... recognizing the characteristics unique to arcing and by functioning to de-energize the circuit when an arc fault is detected." Note the phrase "de-energize the circuit." De-energize means to disconnect the circuit from a source of voltage. An AFCI receptacle may serve to provide point-of-use protection for specific applications, but it would **not** protect the entire branch circuit. A Receptacle AFCI may detect a line-side arc and open, but it cannot remove the source of voltage from the circuit. Disconnecting the circuit from the voltage is critical to making sure that the arcing event is halted. Additionally, it is important to understand that the AFCI protection is for the entire branch circuit and not just for what is downstream of the receptacle.

What is an Outlet Branch Circuit (OBC) AFCI?

Since the so-called OBC AFCI does not appear in the UL 1699 Standard or any other code or standard, it does not have a clear definition. However, the device as presented to the UL Standards Technical Panel (STP) was a receptacle AFCI that provided protection equivalent to that of a Combination AFCI for equipment plugged into it and for receptacles that were fed from it on its load side. It also provided detection for series arcs on its line side and would interrupt them by opening the circuit at the receptacle. If the arc involved line-to-ground or line-to-neutral faults, it would not interrupt them. It could not de-energize any of the arcing conditions on its line side, but would de-energize arcing conditions on its load side.

(The UL Standards Technical Panel is a group of experts in areas related to product(s) covered by the panel. Members are balanced among users, manufacturers, and general interest participants (usually inspectors) who come from a variety of backgrounds. The STP serves to advise UL regarding requirements for the product(s) and serves as the consensus body to review and vote on proposals for standards that are an American National Standards Institute / UL Standard for Safety.)

Is the OBC AFCI recognized in UL 1699?

As indicated above, the OBC AFCI does not appear in UL 1699 or any other standard known to the authors. The UL 1699 STP rejected the proposal to include it for a variety of reasons, the primary one being its inability to fulfill its claim of protection on its line side.

Why Does the OBC AFCI Not Satisfy the NEC?

The OBC AFCI cannot de-energize an arc fault on its line side. To de-energize means to disconnect the source of voltage. Also, the OBC AFCI claims to detect series arcing faults on its line side, but cannot protect against a line-to-neutral or a line-to-ground arc fault on its line side. In other words, it only provides AFCI protection on its load side. Therefore, it does not protect the entire circuit.

Did NEC Code-Making Panel 2 Endorse the OBC AFCI?

Contrary to what has been said in the field, the CMP-2 did not endorse the OBC AFCI. The CMP-2 heard presentations on the OBC device, but did not accept the proposals. Instead, the panel made it clear that to meet NEC 210.12 (A) requirements an AFCI had to be a listed device and had to protect the ENTIRE branch circuit. The CMP-2 expected the issue of the OBC device to be dealt with in the standards process.

In fact, a member of CMP-2 asked a UL representative in attendance if the OBC requirements were already in UL 1699 and the response was “no” but that UL had drafted requirements. An additional question was asked as to whether the UL STP had accepted such requirements and the response was “no.”

Has the UL STP published a white paper about AFCIs?

A paper titled “Arc Fault Testing and Arc Fault Scenarios” was drafted by UL for use by STP members in reviewing seven AFCI types. It includes the OBC AFCI, as it was under consideration by the STP. UL has made this paper available on its website along with other publications.

UL has published a number of articles on the subject of AFCIs. Draft versions of these documents were provided to the STP members for review, but the documents published by UL are not endorsed by the STP. The UL publications on AFCIs represent the opinion of UL only and not the opinion of the STP or members of the STP.

AFCI Standards

Why is line-to-neutral arc detection set at 75 A?

One of the major reasons for the development of AFCI technology is that a number of fires are caused by arcing short circuits in fixed wiring that are not detected by an overcurrent protective device before the fire starts.
An overcurrent protective device (a circuit breaker or fuse) has an intentional time delay to allow for elevated current such as would be experienced when operating a microwave oven or starting a vacuum cleaner motor. In other words, when starting a vacuum cleaner the elevated current is needed and contained within the circuit conductors. When the current is an arc, it causes damage continuously. The AFCI distinguishes between a hazardous arc and normal current flow.

