

# A REVIEW ON DETECTION OF ARC FAULT AND FLASH SIGNAL FOR DC DISTRIBUTION SYSTEMS

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**Abstract:** Arc faults have forever been a priority for electrical systems, as they will cause fires, personnel shock hazard, and system failure. For a modern power system, selective high speed clearance of arc faults on DC distribution system is essential and this review indicates the efficient and promising analysis of Arc Fault and Flash Signals in DC Distribution Systems. The different control strategies of Arc Fault and Flash Signal Analysis in DC Distribution Systems are discussed in this paper. The paper prefers use of wavelet transform (WT) which provides a time and frequency approach to investigate target signals with multiple resolutions.

**Index Term:** Arc Fault Analysis, Arc Flash, Dc Distribution, Signal Processing, Wavelet Transform.

## I. INTRODUCTION

Number of electrical conductors and long wires are runs in dc electricity distribution system and dc microgrids. The combination of high dc voltage and degradation of wire insulation causes electric arc. The electric insulation deteriorated due to ageing or different circumstances such as eutherian bites and erosion because of chaffing with trees, building walls or pipes throughout installation. This dc arc might leads to fires, shock hazard, and failure of system or fault in dc distribution system.

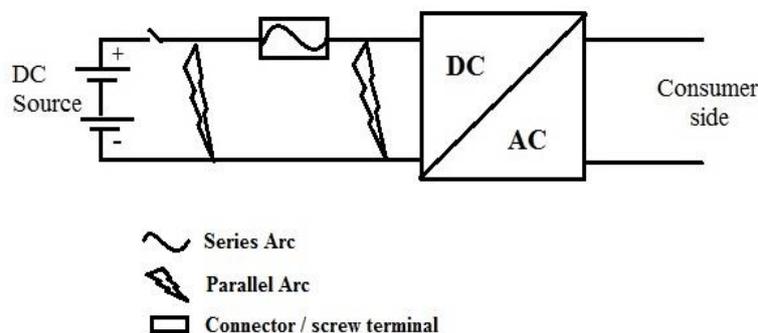


Fig. 1. Example of locations where dc arcing may occur in a distribution system.

Fig. 1 shows that, arc faults are generally divided into two types i.e. series and parallel arc faults. Series arc faults usually occur because of loose electrical connections, breakdown of connectors and parallel faults causes due to erosion of conductors, puncture of the insulation by eutherian bites or when arc established between conductors at different potential.[1],[2] Arc faults can occur in small-scale at residential systems, in large-scale at distribution systems and may pose vital threats to human safety[3].

As long as this drawback exists, dc distribution systems face vital considerations regarding liabilities which threaten their extensive used. Thus, arc fault detection is very important for reliable and safe system operation of grid [4]-[6] and it is imperative for comprehensive adoption of dc microgrid systems[7]-[10]. It is essential to discover arc flash, the pre-fault condition of sparking and dielectric breakdown. The arc flash serve as an early indicator of arc fault and it may last for short duration (less than second). Detecting arc flash is difficult problem[10]. The arc flash involves short-term current flowing through ionizing air or along an ion path and may unable to draw moderately high root-mean-square current or have a high enough  $I^2t$  energy to trip a thermal circuit breaker. This is often significantly true in finite-energy sources, such as several of the dc microgrids and systems energized by renewable energy sources. In these cases, an arc, like the one shown in Fig. 2, may be sustained for hours or even days as a result of the overcurrent protection devices never activated[11].



Fig. 2. Arcing persists at the combiner box <sup>[1]</sup>

Hence, the fire and adverse security remains undetected and unmitigated. In contrast to an ac system within which power electronics are generally found only at the point-of-load, a dc system needs the utilization of dc/dc converters throughout the distribution system, which adds distributed capacitance throughout the system providing various coupling pathways for high-frequency signals. High-frequency noise from the dc/dc converter switching and different electromagnetic interference may alter the arc signature, allowing an arc sustained undetected. In this paper various commercial and advanced techniques are discussed to analysis the arc fault and arc flash signal analysis in DC distribution system. The work in this paper prefers use of wavelet transform (WT) which provides a time and frequency approach to investigate target signals with multiple resolutions.

## II. EXISTING COMMERCIAL METHOD

### 2.1. Arc Fault Circuit Interrupter (AFCI):

Currently there are commercial products available and even used in some applications for ac arc detection in residential ac systems. Known as combination arc fault circuit interrupters (AFCIs), these are used to detect both series and parallel arc faults[11]. AFCIs includes a neutral conductor, separable contact, an operating mechanism arranged for opening and closing separable contact, one current sensor governed to sense current flowing through separable contact and output of sensed current value and a processor.

