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Faults Detection And Classification On Long Transmission Line Using Wavelet Analysis

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Abstract

The disturbances of power systems are aperiodic, non stationary, very short duration and impulsive in nature. The wavelet transform based approaches have been successfully detect and classify the faults due to their ability to express the signal both in frequency and time domain. In this paper, Wavelet Transform based fault detection and classification technique has been proposed. The fault classification technique is developed on the basis of extensive simulation studies carried out on the power system model using SimPowerSystems MATLAB toolbox for different operating conditions. This method detects all ten types of faults (e.g., a-g, b-g, c-g, a-b, b-c, c-a, a-b-g, b-c-g, c-a-g, a-b-c) on the transmission line. Fault data generated by workspace on MATLAB simulation model have been used for fault detection and classification by MATLAB wavelet toolbox. The maximum threshold ratio using remove near zero method and percentage of energy level at highest approximation level of each type of fault are characteristics in nature and are used for distinguishing the fault types.

Key Words: *Transmission line faults, wavelets transform, SimPowerSystems, MATLAB wavelet toolbox.*

1. INTRODUCTION

The main objective of all the power systems in this world is to provide reliable operation i.e. maintain continuity in service and to minimize the outage times whenever abnormal conditions occur. Electromagnetic transients in power systems result from a variety of disturbances on transmission lines, such as faults, are extremely important [1]. When two or more conductors come in contact with each other or with ground in three phase systems, a fault is said to be occur. Faults are classified as single line-to-ground faults, Line-to-line faults, Double line-to-ground faults, and three phase faults. These faults results in poor power quality and damage of power system equipment. So, it becomes necessary to detect and determine the type of fault 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 are some causes that lead to short circuits. Deformation of insulator materials also leads to short circuit faults. Therefore, it is essential to detect the fault quickly and isolate the faulty section of the transmission line. Locating ground faults quickly is very important for safety, economy and power quality [2]. There are various techniques for fault detection and classification. Some of the techniques are: (i) Fuzzy logic-based [3-4] (ii) Artificial Neural Network based [5-6] and (iii) Wavelet Transforms based [2], [7-8]. Although, the Fuzzy and neural-network-based approaches have been quite successful in determining the correct fault type, the main disadvantages of Fuzzy and ANN are; requires a considerable amount of training effort for good performance. . The wavelet transform based approaches have been quite successful in fault detection and classification due to its ability to express faulted signal both in frequency and time domain. 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 [2], [9].

2. WAVELET ANALYSIS

To analyze a signal, the most well-known technique is Fourier analysis, which breaks down a signal into constituent sinusoids of different frequencies. Another way to define Fourier analysis is as a mathematical technique for transforming our view of the signal from a time-based one to a frequency-based one.
The signal's frequency content is of great importance and therefore, Fourier analysis is extremely useful for such signals. However, Fourier analysis has a serious drawback. In transforming to the frequency domain, time information is lost. When analyzing a signal using Fourier transform, it is impossible to tell when a particular event took place [10].
This drawback isn't very important if a signal is stationary i.e. if it doesn't change much over time. However, most of signals contain numerous non-stationary or transitory characteristics such as drift, surges, abrupt changes, and beginnings and ends of events. These characteristics are often the most important part of the signal, and Fourier

analysis is not suited to detecting them. Wavelet analysis represents the windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where needed more precisely low frequency information, and shorter regions where needed high frequency information. One major advantage provided by wavelets is the ability to perform *local analysis* — that is, to analyze a localized area of a larger signal. Wavelet analysis is capable of providing many relevant information that other signal analysis techniques miss like trends, breakdown points, discontinuities in higher derivatives, and self-similarity. Further, because it affords a different view of data than those presented by traditional techniques, wavelet analysis can often compress or de-noise a signal without appreciable degradation which is not possible with many other traditional techniques. A wavelet is a waveform of effectively limited duration that has an average value of zero. Comparing wavelets with sine waves, which are the basis of Fourier analysis, it is found that Sinusoids do not have limited duration — they extend from minus to plus infinity. And where sinusoids are smooth and predictable, wavelets tend to be irregular and asymmetric. Fourier analysis consists of breaking up a signal into sine waves of various frequencies. Similarly, wavelet analysis is the breaking up of a signal into shifted and scaled versions of the original (or *mother*) wavelet [10].