The 75 A level was taken from a survey conducted by UL for the EIA that reported that the lowest short circuit level available at a receptacle within the United States is 75 A. This means that a line-to-neutral fault in a branch circuit will have 75 A or more available. Correspondingly, AFCI testing verifies that the AFCI will detect an arc in a circuit with 75 A available. Therefore, the 75 A detection is to avoid arcing short circuits that are known causes of fire.

During the tests, actual current flowing is somewhat less than 75 A. The test circuit has 75 A available before the arc is introduced. The arc current will be lower because of the impedance of the arc itself. The AFCI must detect the arc current.

Can AFCIs be used in retrofit applications in older dwellings that use two-wire circuits without a grounding conductor?

Yes, they can. A Branch/Feeder AFCI circuit breaker type provides good protection for two-wire circuits. It provides for detection of a low-level short circuit of 75 A or above that would not be detected by an overcurrent protective device. It also provides detection of an arcing ground fault occurrence of 5 A or above. Note that the SQUARE D AFCI actually detects arcing ground fault of 50 mA and above. This protection is as valid in two-wire circuits as in three-wire circuits that include the grounding conductor. The difference is that with the added grounding conductor in the three-wire circuit, an arc of any level may reach the grounding conductor and be detected at levels below 75 A, which provides a degree of protection not available in two-wire circuits.

Why is there a difference in the testing of an Outlet AFCI and a Branch/Feeder AFCI?

As discussions of a standard began to be held in 1994, a rough but scientific experiment was conducted to determine the time and current within which an arc will ignite tissue paper. It was found that arcs above 5 A were likely to ignite if they persisted for a second and those below 5 A were much less likely to start a fire. Since then, other experiments have been conducted that suggest that fire can be ignited with lower current levels, but none of these have been definitive.

The Branch/Feeder AFCI was the first type to be developed. The intention was to protect branch circuit wiring primarily and also to provide protection for extension and appliance wiring to the extent it could. The 75 A detection level was established for reasons noted above for line-to-neutral arcs. The 5 A level was found to be difficult to achieve at that time while also avoiding nuisance operation for the broad range of signals in electrical circuits. A 5 A detection requirement was determined for line-to-ground arcs.

In considering a device located at the receptacle, it was clear that the primary function of such a device would be protection of extension and appliance wiring. Detection of series arcs at the lower current level of a single appliance would be important. Therefore, for the envisioned Outlet AFCI, a 5 A detection level was required in the standard for line-to-neutral, line-to-ground and series arcs.

A Combination AFCI including all the detection capabilities of the Branch/Feeder and Outlet AFCIs was also included in the standard.

Why are all AFCIs not required to pass all the tests Branch/Feeder and Outlet AFCIs must?

As the Standard was first put in place, it appeared that there might be a place for more than one type of AFCI:

- the Branch/Feeder AFCI, for fixed wiring, must be made very unlikely to trip except when a hazardous condition is present. This is a significant technical feat because of the variety of dimmers, computers, motors, and entertainment appliances that can be connected simultaneously.
- the Outlet AFCI, for cord-connected appliances, must be able to detect lower-level series arcs. This type was envisioned to be electrically closer to the appliance. An Outlet AFCI may very well be a receptacle device.
- the Combination AFCI, which combines the functions of both the Branch/Feeder and Outlet AFCI.

There is a place for each of these devices. However, as we look at the need addressed by NEC 210.12 (A), a Branch/Feeder AFCI is necessary to protect the entire circuit. Protection would be enhanced if an Outlet AFCI were added for extension and appliance wiring.

The ideal device, if and when one becomes commercially available, would be a Combination AFCI located at the source of the branch.

Protection

What protection can line-to-ground arc detection offer in two-wire circuits?

Even in two-wire circuits without a grounding conductor, protection against line-to-ground arcs is important. The arc can be to conduit, through moisture, to a metal enclosure, or even to metal furniture. Many arcing occurrences include line-to-ground arcing. When the arc current path is even partially to ground, the AFCI will detect it if it is 50 mA or above when SQUARE D AFCIs are used.

What protection is provided for line-to-ground arcing?

The UL 1699 Standard requires arcs of 5 A and above be detected line-to-ground. It is true that today's AFCIs have ground fault sensing to below 50 mA, exceeding the requirement of the Standard. We consider this good protection because these low current leakages are frequently the beginning of a larger arcing problem.

