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Pattern Recognition Approach for Fault Identification in Power Transmission Lines

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Abstract

This paper presents an improved algorithm for fault detection and classification of transmission line fault current signals using MATLAB/SIMULINK. The proposed algorithm presents a fault discrimination method based on the three-phase current and voltage waveforms measured when fault events occur in the power transmission-line network. The algorithm for fault classification employs wavelet multi resolution analysis (MRA) to overcome the difficulties associated with conventional voltage and current based measurements due to effect of factors such as fault inception angle, fault impedance and fault distance. The proposed algorithm for fault location, different from conventional algorithms that are based on deterministic computations on a well-defined model to be protected, employs wavelet transform. The wavelet transform captures the dynamic characteristics of the non-stationary transient fault signals using wavelet MRA coefficients.

Index Terms– Wavelet transforms Multi resolution analysis (MRA), Fault classification, Transmission lines.

I. INTRODUCTION

Faults on transmission line can be caused by lightning strikes, flashover on contaminated insulator surface, broken conducting line, short circuit between conducting lines, etc. Electromagnetic transients in power systems result from a variety of disturbances on transmission lines, such as faults, are extremely important [2]. A fault occurs when two or more conductors come in contact with each other or ground in three Phase systems, faults are classified as Single line-to-ground faults, Line-to-line faults, Double line-to-ground faults, and three phase faults. For it is at such times that the power system components are subjected to the greatest stresses from excessive currents These faults give rise to serious damage on power system equipment. Fault which occurs on transmission lines not only effects the equipment but also the power quality. So, it is necessary to determine the fault type and location on the line and clear the fault as soon as possible in order not to cause such damages. Flashover, lightning strikes, birds, wind, snow and ice-load lead to short circuits. Deformation of insulator materials also leads to short circuit faults. It is essential to detect the fault quickly and separate the faulty section of the transmission line. Locating ground faults quickly is very important for safety, economy and power quality. Wavelet theory is the mathematics, which deals with building a model for non-stationary signals, using a set of components that look like small waves, called wavelets. It has become a well-known useful tool since its introduction, especially in signal and image processing.

II. WAVELET TRANSFORMS

Wavelet Transform represents the signal as a sum of wavelets at different locations and scales. Wavelet is a wave form of effectively limited duration with an average value of zero. Wavelet is asymmetric and irregular wave. Fig.2.1. represents the typical wavelet. Sharp changes can be better analyzed with an irregular wavelet than using a smooth sinusoid.

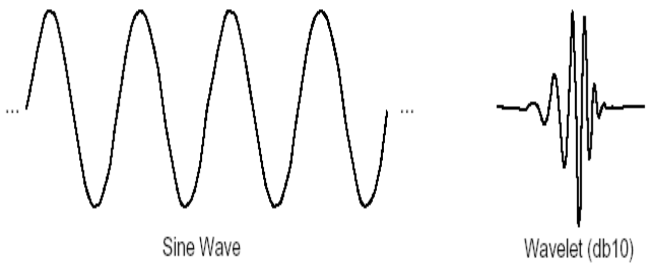

Fig.2.1. Representation of the typical wavelet.

By using wavelets, the sub band information regarding different harmonics can be extracted from the original signal. Db4 as mother wavelet and 12.5 KHz as the sampling frequency decompose the signal and calculate the summation coefficients. The fault current signals are non stationary in nature. Therefore, conventional Fourier transform and short time Fourier transforms are inadequate to deal with such signals. The Wavelet theory and its applications are rapidly developing fields in applied mathematics and signal analysis. The wavelet transform is a tool that divides up data into different frequency components, and then evaluates each component with a resolution matched to its scale. The wavelet transform is useful in analyzing the transient phenomena associated with transmission-line faults and/or switching operations. Wavelet analysis is the breaking up of a signal into shifted and scaled version of the original (or mother) wavelet. Scaling a wavelet means stretching (or compressing) it. Shifting a wavelet simply means delaying its onset [10].

Analogous to the relationship between continuous Fourier transform (FT) and Discrete Fourier Transform (DFT), the continuous wavelet transform (CWT) has a digitally implement able counterpart known as the Discrete Wavelet Transform (DWT).

