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Study on the Feature Space Detection Method of DC Arc Fault for Photovoltaic system

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Abstract. An arc fault on the DC side of the photovoltaic system is a potential safety hazard and is difficult to detect due to the complexity of photovoltaic systems. The detection method of series arc fault in photovoltaic systems is investigated here. The DC arc fault test platform for a photovoltaic system is established to collect the current signal under normal and fault conditions. In this study, the time domain characteristics, frequency domain characteristics, and time-frequency domain characteristics are compared by analysing the current data from the photovoltaic system in before and after fault states: corresponding feature vectors are used to construct the arc fault feature space of the system, and according to the position of the current signal in the feature space the fault is detected, so as to realise effective arc fault feature information. Then the method of establishing the arc fault feature space is introduced and key parameters of the feature space are determined. Finally, the anti-interference ability of arc fault feature space detection is verified. The results showed that the detection method is both feasible and accurate.

1Introduction

In recent years, issues such as the global energy crisis and climate warming have become increasingly prominent. Solar power generation systems have developed rapidly because of their green, clean, and renewable nature. With the increasing size of photovoltaic power generation system and the long-term operation of most photovoltaic equipment, the DC arc fault problem of PV systems becomes more serious [1]. In a DC system, the occurrence of arc faults may be caused by aging or broken insulation of the line, loose metal joints, open circuit or grounding of the line and other faults [2]: because the DC fault arc current does not have zero-crossing, it is more difficult to extinguish than an AC fault arc, and the unique volt-ampere characteristics of the PV system provide conditions for the stable combustion of the fault arc [3]. The stable combustion of an electric arc can generate temperatures as high as thousands of degrees. If the arc cannot be detected and effectively eliminated in an accurate and timeous manner, it may lead to a severe fire [4], therefore, the national electrical code of the United States has established the photovoltaic arc fault circuit protection standard UL1699B, which stipulates that, when the DC bus voltage of the PV system on buildings is greater than 80 V, an arc fault detection device and circuit breaker must be installed [5].

In photovoltaic power generation systems, DC arc faults can be classified into the following categories based on the location of the arc, as shown in Figure. 1: a series arc fault is mainly caused by poor contact between the photovoltaic panels, between the photovoltaic panels and the guide frame, between the junction box and the wiring, and the damaged connection line [6]. In addition, parallel arc faults are caused by a short circuit of positive and negative conductors due to line breaks. Grounding arc faults between damaged lines and ground are generally classified as parallel arc faults. When an arc fault occurs in a PV system, the parallel arc fault usually leads to an increase in system current amplitude, which then reaches the action threshold of the low-voltage circuit breaker and is easily detected by the protective device [7]. In contrast, when a series arc fault occurs in the system, the fault current is small and difficult to detect.

Here, a PV system arc fault test platform is established for data acquisition, and the original current signal is converted by wavelet transform to remove noise. Then, for the fault current, using statistical methods for time domain feature extraction, using Fast Fourier Transformation (FFT) for frequency domain feature extraction and using Ensemble Empirical Mode Decomposition (EEMD) for time- frequency domain feature extraction, and the corresponding feature vectors and criteria of the three are obtained. Finally, based on the feature vectors in the time, frequency, and time-frequency domains, the three-dimensional fault arc feature space is constructed to realise detection of DC series arc fault in a PV system. The accuracy of the proposed method is verified through experimental analysis.

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2EXPERIMENTAL

2.1The Influence of Different Environmental Factors on Arc Fault Detection

The operation of PV generation system is mainly affected by sunshine intensity and environmental temperature, but sunshine intensity is affected by geographical and meteorological factors with great uncertainty, which is difficult to predict. In this paper, the current signals of the PV system under normal state and arc fault state are collected and analysed every half hour during the day. The data collection time is from 07:00 to 18:00. The weather conditions are cloudy and sunny, and the ambient temperature is 15~24°C, light disappears by 17:00, and the result is shown in Figure 1. In this paper. From the single-day voltage variation curve of the PV system in the figure, the environmental factors have a great influence on the DC voltage of the PV system. Theoretically, the single-day voltage range of the PV system should vary from zero to the rated operating voltage, so it is necessary to consider the effect of voltage changes on arc fault detection. From the test data, 15 sets of data with voltages of 50~170V were selected to investigate the effects of different voltages on arc fault detection.

