Arc Fault Protection and Thermal Aircraft Circuit Breakers

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Abstract

The military and commercial aerospace community has identified arcing faults as a major cause of damage to aircraft and danger to personnel. In some extreme cases, arcing is suspected of resulting in significant loss of life. Presently, thermal aircraft circuit breakers are designed to respond to energy levels that damage wire and wire insulation on a system that is properly functioning other than the presence of an overload condition. However, due to the concentration of energy during an arcing event, insulation and surrounding material damage can occur at energy levels that are far below those levels that would damage wire and wire insulation away from the location of the arcing event. Very often these energy levels are also lower than those that would occur in a normally operating system, and as such would not trip a standard thermal circuit breaker.

Arc fault protection devices must be capable of recognizing an arcing event without relying on energy levels alone. Arc fault protection devices being developed by Texas Instruments and Hendry Telephone Products take advantage of the fundamentally chaotic nature of the current signature to recognize an arcing event. Reliance on this fundamental characteristic allows this device to discern an arcing event from non-chaotic current signatures such as motor in-rush, and fluorescent and strobe light start-ups. In addition, proprietary algorithms, delay timers, and sensitivity thresholds are defined to allow discrimination between an undesirable arcing event and the normal types of arcing that occur in a system such as mechanical contact separation in a switch.

Arc fault protection is being incorporated into a package without sacrificing any of the proven thermal circuit breaker protection. The combined thermal circuit breaker with arc fault current interruption capabilities will retain all of the performance characteristics with respect to short circuit interruption, endurance, resistance to environmental conditions, etc., with only minimal growth to its physical size. Physical layout, such as mounting means, and terminal connections have been retained. Thermal overload protection, including dual safety protection when applicable, function independently from arc fault protection to offer excellent fail safe operation that would not be an option on devices that rely more heavily on electronic current level sensing.

Prototype device testing to date has exhibited excellent discrimination between arcing events and normal current signatures. More importantly this has been accomplished while retaining the system compatibility of a thermal circuit breaker.

This paper will outline the work performed to incorporate arc fault detection technology into one easily retrofitted package, with proven thermal overload protection. It will define the goals of this hybrid device as well as preliminary testing results of prototype assemblies.

Background

Thermal circuit breakers were developed to protect a significant length of wire from damage due to over current conditions. Thermal curves represent energy thresholds that would be likely to result in wire damage. The wire damage expected during current overloads in excess of the thermal trip thresholds of traditional thermal circuit breakers is generally large scale, occurring throughout the wiring carrying the overload. Arcing faults concentrate smaller amounts of energy that can damage a more localized area of the wiring. However, the concentration of energy released during arcing faults often results in rapid damage to the circuit experiencing the fault, and collateral damage to other circuits, and combustible materials, in the vicinity of the fault.

Arcing faults can occur with varying levels of impedance. Arcing can occur within connectors. Acing can also occur between system potential and ground, or to other phases, through loads or other impedance. These types of arcing, with lower levels of arcing current, can still concentrate enough energy to damage insulation and ignite combustible materials over relatively longer periods of time. These longer duration arcing scenarios can still result in smoke incidents and collateral damage with potentially catastrophic results.

Arcing events with current signatures that are not within the tripping thresholds of a thermal circuit breaker are suspected of causing numerous smoke events, airplane damage, injury, and in some severe cases loss of life. Most notably, arcing is suspected to have contributed to the TWA Flight 800 and Swiss Air Flight 111 tragedies.

Arc Fault Protection Devices, AFPDs, are being developed to augment the thermal protection devices currently utilized in aircraft wiring systems. The exact details of the mission of AFPDs are still being refined. However, the overall mission of such a device is very clear. AFPDs will reduce collateral damage caused by arcing events that do not produce enough system level energy to trip the thermal sensing mechanisms currently in use, without adding a significant number of unnecessary interruptions in airplane power. Most importantly, AFPDs will accomplish this without sacrificing any of the overall system safety currently provided by thermal aircraft circuit breakers.