III. FAULTS CLASSIFICATION USING WAVELET TRANSFORM

The discrete wavelet transform (DWT) is normally implemented by Mallat's algorithm its formulation is related to filter bank theory. Wavelet transform is largely due to this technique, which can be efficiently implemented by using only two filters, one high pass (HP) and one low pass (LP) at level (k). The results are down-sampled by a factor two and the same two filters are applied to the output of the low pass filter from the previous stage. The high pass filter is derived from the wavelet function (mother wavelet) and measures the details in a certain input. The low pass filter on the other hand delivers a smoothed version of the input signal and is derived from a scaling function, associated to the mother wavelet [9] & [10].

Given a function $f(t)$, its continuous wavelet transform (WT) will be calculated as follows:

$$DWTX(m,n;Y)=\sum_{-\infty}^{+\infty} x(u)\,y_{m,n}(u)$$

Where Y_n, m (u) = $s_m/2$ Y (s_{m0} , u − nt_0). The most natural choice (s_0 = 2, t_0 = 1) corresponds to the dyadic sampling of the time-scale plane. Using such a sampling we obtain that the family of atoms Y_n, m (u), m, n, Z form an orthonormal basis.

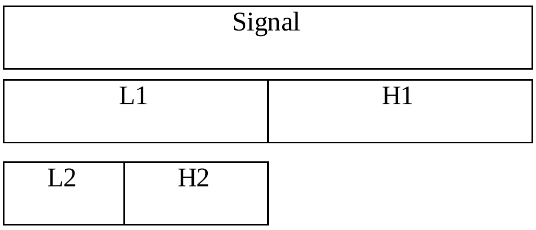

Fig.3.1.Discreet Wavelet Transform (DWT) representation of a Signal.

Splitting of MRA subspaces:

$G_0(z) = 1/2\ g_0[k]z_k$

$G_1(z) = 1/2\ g_1[k]z_k$

3.1. Wavelet Decomposition Scheme by Multi-Resolution Analysis:

In MRA, wavelet functions and scaling functions are used as building blocks to decompose and construct the signal at different resolution levels. The wavelet function will generate the detail version of the decomposed signal and the scaling function will generate the approximated version of the decomposed signal. That is wavelet function constitutes the high pass digital filter and the scaling function constitutes low pass digital filter. Let c_0 (n) be a discrete –time signal recorded from a physical measuring device. This signal is to be decomposed into a detailed and smoothed representation.

From the MRA technique, the decomposed signals at scale 1 are $c_1(n)$ and $d_1(n)$,where $c_1(n)$ is the smoothed version of the original signal (or approximation), and d1(n) is the detailed representation of the original signal $c_0(n)$ in the form of wavelet transform coefficients.

They are defined as

$$c_1(n)=\sum_k h(k-2n)c_0(k)$$

$$d_1(n)=\sum_k g(k-2n)c_0(k)$$

Where h (n) and g (n) are the associated filter coefficients that decompose c_0 (n) in to c_1 (n) and $d_1(n)$ respectively. That means in first stage decomposition the original signal is divided into two halves of frequency bandwidth. The next higher scale decomposition is now based on the signal $c_1(n)$. The decomposed signal at scale 2 is given by

$$c_2(n)=\sum_k h(k-2n)c_1(k)$$

$$d_2(n)=\sum_k g(k-2n)c_1(k)$$

Higher scale decompositions are performed in the same way as described above. Thus the procedure is repeated until the signal is decomposed to a pre-defined certain level. The set of signals thus attained represent the same original signal, but all corresponding to different frequency bands.

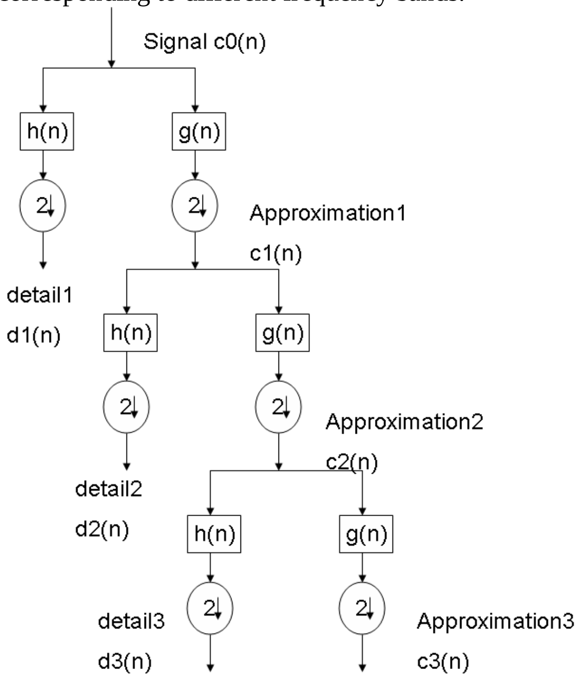

Fig.3.2. Representation of Multi-Resolution Analysis.

