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Detection of Sag and Swell Disturbances in a Micro Grid Using Wavelet and Wavelet Packet Transform

[1]Basanta K. Panigrahi, [2]Prakash K. Ray, [3]Pravat K. Rout, [4]Kumaresh Pal and [5]B. Mohanta

[1]Department of EE, S'O'A University,
Bhubaneswar, India.
basanta1983@gmail.com;
[2]Department of EE, IIIT,
Bhubaneswar, India,
pkrayiiit@gmail.com
[3]Department of EEE, S'O'A University,
Bhubaneswar, India.
pravatrout@soauniversity.ac.in
[4]Department of EEE, MITM,
Jamshedpur, India.
Kumaresh.Pal@rediffmail.com,
[5]Department of EEE,
CUTM, Bhubaneswar, India.
bibhusmita92@gmail.com

Abstract

Due to power quality issues the fault analysis and detection is essentials for utilities. The failure of insulation is considered to the most important cause for the failure of the transformer. During the impulse test the comparison of neutral currents at full voltage and at reduced voltage is done for the detection of fault in power transformer. The minor faults like inter-fault cannot be determined by this. A new approach for the detection of this fault is done in this paper, which is based on the wavelet transform. The obtained results from the experiment are analysed using Haar wavelet and dB-4 discussed.

1. Introduction

Different signal processing techniques are being implemented in this context, out of which wavelet transform (WT) is an efficient technique for detection based on time-frequency localization (Dubey et al. 2011, Cheng et al. 2008). In identifying disturbance features WT is very versatile and can easily detect any irregularities in the signal. By the detection techniques any sudden changes are to be detected, so that to protect the power system from any type of disturbances a suitable solution can be adapted. The proposed method performances under different operating scenarios are being analyzed like in presence of noise, harmonics and frequency variations. Wavelet transforms (WT) [1-2]. Wavelet Transform (WT) and Wavelet Packet Transform (WPT) have been purposed for the detection of PQ problems [3]. In steady state power harmonics analysis can be done by using Discrete Fourier Transforms (DFT). Wavelet transforms (WTs) and Wavelet packet transforms (WPTs) are the solutions to the problems of DFT and STFT. Both the Wavelet transforms (WTs) and Wavelet packet transforms (WPTs) does the Non stationary signal analysis. Characterization of Power Quality (PQ) disturbances has become more efficient and effective with the emergence of Wavelet Transform (WT) [5]. In power system, Wavelet transforms (WTs) are very fast and effective for the detection of PQ disturbances. Discrete wavelet transform (DWT) has the advantage of multi resolution analysis (MRA) based signal decomposition (MSD) which analyzes signal with different resolutions of different frequencies [7-8].

2. Power Quality Disturbance Detection

Wavelet Transform

Wavelet is a method which is applied to decompose a signal/function into different components and associate a frequency band to each of them. WT also changes the frequencies and scales of the analyzed signal and components. WT requires different set of possible basis functions which can be formulated to improve the performance and does not require a fixed basis function as in case of Fourier transform (FT). The voltage signals of the system is extracted and processed by Haar mother wavelet to detect and decompose the disturbances (Fernandez et al. 2002, Yadav et al. 2014). To obtain approximation (A) and detail (D) coefficients the voltage is then filtered out by a series of low and high pass filters. The decomposition in of approximation and detailed components are expressed as:

$$A_1(n) = \sum_k H(k-2n)\, C_0(k);$$
$$D_1(n) = \sum_k G(k-2n)\, C_0(k) \tag{1}$$

Where, $H(n)$ is low-pass and $G(n)$ is the high-pass components of filter. For every decomposition scale, approximate and detail coefficients $(A_1(n) \& D_1(n))$

is determined for time-frequency analysis of the signal, $C_0(n)$.

$$E_{signal} = \frac{1}{T}\int_0^T |V(t)|^2 dt = \sum_{n=0}^{K} |V[n]|^2 \quad (2)$$

Where T and K are time period and signal length, respectively, and $V[n]$ is Fourier transform of the signal. Then, energy can be calculated by WT (Ackermann et al. 2005).

$$E_{signal} = \int |y(t)|^2 dt = \sum_{k=-\infty}^{\infty} |c(k)|^2 + \sum_{j=jo}^{\infty}\sum_{k=-\infty}^{\infty} |d_j(k)|^2 \quad (3)$$

The standard energy and deviation is calculated from the detail component (d1) of the voltage signal. A signal processing algorithm which is used in detection of abnormal operating conditions based on decomposition of the power signals into different ranges of frequencies by the help of a series of high-pass and low-pass filters is called the wavelet transform.