The processor used is digital signal processor (DSP) or microprocessor. The processor included three regular arrangements: a first arrangement dispensed parallel arc fault detection, a second arrangement dispensed series arc fault detection, and third arrangement is to enable first arrangement and disable second arrangement for preset time when the sensed current value is greater than preset value and to enable second arrangement and disable first arrangement for preset time when the sensed current value is less than preset value. An AFCI is a device deliberated to relieve the effect of arc fault by functioning to de-energize an electrical circuit when an arc fault is detected[11]-[13]. But some research has shown that neither branch/feeder AFCI nor combination AFCI would accurately detect all series arc faults [14]. This might be occurring due to how the threshold detection algorithm was calibrated and the assumptions made in the filter as to the frequencies in which the arc signature signal appears.

### 2.2. Short time Fourier transform (STFT):

Another commercial approach to detect arc fault in PV dc system is Fast Fourier Transform (FFT). Even though the conventional Fourier transform is deeply analyzed and significantly used, the actual fact that it works best for periodic signals is vital limitation. The nature of arc faults in power systems are not periodic. The traditional fourier transform only gives frequency information, not enough time-domain information is provided to precisely verify the fault occurring time and location[15][16].

The short-time Fourier transform (STFT) is a Fourier- related transform used to confirm the sinusoidal frequency and phase content of local sections of a signal because it changes over time[17]. This transform still includes a basic downside in that, the length of the window utilized in the STFT is the same for all frequencies which results in a fixed resolution. The window length selection then becomes a trade-off between sensible frequency resolution and time resolution. A large number of samples are needed to get high-frequency resolution, which successively causes low-time localization. A shorter window provides better time localization however low frequency resolution. It also indicates the value for minimization of the spectral leakage within the system, it is necessary to decide on the window size to satisfy the coherent sampling requirement. However, the arc fault signature is distributed during a wide frequency band. Actually, it is not possible to decide on a perfect window to accurately extract all the relevant information using Fourier transform based methods[11].The discrete short time Fourier transform (STFT) is employed for time frequency analysis of non-stationary signal. It deteriorate the time varying signals into time frequency domain component, hence it supplies an insight in time evolution of each signal component[18]. The discrete STFT may be appropriate for time frequency domain analysis of harmonic related disturbances, however it is not ideal for capturing abrupt disturbances or short transient signals.

### III. WAVELET TRANSFORMATION (WT) BASED TECHNIQUE FOR FAULT ANALYSIS

Wavelets are functions that satisfy certain requirements. The wavelet transform (WT) is a linear transformation similar to the Fourier transform, but not as FFT. The basic function of Fourier transform are localized in frequency but not in time while wavelet transform are localized for both frequency and time [19]-[22]. There are number of applications of WT as various type of signals and problems occur in power system engineering, such as power system measurement, fault detection, load forecasting. Also it gives relevant information about power system transient which results from variety of disturbances on transmission line such as lightning stroke, switching [20]. This requires the use of various analysis methods for handling number of signals in terms of their time-frequency localization, in which wavelet transformation method is used [21].

The wavelet analysis procedure is based on a wavelet prototype function called a —mother wavelet, that provides a localized signal processing method to decompose the differential signal into a series of wavelet components, each of which is a time-domain signal that covers a specific frequency band [22],[23]. Wavelets are particularly effective in approximating functions with discontinuous or sharp changes like power system fault signals. For better feature extraction and signal analysis, proper choice of mother wavelet is important.

The continuous wavelet transform  $F_{CWT}(a,b)$  of signal  $x(t)$  is defined as

$$F_{CWT}(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} x(t) \cdot \psi\left(\frac{t-b}{a}\right) dt$$

Where,  $\Psi$ - wavelet function,  $a$ - Scale factor,  $b$ - shift factor

The application of wavelet transform for power system mainly used discrete wavelet transform (DWT). The representation of DWT of discrete signal  $x(n)$  is expressed as

$$F_{DWT}(m,k) = \frac{1}{\sqrt{a_0^m}} \sum_n x(n) \cdot \psi\left(\frac{k - nb_0 a_0^m}{a_0^m}\right)$$

Where  $a_0^m$  is scale factor and  $nb_0 a_0^m$  is shift parameter.

A special case of transform occurs when  $a_0 = 2$  and  $b_0 = 1$  which is called a dyadic transform. After that DWT can be implemented by multiresolution analysis (MRA) by using multistage digital filter as shown in figure 3. The filter output then decomposes the signal to low-frequency component called approximation signal  $A(n)$  and high-frequency component called detail signal  $D(n)$  [24] where  $n$  is total number of sample.

