INNOVATIVE POWER SYSTEM TRANSIENT DISTURBANCES 
DETECTION AND CLASSIFICATION USING WAVELET ANALYSIS

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ABSTRACT

This paper presents an innovative method for detecting and classifying various power system disturbances using wavelet analysis. The proposed method employs a multiresolution analysis (MRA) using localized wavelet basis functions. The non-linear sub-band time-frequency structure extracted using the MRA can provide the needed features to detect and classify any power system transient disturbance. The proposed method is used in two main applications namely in power transformer protection and in power quality improvement and monitoring applications. The results of applying the proposed method show quick, accurate and effective response to all types of the disturbances.

1. INTRODUCTION

There are many types of disturbances likely to take place in different components and elements of a power system. The energy storage nature of these components and elements is capable of producing oscillatory transient disturbances with complex characteristics such as non-periodic, non-stationary, short duration, fast decaying, impulse super-imposed and/or high frequency components [1]. Such transient disturbances can cause critical impacts on load flow, system stability and reliability. Under voltage, harmonic distortions, voltage dips, voltage sags and over-voltage conditions, different faults, magnetizing inrush currents, etc. are just few examples of such transient disturbances [1-2]. The accurate detection and classification of abnormal conditions can help in taking effective countermeasure(s) to maintain acceptable stability and reliability levels of operation [3].

Many techniques using the conventional signal processing tools have been developed and used to detect and classify transient disturbances. Some of these techniques are: Fourier analysis, Kalman Filters, the Park's transformation, artificial neural networks (ANN), fuzzy logic and reactive power methods [3,4]. These early methods are based on linear frequency division, which requires the signal to be stationary during the disturbance. Also some of them are based on training data and system parameters. The application of the aforementioned classical methods made it possible to diagnose and identify power systems events successfully under certain conditions [4]. However, the natures require signal-processing tools that are able to overcome the limitations of the traditional tools.

Recently, the wavelet analysis has been applied in some areas including power systems for detecting and classifying transients. Wavelets analysis performs better with non-periodic and non-stationary signals, which may contain short duration impulse super-imposed transients components in a power system [5-6]. In addition, the wavelet analysis can provide an effective capability of detecting transient events having complex time-frequency relationships taking place for very short time durations. The multiresolution analysis (MRA) created by wavelet functions can extract and localize all the frequencies present in the processed signal. Such an analysis is capable of providing high frequency resolution and acceptable time localization at high frequencies, while it is able to provide acceptable frequency resolution and high time localization at low frequencies [6].

The application of any wavelet transform on a signal produces approximations and details at each level of resolution. The approximations can provide detection capabilities, while the details can provide capabilities of classification and localization of all the frequencies present in the processed signal [6-7].

In the beginning, the wavelet analysis is briefly introduced. Then the algorithm of disturbance
detection and classification is developed. Finally, the results of some investigated transient disturbances are presented.

2. WAVELET ANALYSIS (WA)

The wavelet analysis can be viewed as passing an input signal through a filter bank with variable central frequency and bandwidth [5]. The coefficients of such a filter bank are determined by the selected mother wavelet [6-7]. Such a filter bank is composed of multi stages, each stage is composed of a high pass and a low pass filters [7]. This structure of the wavelet filter bank guarantees the detection and localization of all frequencies present in the decomposed signal [6-7]. This filter structure can create a multiresolution analysis that can be viewed as adapting the mother wavelet or its dilated and frequency-shifted versions for approximating the processed signal at a certain frequency at a certain time [6-7].

Each level of resolution produces approximation as well as details. The approximations of level 1 of a discrete signal $f[n]$ are defined as [7].

$$a^1[n] = \sum_{k=-\infty}^{\infty} f[k]G[n-k]$$

(1)

Where $G[n]$ is the low pass filter determined by the selected mother wavelet. The details of level 1 of a discrete signal $f[n]$ are defined as [7].

$$d^1[n] = \sum_{k=-\infty}^{\infty} f[k]H[n-k]$$

(2)

Where $H[n]$ is the high pass filter determined by the selected mother wavelet. It is to be noted that the frequency scaling is carried out after each filtering operation through a downsampling process [5-7]. Figure 1 shows a tree of wavelet decomposition process of the signal $f[n]$.

Such an analysis breaks the discrete signal $f[n]$ into several localized sequences with a nonlinear frequency subdivision. In this paper the Daubechies mother wavelet ($db4$) is used to determine the coefficients of the desired wavelet filter bank ($\{G\}$ and $\{H\}$).

