Electrical Series Arc Detection using Continuous Wavelet Transforms

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Abstract

Electrical arcing is a leading cause of fires in residential, commercial and industrial buildings. Electrical arcing was the cause of 16% of all residential building fires in the US between 2014-2016, resulting in 2,695 deaths, 12,000 injuries and $7 billion in property loss [1]. Similarly, in large non-residential building fires, arcing was the cause of 15% of fires, 90 deaths and $2.4 billion in property loss per year [2]. In the UK, electrical fires, including those caused by arcing, were responsible for 37% of all residential fire-related fatalities between 2017 and 2018, causing 283 deaths [3].

Other electrical problems, such as over-current and earth leakage faults are dealt with by common electrical protection devices like the stand-alone Arc Fault Circuit Interrupter (AFCIs). While such devices can be purchased commercially, the uptake has been slow because, installation is not mandatory in most jurisdictions and industries and because of the high rates of false-alarm trips when used with certain appliances.

This paper describes the detection of electric arcs using advanced spectral decomposition methods on high frequency samples of current and voltage waveforms. The method can be made very sensitive to individual arc events and tuned to suit specific applications and load types via adjustable thresholds.

Introduction and Approach

Electric arcs introduce high frequency anomalies in specific frequency components of an electric load profile. Such anomalies can be effectively detected through spectral decomposition methods. Spectral decomposition or time-frequency analysis is the process of decomposing signals into amplitude and phase spectrums. Most common spectral decomposition methods include Fourier Transform, Short-Time Fourier Transform, Continuous Wavelet Transform and Matching Pursuit Decomposition. All the decomposition methods differ in the frequency and time resolution they can provide.

Continuous Wavelet Transform (CWT) was selected for its ability to decompose signals at continuous scales or frequencies. The scales at which arc characteristics are identified, are controlled by using well-known wavelets of varying widths. The width of a wavelet is proportional to the central frequency, being shorter at higher frequencies. In effect, this provides high time resolution at high frequencies and high frequency resolution at low frequencies, allowing identification of electrical arc characteristics with high precision. Unlike other approaches such as discrete wavelets and Fourier transforms, CWT is able to efficiently target specific frequency ranges in which arc signals are known to occur, giving high-precision results and speed benefits which allow for real-time multi-channel detection of individual arc events.

In the current study, Morelet wavelet was used to effectively identify high frequency anomalies as it can quantitatively represent the energy attenuation in loads with electric arcs. The square of the decomposed wavelet-based coefficients is equal to the power spectrum of the load, referred to as a scalogram. The maximum power for each time step, if above a threshold, triggers an anomalous high frequency activity associated to a single
arc event. The algorithm can identify multiple arcs within a single voltage or current cycle. This allows secondary alarm thresholds to be set on the total number and power of the arc events within a given time window.

A lab-based test bed was constructed to generate synthetic electrical arcs of varying magnitudes and frequency of occurrence, by attaching a variable-speed shaker motor to a loose neutral-wire conductor supplying an arbitrary load. This simulates a common arc condition that often occurs in electrical switchboards, where vibration or conductor oxidisation can cause high resistance joints which heat up and create thermal creep in loosened screw terminals, generating a spark gap and eventually combust.

A dataset of manually generated electric arcs was created with this test bed by using an embedded electronic system on a library of electric loads including LED flood light, fan heater and pedestal fan (shown in Figures 1 & 2). The derived arc event thresholds were then tested on a library of more than 100 arc-free load waveforms and no false alarms resulted. It was found that thresholds when set globally were robust to switching noise and unusual load characteristics.

Figure 1 shows an example of using the proposed approach on a captured load current profile of an LED floodlight with and without the presence of electric arcs.

Figure 1: Captured LED floodlight load profile with (b) and without (a) generated electric arcs. Plots (c) and (d) are zoomed-in representation of the same data. Red dots show the location of individual arc events, observed as spikes in (d). Plots (e) and (f) are the relative power spectrum maxima in a CWT scalogram for the captured load waveform.
Similar observations were obtained (Figure 2, below) for pedestal fan and the fan heater with electric arcs.

Figure 2: Captured load profiles for (a) Pedestal Fan and (b) Fan Heater with electric arcs. (c), (d) represents the same data zoomed for visualization. Notice that the arcs (red stars) are detected with accurate time-stamps. (e) and (f) are the power spectrum maxima in a CWT scalogram for the captured load.

References