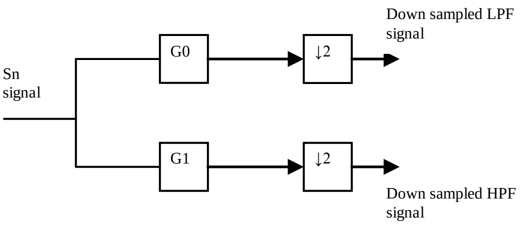

Fig.3.3. Channel analysis filter bank

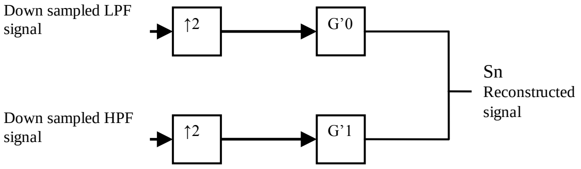

Fig.3.4. Channel synthesis filter bank

Wavelet transforms converts amplitude versus time signal to scale versus time signal. Wavelet is a waveform of effectively limited duration that has an average value of zero. The actual implementation of discrete wavelet transform is done by multi resolution analysis. By MRA, a signal can be analyzed is decomposed into a smooth approximation. The approximation is further decomposed into an approximation and a detail and the process is repeated. The decomposition of signal is obtained by successive high pass and low pass filtering of the time domain signal. The successive stages of decomposition are known as levels and the above procedure is known as sub band coding. The sub band information is useful for fault classification. The transmission line faults in power system are usually classified as Symmetrical faults and Unsymmetrical faults. A three-phase fault is called a symmetrical type of fault. In a three phase fault, all the three phases are short circuited.

There may be two situations—all the three phases may be short circuited to the ground or may be short-circuited without involving the ground. Single-phase to ground, two phase to ground, phase to phase short circuits; single phase open circuit and two phase open circuit are unsymmetrical types of faults [1].

IV. FAULT CASES STUDY AND RESULTS

A 3 phase transmission line rated 400kV and length of line is 300km has been considered for the case study. The circuit diagram of the transmission line fault analysis is shown in Fig.4.1.

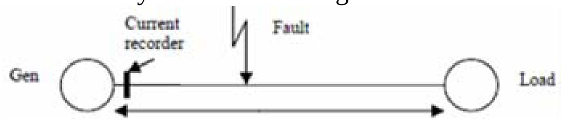

Fig.4.1. Sample power system network

The fault analysis of transmission lines involves transient phenomena. Therefore, the positive, negative and zero sequence parameters of the source as well as transmission lines are necessary.

Table: 4.1. Sequence Parameters of Source and Line

The various line parameters pertaining to

Source parameters (Impedance Ω)	Positive, negative sequence	0.45+j5
	Zero sequence	0.675+j7.5
Line Inductance (mH/km)	Positive, negative sequence	0.95
	Zero sequence	3.25
Line capacitance (μF/km)	Positive, negative sequence	0.0124
	Zero sequence	0.0084
Line resistance (Ω/km)	Positive, negative sequence	0.0234
	Zero sequence	0.3885

source as well as transmission line are shown in table. An active load of 500MW and a reactive load of 20MVAR (inductive) are used for the analysis.

The fault may appear at any instant of time, and thus voltage or current ranging from 0 to 360 degrees. The angle at which fault occurs is called fault inception angle and it effects the amplitude of fault current. The fault distance changes then corresponding line impedance changes which is going change the fault current. Fault resistance also affects the fault current. Fault resistance increases fault current decreases [1].

The faults currents are generated using MATLAB shown in figures for fault condition of L-G, L-L, and L-L-L. More ever, the sampling time considered in the analysis is 80us, which correspond to a sampling frequency of 12.5 kHz, and the total number of wavelet levels considered is 10.