3. DISTURBANCE DETECTION AND CLASSIFICATION

The existence and the time location of the wavelet extracted sub-band frequency coefficients can provide important information about the frequencies and the time of their occurrence of the analyzed signal $f[n]$. Such information that can be used to identify any frequency component present in $f[n]$ and are known as signatures. As the number of levels of resolution increases, the number of frequency sub-bands increases, offering better, accurate and more detailed representation of the extracted frequency coefficients. The first level of resolution is able to provide means of detecting the existence of any disturbance (high frequency components superimposed on the signal fundamental frequency). Higher levels can provide information about the nature of such high frequency components according to their sub-bands frequency coefficient values and time location.

The disturbances likely to occur in power transformers are the transient components that decay quickly; as a result, the desired features are located in the high sub-band frequency coefficients present in the processed signal. The proposed wavelet disturbance detector and classifier algorithm is to construct the frequency sub-bands such that the disturbances can be detected and classified. In addition, important features for signal classification are characterized by local information in both time and frequency domains. This fact is true particularly for signals with transient components. Thus, the frequency-time relationship implying the localization of all frequencies in time provides effective settings for extracting different features of the analyzed disturbance. The extraction of these features can provide an efficient tool for recognizing and classifying the investigated disturbance.

The frequency components can be extracted from the details (outputs of high pass filters). The details of each level of resolution ($d^j$) details contain frequency components with more or less the shortest duration and highest transient components. The evaluation of the sub-band frequency coefficients in the second level of resolution provides an accurate
and effective classification tool for the investigated disturbances. Figure 2 shows a flow chart of the proposed algorithm.

![Flowchart for the proposed disturbance detector and classifier algorithm](image)

**Fig. 2** Flowchart for the proposed disturbance detector and classifier algorithm

4. TEST CASES FOR THE PROPOSED ALGORITHM

The proposed algorithm for disturbance detection and classification is developed, and can be tested on collected data. Several cases were tested. However, few of them are presented in this paper. The test cases to be presented in this paper are:

- Power transformer magnetizing inrush currents
- Power transformer internal fault currents
- Harmonic distortion
- Voltage dip

These test cases represent different common transient disturbances in power systems. In addition, these cases represent faulty as well as non-faulty conditions.

## I- Magnetizing Inrush Current

In this case, a 3φ, 5 kVA, Δ-Y, 60 Hz power transformer is energized and the differential current is collected, then MATLAB is used for carrying out the wavelet analysis. Figure 3 shows the three sub-bands frequency coefficients of the inrush current.

![Sub-bands frequency coefficients for the magnetizing inrush current](image)

**Fig. 3** The sub-bands frequency coefficients: (a) is $a_1$, (b) $d_1$, (c) is $aa$ and (d) is $dd$ for the magnetizing inrush current

## II- Power Transformer Internal Fault

In this case, the same power transformer used in section I is used, and a single-line to-ground fault is created on the secondary side, and the differential current is collected. It is to be noted that the

![Sub-bands frequency coefficients for the fault current](image)

**Fig. 4** The sub-bands frequency coefficients: (a) is $a_1$, (b) $d_1$, (c) is $aa$ and (d) is $dd$ for the fault current
transformer is not loaded. The MATLAB is used to carry out the wavelet analysis. Figure 4 shows the three sub-bands frequency coefficients of the fault current.

**III- Load Side Harmonic Distortion**

In this case, the load voltage is simulated with 3rd and 5th harmonics present. The MATLAB is used to carry out the wavelet analysis. Figure 5 shows the three sub-bands frequency coefficients of the load line voltage.

**IV- Load Side Voltage Dip**

In this case the load line voltage is assigned a value of 0 V for short time. The MATLAB is used to carry out the wavelet analysis. Figure 6 shows the three sub-bands frequency coefficients of the load line voltage.

The tested cases in this paper show that the wavelet analysis is capable of generating sub-bands frequency coefficients that are able to detect and classify any disturbance. Also, the disturbances tested using the proposed algorithm have frequency coefficients, which are localized with time.

The proposed disturbance detector and classifier has been implemented and tested on-line. However, the limitation of the paper size dose not allow for presenting more results.

**5. CONCLUSION**

In this paper, an innovative algorithm for accurate, quick and reliable transient disturbance detection and classification has been developed and tested. The proposed algorithm is based on the wavelet analysis, which can carry out signal analysis regardless of the signal characteristics. Some cases are tested in this paper including protecting a power transformer, and classifying non-fault disturbances related to power quality issues. The test results show powerful capabilities of the proposed algorithm to detect and classify different disturbances.

**REFERENCES**