Mathematically, the process of Fourier analysis is represented by the *Fourier transform*:

$$F(\omega) = \int_{-\infty}^{+\infty} f(t).e^{-j\omega t}dt$$

Which is the sum over all time of the signal *f(t)* multiplied by a complex exponential.
The *continuous wavelet transform* (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function:

$$C(scale, position) = \int_{-\infty}^{+\infty} f(t)\,\Psi(scale, position, t)\,dt$$

The result of the CWT is many *wavelet coefficients* C, which are a function of scale and position [10].

2.1 One-Stage Filtering: Approximations and Details

For many signals, the low-frequency content is the most important part. It provides the signal its identity. The high-frequency content, on the other hand, imparts nuance.The approximations are the high-scale, low-frequency components of the signal. The details are the low-scale, high-frequency components. The filtering process, at its most basic level, looks like as shown in figure1.

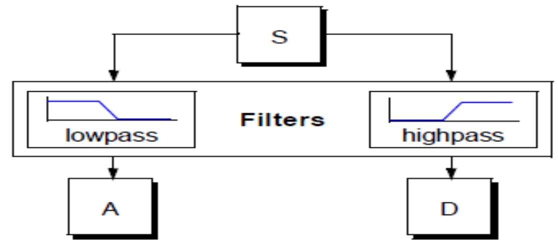

Fig -1: One-Stage Filtering: Approximations and Details

The original signal, S, passes through two complementary filters and emerges as two signals. However, if perform this operation on a real digital signal, we wind up with twice as much data as we started with.
Suppose, for instance, that the original signal S consists of 1000 samples of data. Then the approximation and the detail will each have 1000 samples, for a total of 2000.
To correct this problem, we introduce the notion of *downsampling*. This simply means throwing away every second data point [10].

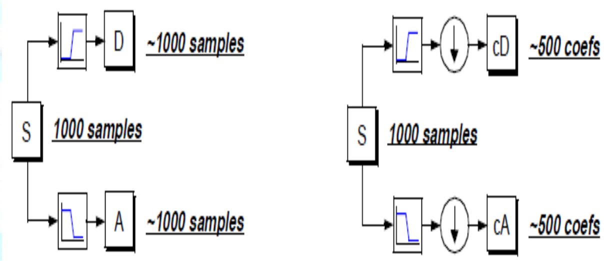

Fig -2: signal without and with down sampling

2.2 Multiple-Level Decomposition

The decomposition process can be iterated, with successive approximations being decomposed in turn, so that one signal is broken down into many lower-resolution components. This is called the wavelet decomposition tree [10].

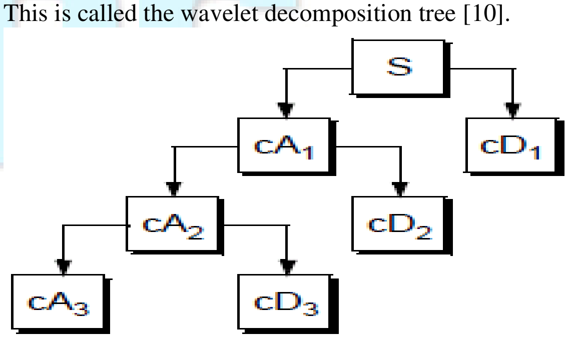

Fig -3: Multiple-Level Decomposition

3. SYSTEM STUDY AND WORK PROCESS

Figure 5 shows a transmission line having a voltage of 400 kV, 50 Hz and length of 300 km for the simulation.

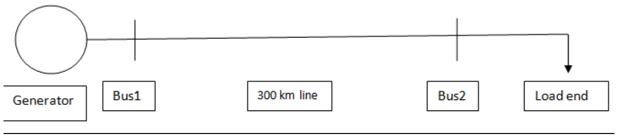

Fig -5: power system model

The positive sequence parameters such as resistance, inductance and capacitance values of the transmission line are 3.189 Ω, 280.11 mH, and 3.82 µF respectively. The negative sequence line parameters are same as the positive parameters. The zero sequence line parameters are 115.92 Ω, 1237.9 mH, 2.33 µF respectively.