Therefore a 10^{th} level wavelet output corresponds to a frequency band of 6.25-12.5 kHz. Down sampling by two at each succeeding level will lead to a 3rd level output corresponding to a frequency band of 97-195 Hz,i.e. it includes 2nd and 3rd Harmonics components which are predominant in case of transmission line faults. The wavelet toolbox in MATLAB has been used for DWT operation. Different decomposition levels such as a3 (Approximation at level three); detail levels one, two, three, represented as d_1, d_2, d_3, respectively can be extracted using wavelet toolbox. The tables give summations of wavelet coefficients of 3 rd values for current in phases A, B and C respectively for L-L-L fault for different fault inception angles and fault locations. Similarly we can tabulate for other type of fault also. For all other faults such as single line to ground (L-G), double line to ground (L-L-G), double line (L-L), and three phase symmetrical (L-L-L) faults also have been extensively investigated for about 1000 simulations with different values of fault impedance value and fault inception angles. Thus it was verified that the algorithm consistently yielded right classification and all cases have not been reported as it would turn to be voluminous [1].

Different types of power system faults are created using simulation model as shown, at different fault distances having different fault inception angles with different fault resistance. The wave forms are shown below.

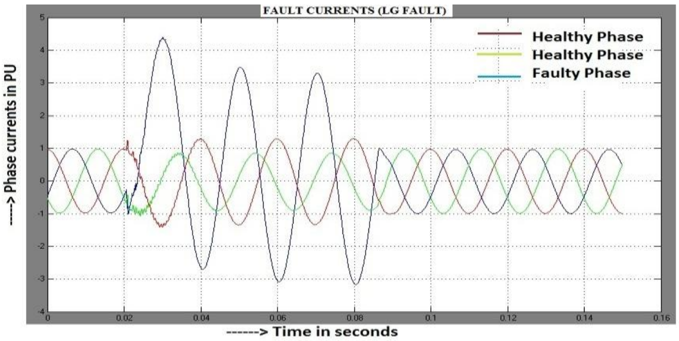

Fig.4.2. $\mathbf{I_a}$, $\mathbf{I_b}$, $\mathbf{I_c}$ for LG Fault at D==200Km, FIA=60^0

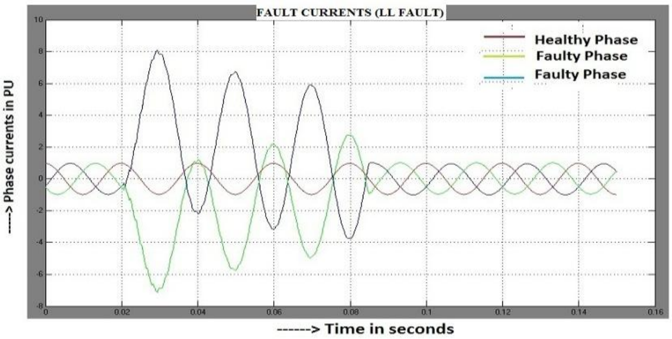

Fig.4.3. $\mathbf{I_a}$, $\mathbf{I_b}$, $\mathbf{I_c}$ for LL Fault at D==200Km, FIA=60^0.

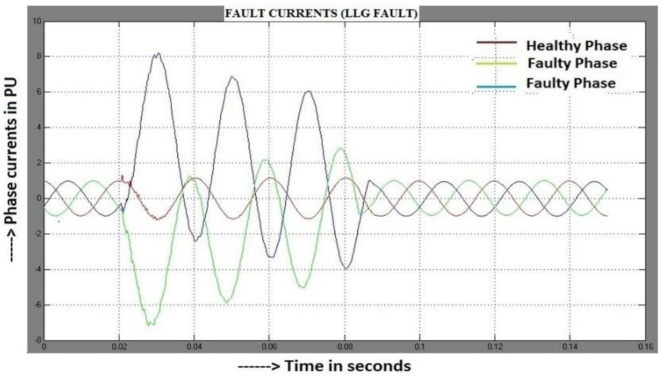

Fig.4.4.. $\mathbf{I_a}$, $\mathbf{I_b}$, $\mathbf{I_c}$ for LLG Fault at D==200Km, FIA=60^0.

