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Detection of serial arc fault on low-voltage indoor power lines by using radial basis function neural network

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ABSTRACT

Dangerous serial electric arc faults on low voltage power lines must be detected before fire hazards occur. The detection technology is requested to have high accuracy. However, the characteristics of line current waveform during serial arc faults are complicated. This paper uses the approach of a radial basis function neural network (DRBFNN) to identify the occurrence of serial arc faults. At first, the discrete wavelet transform (DWT) is employed to obtain the time–frequency domain characteristics of line current waveforms to reflect the serial arc fault patterns. Then some measured data are used to train the DRBFNN. Finally, this study compares the detection results under different loading conditions and operation conditions. It also compares the detection results with other two methods, detection of sub-spectrum energy (DSE) and high frequency detection by wavelet transform (HFDWT). It can be observed that DRBFNN has better ability than DSE and HFDWT to detect serial arc faults.

Introduction

According to U.S. fire departments report, more than 4700 home fires in 2007–2011 involving electrical failure or malfunction [1]. Wiring and related equipment occupied 63% home fires in 2007–2011, involving electrical distribution or lighting equipment [2]. Thus, it is important to detect dangerous faults on indoor power lines. Then the National Electrical Code (NEC), USA, required installation of arc fault circuit interrupters (AFCIs) on low voltage indoor power lines [3]. The AFCIs want to significantly mitigate the fire hazards caused by electric arc faults [4], where the serial arc faults occur more often than parallel arc faults [5]. However, serial arc faults are still hard to be detected by commercial AFCIs [6]. Fortunately, the intelligent detection technology would have better performance than commercial AFCIs [7].

There are many studies about arc fault detection [8–14]. The phenomenon of arc faults can be detected by comparing some characteristics of voltage or current waveforms in power lines with a threshold. For instances [8,9], the magnitude of voltage waveforms can be measured and the variation rate of current can be calculated. The distinctive data can be compared with threshold values to identify whether arc faults occur or not. In some studies [10–12], they extract the suitable frequency components from voltage or current waveforms in a power line and then compare the components with threshold values to detect arc faults. The signals of adaptive frequency bands can be extracted from current waveforms of power lines and the peak value can be compared with a threshold [10]. In [11], it utilizes the discrete wavelet transform (DWT) to analyze the waveforms, calculate the summation of the absolute values in sub-bands within one power cycle, and compare the summation with a threshold. The signal in appropriate frequency bands can be extracted from current waveforms and then the serial arc fault can be identified by comparing frequency-domain characteristics within 2–4 kHz with a threshold [12]. In [13], it discusses how to detect arc faults in switchgears and controlgears, whose key point is development of new advanced sensor technologies. In [14], it innovates a new algorithm to detect series arc faults by using current variations in a DC circuit. However, different home appliances have different characteristics and consume different electricity power. Thus, the threshold is difficult to determine. The RBFNN is more powerful for data classification and has faster learning rate than the back propagation neural network (BPNN) [15]. Thus, some studies [16,17] design smart systems by using radial basis function neural network (RBFNN).

This study uses the RBFNN to detect serial arc faults. It calculates the average total harmonic distortion (THD) of current waveform within 30 power cycles. If the average THD of current is higher than a given value, the RBFNN I is utilized, otherwise, the RBFNN II is employed. Each RBFNN utilizes the DWT and multi-resolution to analyze the frequency components of the current waveforms. The load characteristics can be reflected by the

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signal energy in different sub-bands. After the training process, RBFNNs can detect the serial arc faults correctly. From the test results under different loading conditions and operation conditions, the performance of detection by radial basis function neural network (DRBFNN) is better than detection of sub-spectrum energy (DSE) and high frequency detection by wavelet transform (HFDWT), where threshold values are used.

Characteristics of serial arc fault on low voltage power line

Arc faults on a low voltage power line can be divided into parallel and serial faults. Parallel arc faults are similar to short circuit faults, and high fault currents let them can be detected easily [5]. However, the current waveforms do not change dramatically between normal operations and serial arc fault conditions. Therefore, it is hard to detect serial arc faults by using the traditional protection devices. So only the detection of serial arc faults is investigated in this paper.

Electric power still can be delivered through the serial arc fault point. Nevertheless, the arc fault current carries non-linear, non-sinusoidal, and discontinuous characteristics [12]. In Fig. 1, the shape of the voltage across the fault gap in a low voltage power line is similar to a square waveform when serial arc faults occur. Usually the protection devices are installed at the power source. To detect the faults by using the data at the power source switch, this study employs characteristics of the power line current waveform which is measured at the power source terminal. The characteristics of serial arc fault in time domain and frequency domain should be well studied to develop the detection technology.