3.1 Simulation Studies

The fault classification technique is developed on the basis of extensive simulation studies carried out on the power system model as shown in figure 6 using MATLAB toolbox for different operating conditions. Fault data generated by workspace on MATLAB simulation model have been used for analysis by MATLAB wavelet toolbox. The maximum threshold using remove near 0 method of compressed signal and percentage energy level at highest approximation level i.e. at level 4 are used for detection and classification of faults.

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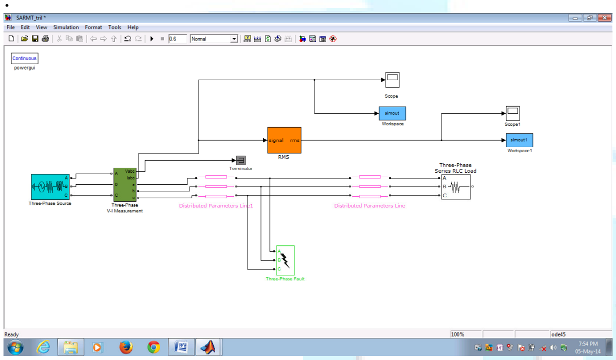

Fig -6: simulation model

3.2 Fault Detection

In this proposed method, wavelet transform is first applied to decompose the current signals of power system model into a series of wavelet components each of which covers a specific frequency band. The time and frequency domain features are obtained for normal and different types of fault currents. The sample of these current for 0.4 second is taken and is processed in MATLAB wavelet toolbox. One of the popular mother wavelets suitable for a wide range of applications used is Daubichies's wavelet. In this work Db1 level 4 wavelet is used.

To implement the wavelet transform, the original signal is obtained from the workspace. The wavelet transform is applied to normal and all type of faults waveform. Wavelet transform coefficients for each condition obtained. The maximum threshold using remove near 0 method of compressed signal and percentage energy level at highest approximation level i.e. at level 4 is obtained. The signal data is generated by SimPowerSystems model in MATLAB.

4. RESULT AND DISCUSSION

Different types of faults have been considered for the purpose of analysis. These faults are detected based on recognizing their shapes and differentiating them from the normal current wave shapes using wavelet transform. The maximum threshold using remove near 0 method of compressed signal and percentage energy level at highest approximation level i.e. at level 4 are used for detecting and classifying the faults.
These are as follows:

NORMAL CONDITION

The currents for this case is obtain with no fault condition on power system simulation model as shown in figure 7 and stored. These current are then processed through wavelet toolbox to obtain there wavelet response as shown in figure 8.

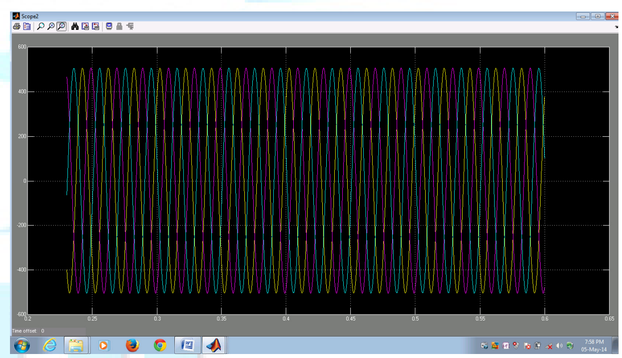

Fig -7: normal condition

With the help of wavelet transform when there are no faults, the percentage of energy levels at highest approximation level i.e. at level 4 and maximum threshold value using remove near 0 method by compressing signal is collected for each phase. Then we calculate the ratios of threshold values of compressed waveforms of each phase corresponding to themselves which are given in table 1.
These values of percentage of energy levels and ratios of threshold for normal condition can be taken as reference for further work.

