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Detector of DC Series Arc Fault in a Large Photovoltaic System using Discrete Wavelet Transform

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Abstract

In this paper, the frequency analysis methods can detect the fire accident of the solar arc we propose Discrete Wavelet Transform (DWT). The DWT can express time-axis information even in the frequency domain. In case of DWT algorithm, it was implemented based on Arduino linked with MATLAM. The DC arc accident has been implemented using standard using Rogowski coil. This coil is used to simulate the current sensor for large-capacity PV system application. The constructing and simulated DC series arc generation circuit was verified under actual arc generation conditions. In addition, the performance of the accident detector manufactured was studied The experiment results and its simulation demonstrate, the proposed method is more efficient than others.

Keywords: large-capacity PV system, Discrete Wavelet Transform (DWT), DC arc accident, Rogowski coil

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1. Introduction

The DC arc accidents are a the mein reason for potential fire hazard in solar systems. The photovoltaic power generation system is implemented with many connectors and cables, and the parts are used for a long period of operation of the power generation system have reduced insulation strength and loosened wiring due to aging by sunlight and damage caused by cause arcing accidents [1], [2] and [3].

In order to prevent damage along life and property from fire accidents, the photovoltaic power generation system must detect and extinguish the occurrence of DC arc accidents and must satisfy the operation safety guidelines [4].

For effective DC series arc fault detection, a detection method different from the AC power generation system is required. In the case of an AC power generation system, the arc can be detected from the instantaneous information of the voltage or current when the arc occurs because the energized voltage and current have a constant cycle. However, in the case of a DC power generation system such as photovoltaic power generation, it is difficult to instantaneously analyze the arc generation because the energized voltage and current. In this paper, we design a DC series arc accident detector based on the MATLAB using digital signal processor (DSP) and the results has compared and analyzed with the fast Fourier transform (FFT) and discrete wavelet transform (DWT). We propose the methods of frequency analysis to analyze the physically accident arc and implement the detection.

2.The system characteristic of detection solar arc accident

The DC arc accident of photovoltaic system is simulated by designing and implementing the system as shown in Figure 1. The single-phase input power supply (V1) is rectified to generate a voltage of 220 V in the capacitor bank (C1), the current limiting resistor (R1) controls the conduction current when an arc occurs, and the turn-on and turn-off states are manually set. A simulated arc is generated using the regulated switch (SW1).

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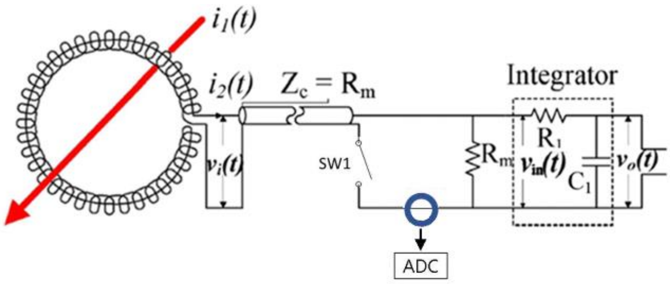

Fig. 1 Circuit of a photovoltaic DC series arc fault detection and block diagram of an arc fault detector

The DC series arc is measured as a high-frequency component in the conduction current, and the arc fault detector receives the arc information of the conduction current through the Rogowski coil. The high frequency component of the input DC series arc current is subjected to analog to digital conversion (ADC) of 16 bit, 238 kHz and analyzed by FFT or DWT to help determine the occurrence of an arc accident. If it is determined that an arc accident has occurred, the LED blinks to visually notify the user of the arc occurrence. The picture of the implemented system is shown in Fig. 2, and the measured waveform of 220 V A DC series arc accident occurrence is shown in Fig. 3.

Fig. 2 Picture of a photovoltaic system D C series arc fault and fire damage

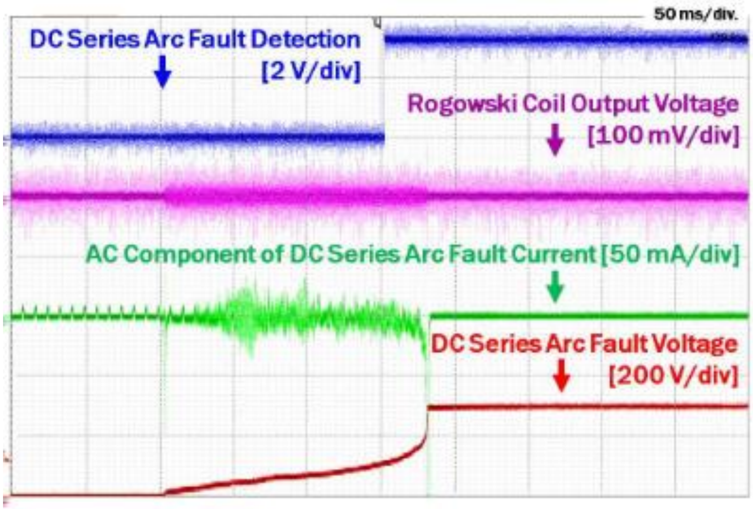

Fig. 3 Experimental waveform of a photovoltaic DC series arc fault detection

As SW1 is turned off, a DC series arc occurs and the DC series arc fault voltage in Figure 3 rises gradually. At the same time, the DC series arc fault current starts to decrease from 4.2A to 0A, and if you look at the AC component of the measured current, it can be seen that a high-frequency current component is generated according to the arc generation. The generated frequency component is inserted into the DSP calculation through the Gosky coil, the frequency analysis result is used to judge the DC series arc accident.

