How Arc Fault Detection Devices Minimize Electrical Fire Threats

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Executive summary

Arc faults in low voltage electrical installations within buildings pose significant safety risks. Electric arcs in conductors and connections are not detected by existing protective devices such as circuit-breakers or residual current devices (RCDs), even though these arcs cause fires. To minimize the threat of electrical installation-related fires, electricians, contractors and building occupants need to consider deploying new Arc Fault Detection Devices (AFDD). This paper discusses new break-through in the field of electrical protection, and identifies critical application areas where AFDDs enhance safety.

Introduction

Over time, electrical installations in buildings deteriorate. The severity of deterioration often depends on environmental factors (such as heat, humidity, damage during usage, corrosive chemical reactions, and aging insulation).

Electrical installations should always be treated with caution. The nature of electrical installations is such that potential hazards such as electric shocks, burns, explosion and fire can occur if proper safety precautions are ignored or neglected.

Organizations that track building safety such as The European Fire Academy (EFA) and many property and casualty insurance companies report that 25% of building fires are electrical in origin. These faults can be triggered by overloaded circuits, short-circuits, earth leakage currents, overvoltages and/or electric arcs in cables.

In today's modern office buildings, laboratories and factories, commonly used technologies such as residual current devices (RCDs), circuit-breakers and surge protection devices (SPDs) address the problems of electric shock, circuit overloads, and lightning-induced surges. However, until recently, no technologies had emerged to provide adequate protection from electrical arcs in connections and cables.

These electrical arcs can trigger electrical fires. This presents a threat to both property and to human safety. Yet the general public is far less aware of the dangers of electrical fires than they are of electrocution.

To address this issue, devices that provide arc fault protection have been introduced to the marketplace. Known as arc fault detection devices (AFDD), these protective devices open the relevant circuit when they detect the presence of dangerous electrical arcs, thus preventing the outbreak of electrical fire. Arc fault detection devices are modular in nature and are commonly installed within single phase final.

The US was one of the first countries in the world to begin implementing arc fault detection devices. Known in the US as Arc Fault Circuit Interrupters (AFCIs) these devices have been in use since 2002. Data from the US suggests that electrical safety statistics are moving in a positive direction (see **Figure 1**), although the number of installations of these devices is still small. Now, in the rest of the world, the level of interest and focus in addressing this arc fault protection issue is increasing.

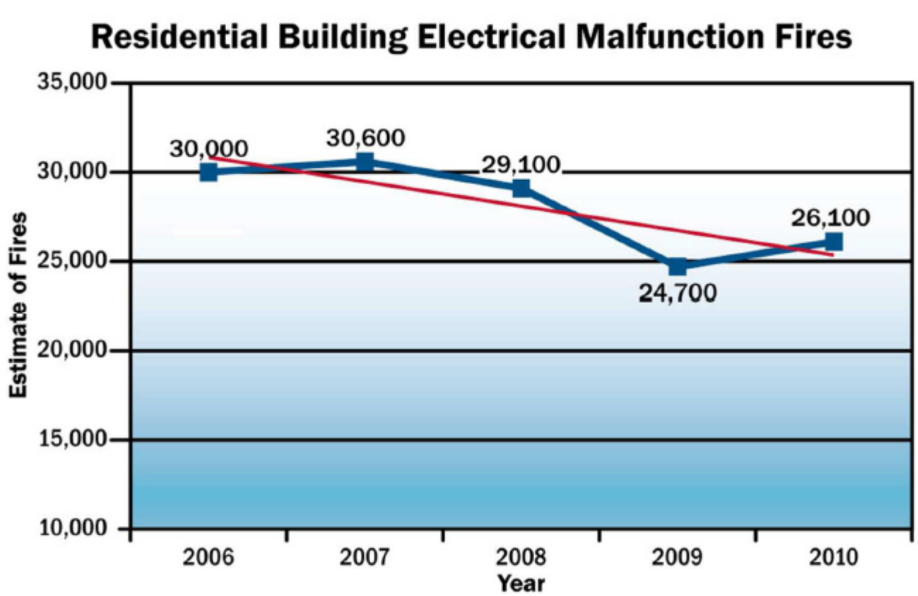

Figure 1

National Fire Protection Association (NFPA) figures show a drop in the number of electrical installation-related fires in the US

