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Smart detection technology of serial arc fault on low-voltage indoor power lines

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ABSTRACT

This paper employs the discrete wavelet transform (DWT) and an artificial neural network to identify the occurrence of serial arc faults on indoor low voltage power lines. Electric arc faults on power lines must be detected in order to turn off the electric power sources before fire events occur. However, since the characteristics of line current waveforms during serial arc faults are complicated, smart detection technology is required to have high accurate recognition. The DWT is utilized to obtain the time-domain characteristics of line current waveforms, and the signal energy of some sub-bands is useful information to reflect the serial arc fault patterns. And then, a radial basis function neural network (RBFNN) is trained by using the data of signal energy obtained from DWT. After the training process, the RBFNN has excellent ability to identify the serial arc-fault conditions. At last, the accumulative RBFNN outputs of 30 power cycle line current data are used to certify the occurring of a serial arc fault on the line. This study also compares the results of detecting serial arc faults with a commercial arc-fault circuit interrupter (AFCI) to reveal the goodness of the purposed method.

Introduction

According to the report from the National Fire Protection Association, a certain percentage of the house fires are caused by unsafe usage of electricity [1]. So, the arc fault circuit interrupters (AFCIs) became concerned for home fires caused by damage in the power cords [2]. The National Electrical Code (NEC) required installation of AFCIs on indoor low voltage power lines [3]. The AFCI is a safety device for low-voltage power lines to prevent fire accidents from arc faults. The signal detection circuit is important in designing an AFCI because this circuit must be able to determine whether an arc fault occurs or not correctly. However, the probability of a commercial AFCI to perform correctly is approximately 50% in the test report [4].

There are many studies about arc fault detection [5–9]. The study in [6] wants to estimate the amplitude of arc voltage if an arc fault occurs. Then, difference between arc and permanent faults will be achieved by comparing the estimated amplitude of arc voltage with a given threshold. The basic principle of arc fault detection in [7] is based on detecting the rate of change of line current during an arc fault and comparing it with a threshold. In [8], the signals of adaptive frequency bands can be extracted from line current waveforms to compare the maximum magnitude with a threshold to detect arc faults. One study utilizes the discrete wavelet transform (DWT) to analyze the experimental data, calculate the summation of the absolute values in one power cycle, and compare the summation with a threshold to detect the high impedance arc fault [5]. Another study [9] illustrates that the series arc fault let the line current have important components within 2 to 4 kHz. The phenomenon of serial arc fault can be detected by comparing the frequency components with a threshold [9]. However, different home appliances have different electrical characteristics. Thus, it needs to adjust the threshold for different home appliances.

This study employs the DWT and the concept of multi-layer resolution to analyze the frequency components of the line current waveforms. The load characteristics can be reflected by the signal energy in different sub-bands. Then, the radial basis function neural network (RBFNN) [10,11] is used to design a smart method to detect the serial arc faults. The line current waveforms of the system under normal operation or a serial arc fault are used to train the RBFNN. In [12], the back-propagation neural network (BPNN) has been utilized to detect serial arc faults. However, the impulse current components can influence the detection easily, so that the performance is not good enough even for a single load under on/off switching. In this paper, the RBFNN is employed. The RBFNN structure is simpler than the BPNN, and the RBFNN can overcome

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the difficulty of impulse current components under on/off switching conditions. Moreover, the RBFNN is suitable for function learning and modeling [13]. Therefore, this study utilizes the DWT to obtain the signal energy of the line current waveforms, and the RBFNN to detect the serial arc faults. From the test results, the purposed method is better than the commercial AFCI. The RBFNN can identify correctly the occurring of serial arc faults.

Characteristics of serial arc fault on low voltage power line

There are typically two types of arc faults on low voltage power lines, parallel and serial. Parallel arc faults are similar to short circuit faults [14], and therefore can be detected easily. Serial arc faults, as shown in Fig. 1, might occur when there is discontinuity on the conductors of power lines. Electric power still can be delivered through the serial arc point, but nevertheless, the arc fault current carries non-linear, non-sinusoidal, and discontinuous characteristics [9]. Furthermore, the serial arc and the load are in series connection, and thus, the line current magnitude is reduced. So it is hard to detect the serial arc faults by the traditional overcurrent protection devices.