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2.1 Fast Fourier Transform

Analysis of applied frequency characteristics The DC series arc fault current in the ADC time domain is converted to the frequency domain according to Equation (1) [5], and the result is shown in Figure 4.

$$X(k) = \sum_{n=0}^{N-1} x(n) e^{-j\frac{2\pi}{N}nk} \quad (1)$$

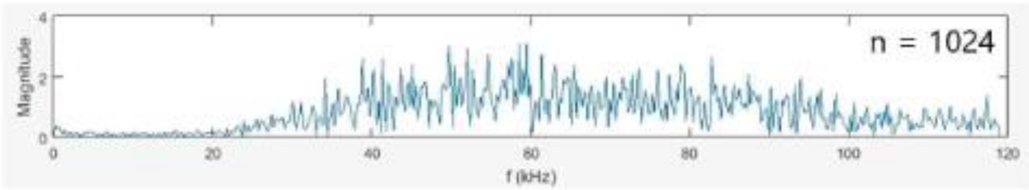

Fig. 4 FFT result of a photovoltaic DC series arc fault detection

X(k) is the frequency domain, x(n) is the time domain, and N is the number of samples in ADC. As a result of FFT analysis, the magnitude of the frequency component is 0-20 kHz, and the magnitude of the sampling frequency component is 30-100 kHz. Therefore, in the case of FFT, if a frequency component of 30 kHz or higher exists, it can be judged that a DC series arc accident has occurred, but the performance of the arc accident detector greatly depends on the set or not set for standard values of arc accident occurs.

In an actual photovoltaic system, switching noise of boost converter according to MPPT algorithm and switching noise of inverter for grid connection exists. There is a switching frequency of less than 50 kHz. Generally, the characteristics of the photovoltaic system and its device converters depend on the power generation capacity.

As a result, the frequency ranges of the DC series arc accident and the operating switching noise range. The photovoltaic systems need an overlap technology to distinguish the DC series arc accident.

2.2 Discrete Wavelet Transform

In principle, the wavelet transform analyzes the input signal by contracting, expanding, and translating the basis function. The Applied frequency characteristic analysis and wavelet continuous wavelet transform is expressed as follows:

$$\Upsilon(s,\tau) = \int f(t) \cup_{s,\tau}^{*}(t)dt \quad (2)$$

f(t) is the input signal, Ψ(t) is the basis function or wavelet function, and Ψ(t)* is the complex conjugate of the basis function. Since the actual implementation of wavelet transform uses a sampled signal rather than a continuous signal, then the DWT discrete wavelet transform can be achieved. Therefore, the basis function is expressed as the following equation.

$$\bigcup_{j,k}(t) = \frac{1}{\sqrt{a^j}} \bigcup\left(\frac{t-kb}{a^j}\right) \quad (3)$$

j is the stand of scales and k is the translation. Generally, they are performed for a = 2 and b = 1, where j contracts and expands the basis function and k moves the basis function [6].

DWT expresses the frequency component of the input signal similarly to FFT, but in the case of FFT, the input signal is expressed as the sum of the sine functions of countless frequencies, and in the case of DWT, the input signal is expressed not as a sine function but as a base function of various shapes. Representative base functions used in DWT include Haar and Daubechies. In this paper, the DC series arc accident signal was analyzed using Daubechies [7] as a basis function, and the result is shown in Figure 5.