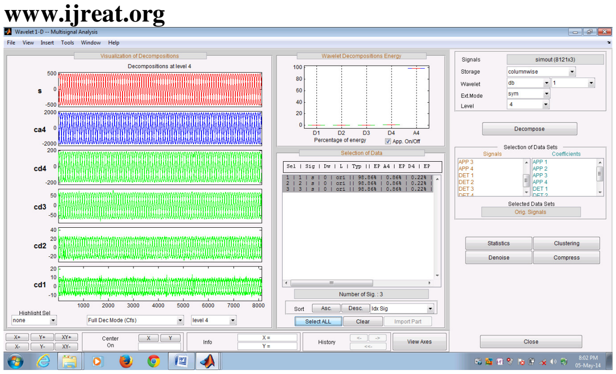

Fig -8: WT of normal condition

Table -1: Normal condition

Fault condition		Normal
Max. threshold	A	8.127
	B	8.155
	C	8.156
Threshold ratio	A	1.00
	B	1.00
	C	1.00
% energy level	A	98.86
	B	98.86
	C	98.86

SINGLE LINE TO GROUND FAULT (LG fault)

The currents for this case is obtain with ground fault condition on power system simulation model as shown in figure 9 and stored. These current are then processed through wavelet toolbox to obtain there wavelet response as shown in figure 10.

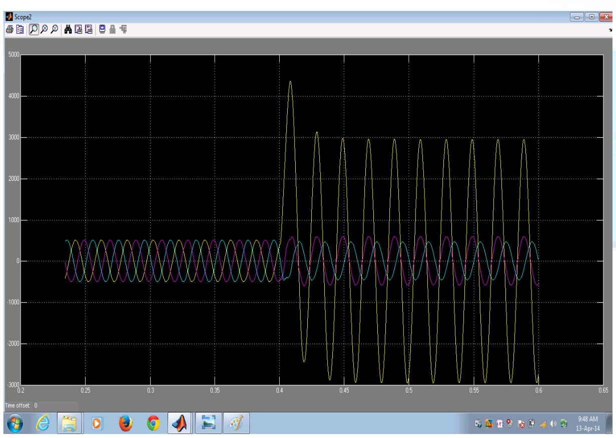

Fig -9: LG fault

The wavelet transform shows that there is abnormal response in any one phase. The percentage of energy level at highest approximation level i.e. at level 4 and maximum threshold value using remove near 0 method by compressing signal is collected for each phase. Then we calculate the ratios of threshold values of compressed waveforms of each phase with respect to the respective normal phase as shown in table 2. We take normal condition as reference and compare these to abnormal one. The ratio of threshold for faulty phase is more than respective normal phase indicating occurrence of fault on that phase.

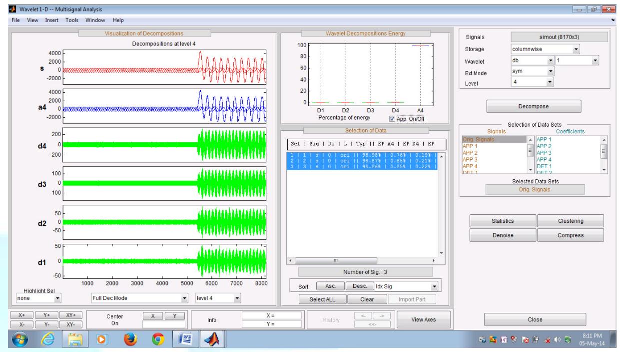

Fig -10: WT of LG fault

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Table -2: LG fault

Fault condition		A-g	B-g	C-g
Max. threshold	A	18.453	8.095	8.745
	B	8.572	18.401	8.069
	C	7.892	8.765	18.718
Threshold ratio	A	**2.27**	0.99	1.07
	B	1.05	**2.26**	0.99
	C	0.97	1.07	**2.29**
% energy level	A	98.97	98.63	98.65
	B	98.86	98.96	98.59
	C	98.86	98.68	98.89

LINE TO LINE FAULT (LL fault)

The currents for this case is obtain with phase to phase fault condition on power system simulation model as shown in figure 11 and stored. These current are then processed through wavelet toolbox to obtain there wavelet response as shown in figure 12.