Characteristics of serial arc fault in time domain

When a serial arc fault occurs, the line current has a shoulder phenomenon [18]. It means that a flat waveform is generated when the current is crossing zero ampere as shown in Fig. 2. Therefore, the shoulder phenomenon appears every half power-cycle. This study focuses on the system whose power frequency is 60 Hz, so that, the shoulder phenomenon will appear every 8.33 ms when serial arc faults occur. The line current magnitude during serial arc fault condition is smaller than that during normal operation due to the voltage drop across the arc [18,19]. It means that the serial arc can be described as equivalent impedance which will reduce current on the power line.

Characteristics of serial arc fault in frequency domain

By observing Fig. 2, the current waveform has a jumping increasing rate just after a shoulder. The precipitous edge is from 10 μs to 100 μs, and the arc current spectrum is between 2 and 5 kHz [5]. The serial arc cause unsymmetrical distortion [20]. It means that harmonic components will be produced during serial arc faults. The line current waveform under a serial arc fault has significant high frequency components. Thus, the frequency domain characteristics are more suitable for identifying serial arc faults than time domain characteristics.

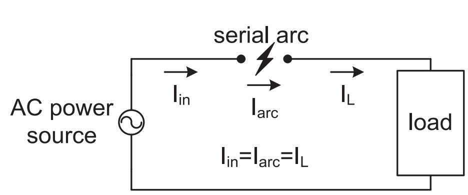

Fig. 1. Schematic diagram of low voltage power line with a serial arc fault.

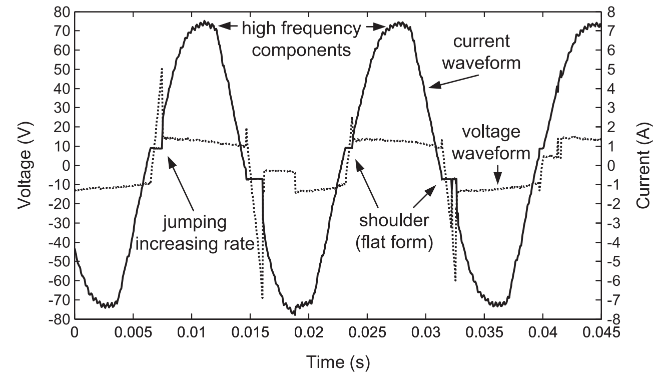

Fig. 2. Current and voltage waveforms of a power line feeding a vacuum cleaner and a parallel resistor under serial arc fault.

Wavelet transform

For different degrees of distorted waveforms, the DWT is more suitable than the Fourier transform to analyze them [21]. Furthermore, the Daubechies 10 of the mother wavelet can separate fundamental and harmonic components from electric power signals accurately [21,22]. Therefore, the mother wavelet is Daubechies 10 in this study. The wavelet transform converts a time domain signal into the time–frequency domain [23]. For a continuous signal $x(t)$, the wavelet transform is defined as

$$\psi_{a,b}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right) \quad a > 0,\ b \in R \tag{1}$$

where a and b are the time scale and time shift, respectively. The ψ is a wavelet function. The discrete wavelet function can be defined by using the dyadic grid-sampling method. Thus, the dyadic orthogonal wavelet function can be written as

$$\psi_{m,n}(t) = 2^{-m/2}\psi(2^{-m}t - n) \tag{2}$$

where m is the parameter about dilation and n is the parameter about position.

Wavelet analysis is a good tool to separate a signal into low- and high-frequency sub-signals. The multi-resolution can be used to realize a filter. As an example of multi-layer resolution in Fig. 3, the original signal c_0 is decomposed into two sub-bands, that is, the low- and high-frequency components, respectively, c_m and d_m

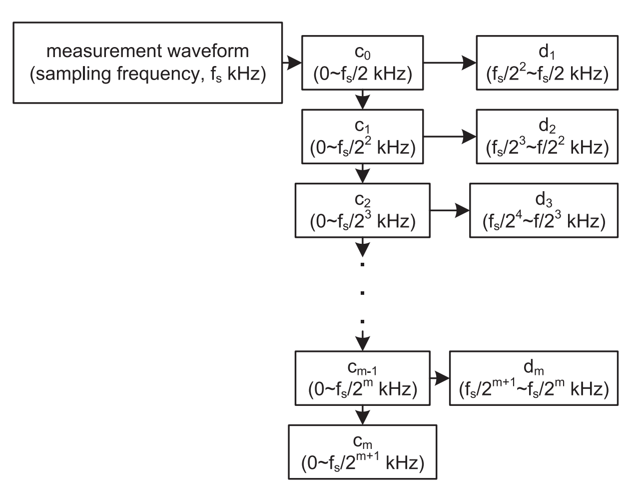

Fig. 3. Multi-layer resolution of a signal by using DWT.