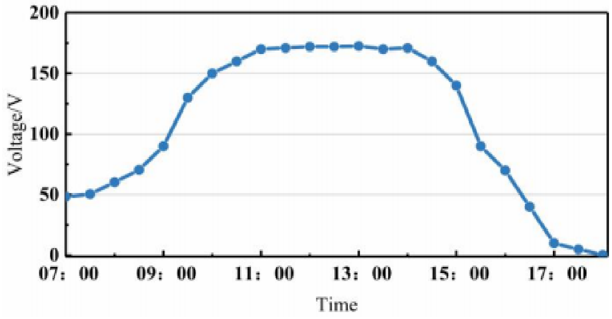
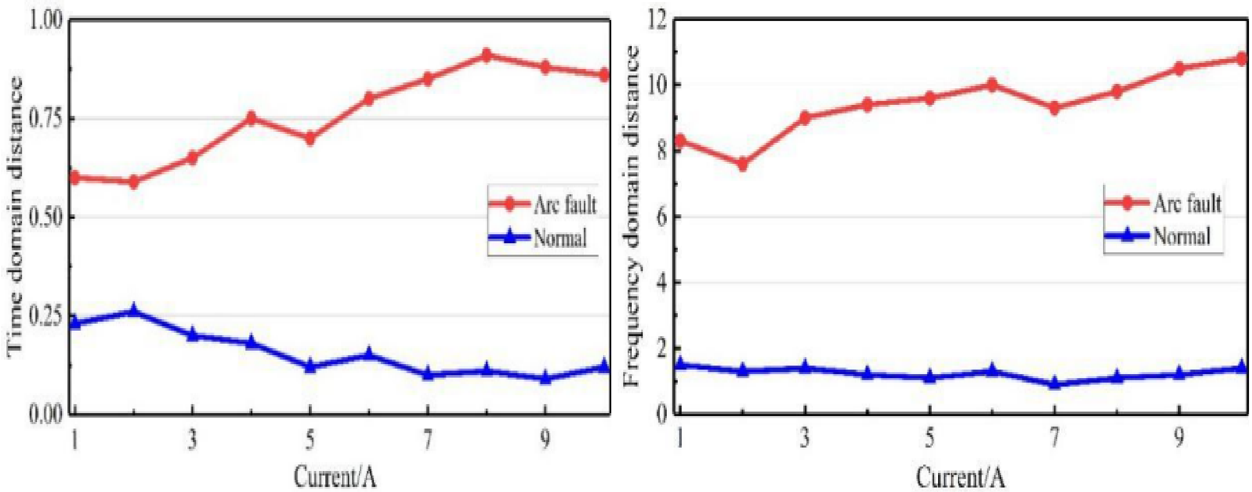
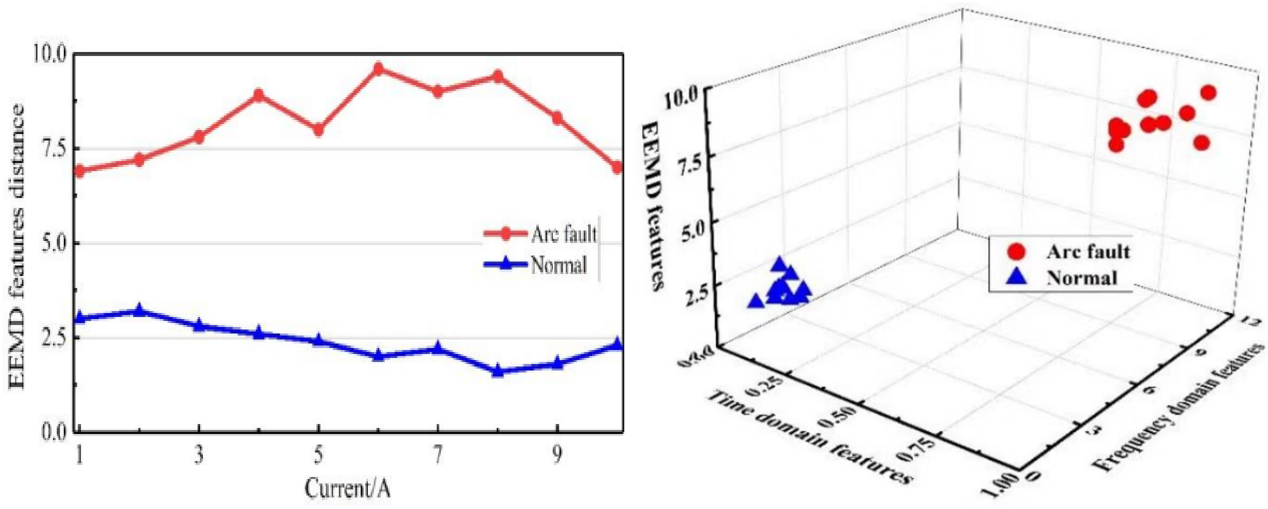