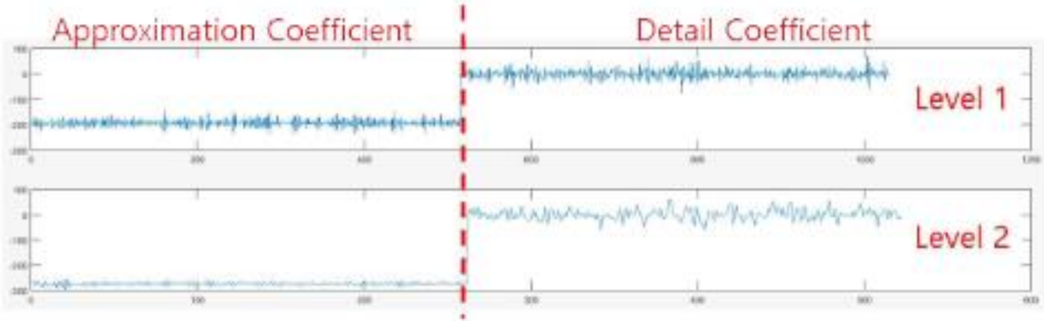

Fig.5 DWT result of a photovoltaic DC series arc fault detection

The input signal goes through DWT to get the result of approximation coefficient and detail coefficient. The detail coefficient of level 1 shows the frequency characteristics of 59 kHz to 119 kHz for the DC series arc fault signal that is the input signal, and the detail coefficient of level 2 shows the frequency characteristics of 29 kHz to 59 kHz. Therefore, the frequency domain FFT analysis of DC series arc accident identically was detected and utilized. Furthermore, in order to minimize false detection, it is designed and implemented so that it can be adjusted according to the switching noise of the power generation system in which the arc generation reference voltage is installed. By this process (Discrete Wavelet Transform), the DC series arc accident detector can be developed.

3. Modified for solar serial arc accident detection

The DC series arc accident detection process can be summarized as follows: after FFT or DWT is performed, the frequency information of the measured arc accident can be detected as an arc accident if the size of the frequency range of 30kHz to 100kHz exceeds the arc accident judgment standard value. Among them, the DWT was designed and implemented as a multiresolution analysis method, and the DWT algorithm was modified to detect a large-scale solar light series arc accident with the method shown in Figure 6, reducing the existing execution time of 42ms to 13ms by about 70%. If the ADC result obtains N input signal samples (square root of N = 2), the DWT conversion of level 1 requires 4N multiplications and N additions to be performed. Furthermore, if the DWT transformation of multiresolution analysis is performed up to the last level, it takes about 8N multiplication operations.

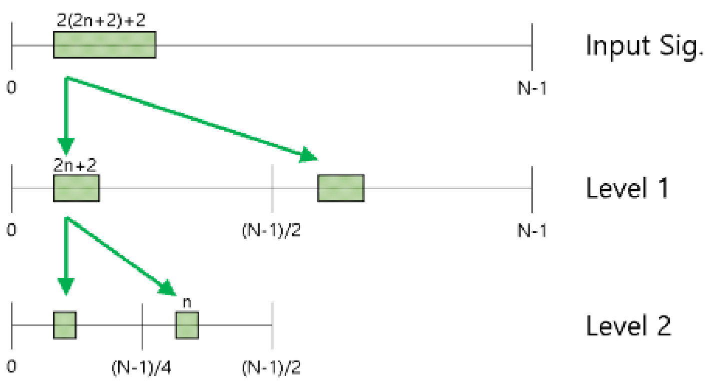

Fig.6 Modified DWT algorithm operation diagram

However, since solar DC serial arc accident detection requires only the detail coefficient of a specific frequency domain, frequency information for arc accident detection can be calculated without performing DWT on all samples of the input signal. This is an applicable method and is different from the FFT operation process because the DWT result expresses frequency information and time information at the same time. For example, if the 29kHz~59kHz detail coefficient frequency characteristic of Level 2 is used to determine the presence or absence of a DC series arc accident, the DWT result is expressed as a time axis. It is possible to judge whether an arc accident has occurred only with the number of n samples. To calculate the number of n samples in the detail coefficient of level 2, the number of samples required for level 1 and input signal is 2n+2 and 2(2n+2)+2, respectively, as shown in Figure 6. As a result, instead of performing DWT on N input signals, only 4n+6 of input signals are DWT performed, effectively shortening the DWT operation time. The smaller the number of n samples of level 2 for arc accident determination, the shorter the DWT calculation time, but there is a trade-off relationship with the accuracy of the arc accident determination, and it has been confirmed experimentally that the arc accident determination is implemented with 16 level 2 detail coefficients.

Conclusion

This paper presents an algorithm that shortens the calculation time of the discrete wavelet transform (DWT) frequency analysis method applied to a large-capacity solar DC serial arc accident detector. In the case of the frequency analysis method, the frequency components of the DC series arc measured by implementing the widely used FFT method and the newly applied and researched DWT method respectively were analyzed and compared. As a result, both frequency analysis methods confirmed that the frequency component of 30 kHz to 100 kHz was observed when a DC series arc accident occurred, and it was possible to determine whether an arc accident occurred by analyzing the frequency range of the measured area. Furthermore, in addition to confirming arc accident detection, when the DWT algorithm determines whether a DC serial arc accident occurs, the DWT algorithm that selectively considers the level and number of samples without performing DWT on all ADC samples is proposed to reduce the frequency analysis operation time from 42ms to 13ms. effectively shortened

Conflict of interest

The author declares that the publishing of this article does not include any conflicts of interest. Furthermore, the author has strictly adhered to ethical problems such as plagiarism, informed consent, misconduct, data fabrication and falsification, multiple publishing and submission, and redundancy.

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