Buildings such as hotels and retirement homes are good examples of where AFDD safety enhancements would be most welcome. These devices could be placed inside of low voltage electrical switchboards on circuits supplying rooms with sleeping accommodations. Buildings with a high density of occupants, where rapid evacuation is difficult and where the risk of fire spreading rapidly is high or where flammable materials exist in abundance should be equipped with this new technology.

Arc *fault* is not an arc *flash*

Arc Fault Detection Devices do not address arc flash hazard nor switchgear protection

When a short-circuit occurs between live parts and/or between live parts and other conductive parts within an electrical equipment such as a switchgear assembly, the current literally travels through the air, or through nearby emitted gases, from one point to the other. This releases a large amount of energy in a fraction of a second in the form of heat, sound, light, and pressure wave.

Arc flash is **not** in the scope of AFDD. Alternative protective measures should be used:

> U.S regulation has introduced the concept of "arc flash analysis". This provides a calculation of the incident energy and guidance for choosing personal protective equipment. The calculation is dependent of many parameters, including network characteristics and protection plan.
> If it is expected that the arc is contained within the enclosure of the faulty switchgear assembly, then the switchgear should be qualified as arc resistant, and tested for internal arc withstand; both IEC and IEEE address this concept. The performance is part of the design of the switchgear.

Although the two terms, arc fault and arc flash, look and sound similar they are very different and are often confused. Both terms need to be explained in the context of this white paper (see adjacent text box for the arc flash definition).

Electric arc *faults* occur when an electric arc current is generated in a damaged conductor or in terminals, and the energy of the arc is enough to ignite the surrounding material. **This paper addresses the issue of arc *fault* and not that of arc flash.** Arc faults commonly occur most often within the final circuit wiring. The major threat from arc fault is that of fire. The conditions for its development can go undetected for a period of time.

An arc is defined as “a discharge of live electricity through insulation material accompanied by a partial volatilization of the electrode materials.” Under normal circumstances, one cathode and one anode are separated by a thin space of air through which an electric arc is formed. The temperature at the center of the arc can vary between 5 000 °C and 15 000 °C. When a highly ionized, highly pressurized gas is produced in the area of the arc, the result is a release of hot gas and metal projectiles in all directions within the confined area of the arc.

Triggers that lead to the creation of electric arcs

Overvoltage - An electric arc can be considered a high current discharge. It is possible to create an arc between two electrodes by initiating a low current discharge, and by gradually fueling its growth. Gases, in general are good insulators. The difference in potential alone between the electrodes does not allow the passage of current. However, when the applied voltage exceeds a critical value called breakdown voltage, a discharge begins between the electrodes. If the source does not limit the current, this discharge degenerates into an irreversible arc. This is the case with damaged cable insulation. Under the effect of this breakdown voltage, conditions will favor the creation of an electric arc in the phase and in the neutral.