Figure 1 Single-day PV system voltage curve

The time domain characteristic distance, the frequency domain characteristic distance and the EEMD-based time-frequency domain characteristic distance comparison under normal state and arc fault state under different voltages are shown in Figure 2(a)、(b)、(c). It can be seen from the figure that the time domain characteristics distance, the frequency domain characteristics distance and the EEMD time-frequency domain characteristics distance value in the normal state are small and relatively stable, and are distinct from the fault state. The arc fault feature space has a good distinction between the two states, so different environmental factors have no effect on the arc fault detection method proposed in this paper. As shown in Figure 2(d), the arc fault feature space offers good distinction between the two states, so different environmental factors have no effect on the proposed arc fault detection method.



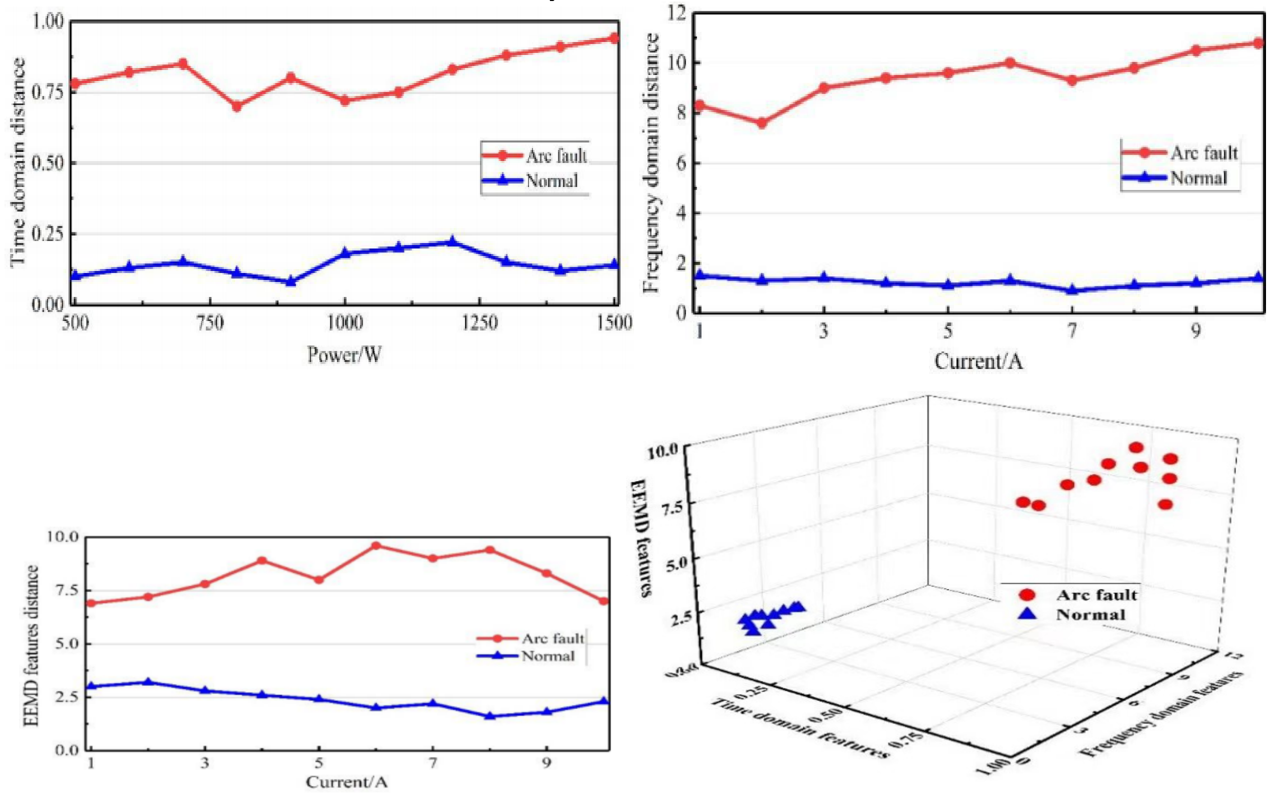


(a) Time domain characteristics distance comparison; (b) Frequency domain characteristics distance comparison (c) Time-frequency characteristics feature distance comparison; (d) The results of arc recognition under different environmental factors

Figure 2 Comparison of normal and arc characteristics at different voltages

2.2The Influence of Different Load Currents on Arc Fault Detection

The amplitude of the output current of the PV system fluctuates greatly with the operating state, so it is necessary to study the effect of the arc fault detection method on the arc fault identification of the PV system under different current levels. In the test, the PV system is kept running at the rated output voltage, and the load current is changed by changing the resistance of the load in the system. Finally, 10 groups of test data of system current from 1A~10A normal state and arc state were selected for analysis.