If there are concerns about nuisance operation with this degree of protection, remember that many circuits have been protected with 5 mA protection by ground-fault circuit interrupters (GFCIs) for many years and nuisance operation is not a problem. However, the requirement of the standard is detection of arcing at 5 A.

What is the difference between AFCI and GFCI?

There is a major difference between the effective functioning of an AFCI as compared to a GFCI. The function of the GFCI is to protect *people* who may come into contact with energized parts connected to receptacles. The function of the AFCI is to protect against faults or damage to wiring and equipment that could initiate fire-causing arcs anywhere in the circuit.

To what degree will an AFCI detect series arcs in a single wire?	The UL 1699 Standard requires that the Branch/Feeder AFCI (the listed circuit breaker type) detect arcs in circuits that deliver 75 A and higher fault current. It does not distinguish between series and parallel. These are short circuit conditions—and are the conditions that drove the industry to develop arc detection. We know that fires occur from these higher energy arcs. The 75 A standard was selected because that is the lowest fault current that was found at a 15 A receptacle in a study of fault current availability done by UL for the EIA. The actual arcing current that is detected is lower than 75 A, since 75 A is available current and is reduced by arc impedance. This means that true series arcs, which are at load current values well below 75 A, are not detected.
Will surge protectors in power strips cause AFCIs to nuisance trip?	No. Any correctly operating surge protector system (with no excessive leakage) will not trip a SQUARE D AFCI circuit breaker.
Under NEC 210.12, which circuits must be protected?	The requirement is clear as written: “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 of the entire branch circuit.” This includes outlets for receptacles, lights, fans, smoke detectors, and so forth in circuits that supply bedrooms.

AFCI Protection in the Home

What constitutes a dwelling unit?	Article 100 of the NEC defines a dwelling unit as “one or more rooms for the use of one or more persons as a housekeeping unit with space for eating, living, and sleeping, and permanent provisions for cooking and sanitation.”
Are hotel/motel rooms or dormitories considered dwelling units?	The rule is stated in the above response and must be interpreted by the authority having jurisdiction (AHJ). If an AHJ considers hotel/motel units dwelling units, they must be so considered for NEC 210.12. One way to make this judgment is to consider whether the units would be considered a dwelling unit if the facility were placed under new ownership and occupied as apartments or condominiums.
Must outlets supplying bedroom smoke detectors be AFCI-protected?	Yes, because they clearly fall under the category of bedroom outlets. Recall that the purpose of the AFCI is to address fire causes. If the potential fire cause is in the smoke detector wiring, the first approach for protection against fire should be to clear the potential cause.
Can AFCIs be used in multi-wire circuits with a shared neutral?	Single-pole AFCIs cannot protect circuits in which the neutral (grounded circuit) conductor is shared or mixed. The reason for this is that current flowing out and returning is monitored for the presence of arcing faults. When one-pole AFCIs are applied, the circuit must have a distinct hot and a distinct neutral conductor. Otherwise, the AFCI cannot distinguish arcing ground-fault occurrences. We can expect general availability of two-pole AFCIs for this application at some point in the future, since present technology is readily capable. The two-pole AFCI has not been generally introduced because of limited demand at present. Contractors and users should understand that there are some drawbacks to using shared neutrals. For example, if a 2P common trip version is used, then both circuits are interrupted during a fault. If the 2P breaker has independent trip, then when a circuit is tripped and an outlet device is removed (assuming a dead circuit), if the home run is split at that point, the wiring in the box is not really dead. Another example of shared neutral wiring disadvantages is the result if the home run neutral is lost—a motor load will take one side of the circuit to zero, putting the loads on the other side to 220 volts. This tends to play havoc with many 120 volt devices. Further, cable manufacturers are apparently planning cables that contain four wires plus ground for exactly this kind of application.

Must lighting or convenience receptacles in bedroom closets be AFCI-protected?

Whether bedroom closets are part of the bedroom is a judgment to be made by an AHJ. However, it is clear that the intent of NEC 210.12 is to provide protection for the entire bedroom. When the closet is an integral part of the bedroom, safe operation would call for the closet wiring to be protected just as other parts of the bedroom.

Performance Testing

Does equipment exist that a contractor can purchase to test for arcing conditions during the wiring process?

We are not aware of any equipment that is presently available nor are we aware of equipment that is being developed. With normally competent installation practices, no special test should be required.