Multiresolution signal analysis using DWT is enforced by filter banks where a wavelet and a scaling function are related to a high-pass and a low-pass filter, respectively. With dyadic wavelet filters (WT), the low-frequency half is more decomposed as compared to binary-tree wavelet filters (wavelet packets), which split each low-frequency and high-frequency elements on each level, resulting in decomposed signals with an equal bandwidth. In this paper, only two wavelet filter implementation is discussed [25][26].

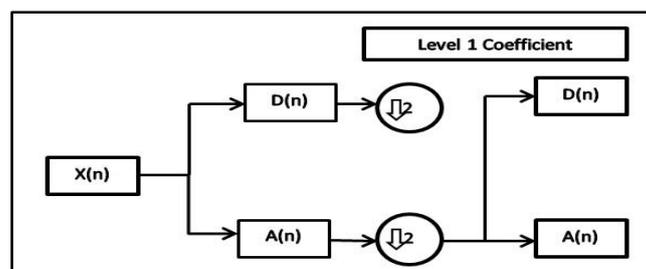


Fig. 3 Signal Decomposition stage for approximation and detail coefficient of DWT

There are several well-known families of orthogonal wavelets like - Harr, Meyer family, Daubechies family, Coiflet family, and Symmlet family [27]. Daubechies wavelets are chosen in reviewed paper due to their outstanding performance in detecting waveform discontinuities [27],[28]. The frequency responses of filter banks of Daubechies 9 (db9), and Daubechies 19 (db19) are shown in Fig. 4 and Fig.5. It can be seen that the frequency response of db19 does not provide equally significant improvement

over db9. Considering the extra computational load brought on by wavelets with more coefficients, db9 presents a good compromise.

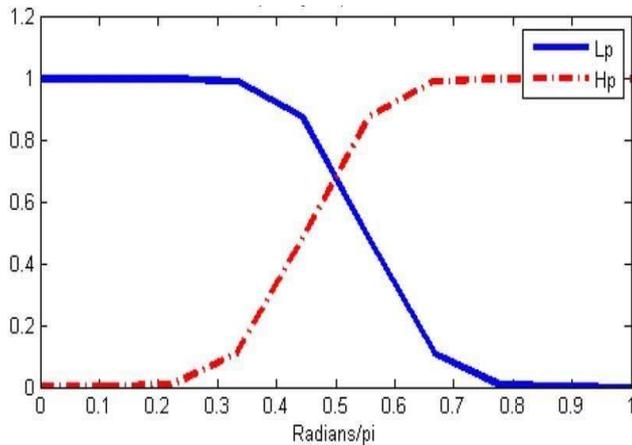


Fig. 4. Frequency response of db9<sup>[11]</sup>

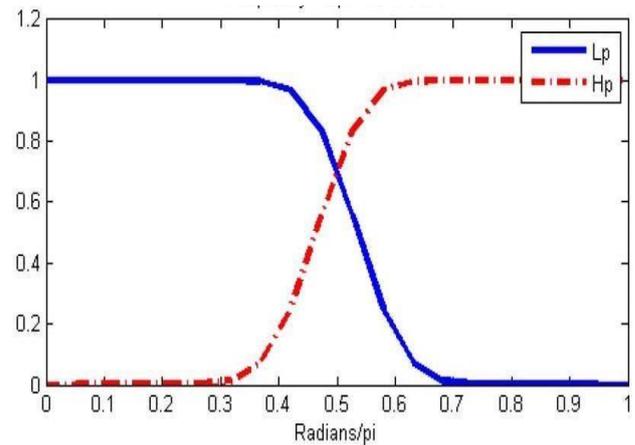


Fig.5. Frequency response of db19<sup>[11]</sup>

Since the goal of wavelet analysis is to separate the arc fault signal from converter noise (which resides in specific frequency bands) and different electrical disturbances (which sometimes occur vary slowly), a narrower transition frequency region results in less information into different decomposition levels and an additional accurate signal approximation. From this literature review we observed that it is possible to detect arc faults effectively by using WT especially when it comes to the practical problem of threshold setting for arc fault determination. However, when using wavelet transformation, the arc signature is significantly distinguished from the non- arcing signal and is easy to be detected when the detection method is embedded in a microcontroller unit for real-time arc fault detection. Furthermore, since the WT preserves the time- domain localization information, the precise time of the arc is available for cross-correlation with other system events to improve the accuracy of arc fault detection.