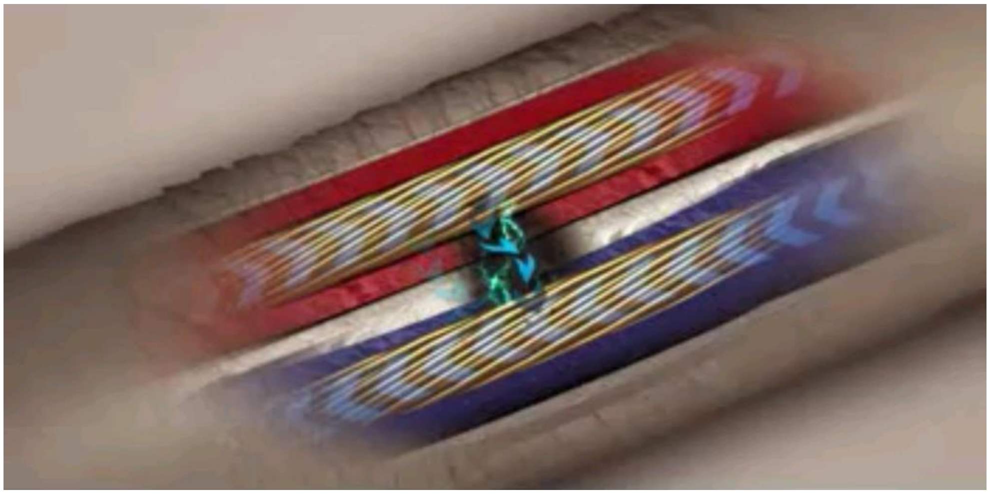

Figure 2

Arc fault cycle begins as low current discharge and grow in intensity over time

Improper contact - If two contacts, where a current normally travels, are separated, conduction is maintained by an electric discharge which initiates within the inter-electrode space. When the two electrodes are brought into contact, they do not occupy the whole of the facing surfaces. Only the rough edges and irregularities on the surface act as support zones. At the moment of the separation of the contacts, the entire current (“I“) passes from one electrode to the other across a tiny surface, which is always less than 1 mm^2 thick. The resistance (“R“) through the contact then increases, and the dissipated energy $R * I^2$ leads to a considerable increase in the local temperature. The boiling point of the metal is then reached and a metallic molten bridge is formed between the two contacts. The elongation of the bridge by the separation of the contacts causes it to rupture, which ejects molten metal in the form of microdroplets at a rate of 100 to 300 m.s-1. Then an arc of metallic vapors is created. This is the case with bad contacts usually found in damaged switches and power strips.

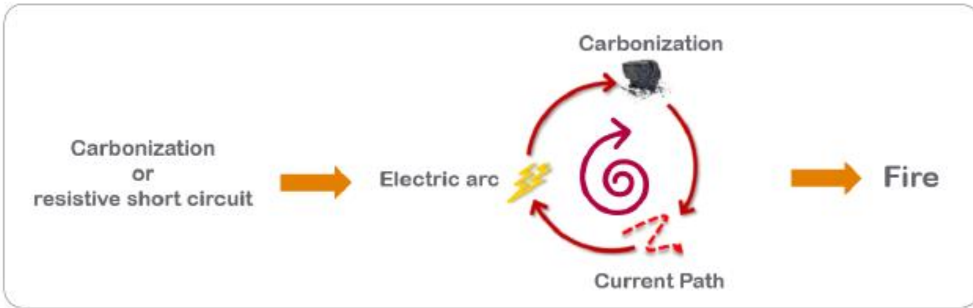

Figure 3

Illustration of how defective cabling can lead to fire

The science behind arc formation

In any building environment where cables are used to transport and distribute electricity, two types of arc fault-related events could occur and lead to a fire:

Formation of a series arc – When a cable is damaged or an electrical connection is loose, a localized hot spot can develop which kicks off the carbonization process of insulating materials in the proximity of this conductor (see **Figure 4**). Since carbon is a conductive material, it allows electrical current to pass through it.

As carbon is deposited, the electrical currents that flow through it generate electric arcs to facilitate their path. Since each arc amplifies the carbonization of the insulating material, a chain reaction occurs to the point where enough carbon is built up for an arc to spark a spontaneous fire. **A series arc fault results from an arc between two parts of the same conductor.**

