Arc Fault Detector

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Abstract – **This paper describes a simple method of high current arc fault detection using dominant characteristics of an arc in aircraft 115V, 400Hz, three phase electrical systems**.

I. INTRODUCTION

A. Definition

An arc fault is an unintended, self-sustaining discharge of electricity in a highly conductive ionized gas, which allows current flow between conductors, limited only by circuit parameters that are predominantly resistive.
An arcing fault current from one phase to ground, limited to 70A, gives a waveform such as is shown in Fig. 1.

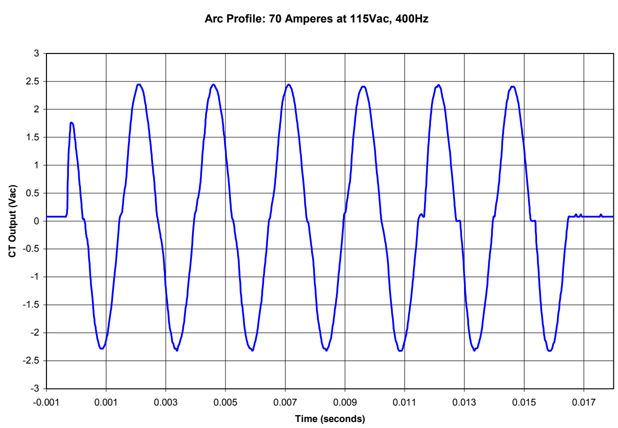

Figure 1.

B. Background

The subject of arc fault detection and circuit interruption has gained a lot of attention in recent years, particularly in the aviation industry. This is primarily due to a spate of in-flight fires which have been linked to faulty electrical systems and wiring on aircraft. Typical causes of faults are wiring chafing, dust build up and moisture [1][2].
Until recently, aircraft circuit breakers, either electromechanical or solid state i.e. Remote Controlled Circuit Breaker, Solid State Power Controller, Solid State Relay etc. were considered the first line of defense. However, research has shown that arc faults, with temperatures as high as 6000°C, can go undetected by these devices.

Aerospace circuit breakers are designed to protect wiring from thermal damage that occurs during an over-current situation. They are able to do this by deploying a bi-metallic element that mimics the thermal effect of current on a wire's insulation. Their electronic counterparts provide the same functions electronically.
Electrical arcing is a localized, high-energy event. Current levels during arcing can significantly exceed the current rating of the circuit breaker. However, arc fault events, like many transients, are very short lived and therefore cause little impact on the bi-metallic element or the electronics. Consequently, conventional circuit breakers and electronic wire protection methods do not interrupt the circuit fast enough to prevent damage or perhaps a catastrophic event like fire.
Domestic arc fault detection for 60Hz, single phase low current loads is mandatory for domestic use, but has yet to be defined for high power 400Hz, three phase aircraft loads. It is these that require improved levels of protection. Typically an arc fault adds to an existing load current causing a fast three-phase imbalance.

II. DESIGN

A. Objectives

The design objectives are to offer three phase, fast, fault detection and protection as a supplement to other wire protection methods. The new design will be incorporated into an existing line of current sensing contactors called 'Electrical Load Control Unit' [ELCU] thus adding to their available features.

B. Functions

The desired functions of the Arc Detecting ELCU were considered to be as follows:

1) Detects a fast fault [arc fault] condition from any line to ground or line to line.
2) Trips open, in response to a detected fault condition and remains open until reset.
3) Reduces nuisance trip during turn-on and power interrupt conditions.

4) Provides familiar circuit breaker type I^2t [Current^2 x Time] wire protection characteristics.

C. Application

The application of the device is in the protection of aircraft wiring to high current loads, typically motor loads such as fans, hydraulic and fuel pumps, or any switching and protection function where the power source is a low impedance power bus. The device, therefore, is not intended to protect against low current level arcs.

D. Principle

The design principle is that a fast arc resulting from a fault condition has well known physical characteristics, which can be recognized and that detection of this arcing may be achieved by using only the dominant characteristics of an arc fault.

III. DESCRIPTION

A. Description

The circuit design shown in Fig. 2 continuously monitors the three phase load currents that are isolated from the monitor circuit by current transformers and looks for a specific imbalance in load currents. When a pre-determined average level of current imbalance is exceeded, within a specified time, then a fast fault [such as an arc] is considered detected and a trip is initiated. As the detected fault current increases, the time to trip decreases. Imbalance caused by load current in-rush during load connection can cause nuisance trips. This is minimized by the choice of the pre-determined arc current threshold and by inhibiting the trip circuitry for a preset time. If the current imbalance condition persists past the preset inhibit time, it is considered a genuine fault [which may typically be an arc] and the circuit is commanded to trip. The level and duration of this type of fault lies between major instantaneous fault currents and existing wire protection curves.