#### IV. FEATURE EXTRACTION USING WAVELET TRANSFORM

The approximation and detail coefficient obtained from wavelet multiresolution analysis (MRA) should not directly used as classifier input[30]. The feature extraction process includes the reduction of resources required to represents a large set of data. The large amount of memory and computation power used for analysis of large number of variables and it also causes classification algorithm to over-fit to training samples. The real time classification algorithm is much easier due to an ideal feature extraction. As we studied previously that wavelet transform is effective in approximating function with discontinuities and extracting sharp changes in power system that are fault signals, with the help of proper choice of mother wavelet it becomes good tool for feature extraction and signal analysis.

Typical feature of our fault signal involves voltage signal, current signal, dc voltage level, dc current level, conductor temperature, frequency spectrum, energy etc. Parseval's theory is applied for feature extraction of arc fault detection. Parseval's theorem, states that if the used wavelets form an orthonormal basis and satisfy the admissibility condition, then the energy of the original signal is equal to the energy in each of the expansion coefficients[29].

$$E_{signal} = \sum_{k=-\infty}^{\infty} |c_j(k)|^2 + \sum_{j=1}^{\infty} \sum_{k=-\infty}^{\infty} |d_j(k)|^2$$

Where, j is scale, k is time, c is approximation coefficient and d is detail coefficient form j<sup>th</sup> level.

#### V. ADVANCED TECHNIQUES BASED ON ARTIFICIAL INTELLIGENCE (AI)

AI based method consist of Artificial Neural Network(ANN), Support Vector Machine(SVM), and other type of machine learning techniques used for DC arc fault detection. The overall procedure of AI based method is shown in fig 8.

##### 5.1. Artificial Neural Network (ANN)

The proposes technique for a fault detection and classification of medium voltage DC (MVDC) power systems (PSs) by incorporating wavelet transform (WT) multiresolution analysis (MRA) technique with artificial neural networks (ANNs)[30]. ANN has the capacity of recognizing fundamental relationship between the input and output patterns. It can consider several features of the input signals simultaneously and compare the patterns according to their mutual similarity instead of the hard thresholds. With reference to the different topologies, the feedforward network is probably the most popular, and it forms more than 80% of the current neural network applications for fault diagnostic[30] [31].

The basic multilayer feedforward network contains one input layer, one output layer, and any number of hidden layers in between these input and output layer[32],[33]. Currently, the design of network configurations to solve a particular engineering problem is still a trial and error process[31] In this review paper, the three layer feedforward neural networks have been adopted for implementing the proposed fault detection and classification method for MVDC PSs. The specific structure of the adopted three layer feedforward neural networks is shown in Fig. 6.

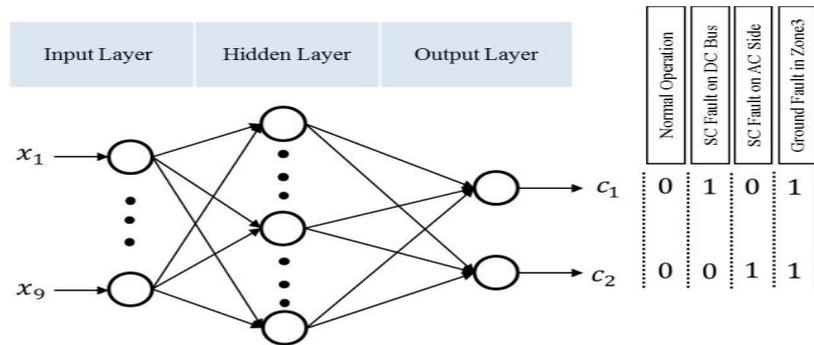


Fig. 6. Structure of a three layer feedforward neural network<sup>[30]</sup>

The three layer feedforward neural network has been shown in this literature paper for nine inputs and two outputs. The outputs are mathematically shown below whether the monitored part is below normal condition or a fault condition, respectively

$$\varphi : R^n \rightarrow \{0,1\}^m$$

$$\varphi(x) = (C_1, C_2, \dots, C_i, \dots, C_m)$$

With

$$C_i=1 \implies \text{fault} \tag{1}$$

$$0 \implies \text{normal} \tag{2}$$

Where  $i = 1, 2, \dots, m$ .  $m$  is the range of output neurons. In this case  $m$  equals to 2.  $n$  is the number of inputs and equals to 9.