The characteristics of serial arc faults in time-domain and frequency-domain are investigated to develop the smart detection technology. Several characteristics of serial arc faults can be observed by the current waveforms of a line feeding a hairdryer or fluorescent lamps. It can be observed that

(a) When a serial arc fault occurs, the line current has a shoulder phenomenon [15]. It means that a flat wave is generated when the current is crossing zero ampere as shown in Fig. 2. Therefore, the shoulder appears every half power-cycle.
(b) Comparing Fig. 2 with Fig. 3, there is a jumping increasing rate of the current at the point just after the shoulder. The precipitous edge is from 10 μs to 100 μs, and the equivalent frequency components are between 2 and 5 kHz [14].
(c) The line current magnitude during a serial arc fault is smaller than that during normal operation [16], comparing the current waveforms in Figs. 2 and 3. It means that the serial arc has equivalent impedance, which will reduce current on the line.
(d) The serial arc cause unsymmetrical distortions [17]. It means that harmonic components will be produced during serial arc faults. Comparing the current waveforms of a power line feeding fluorescent lamps in Figs. 4 and 5, the harmonic characteristics are different.
(e) By observing Figs. 4 and 5, the line current waveform under serial arc faults has significant high frequency components. Thus, high frequency characteristics are suitable for detecting serial arc faults.

Analysis of signal energy by using wavelet transform

The characteristics of power line current waveforms are not periodical during serial arc fault conditions. There are shoulder phenomenon and precipitous rising edge in current waveforms when serial arc faults occur. Since the DWT is a good approach for time–frequency analysis and also suitable for multi-layer resolution, it is a powerful method for arc fault detection. It is also shown in [18] that the DWT is able to describe different degrees of distorted waveforms more accurately than the Fourier transform. The mother wavelet is Daubechies 10 in this study. From some illustrations [18,19], the Daubechies 10 is a suitable mother wavelet to analyze electric power signals. It is enough to separate the characteristics whether serial arc faults occur or not by using this type of DWT and signal energy.

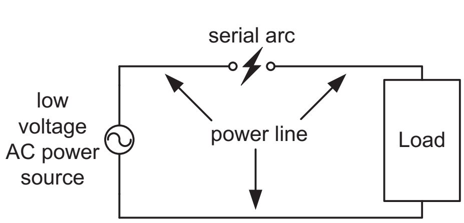

Fig. 1. Schematic diagram of a power line with serial arc faults.

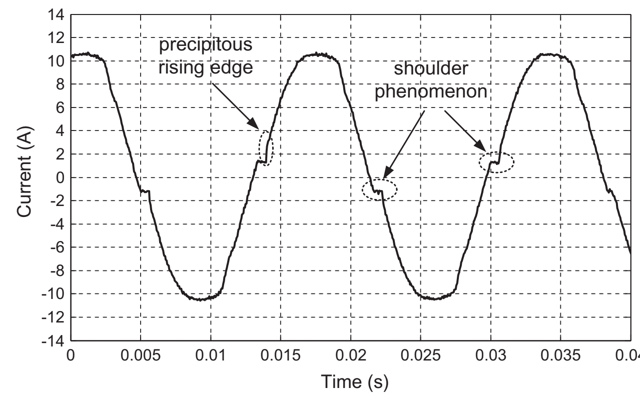

Fig. 2. Current waveform of a power line feeding a hairdryer under serial arc fault.

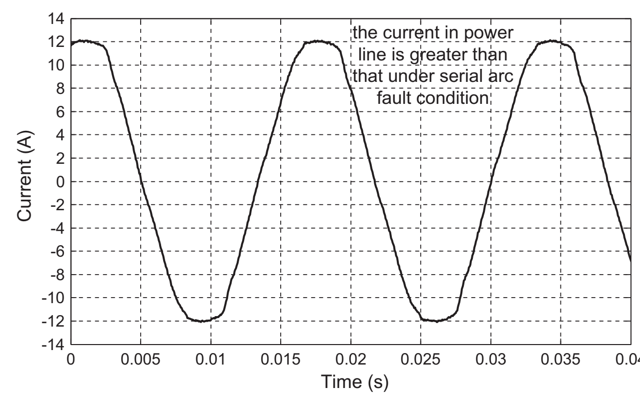

Fig. 3. Current waveform of a power line feeding a hairdryer under normal operation.

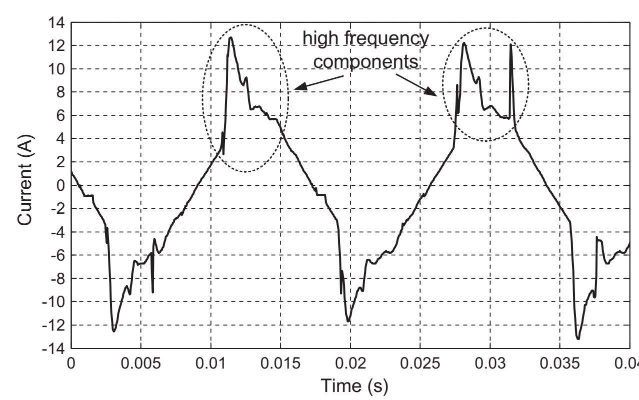

Fig. 4. Current waveform of a power line feeding fluorescent lamps under serial arc fault.