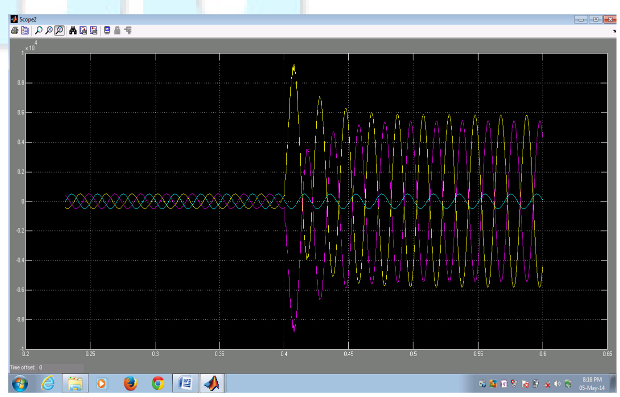

Fig -11: LL fault

The wavelet transform shows that there is abnormal response in any two phases. The percentage of energy level at highest approximation level i.e. at level 4 and maximum threshold value using remove near 0 method by compressing signal are collected for each phase. Then we calculate the ratios of threshold values of compressed waveforms of each phase with respect to the respective normal phase as shown in table 3.

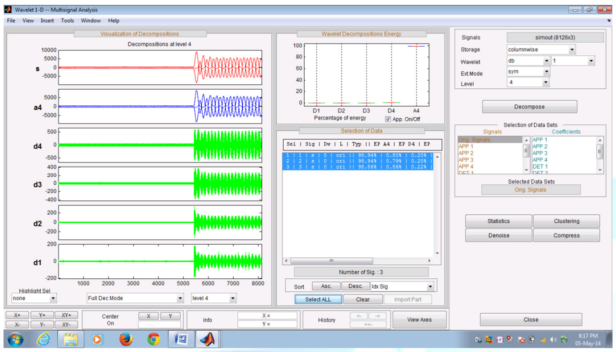

Fig -12: WT of LL fault

We take normal condition as reference and compare these to abnormal one. The ratio of threshold for faulty phases is more than respective normal phases indicating involvement of those phases during fault condition. Also percentage of energy level of healthy phases in faulty condition is equal to that of normal condition indicating absence of ground during double line fault as shown in table 3.

Table -3: LL fault

Fault condition		AB	BC	CA
Max. threshold	A	20.459	8.120	20.399
	B	20.361	20.594	8.148
	C	8.167	20.333	20.571
Threshold ratio	A	**2.52**	0.99	**2.51**
	B	**2.50**	**2.52**	0.99
	C	1.00	**2.49**	**2.52**
% energy level	A	98.90	**98.86**	98.90
	B	98.91	98.81	**98.86**
	C	**98.86**	98.80	98.90

DOUBLE LINE TO GROUND FAULT (LLG fault)

The currents for this case is obtain with double line to ground fault condition on power system simulation model as shown in figure 13 and stored. These current are then processed through wavelet toolbox to obtain there wavelet response as shown in figure 14.
The wavelet transform shows that there is abnormal response in any two phases. The percentage of energy level at highest approximation level i.e. at level 4 and maximum threshold value using remove near 0 method by compressing signal are collected for each phase. Then we calculate the ratios of threshold values of compressed waveforms of each phase with respect to the respective normal phase as shown in table 4.

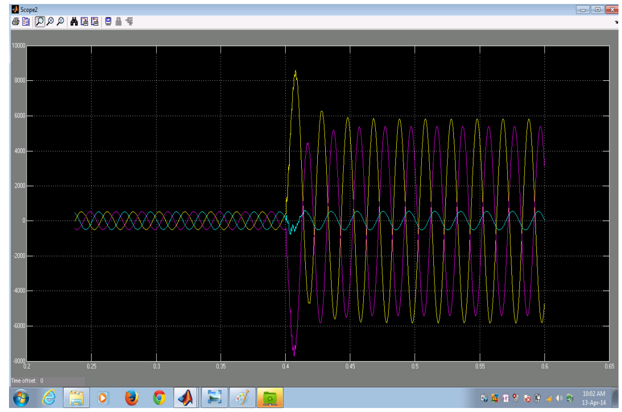

Fig -13: LLG fault

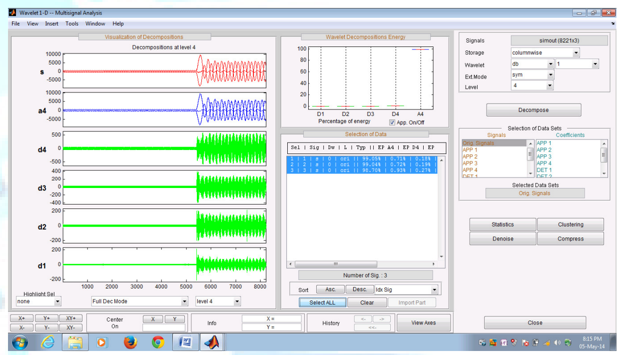

Fig -14: WT of LLG fault

We take normal condition as reference and compare these to abnormal one. The ratio of threshold for faulty phases is more than respective normal phases indicating involvement of those phases during fault condition. Also energy level of healthy phases in faulty condition is different from normal condition indicating presence of ground with double line fault as shown in table 4.