### 5.2. Support Vector Machine(SVM)

Another technique used for arc fault detection is SVM. SVM is supervised machine learning algorithm, used for fast solving binary classification problem. The main concept of SVM is to create Hyperplane as shown in fig.7. It used to separate data with maximized margins for both sides. The nearest data samples to hyperplane in feature space are mentioned as “support vector”[34]. In case of data points gathered so that liner separation is not possible, the data point can be plotted into feature space where liner separation is possible. The optimal separating hyperplane is the separating hyperplane that create the maximum distance between the plane and nearest data.[29] The performance of SVM is depend on quality of training data. Both the ANN and SVM are heuristics techniques thus their reliability is hard to prove[35].

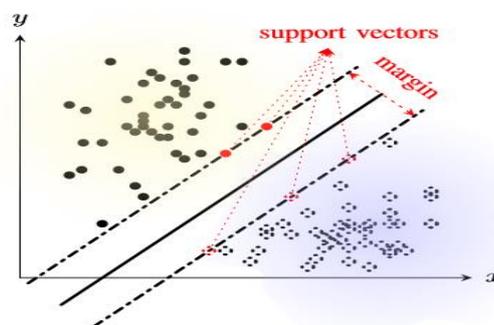


Fig.7. SVM operation<sup>[34]</sup>

### 5.3. Other Machine learning techniques based on Decision Tree(DT)

The DT is more popular and efficient way to built classifier which used to classify the arc faults. The fault classification is carried out by involving wavelet based feature. DT algorithm is based on supervised learning algorithm. The protection scheme contains current data for one cycle using wavelet transform and statistical feature. This feature is helpful for DT model for fault detection and classification[35]. The transparent data mining model is also called as DT. Data mining is a tool between system variable of a dataset consisting data related to the system. The model designed by data mining used for description and prediction

of system output. The predictive data mining produces system model using input dataset and can be utilized for estimation, and classification. Descriptive data mining discovers relationship in large dataset[36].

The projected fault diagnostic algorithm relies on the signature analysis of the monitored signals, performed with WT-based MRA techniques for feature extraction and AI technique for feature classification. The flowchart of the proposed algorithm is shown in Fig. 8. At the data acquisition stage, the monitored signal selected for fault diagnostic is sampled. Then, the WT-based MRA technique is employed for decomposing every signal into low frequency approximation and high frequency details. Parseval's theory is applied to extract the feature vectors of each sampled signal. The extracted feature vectors are then used as the inputs in above method for classification. The outputs of this above method indicate the fault types.

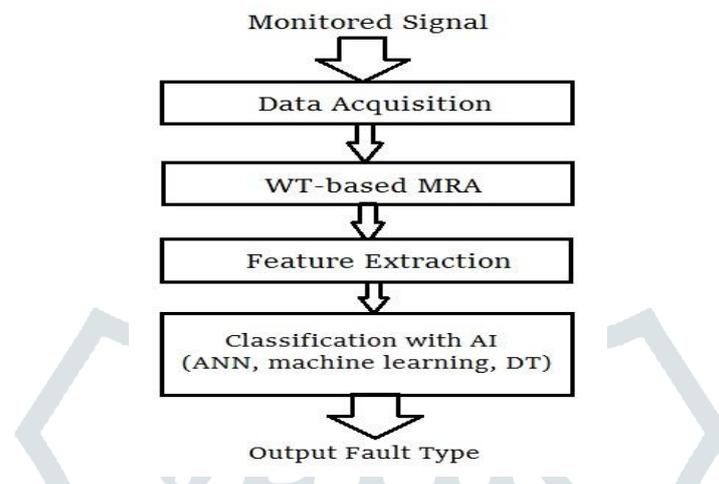


Fig. 8. Flowchart of the proposed algorithm.

## VI. CONCLUSIONS

In this paper various techniques of arc fault and arc flash analysis for dc distribution system are reviewed. The fundamental feasibility of applying WT has been presented. Also the commercial method such as AFCI and Discrete STFT method has been presented for DC applications. The presence of switching harmonics and electrical noise will mask the arc signal, creating detection of an arc difficult. Fourier analysis is usually ineffective to find transient signals and abrupt changes like sudden arc faults and arc flashes. If the duration of the arc flash lasts for a very short period of time as compared with the sampling window of FFT, it's seemingly that the arc flashes won't be observable. However, WT is very effective with detecting the exact instant the signal changes. The results recommend by author[11] that the WT approach is not simply capable of analyzing arc fault in dc systems but that it also provides a more promptly detectable signal and better performance than the FFT technique. AI based technique is also discussed in this paper to classify these extracted features to identify the fault types automatically, with its strong capability of generalization and training mechanism. All these AI based technique used to classify and detect the location of arc fault. Wavelet transformation is important parameter for this method. Without wavelet MRA technique this method is unable to perform.

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