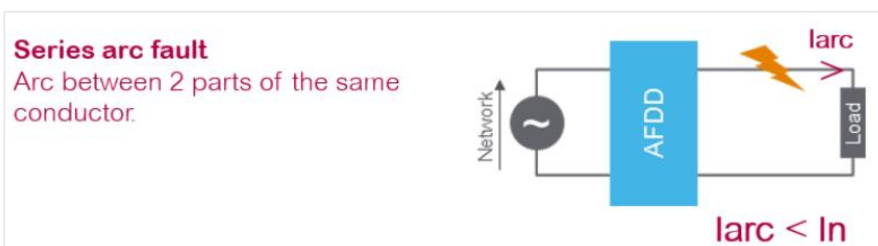

Figure 4

Illustration of a series arc example

Formation of a parallel arc - Once the insulation between two live conductors (copper being the most common of conductors in electrical cables) has become damaged, a significant current is able to flow between the two conductors (see **Figure 5**). However, it is too weak to be considered a short-circuit by the circuit-breaker. RCDs cannot detect the anomaly unless the current goes to earth.

While flowing through the insulation materials, these leakage currents optimize their paths by generating arcs that gradually transform the insulating material into carbon. The carbonized insulation then amplifies the leakage current between the two conductors. Thus, a chain reaction is produced that amplifies the quantity of arc current and carbon until the first flame appears (i.e., the carbon is lit by one of the arcs). **A parallel arc fault is produced as a result of an arc between two different conductors.**

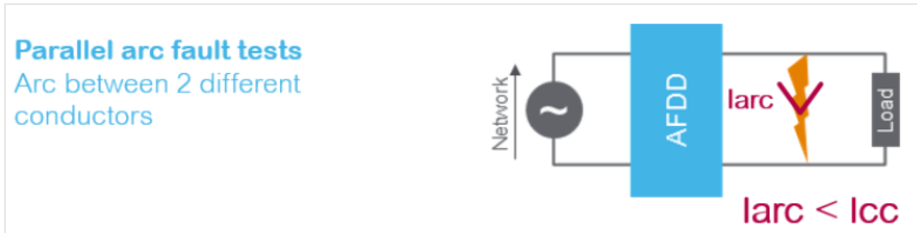

Figure 5

Illustration of a parallel arc fault example

Figure 6

Damaged cables provide fertile ground for arc fault-induced carbon build-up that then fuels a fire

Much analysis has been performed regarding the nature of these faults and their detection. This analysis focuses on the deformation of electrical current signals (wave forms) in order to assure that detection is accurate and that the triggering of false alarms is avoided.

How arc fault detection devices work

AFDDs constantly monitor and analyze patterns and the high frequency component in electrical current and voltage waveforms. They are on the look-out for the random, non-predictable yet persistent patterns of waveform that denote a potentially dangerous arc.

When the AFDD senses a potentially dangerous wave pattern, it trips, thus isolating the faulty circuit. An AFDD can work in conjunction with a circuit-breaker or residual-current circuit-breaker with overcurrent protection (RCBO). It may also incorporate its own switching function.

AFDDs react very fast to the slightest change in wave patterns. Speed is of the essence as an electrical arc can degrade in a flash (literally), igniting any nearby inflammable material and causing a fire.

Arc fault detection devices are extremely sensitive and designed to sense and respond only to potentially dangerous arcs. They use a specific algorithm to distinguish between dangerous and working arcs – i.e. the harmless sparks that you see when you flick a switch or pull a plug.