Arcing Fault Event Definition

The overall mission statement of the AFPD is not a challenging exercise, however, to reduce collateral damage caused by arcing events, some definition of such events must be formulated. An exact working definition of an arcing fault is likely one of the single most daunting tasks encountered during the development of arc fault sensing technologies. Arcing faults are discharges of current from one conductor to another of varying amounts of energy that result in some form of intolerable damage. All arcing events are not arcing faults. In normal airplane operation the mechanical opening and closing of contacts, on a system carrying current and voltage that are above minimum levels to be considered a "wet circuit", results in some level of arcing. These arcing situations are not arcing faults. The variations in airplane equipment result in extremely complex and highly variable current signatures. Consideration of these variations precludes the definition of an arcing fault in physical terms such as luminescent, heat generating, rapid current rise, or even regularly occurring flat portions at the zero crossover of the alternating current wave. All of these conditions can be found on a normally operating airplane system.

Any working definition of arcing fault events must rely on the random nature of arcing, and must combine this random nature with empirical knowledge of arcing fault event signatures that cause damage in the applications. Further, to minimize nuisance tripping this working definition must consider arcing that is common to a normally operating system.

Proven Thermal Protection - Minimizing Implementation Risks

Texas Instruments and Hendry Telephone Products are incorporating arc fault protection technology into thermal circuit breakers. Even the newest commercial and military aircraft wiring system designs rely on proven thermal circuit breaker protection that has evolved through well over 30 years of application and production experience. The design philosophy employed by Texas Instruments and Hendry Telephone Products incorporates this new technology without sacrificing existing protection. A major component of this philosophy ensures that thermal overload sensing elements do not reference the condition of the arc sensing circuit. The implication of this requirement is that damage to, or complete loss of the arc sensing circuit does not compromise the level of thermal overload protection provided by a device responsible for both arc fault and thermal overload protection. This design strategy allows the end user to implement this technology without concerns that undiscovered failure modes of the circuitry will reduce the overall system safety.

A degree of freedom has been maintained between the arc fault sensing and the thermal overload sensing to preserve the existing level of thermal protection. This degree of freedom is maintained on both the logic level and the mechanism level. The arc sensing logic does not react to non-arcing overload scenarios, reducing the likelihood of nuisance trips. In turn, the thermal overload sensing elements do not reference the condition of the arc sensing circuit. This is one of the most important design criteria for reducing risk while implementing AFPDs. Allowing the thermal protection to rely on, or even reference, the condition of the arc sensing circuit could put the thermal protection of the entire airplane in jeopardy. In the relatively low likelihood that the AFPD is exposed to unforeseen over temperature, over voltage, severe EMI, decompression, or other damage, a loss of circuit function could leave the airplane vulnerable to a simple circuit overload. A simple overload, without the current level of thermal protection, can quickly result in large-scale system wide collateral damage.

The same design philosophy is carried over to the tripping mechanisms that separate the mechanical contacts of the AFPD being developed by Texas Instruments and Hendry Telephone Products. The arc fault tripping mechanisms do not affect the device's ability to react to a non-arcing overload. This is accomplished in such a way as to allow a device to thermally trip, regardless of the state of the arc fault tripping mechanics, at rest, trying to trip, etceteras. Maintaining a degree of freedom between the tripping mechanisms rather than defining a hierarchy for different types of tripping also allows the arc fault trip mechanism to trip the device regardless of the condition of the thermal trip mechanism.

The design philosophy of maintaining a degree of freedom between the arc fault sensing and the thermal overload sensing is targeted at reducing the risk of implementation. Maintaining proven thermal overload protection allows a narrower focus on the arc fault sensing behavior when determining the risks of implementation. In this way the end user need only focus on defining the level of the arcing faults that are to be cleared and the required level of protection against nuisance tripping.