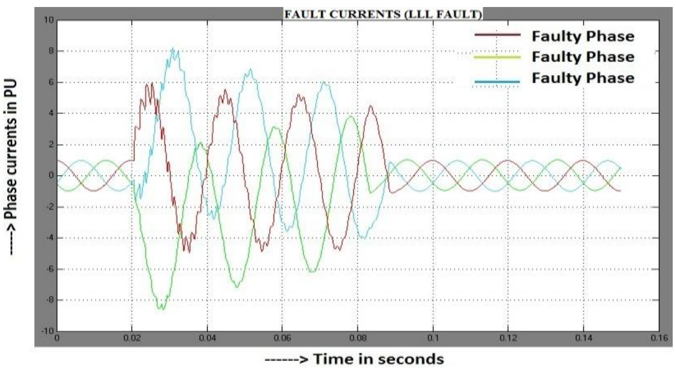

Fig.4.5. $\mathbf{I_a}$, $\mathbf{I_b}$, $\mathbf{I_c}$ for LLL Fault at D==200Km, FIA=60^0.

In order to reduce the computational burden the sampling frequency should not be too high but it should be high enough to capture the information of fault. By randomly shifting the point of fault on transmission line, more number of simulations was being carried out. The generated current signal for each case is analyzed using wavelet transform. A sampling frequency of 12.5 kHz is selected. Daubechies wavelet Db4 is used as mother wavelet since it has good performance results for power system fault analysis. Detail coefficients of fault current signal in 6^{th} level (d6), gives the frequency components corresponding to second and third harmonics. On this basis, summation of 6^{th} level detail coefficients of the three phase currents I_a, I_b and I_c are being used for the purpose of detection and classification of faults in the transmission line.

V. FAULT DETECTION AND CLASSIFICATION ALGORITHM

In the simulation model, different types of faults are created at different FIA. The current wave forms are shown in the figures. Let $\mathbf{S_a}$, $\mathbf{S_b}$, $\mathbf{S_c}$ be the summation of sixth level detail coefficients for current signals for A, B, C phases respectively. Tables (5.1. to 5.4.) show the values of $\mathbf{S_a}$, $\mathbf{S_b}$, $\mathbf{S_c}$ for different types of faults.

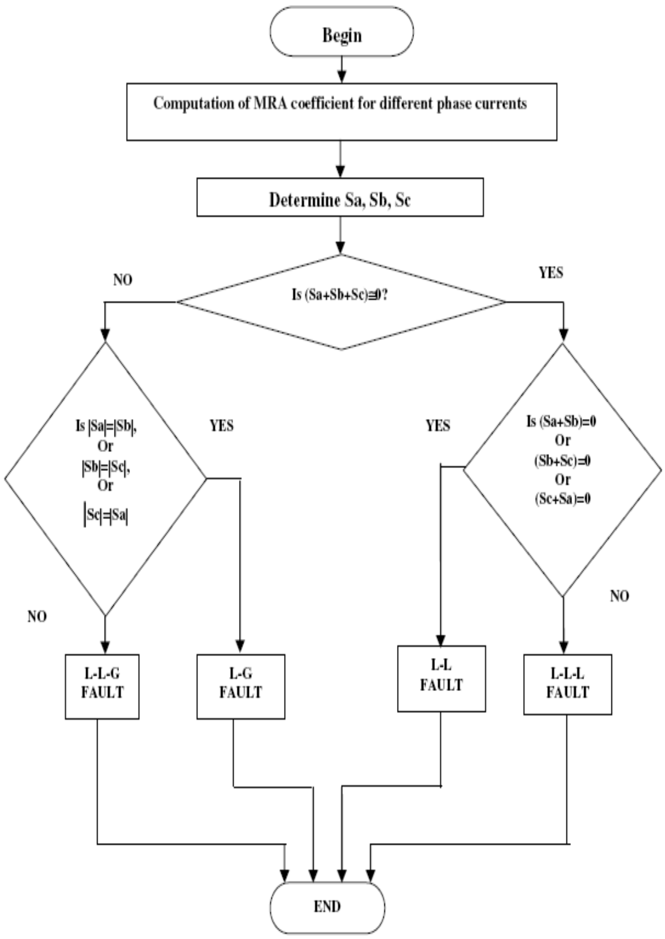

Fig.5.1.Algorithm for Transmission line fault classification

From these tables it is observed that the magnitudes of S_a, S_b, S_c increases whenever any fault occurs in a transmission line. Based on the sampling rate the signal is divided into 12 decomposition levels. Among different levels only 6th level is consider for analysis because the frequency corresponding to this level is covering 2^{nd} and 3^{rd} harmonics which are dominant in the fault conditions. Based on 6^{th} level detail coefficients, an efficient algorithm proposed [1].

