Paper Number

Arc-fault Circuit Interrupters

For Aerospace Applications

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ABSTRACT

Circuit Breakers have historically been the preferred protection for aerospace wiring. Present designs are based on technologies that are 40 years old. Advancements in electrical circuit protection introduced by the residential and commercial industries have been slow finding their way into aerospace applications. Ground fault circuit interrupters (GFCI) for personnel protection have been available in the home since the early 1970's. GFCI can detect phase to ground arcs as low as six milliamps, but cannot detect series arcs or improve line to neutral fault trip times.

Arc-fault detection technologies are a new and exciting innovation in circuit protection in the US. Proprietary Arc-fault technology from Square D has been adapted to detect parallel or line to neutral arcs by listening for the unique signatures which arcs generate. This adaptation can detect arc currents well below the trip curves of today's Mil-Spec aircraft circuit breakers. This enhanced detection capability may provide improved protection from arcing conditions that may cause fires onboard aircraft.

INTRODUCTION

Definition: An arc-fault circuit interrupter (AFCI) is 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.

Aircraft circuit breakers have historically been the best available protection for aerospace wiring. Today's design standards are based on technologies that are 40 years old. In aircraft breakers the protection is provided two ways. Overload currents operate either a bimetal trip latch or hydraulic damped magnetic plunger. The "instantaneous trip " feature is a high current magnetic trip action found on some aircraft breakers. The time to trip during an overload is determined by the time it takes to heat a bimetal to the temperature that delatches the breaker. Fig 1

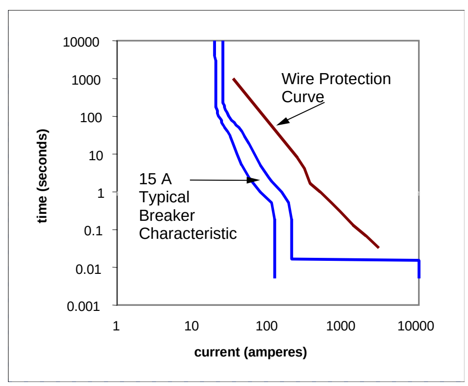

Figure 1

The more current that heats the bimetal, the shorter the time it takes to trip the breaker. A hydraulic-magnetic style of breaker contains a magnetic slug sealed in fluid which moves to a trip position in response to the square of the current. These circuit interruption devices are selected by aircraft design engineers to protect the aircraft wiring from overheating or melting. During arcing faults these currents are often small, short in duration and well below the overcurrent time protection curve designed into these breakers. Recent events have brought these limitations in design and function to the forefront. "Electrical arcing failure "as the ignition source, has been suspected in several recent airline disasters.

MAIN SECTION

Like today's Mil-Spec breakers, proprietary arc-fault technology from Square D can be applied to Alternating Current (AC) and may be applicable to Direct Current (DC) electrical power systems on aerospace vehicles. This Arc-fault technology was developed by Square D to help prevent electrical fires in US homes and incorporates electronic circuits that can detect the arc signature, and differentiate it from normal load arcing (motor brushes, switch and relay contacts etc.).

Arcing in a faulted AC circuit often occurs intermittently in each half cycle of the voltage waveform. The complex arcing event causes sputtering arc's that vary the current from normal load patterns. The precursor to the arc may be a high resistance connection leading to a "glowing contact" and then a series arc, or a carbon track leading to line-to-line or parallel arcing. In a home circuit breaker equipped with Ground Fault Circuit Interrupter (GFCI), a carbon or moisture track can be detected early if the short is to ground. In many aircraft circuits, the neutral conductor is not available to complete the necessary ground fault detection circuit and GFCI protection is not possible. With the introduction of AFCI breakers in 1998, protection of arcing shorts from line to line, not involving ground, can also be detected and interrupted. In Fig. 2, two detection zones are shown for UL-1699 approved breakers. Zone 1 is the parallel arc detection region between 75 amps and the thermal-mag curve. Zone 2 is an arc detection region where a ground fault path is available.

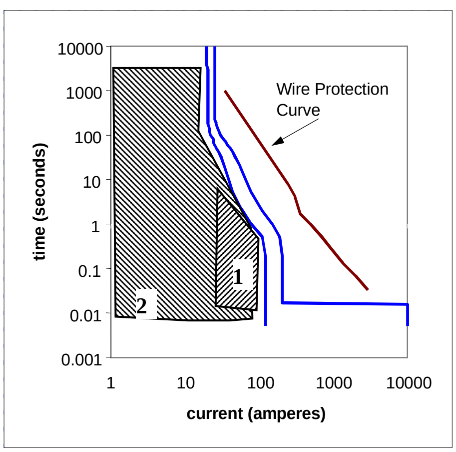

Figure 2

In the Arc-fault Interrupter, the additional electronic devices monitor both the line voltage and current "signatures". In a normal operating circuit, common current fluctuations produce signatures which must not be mistaken for an arc. Starting currents, switching signatures and load changes (normal or "good arc" events) are recognized in the AFCI as normal load signatures. Deviations or changes from these normal signatures are monitored by electronic circuits and algorithms to determine if arcing is occurring. When these arc-fault signatures are recognized, the circuit is interrupted and power is removed. The speed of this detection as well as the arc magnitude is a programmable parameter at the time of manufacture. The particular signatures identified as arcs, but not loads, are part of the proprietary arc-fault technology of Square D Company.