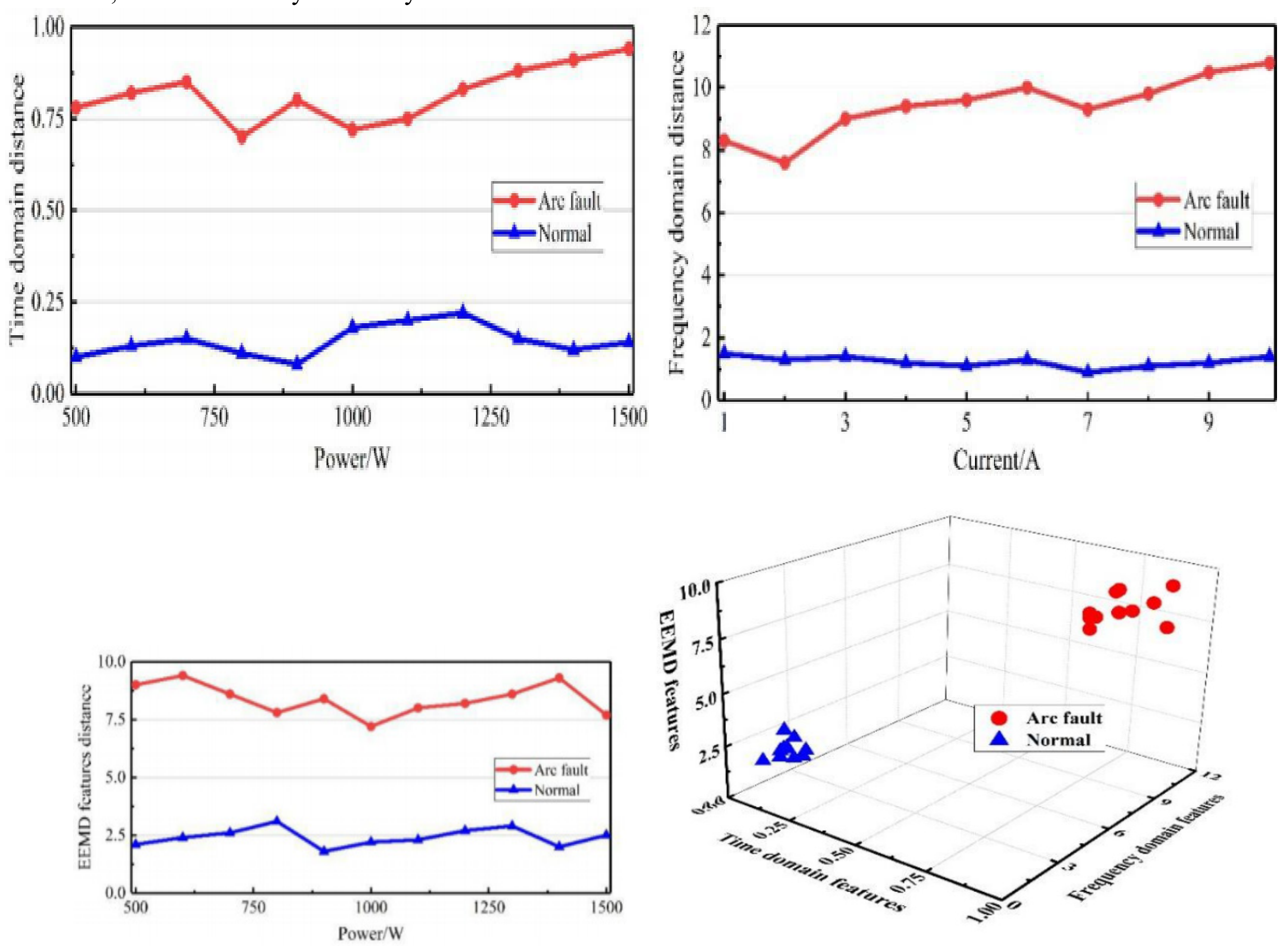
(a) Time domain characteristics distance comparison;(b) Frequency domain characteristics distance comparison; (c) Time-frequency characteristics feature distance comparison;(d) The results of arc recognition under different load currents

Figure 3. Comparison of normal and arc characteristics under different load currents

The time domain characteristics distance, the frequency domain characteristics distance, and the EEMD-based time-frequency domain characteristics distance comparison curve are shown in Figure 3(a), (b), (c). The results of arc recognition under different load currents is shown in Figure 3(d). It can be seen from Figure 3(a), (b), (c). that the time domain characteristics distance, the frequency domain characteristics distance and the EEMD time-frequency domain characteristics distance in the fault state are clearly distinguished from the normal state, and the two states are in the corresponding range in the feature space, so different load currents have no effect on fault detection.