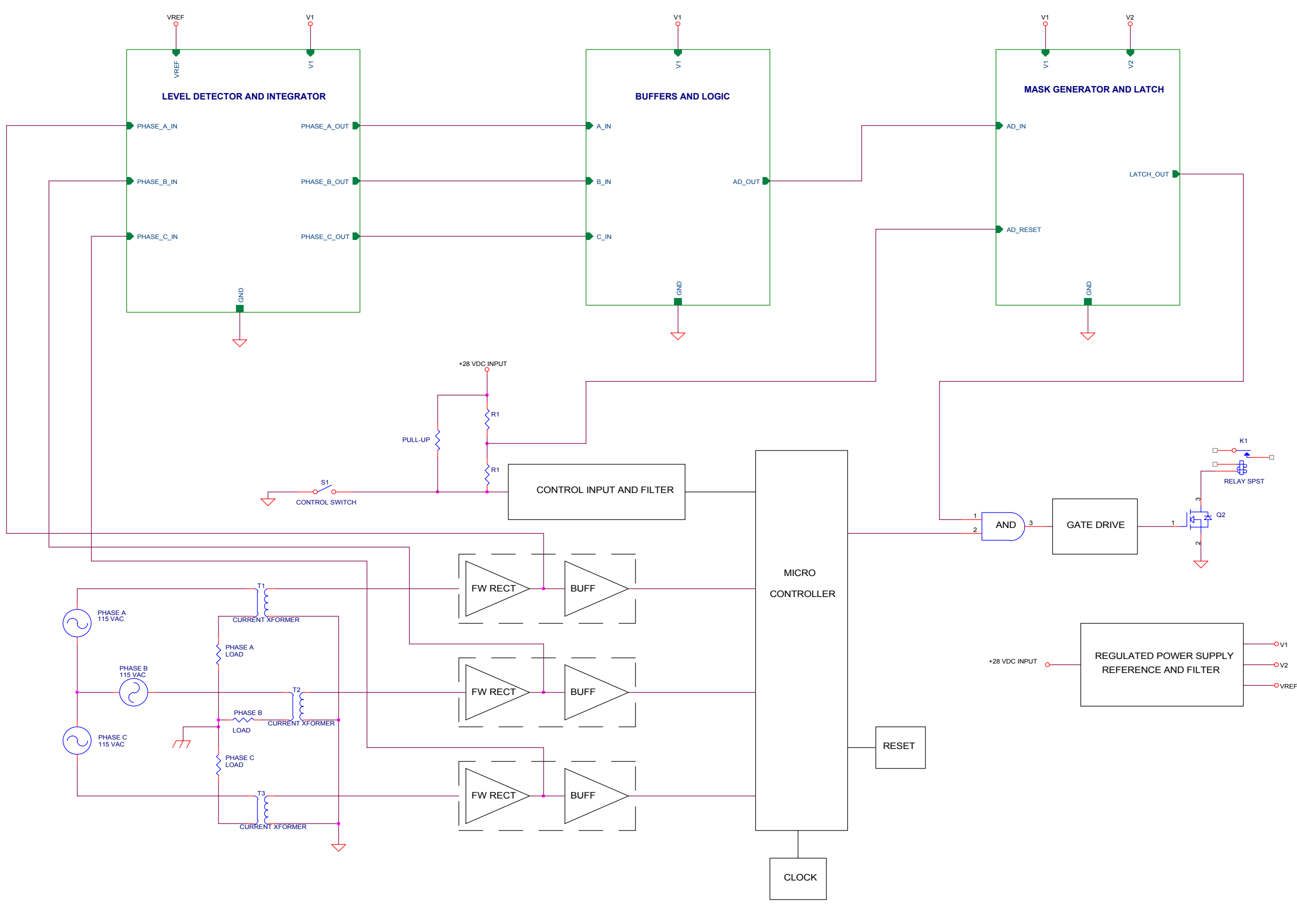

Figure 2.

This device is intended to limit the duration of fast occurring damage, typically due to an arc, which is below the instant trip and before the I^2t trip levels as shown in Fig. 3.

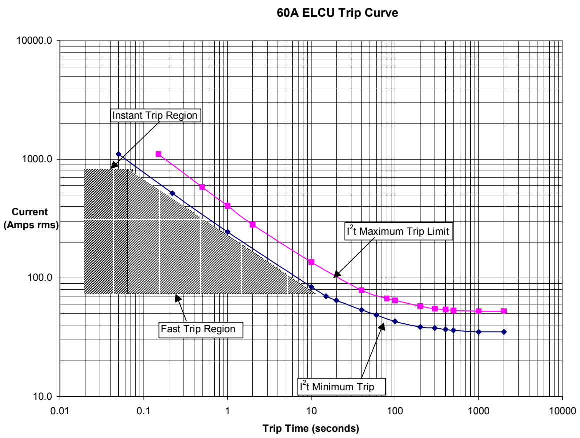

Figure 3.