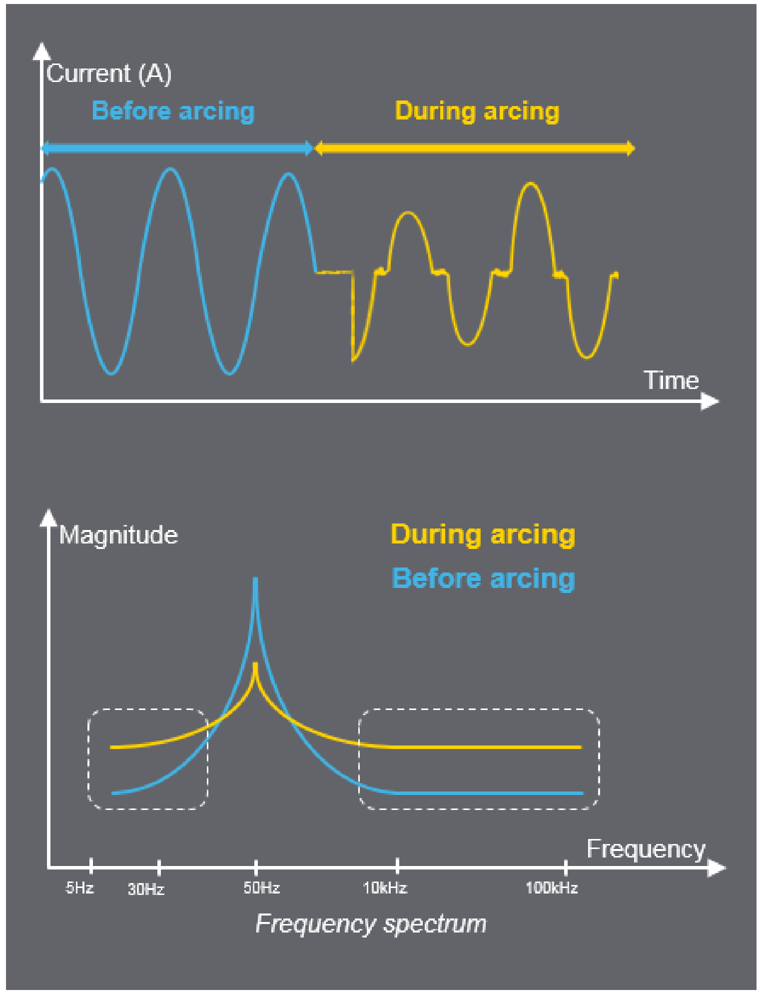

Figure 7

Anomalies in electric currents that could indicate the presence of potentially dangerous arc faults

AFDDs cross reference information involving several different electrical parameters in order to ensure that arc fault detection devices are only activated by the appearance of dangerous arcs.

The various parameters that are analyzed include the following:

- The current of the arc (a series arc is dangerous as soon as its value equals or exceeds 2.5 Amps).
- The duration of the appearance of the arc (very short durations, for example, are characteristic of the normal operation of a switch).
- The irregularity of the arc (the arcs of motors, for example, are fairly regular and as such should not be considered dangerous).
- The presence of disturbances at varying levels of different high frequencies is characteristic of the passage of a current through heterogeneous materials (such as cable insulation).

Examples of electric arcs that correspond to normal functioning include arcs created by switches, contactors, impulse switches, and other control devices when contacts are opened. Arcs created by motors of the different electrical loads connected to a circuit (like portable electrical tools, or vacuum cleaner motors) are also normal.

Why the new demand for AFDD?

Until recently it was not technologically feasible to build arc fault protection devices at a reasonable cost and in an acceptable size format. But now, the ability to miniaturize electronic components and the means to digitize such components makes the affordability and reliability of such devices a reality. Today's AFDD designs are comparable in size to miniature circuit-breakers (although each have a separate, different function). Innovations in digitization now permit that AFDDs perform extensive data analysis in real time. That speed is critical to providing an accurate assessment of the environmental conditions.

Another driver of AFDDs involves the recognition by government and safety authorities that faulty electrical systems pose a serious threat of fire risks to buildings and their occupants. Worldwide, electrical system mishaps are the cause of 25% of all fires – with 80% of building fires occur in dwellings. Dwelling fires in the UK in 2011-2012 accounted for nearly 300 fatalities and over 11,000 injuries. In 1994 in the US nearly 43,000 fires in homes originated from electrical distribution, resulting in 370 deaths and 1440 injuries.[1] In France about 25% of home fires (62,500 a year) arise from electrical faults, resulting from overloaded circuits, short circuits, earth-tracking currents and electric arcs in cables and connections.