The transmission line faults in a power system are usually classified as L-G, L-L-G, L-L and L-L-L. Let S_a, S_b, S_c be the coefficients obtained from the summation of 6^{th} level wavelet detail coefficients for currents in phases A, B and C. When the algebraic sum of S_a, S_b, S_c is zero, then it can be either L-L-L or L-L. To differentiate these two, the summation of any two phases is zero, and remaining healthy coefficient is very small value in L-L fault. Algebraic sum is not equal to zero, then it be either L-G or L-L-G. If the absolute values of any two coefficients are equal and much smaller than absolute value of remaining coefficients, then it is L-G fault. If the absolute value of any two coefficients is not equal to zero and is always much higher than the absolute value of remaining coefficients, then it is an L-L-G. The results tabulated show the efficiency of the fault classification of algorithm using db4 wavelet for different fault locations, fault resistances and FIA and the algorithm was verified.

Table: 5.1. L-G fault with different fault distances the values of S_a, S_b, S_c with FIA= 60^0

	10(km)	50(km)	100(km)	150(km)	200(km)
S_a	15.1059	4.9285	2.8547	2.1022	1.7146
S_b	-0.0126	0.0132	0.0171	0.0173	0.0192
S_c	-0.0977	-0.0717	-0.0680	-0.0679	-0.0659

The summation of detail coefficients of all three phases sum is not equal to zero for L-G and L-L-G, which is used to discriminate L-G, L-L-G from L-L and L-L-L. Faulty phase summation value is very high compared to healthy phases. Healthy phase summation values are almost equal.

Table: 5.2. L-L-G fault with different fault distances the values of S_a, S_b, S_c with FIA=60^0

	10(km)	50(km)	100(km)	150(km)	200(km)
S_a	15.7126	5.9805	3.6592	2.7750	2.3212
S_b	4.3505	0.3525	-0.1435	-0.3453	-0.4294
S_c	-0.1454	-0.1748	-0.1912	-0.2064	-0.2219

The summation of detail coefficients sum is not equal to zero and all three phases have different summation values (summation coefficients of any two phases is not equal), which is used to discriminate L-G from L-L-G.

Table: 5.3. L-L fault with different fault distances the values of S_a, S_b, S_c with FIA=60^0

	10(km)	50(km)	100(km)	150(km)	200(km)
S_a	5.3812	2.8239	1.9327	1.5714	1.3852
S_b	-5.3613	-2.8041	-1.9129	-1.5514	-1.3652
S_c	-0.0199	-0.0197	-0.0198	-0.0199	-0.0199

The summation coefficients in any two phases are equal and the third healthy phase value is very less compared to two faulty phases.

Table: 5.4. L-L-L fault with different fault distances the values of S_a, S_b, S_c with FIA=60^0

	10(km)	50(km)	100(km)	150(km)	200(km)
S_a	23.9728	10.0702	6.0231	4.4194	3.5874
S_b	12.3156	4.4424	2.1780	1.2965	0.8346
S_c	-36.2884	-14.5126	-8.2011	-5.7159	-4.4220

The summation of detail coefficients of three phases sum is zero but all three phase summation values are different, in L-L fault two phases have a same value, which is used to discriminate L-L from L-L-L.

VI. CONCLUSION

Wavelet multi resolution analysis is found to be most suitable for extracting the information from transient fault signals. Second and third order harmonics are dominant in the fault signals and are hence chosen for the analysis (d6 coefficients) and Db4 as mother wavelet. Using wavelet MRA technique, the summation of detail coefficients for sixth level are extracted from the current signal. From the magnitude of detail coefficient summations, the presence of fault in a particular phase is detected. A generalized algorithm based on wavelets has been verified for the classification of transmission line faults. The most important of this algorithm is independent of fault location, impedance and inception angle. S-Transform is an extension to the idea of wavelet transform, and is based on a moving and scalable localizing Gaussian window. It can be used for the detection of power system fault analysis.

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