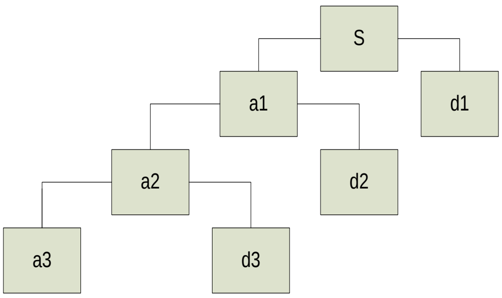

Figure 1: Wavelet Decomposition Tree

A time-frequency multi-resolution analysis that is greatly useful for identifying any short of abrupt variations in the electrical parameters such as voltage, current, frequency, phase etc is usually provided by WT. Here, for the fault detection analysis Daubechies4 (dB4) is being used as the mother wavelet basis function (Ukil & R. Živanović 2007). Usually, the signal is divided into a set of approximate (a) and detail (d) co-efficient representing the low-frequency and high frequency bands respectively. The decomposition is as presented above in Figure 1. Considering a voltage signal of the power system as $V(t)$, the continuous wavelet transform (CWT) is expressed as:

$$CWT(V,M,N) = \frac{1}{\sqrt{a}}\int_{-\infty}^{\infty} V(t)\Psi^*\left(\frac{t-N}{M}\right)dt \quad (4)$$

Where M and N are called as dilation and translation parameters and Ψ is known as the wavelet basis function. Now WT in discrete form as:

$$DWT(V,M,N) = \frac{1}{\sqrt{M_0^m}}\sum_k V(k)\Psi^*\left(\frac{n-kM_0^m}{M_0^m}\right) \quad (5)$$

Wavelet Packet Transform

Wavelet Packet Transform (WPT) is one of new technology used for the classification of fault and for the identification of the faulted section in the power system [6]. In Wavelet Packet Transform (WPT) feature extraction is done by decomposing the signal into different frequency bands of both low and high pass components by low and high pass filters. By selecting the original image feature extraction method is used for getting the desired information. To decompose the original PQ signals into frequency bands the WPT was first applied. It has the ability to decompose the signals at different resolutions and for this reason precise feature extraction is possible from non-stationary signals. Features like energy, entropy are extracted after decomposition from the signal [4]. Decomposition of signals as shown in Figure 2. The functions generated from one single function by dilations and translations of a unique admissible mother wavelet $\psi(t)$ are the Continuous wavelets functions;

$$\psi_{ab}(t) = \frac{1}{\sqrt{a}}\psi\left(\frac{t-b}{a}\right), a, b \in \Re, a \neq 0 \tag{6}$$

Here a, b and t is are the scale, translation parameters and time respectively. The function set $\Psi_{a,b}(t)$ is called wavelet family. Both the scaling and wavelet functions are used for the transform representation. Generally, discrete wavelet family parameters scale and shift parameters are given by $a = a^j 0$ and $b = kb0$ aj0, Here j and k are integers.

Discretized parameters function family becomes:

$$\psi_{j,k}(t) = a_0^{-j/2}\psi(a_0^{-j}t - kb_0) \tag{7}$$

Where $\Psi_{j,k}(t)$ is called the discrete wavelet transform (DWT) basis.

For getting the detailed and approximation information, Discrete wavelet transform decomposes the signal at different resolution and at different frequency band. Two different set functions such as scaling functions $\varphi(t)$ and wavelet function $\psi(t)$ are employed for DWT. These are related with which high-pass and low-pass filters.

The original signal $x(t)$ can be decomposed to:

$$x(t) = \sum_k c_j(k)\varphi_{jk}(t) + \sum_{j=1}^{j}\sum_k d_j(k)\varphi_{jk}(t) \tag{8}$$

Where j is the level number of the wavelet decomposition, $j = 1,2, \dots .J$ with J the time of the wavelet decomposition. c_j and d_j are the approximation coefficients and detail coefficients of $x(t)$, respectively.

