Eliminating False Positives in the Detection and Location of sub 3ms Faults on AC/DC Lines

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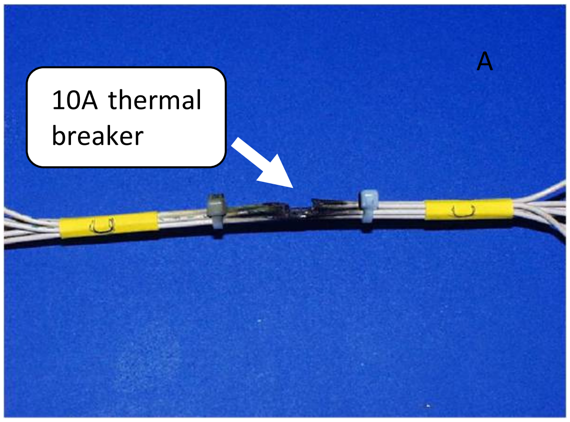
Introduction

Arc faulting occurs on powered wires for a number of reasons and under many different conditions. By nature an arc fault is highly variable in terms of magnitude and duration. The risk to human safety and enormous cost of arcing power wires prompted a great deal of research and development, but to date these technologies have not been broadly adopted.

Consider the two images below in Figure 1, which shows the damage associated with power wires protected with a standard thermal breaker (left) and an arc fault breaker (right). To date very few aircraft platforms have adopted the AFCB technology.



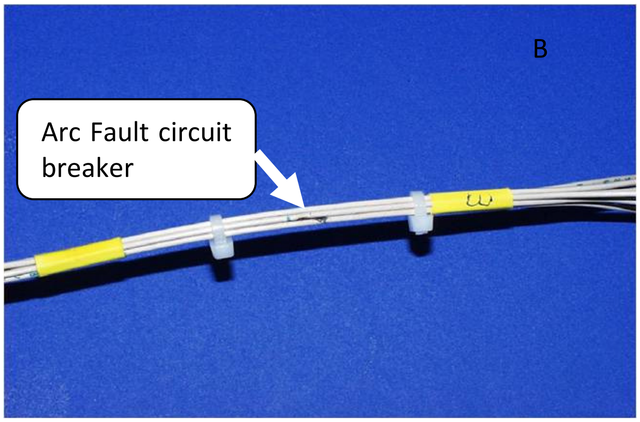


Figure 1: Wire damage comparison between thermal breaker (A), and arc fault circuit protection (B).

Significant wire damage occurs often when the faulting circuit is protected with a thermal technology, as shown on the left. Wires that have been blown apart or severely burned during an arc fault are easier to find and repair, but the repair is almost always reactionary and very expensive. The damage to wires protected by an arc fault circuit breaker is much less dramatic and often not visible at all, which is illustrated above on the right (A). Not only is the damage difficult to find after the fact, but the wires are typically operational, preventing standard troubleshooting techniques from finding the damage.

Arc Fault Location/Detection Technology

Arc fault circuit breakers are sensitive enough to detect arc faults, but these breakers also falsely identify several normal circuit behaviors as arc faults, leading to “false positive” indications. Along with secondary power systems that may be pulse width modulated, lightning strikes to the exterior of an aircraft induce voltage and current profiles that resemble arc faults. The protection that existing arc fault circuit breakers can provide is overshadowed by nuisance breaker tripping on non-fault events, which has reduced the overall effectiveness of this approach.

Nuisance breaker tripping and the difficulty of finding arc fault damage on arc fault breaker protected circuits demand a new and innovative approach to this substantial aerospace wiring challenge. LiveWire has developed an arc fault location/detection technology that promises to remove false or nuisance breaker performance and simultaneously provide arc fault location.

The advancements presented in this paper show the capabilities of LiveWire’s arc fault location technology for both AC and DC powered circuits with a single hardware/software solution.

Arc Fault Definitions

Arc fault circuit interrupters and circuit breakers are rigorously tested and evaluated based on the key points included here. Not all specifications are summarized in this document; however the definition of “arc fault” is derived from the points here.

AC single & 3-phase 400Hz power (AS-5692 Rev A)

After visible arcing has occurred on the guillotine test for approximately 1 second the test may be terminated. A minimum of 8 half cycles of arcing current within 100 ms shall occur. If less than 8 half cycles of arcing occur the test will be repeated (43).

Arcing Half Cycle: The trace for the actual current and arc voltage must be analyzed to determine if an arcing half cycle has occurred. An arcing half cycle has occurred if the arc voltage is above 15 volts over at least 5% of the time of the half cycle (0.0625 milliseconds for 400 Hz), and current flow is present at or above 1 amp. A complete sinusoidal half cycle of current flow is not considered to be an arcing half cycle (31).