Is equipment available for testing after wiring is installed so that contractors can demonstrate that their work has been competently completed?

Again, we are not aware of special equipment available for such testing. If wiring is installed competently, there should be no reason for any testing that is not done for a circuit without an AFCI. However, there are two possible practices that can be used to test the installation, if a test is desired:

a. Probably the best test is to install an AFCI, at least temporarily, in the circuit. For this test to be effective, the circuit must be complete, since it must be energized as in service with 120 volts. First, use the test button to verify that the AFCI is functioning properly. Then leave the AFCI in the energized circuit for some period of time. If it does not trip, that is an indication that the circuit is acceptable.

b. As with any installation, an insulation resistance (Megger device) test can be done to verify that the wiring and connections are properly insulated. With this test, high voltages are applied. Be sure to keep personnel away from circuits being tested and follow safety practices described in NFPA 70E, Part II.

   To perform this test, disconnect all loads and verify that unconnected wire ends are insulated. Disconnect the load wire to any AFCI or GFCI in the circuit because these devices may be damaged by high voltage. Use an insulation resistance tester that will apply a direct current voltage of at least 500 volts to the circuit under test. All resistance readings should be at least one megohm (1,000,000 ohms). A successful test will indicate that the insulation is intact and initiation of an arc would be highly unlikely for the portion of the circuit tested.

Recognize that neither of these tests will identify loose connections. Good workmanship is required as always.

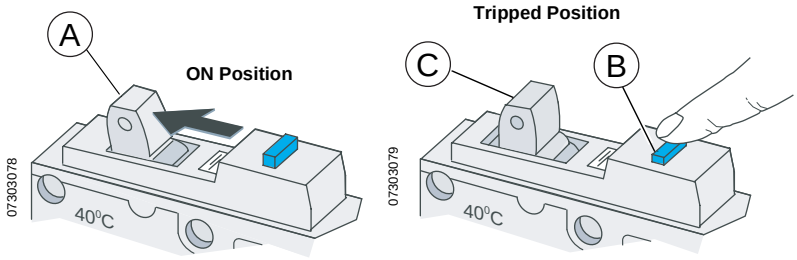
Does equipment exist to test the AFCI to determine that it is functioning properly?

The most effective test is the self-test supplied with the AFCI. To test the unit:

1. Install the unit in a load center.
2. Turn OFF all loads downstream of circuit breaker.
3. Turn ON power to the load center.
4. Turn ON circuit breaker handle (A).
5. Push the blue test button (B). If circuit breaker is operating correctly, circuit breaker will trip, and the handle will move to the tripped or center position (C).

This test injects a signal into the AFCI's sensor that looks like an arc to the AFCI. By doing so, it tests all of the AFCI's systems and tripping parts.

We are not aware of commercially available testers.



Tripping

Under what conditions will an AFCI trip?

The circuit breaker Branch/Feeder AFCI incorporates functions of both an overcurrent protective device and an arc-detection device. It is designed to trip under the following conditions:

- Overcurrent—For any current above its current rating it will trip according to its circuit breaker time-current characteristic.
- Hazardous arcing—The Standard requires tripping at arcing current levels of about 75 A and above. Commercial AFCIs will actually operate at some level below 75 A. The AFCI will operate faster than a fuse or circuit breaker under short circuit overcurrent conditions up to about 125 A.
- Arcing ground faults—The Standard requires tripping on faults to ground of 5 A and greater. Commercial units will actually detect ground faults of 50 mA and greater. Tripping will be instantaneous, with no intentional delay.
- Abnormal environments—Some abnormal events may also cause tripping, such as high voltage surges from lightning or utility line surges, voltage or frequency fluctuations from poorly regulated backup generators, or mechanical shock.
- Neutral grounding—If the neutral conductor (grounded-circuit conductor) of an AFCI-protected circuit touches grounded metal, the AFCI will trip if the path to ground has very low impedance.

If an AFCI trips, how can the problem be located?

An orderly search for the problem is probably the best approach. There is no single correct answer to this question. We are not aware of specialized equipment that would help locate a problem. The skill and experience of the electrician will help. Remember that the circuit breaker AFCI will trip from an overcurrent sensed by the circuit breaker or from an arcing occurrence sensed by the AFCI function, including a ground fault.