UL-1699 approved AFCI circuit breakers are available commercially for residential installation. These are now in the NEC and will be required in new home bedroom circuits in 2002. Since the electrical loads in residential circuits can vary widely, their programming is set to allow for almost an infinite combination of household loads. The AFCI function complements the GFCI as well as magnetic and thermal overload components. These breakers are designed for form, fit, and function in place of standard residential circuit breakers.

The design of AFCI devices for aerospace applications would be a special adaptation of those for residential use. The homeowner expects to be able to plug any load into an outlet without nuisance tripping from an AFCI, whereas the aerospace loads on a given circuit are fixed by design. The load on each aircraft breaker is carefully planned. Deviations from the original OEM specifications require special analysis and FAA approval. Fixed loads coupled with standardized wiring practices, connectors and certifications reduce the circuit variations and make aircraft more similar to each other than the loads found in a home. This coupled with stable, regulated power sources may allow for much faster reaction times or trip curves for AFCI devices designed for aerospace applications. In addition, 400Hz AC power used in modern aircraft allows for more waveform comparisons in a given period of time. Standard 60 Hz UL recognized devices are designed to detect arc-faults in as little as 70 milliseconds, at 400Hz the same detection may take only 10.5 ms. The increase in frequency coupled with fixed loads indicate that the technology would likely be successful in preventing the electrical ignition source of aircraft fires. Proprietary arc-fault technology of Square D may be board-mounted in avionics power supplies and placed, if needed, at individual electrical loads. They can be designed to communicate with one another or data recorders to monitor the condition of electrical wiring and components. Maintenance data recorders can be reviewed after flight and pending failures identified and maintenance interventions can take place prior to system failure.

Proof of Concept

Laboratory tests have shown that AFCI breakers containing Square D proprietary arc-fault technology can detect faults and trip faster than aircraft circuit breakers and are significantly faster at detecting arcing faults in aircraft wiring. Fig 3

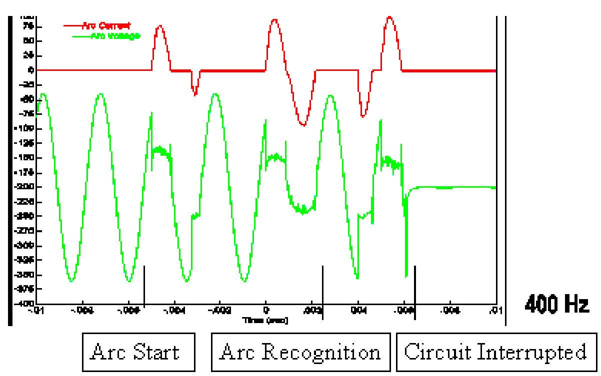

Figure 3

Experiments were performed at International Aero Inc. with Square D Company to determine the differences between aircraft breakers and an Square D AFCI breakers adapted for aerospace. These tests were based on the FAA Wet Arc Testing protocols developed to determine susceptibility of aircraft wire to arcing.

A five ampere rated (5A) Mil-Spec aircraft circuit breaker was placed in series with a fifteen ampere Square D Company Arc-D-Tect, AFCI, specifically adapted for 400Hz applications. Power was applied to an aircraft water boiler drawing 1.95 amps through the subject breaker and AFCI device. Arc's in the range of 75-100 amps were induced into the input to the boiler by dragging a 20ga wire between input to the boiler to ground. In every test the prototype AFCI interrupted the power before the Military-Standard aircraft breaker. These experiments indicate these devices can be adapted for use in aircraft AC circuits. Additional tests are ongoing to determine the detection differences with modified AFCI devices and standard aircraft circuit breakers. As well as to the susceptibility of thermal acoustic insulation material to ignition from electrical arcs, and the ability of AFCI to mitigate the ignition.

There are two types of arcing faults in aircraft electrical circuits and wiring: Parallel and Series**.**

Parallel Arcs

Parallel arcing occurs when there is a arc between two wires or wire-to-frame and the current is limited by the impedance of the voltage source, the wire, and the arc. When the fault is solidly connected ("bolted fault"), the normal aircraft breaker trips very quickly with little heating of the wire or damage at the fault point. Occasionally, however, an arc blows apart the faulted components creating a larger arc voltage and reducing the fault current below the trip curve and causing "ticking faults". The average current may not be sufficient to trip a conventional breaker by heating of the bimetal strip or the peak current may not be large enough to trigger the magnetic trip latch. Parallel arcing is generally more hazardous than series arcing. The energy released in the arc is much higher with temperatures in excess of 10,000 Deg. F. This causes pyrolyzation or charring of the insulation, creating conductive carbon paths and ejecting hot metal that is likely to encounter flammable materials.