Arcing Time Duration & Maximum Arcing Half Cycles

The arcing time duration is used to define an arcing event that rises to a level that requires clearing. An arcing event that rises to a level that requires clearing is defined as the accumulation of a number of arcing half cycles that occur within a predetermined period of time. The predetermined period of time is the Arcing Time Duration. The number of arcing half cycles, which must occur before the event is deemed requisite of being cleared, is the Maximum Arcing Half Cycles (32).

Guillotine testing (manual arc faults induced with a knife blade) is governed by the logic flow shown in Figure 2, which was taken from AS-5692 Revision A.

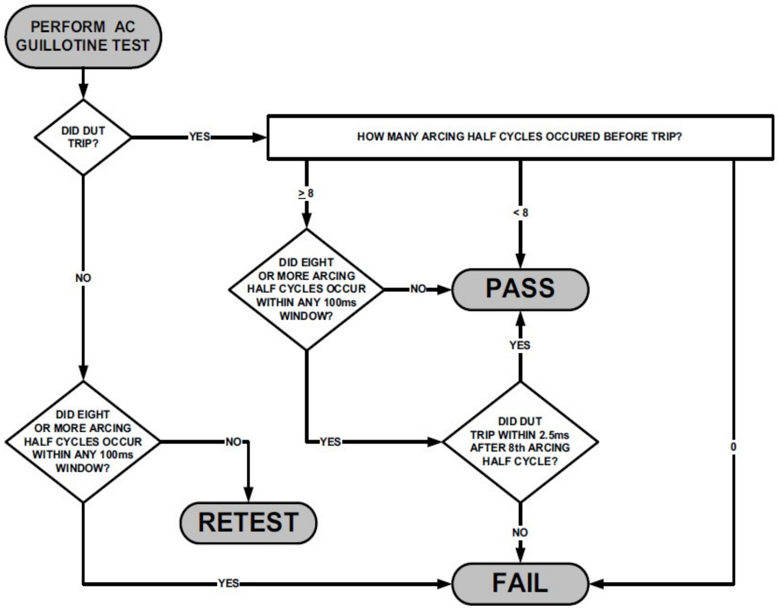


Figure 2: Guillotine arc fault test logic flow, taken from AS-5692 Revision A specification.

The arc fault voltage requirement isn't found in the logic flow of Figure 2, but is noted above defines the circuit voltage during an power fault that must be maintained to define the fault as an arc fault (15% of normal voltage during 8 half cycles used to trip the AFCB).

Arc Fault Location & Detection

The detection and location capabilities of the LiveWire's arc fault technology are illustrated in a series of GUI screen shots showing SSTDR signatures and corresponding current and voltage measured in real time as the events took place.

The test results for a representative 28 VDC arc fault are presented here in Figure 3 & Figure 4.

Figure 3: Short duration (1.2 ms) 28 VDC arc fault test and GUI result display.

Figure 4: Longer duration 28 VDC arc fault test and graphical result display.

Arc Fault Location versus Cable Position

Seven locations along a fifty foot cable were marked and used to investigate arc fault location accuracy (every five feet). The tabulated data in Figure 5 illustrated the arc fault location performance of the technology, where the error was the standard deviation of all reported faults at the corresponding location.

Actual Fault Location (ft)	Reported Fault Average (ft)	Reported Fault Deviation (ft)	Fault Location Error (ft)
0	0.635	0.084	± 0.635
5	5.371	0.255	± 0.371
10	10.643	0.060	± 0.643
20	19.617	0.195	± 0.383
30	29.320	0.226	± 0.680
40	39.784	0.842	± 0.226
45	44.827	0.111	± 0.183

Figure 5: Tabulated DC arc fault location result summary.

Similarly, the 400Hz arc fault location performance was determined and tabulated in Figure 6.

Actual Fault Location (ft)	Reported Fault Average (ft)	Reported Fault Deviation (ft)	Fault Location Error (ft)
0	0.615	0.615	± 0.615
5	5.916	0.168	± 0.916
10	9.883	0.815	± 0.117
20	20.233	0.144	± 0.233
30	29.875	0.097	± 0.125
40	40.624	0.171	± 0.624
45	44.778	0.173	± 0.222

Figure 6: Tabulated 400Hz AC arc fault location result summary.

Summary

LiveWire has developed a very sensitive and accurate arc fault location and detection technology to address the significant risks to safety and enormous costs associated with aircraft loss and repair. This technology has been demonstrated to be equally valid across AC and DC power circuits with a single hardware/software solution. Through the innovative combination of multiple types of data, false positive arc fault tripping has been essentially eliminated. Arc fault location also provides significant value to aircraft maintainers, as wiring faults can be quickly identified and located for repair.