The AFCI will be sensing an arc that occurs because insulation or isolation is not adequate. The problem or fault may be one or a combination of these three conditions:

1. Line-to-ground
2. Line-to-neutral
3. Series arc in broken or separated conductor (could be a loose connection). Note that the Branch/Feeder AFCI will not generally detect a series arc because series current is usually below the detection level.

Here are some steps that may be useful.

a. Gather information from people who have used the circuit regarding any buzzing noises, visible arcing, the odor of smoke, or similar indications of improperly operating or defective appliances or equipment. This information may lead to the fault location. If arcing is suspected in an extension cord or a cord-connected appliance, immediately unplug the suspected unit.

b. Unplug all appliance and extension cords connected in the circuit. If tripping continues to occur when the AFCI is turned on, the fault is in the fixed wiring system.

c. Similarly, turn off all fixed appliances such as lights and ceiling fans that have switches. Since these circuits cannot be fully disconnected (line, neutral, and ground), tripping occurrences with their switches turned off does not necessarily mean that they are fault free.

d. If the AFCI does not trip when all plugs are disconnected, turn the AFCI on again and reconnect the plugs one by one. Then turn on fixed lights and appliances. This procedure may locate the faulted cord or appliance.

e. Because arcs are sometimes sporadic, turning off the circuit may temporarily clear the arc and it may not immediately reappear when the circuit is re-energized. For this reason, the arc may not be located by unplugging and reconnecting appliances. If the arc has been located to be in the fixed wiring system, or if the arc has not been located by removing plug-in loads, some of the following techniques may be helpful:

   —Examine appliance cords, plugs and equipment carefully for indications of damage.

   —With the circuit de-energized, examine connections to the AFCI, receptacles, lighting fixtures, and other appliances.

NOTE: De-energize the load center by turning off the main disconnect, if possible, before step f, below. By means of a reliable voltmeter, verify that voltage is not present.

f. Apply the insulation resistance test as described on page 7 to check for insulation adequacy line-to-neutral, line-to-ground, and neutral-to-ground. Alternatively, use an ohmmeter to check for electrical continuity line-to-neutral, line-to-ground, and neutral-to-ground. Continuity indicates presence of a fault. The insulation resistance check is the preferred method.

g. Indication of adequate insulation in a circuit that has been identified as having an arc fault may point to a series fault, that is a broken conductor or a loose connection.

h. The line-to-ground sensing is for small leakage current of about 50 mA (0.050 A) and above. It may not be visible as an arc. Any technique used to find a ground fault would be useful for locating an arc to ground.

i. Once the fault is located, damage must be repaired or improperly operating equipment or appliances must be replaced.

In most cases, the steps noted above will help locate the fault. It is important to recognize that the AFCI has provided an indication of a condition that could become a fire hazard. Do not continue to use the circuit without a correction.

Will an AFCI trip when no arc exists on the circuit, for example when equipment with unusual power requirements is used?

The AFCI has been designed to avoid unwanted tripping that might result from equipment of any kind. UL 1699 requires an extensive series of tests with a variety of equipment in six different categories that may have signatures similar to arcs. In addition, Square D has done testing to identify and counter suspected causes of unwanted tripping that may not be included in the UL Standard. Messaging systems that use the power conductors for carrying signals are included among equipment that is not expected to cause tripping. Unwanted operation is not expected.

If repeated tripping occurs with an appliance on a circuit protected by an AFCI, it would be wise to check the equipment, its plug, and power cord carefully. Plug it into a circuit protected by a GFCI. GFCI tripping would indicate leakage to ground.

A very high voltage surge, such as might result from a lightning strike, will cause tripping in some circumstances.

Are circuit breaker AFCIs suitable for use in panelboards for commercial applications?

Yes.

AFCI instructions have an FCC radio frequency interference statement indicating interference issues could exist. How much of an issue is this?

The statement found in AFCI installation instructions is required by the FCC on all electronic equipment with higher operating frequencies. The statement wording found in the AFCI instructions is identical to the FCC-mandated statement. It means that AFCIs have been tested and found to comply with FCC requirements and are unlikely to cause interference or to be interfered with. AFCIs have not been demonstrated to cause interference issues in the residential environment where they where designed to operate.

Square D Company
PO Box 3069, 3700 Sixth St. SW
Cedar Rapids, IA 52406-3069 USA
1-888-SquareD (1-888-778-2733)
www.SquareD.com