Figure 8

Electrical system issues are recognized as the cause of 25% of all fires

Maturation of standards

In 2008, IEC decided to initiate standardization work for Arc Fault Detection Devices, leading to publication of AFDD product standard IEC 62606 "*General requirements for arc fault detection devices".* Since 2013, to ensure safe behavior, all AFDDs have to comply to the IEC 62606 standard.

A recent amendment of installation standard, IEC 60364-4-42, was published in 2014 for countries applying IEC standards (Europe and other parts of the world).

[1] U.S. Consumer Product Safety Commission (CPSC), 1994 Residential Fire Loss Estimates

IEC 60364 makes the following recommendations surrounding the installation and application environments of AFDDs in residential and commercial buildings:

- In locations with sleeping accommodations (e.g., hotels, nursing homes, bed-rooms in homes)
- In locations with risks of fire due to high quantities of flammable materials (e.g., barns, wood-working shops, stores of combustible materials)
- In locations with combustible constructional materials (e.g., wooden buildings)
- In fire propagating structures (e.g. high-rise buildings)
- In locations where irreplaceable goods are housed (e.g., museums)

It is recommended that AFDDs be installed at the place of origin of the low voltage final circuit to be protected (i.e., switchboard of an electrical installation).

At this early stage, national standards committees are being given the latitude of deciding if the use of AFDDs is to be made a requirement or a recommendation. Commercial buildings are becoming more and more common as places where AFDDs are being installed.

Although standards play the vital role of enhancing safety, they are often focused on new installations only, which represent less than 1% of the total number of buildings. Studies show that safety levels in older buildings are far below current standards. AFDDs represent a way to raise safety levels in existing buildings.

Installation hints and tips

During renovation work, safety considerations come into play that will influence the nature of the electrical installation. In addition to upgrading the switchboard with modern circuit-breakers and RCDs (for overcurrent and electric shock protection), the installation of AFDD (where a substantial arc fault risk is known to exist) is highly recommended.

More specifically, installers should be alerted to the following:

- Protruding cables (risk of knocks)
- Outside cables (greater risk of deterioration)
- Unprotected cables in secluded areas (like storage rooms)
- Shoddy or primitive workmanship regarding the way original circuits were installed (circuits held in place by wood beading)
- Circuits in buildings with wooden structure
- Aging, deteriorating wiring or wiring for which the connection boxes are inaccessible.

Leading manufacturers of quality AFDDs can assist installers, electrical contractors and electricians with the design and installation of AFDD solutions.

Conclusion

Building modernization initiatives should take into account the importance of low voltage electrical systems safety. Conditions such as overcurrent, electric shock, over-voltage and arc faults are avoidable if proper attention is given to installing up to date power protection technologies. Benefits include lower risk of injury to humans, lower risk of damage to building assets, and peace of mind for stakeholders who own and manage buildings.

The challenges of electrical safety are real, but the strategies and techniques to address these challenges are tested and proven. New AFDD devices now act as a supplement to the overall safety equation by addressing a safety gap covered neither by circuit-breakers nor by residual current devices (RCDs). However, to date, very few buildings have launched initiatives to help better protect themselves from arc faults and the fires they can trigger.

Prudent steps for initiating the process of addressing the arc fault issue include the following:

- Identify a trusted partner and advisor who is familiar with the design and function of these devices.
- If designing a new construction site, consult with experts who can analyze both electrical system safety requirements and costs and who can validate the design.
- For renovation projects, audit existing sites to determine the level of deterioration in the core wiring systems. Based on audit findings, propose a budget and assemble a project team for implementation of the modernization and safety plan.

About the authors

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Simon Tian holds a Ph.D. in Electrical Engineering from Ecole Normale Superieure de Cachan, France. He has worked at Schneider Electric for more than 25 years in R&D for advanced power protection including earth-leakage protection, and arc fault protection. Mr. Tian is presently the Offer Architect for final distribution protection devices.