Package

Another challenge that must be addressed during AFPD development is package size. Thermal circuit breakers currently used on commercial and military aircraft are as small as a postage stamp and about ½ inch thick. The cost ramifications of equipment weight and size associated with fewer passengers in commercial aircraft, less munitions capacity on military aircraft, and shorter range for both, is responsible for driving the size of thermal circuit breakers to their current dimensions. While these constraints must still be considered for AFPD development, another constraint to package size has become as imperative. This constraint is defined by the fact that much of the need for arcing fault protection is encountered on systems with aging wiring. Aging wiring on older aircraft must be addressed with an AFPD that can be retrofitted into service with a minimum of disruption to the rest of the airplane system. A key to achieving this goal, and consequently the new constraint that must be considered, is that the size of the AFPD must be as close as possible to the size of the thermal circuit breaker that it is replacing. Minor increases in package sizing, while maintaining the same wiring and bus connections as existing thermal circuit breakers, have resulted in a package that offers over 90% compatibility, by some estimations, on commercial aircraft.

Prototype Testing Results

Prototype test devices, designed and produced by Texas Instruments and Hendry Telephone Products to support development programs at Boeing Aircraft Company, are currently being flight tested by Boeing Aircraft Company. Lab testing performed, on aircraft mock-ups at the power labs of the Boeing Aircraft Company, as a requirement for approval for flight testing yielded positive results. Additional testing at Boeing Aircraft Company, as well as testing internal to Texas Instruments and Hendry Telephone Products has resulted in prototype devices with excellent arc fault discrimination, in a package that also meets commercial and military specifications for performance of a thermal circuit breaker. Texas Instruments and Hendry Telephone Products have also participated in, or benefited from, data collected by Boeing Aircraft Company, Delta Airlines, the FAA, and NAVAIR on ground testing of actual airplane system. Much of this collection was focused on identifying possible nuisance loads. This was particularly valuable on some of the older aircraft systems that were tested. In some case the data collected also simulated arcing faults on the actual aircraft systems. This data is being used to further develop arc fault protection devices and to develop performance specifications for arc fault protection devices.

Conclusions

The military and commercial aerospace community has identified arcing faults as a major cause of damage to aircraft and danger to personnel. In some extreme cases, arcing is suspected of resulting in significant loss of life. Presently, thermal aircraft circuit breakers are designed to respond to energy levels that damage wire and wire insulation on a system that is properly functioning other than the presence of an overload condition. However, due to the concentration of energy during an arcing event, insulation and surrounding material damage can occur at energy levels that are far below those levels that would damage wire and wire insulation away from the location of the arcing event. Very often these energy levels are also lower than those that would occur in a normally operating system, and as such would not trip a standard thermal circuit breaker.

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Definitions

Dual Safety Circuit Breaker – A circuit breaker with a secondary fusing element integrally linked to the operation of the main contacts, such that in the event of an overload, when the main contacts' mechanism is disabled or malfunctioning, the secondary fusing element will interrupt the current before wire or system damage occurs.

Thermal Circuit Breaker - A circuit breaker using a current carrying thermal element, such as a bimetal, as the primary current sensing member. Thermal Circuit Breakers are dependent upon temperature rise in the sensing elements for actuation. Normal operation is achieved by the deflection of a thermal element (e.g. bimetal) which will open a circuit when a predetermined calibration temperate is reached. Temperature rise in the sensing element is caused principally from load current I^2R heating. The thermal element will also integrate the heating or cooling effects from external sources with load current heating. Thus, corresponding ambient temperature fluctuations will tend to derate (effectively lowering) or uprate (effectively raising) the ampere rating of the breaker from the specified ampere rating at the specified temperature rating (typically 25^0C).

Short Circuit Interruption - The ability of a circuit breaker to interrupt very high available current levels which would be encountered during short circuit events. Short Circuit Current (Fault Current) is typically set as maximum current that the system can produce at the point of application of the protective device.

Nuisance Trip - An unintended interruption of power to a circuit.

Wet circuit - A circuit with enough available current and voltage to sustain an arc. The exact levels are highly material, geometry, and environmentally dependant. Values, representative of some material & geometry configuration are stated as 12 volts, and 100 milliamps, at sea level.

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