2.3The Influence of Different Output Power on Arc Fault Detection

Due to the different capacity, grid-connected mode and control algorithm of the PV system, the operating state and output power of the system will also change. Therefore, it is necessary to study the influence of different output power on fault arc detection. In this paper, the current data of the normal and arc states of the PV system under different output powers are obtained by changing the light intensity of the PV system and the number of PV panels in the PV array. The time domain, the frequency domain and the EEMD time-frequency domain characteristics quantity extraction of the collected current signal are obtained to obtain the feature distance in the corresponding direction as shown in Figure 4(a), (b), (c). The comparison shows that the time domain characteristic distance, the frequency domain characteristic distance and the EEMD time frequency domain characteristic distance are very different from the normal state in the arc fault state, which indicates that the arc fault identification method in this paper is not affected by the output power of the PV system.



(a) Time domain characteristics distance comparison;(b) Frequency domain characteristics distance comparison;(c) Time-frequency characteristics feature distance comparison ;(d) Analysis of interference characteristics of inverter and local shadow

Figure 4. Comparison of normal and arc characteristics at different powers

The comparison shows that the time domain characteristic distance, the frequency domain characteristic distance and the EEMD time frequency domain characteristic distance are very different from the normal state in the arc fault state, which indicates that the arc fault identification method is not affected by the output power of the PV system (Figure 4(d)).

2.4 The influence of Inverter Interference and Shadow Occlusion on Arc Fault Detection

In the actual operation process, the PV system is often disturbed by the internal inverter and the external environment, which causes a large disturbance of the current, which may cause the time-frequency domain characteristics of the current signal under interference and the time-frequency under the fault state. The domain characteristics are confusing, leading to false positives in arc fault detection, so it is necessary to investigate whether the detection of arc faults under these disturbances is still accurate. The test collects the current signal of the two kinds of interference states during the transient adjustment of the inverter and the partial shadow of the PV panel. In each state, 15 sets of data are collected for analysis and obtained in the characteristic arc fault feature space. The distribution results are shown in Figure 5. It can be seen from the figure that the current data in the two special states does not overlap with the arc fault area, thereby causing mis-judgment. Therefore, in the case of PV system interference and partial shadow occlusion, the arc fault detection method proposed in this paper will be divided into non-fault areas and will not receive interference.

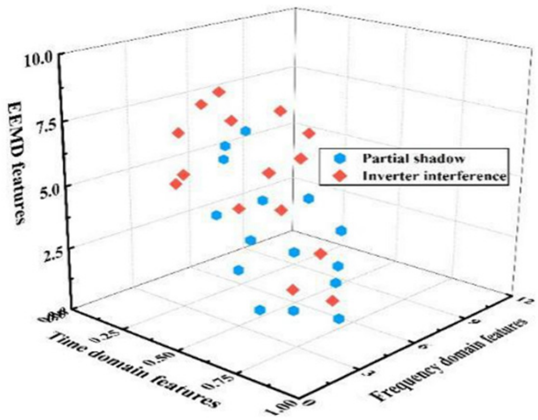


Figure 5. Analysis of interference characteristics of inverter and partial shadow

3 Conclusion

Considering that a DC arc fault in a PV system is extremely harmful and difficult to detect, we propose a DC series arc fault detection method applicable to a PV system. Firstly, an arc fault experimental platform of the PV system is built to compare and analyse the time domain characteristics, frequency domain characteristics, and time-frequency domain characteristics from EEMD of the current data under normal and arc fault states in a PV system, and extract the characteristic values that can be used to detect DC arc faults. Then, based on the corresponding feature vectors constructed in the time domain, frequency domain, and EEMD time-frequency domain, a multi-dimensional complementary arc fault feature space is proposed to detect arc faults in PV systems. Herein, the arc fault feature space is divided into three parts: a normal area, interference area, and fault area, and a criterion with high reference value is proposed. Finally, a series of tests on a PV system under different operating conditions and external environmental factors verify that the detection method has good anti-interference performance, which is of great significance for the development of arc fault detection devices for use on PV systems.

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