B. Physical Requirements

The physical requirements include form; fit and function to enable direct replacement of existing products.

The available space envelope for some applications may be able to be increased but the mounting footprint is maintained the same as the unprotected device to provide a direct replacement.

There is also a weight increase of 5% due to the added components and increase in height.

C. Physical Implementation

A minimal increase in overall volume was required for the module be fully integrated and connected into the basic assembly.

A single layer PCB is used to hold all additional components.

The prototype has an external physical difference of an increase of 1.0 inches in height, which may be seen as a housing extension in Fig.4.

The circuit may be integrated within the existing envelope.

D. Circuit Description

Fig.2 is a block diagram of the model ZE ELCU contactor with the addition of the Arc Detecting, or fast trip, module circuitry.

Existing circuit functions are employed with the addition of logic, filtering and integration functions.

The major functions of the circuit of Fig.2 are:-

1) Filtering of the incoming signals to remove noise.

2) Logical comparison of signals to ensure a stable signal source.

3) Setting of level related thresholds.

4) Setting of time related thresholds.

5) Coil disconnection when a fast fault is detected.

6) Latching the fault detected condition until power removed.

Figure 4.

IV. PERFORMANCE

A. Tests

The Arc Detecting ELCU was tested with both a manually operated chaotic arc generator and an electronically controlled arc generator. The electronically controlled high current arc generator was designed to provide the equivalent of repeatable but programmable arc faults with timing consistent with testing proposed for lower level single-phase arc detecting devices. The ELCU was also tested on a representative aircraft power panel, in a power system laboratory, with a representative system load.

B. Test Results

1) The ELCU tripped to arc faults induced using a manual arc fault generator, both in the laboratory and in the power panel configuration. Typical individual arc waveforms superimposed on the load current are shown in Figs. 6 and 7.

2) The ELCU tripped to varying configurations of partial sine arc fault where each fault configuration provided greater than the minimum setting levels within the preset time periods.

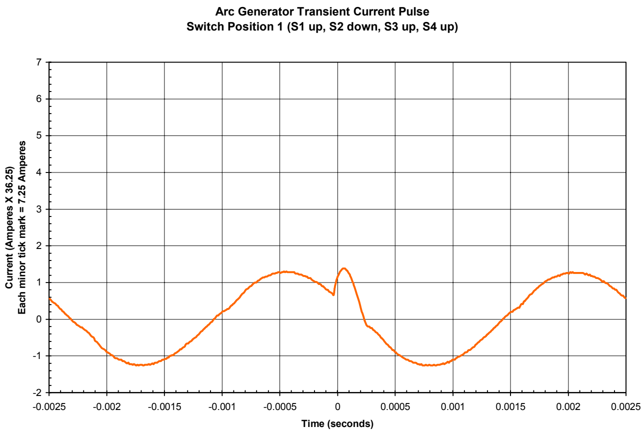

Figure 6.

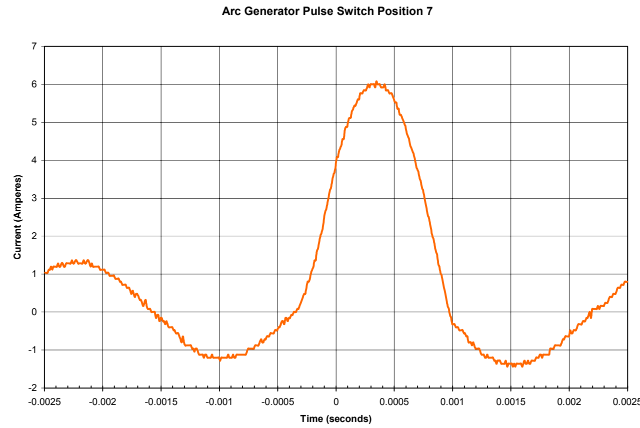

Figure 7.

V. CONCLUSION

Aircraft safety can be improved by preventing arc faults from leading to catastrophic events. The Arc Detecting ELCU is capable of opening an electrical circuit in response to the detection of high-level arc faults. The existing performance characteristics are maintained.

ACKNOWLEDGMENTS

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REFERENCES

[1] “No-Fault Design” by Rick DeMeis, Design News Sept.4, 2000.

[2] FAA Aging Transport Non-Structural Systems Plan, July 1998.