Series Arcs

Series arcing may begin with corrosion in pin-socket connections or loose connections in series with the electrical loads. Loose terminal lugs, misarranged or cross-threaded electrical plugs, broken conductor strands inside a wire are also possible sources. The voltage drop across a poor connection begins at a few hundred millivolts and slowly heats and oxidizes or pyrolizes the surrounding materials. The voltage drop increases to a few volts at which time it becomes a "glowing connection" and begins to release smoke from the surrounding polymer insulation. The result may be observed as flickering lights or motor jogging. Series arc current is always limited to a value by the impedance of the electrical load that is connected to the circuit. The amount of power from a series arc is far less than in a parallel fault. Series arcing is much more difficult to detect than parallel arcing. The signature of the series arc is an unusual signature of the normal load current which can be included in the arc-fault detector. Series arcing is particularly treacherous because the arc current remains well below the trip curve of the Mil-Spec aircraft breaker. These arcs cause load voltage drops and heating of the wire, pin and sockets, or terminal lugs. This heating can lead to component failure and ignition source.

Potential Application

Care needs to be taken in the adaptation of AFCI into aerospace. Critical and essential electrical circuits need protection which cannot nuisance trip. Most aircraft electrical loads are on branched circuits which provide a mixture of current waveforms to the breaker. A single breaker in the cockpit may feed several unrelated systems. Nuisance tripping is not acceptable as several systems may be powered by one breaker. Careful analysis must be used in design and implementation of arc detection in aerospace. Even with these reservations, AFCI has the potential to be one of the single largest improvements to aircraft safety in 25 years.

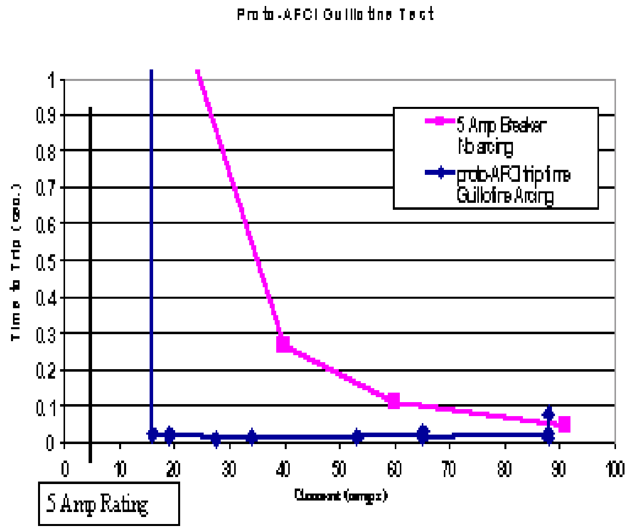

Figure 4

Figure 4 shows an arc-fault test result of a 5-Amp Square D prototype AFCI adapted to 400Hz application. THERMAL-MAGNETIC Reference (TOP), PROTOTYPE AFCI (Bottom)

CONCLUSION

Arcs or electrical ignition are typically caused by loose connections, broken or shorted wires in a power distribution system. In aircraft wiring, vibration, moisture temperature extremes, improper maintenance and repair all contribute to wiring failure. This occasionally leads to arcing and may ignite combustible materials. Furthermore, carbon tracking can deteriorate the wire insulation, exposing the conductors and resulting in intermittent short circuits between individual wires or to the air frame. These shorts can cause damage to delicate avionics and cause system malfunctions in-flight. Arc-fault detection which has been developed recently for residential use may be adapted for aircraft use. Elimination or reduction of these hazards to flight is offered to the industry with proprietary Arc-fault technology from Square D.

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REFERENCES

1999 NEC Code

During the 1999 code cycle, code panel 2 (branch circuits) voted to make the installation of AFCI devices mandatory for all 15 and 20 Ampere (125V or less) bedroom circuits in dwelling units beginning January 2002. The year 2002 was chosen to "permit these new devices to be introduced into the public domain on a gradual basis." In their substantiation, the panel specifically stated that the devices could be installed earlier than the 2002 requirement and in circuits other than bedrooms

Section 210-12b: “Dwelling Unit Bedrooms. All branch circuits that supply 125-volt, single-phase, 15 and 20-ampere receptacle outlets installed in dwelling unit bedrooms shall be protected by an arc-fault circuit-interrupter(s). This requirement shall become effective January 1, 2002."

George D. Gregory and Gary W. Scott, “The Arc-Fault Circuit Interrupter, an Emerging Product”, *IEEE Trans. Ind. Applicant.*, vol. 34, pp. 928-933, Sep./Oct. 1998

DEFINITIONS, ACRONYMS, ABBREVIATIONS

AFCI	Arc-fault Circuit Interrupter
GFCI	Ground Fault circuit interrupter
MIL-Spec	Military Specification
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NEC	1999 National Electrical Code
FAA	Federal Aviation Administration
UL	Underwriters Laboratories