Table -4: LLG fault

Fault condition		AB-g	BC-g	CA-g
Max. threshold	A	20.794	8.260	20.597
	B	20.622	20.709	8.398
	C	8.384	20.463	20.686
Threshold ratio	A	**2.56**	1.02	**2.53**
	B	**2.53**	**2.54**	1.03
	C	1.03	**2.57**	**2.54**
% energy level	A	99.02	**98.87**	98.98
	B	99.00	98.86	**98.74**
	C	**98.70**	98.84	98.94

THREE PHASE FAULT CURRENT (LLL fault)

The currents for this case is obtain with three phase fault condition on power system simulation model as shown in figure 15 and stored. These current are then processed through wavelet toolbox to obtain there wavelet response as shown in figure 16.

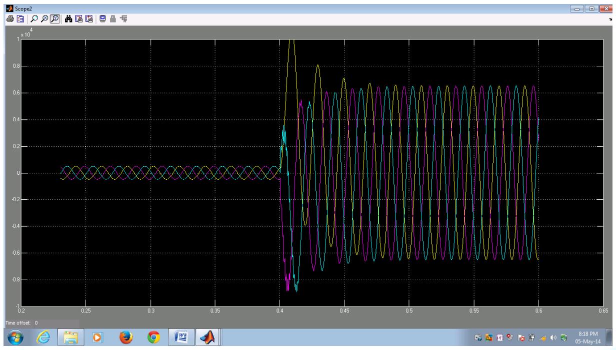

Fig -15: Three phase fault

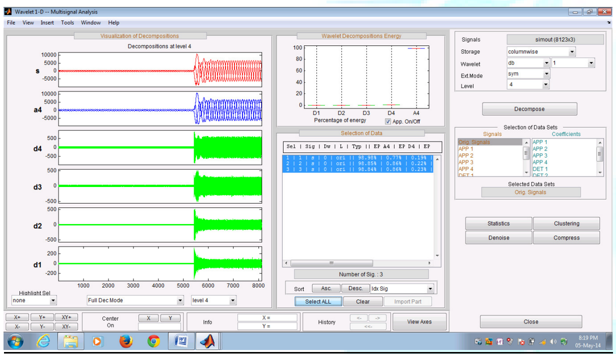

Fig -16: WT of three phase fault

The wavelet transform shows that there is abnormal response in all phases i.e. A, B and C. The percentage of energy level at highest approximation level i.e. at level 4 and maximum threshold value using remove near 0 method by compressing signal are collected for each phase. Then we calculate the ratios of threshold values of compressed waveforms of each phase with respect to the respective normal phase as shown in table 5.
We take normal condition as reference and compare these to abnormal one. The ratio of threshold for faulty phases is more than respective normal phases indicating involvement of all phases during fault condition.

Table -5: LLL fault

Fault condition		ABC
Max. threshold	A	20.612
	B	20.791
	C	20.923
Threshold ratio	A	**2.54**
	B	**2.55**
	C	**2.56**
% energy level	A	98.94
	B	98.84
	C	98.84

5. CONCLUSIONS

The disturbances of power systems are aperiodic, non stationary, very short duration and impulsive in nature. The wavelet transform is a powerful tool for the analysis of faults i.e. transient signals due to its ability to extract information from transient signals simultaneously in time and frequency domain. Different types of faults have been considered here for their analysis. These fault conditions are detected and classified based on comparison of maximum threshold ratio obtained using remove near 0 method and percentage of energy level at highest approximation with respect to those of normal condition which are obtained with the help of MATLAB wavelet toolbox. The simulated results show that this fault detection and classification scheme using wavelet transform is found to be precise and reliable.

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