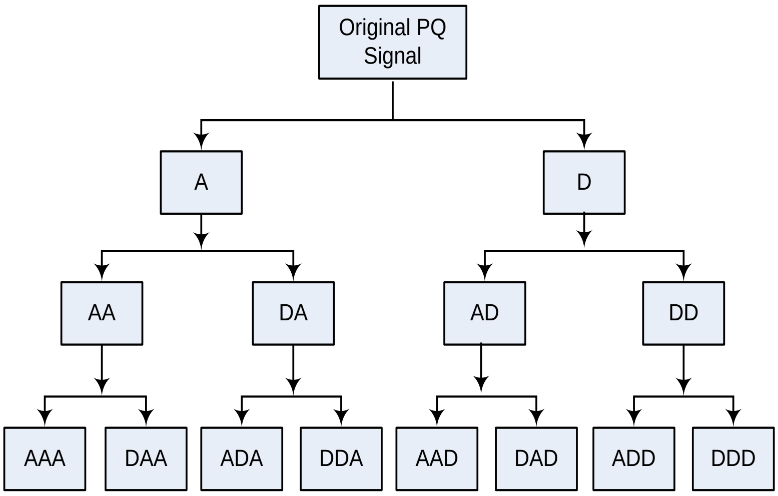

Figure 2: Wavelet Packet Decomposition Tree

3. Result Analysis

Fault Detection using Wavelet Transform

At point of common coupling (PCC) the voltage signal is taken offline under AG fault. Based on filtering through a set of low-pass and high-pass filters the signal is processed through WT which detects the fault instantly. The voltage signal with its detection result is shown in Figure 3. Similarly, the detection result using AB and ABCG fault is shown in Figure 4 and Figure 5 respectively. These results clearly show that WT detect the fault initiation instant nicely. But, as noticed when the fault is cleared, as shown in Figs., the recovery to normal waveform by wavelet transform is un-noticed.

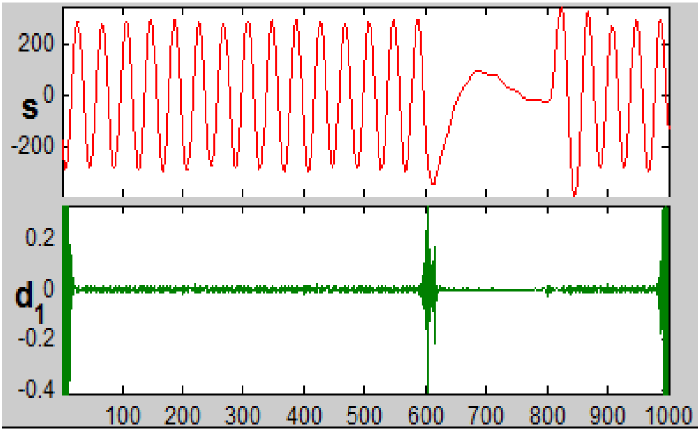

Figure 3: Detection of Phase-to-Ground Fault in Wind System Connected to Grid (Red-Voltage Signal; Green-WT Output)

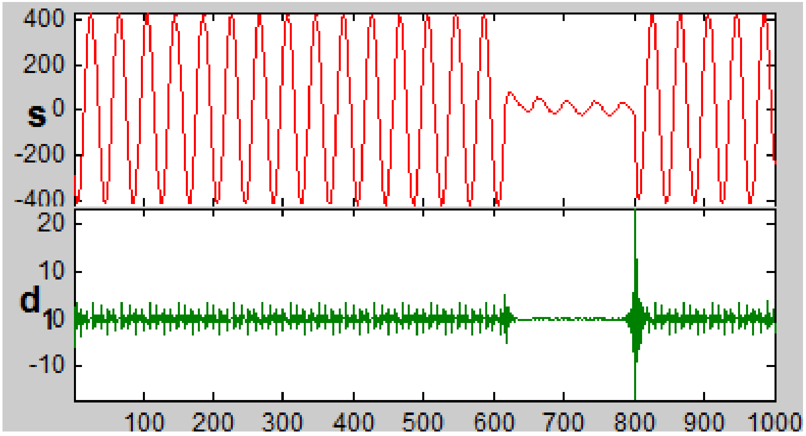

Figure 4: Detection of Phase-to-Phase Fault in Wind System Connected to Grid (Red- Voltage Signal; Green-WT Output)

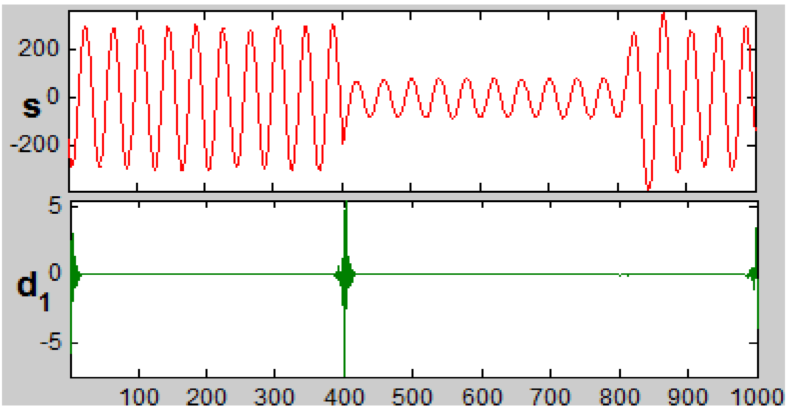

Figure 5: Detection of three-Phase-to-Ground Fault in wind System Connected to Grid (Red- Voltage Signal; Green-WT Output)

The study of detection of fault disturbances is presented by this sub-section. The voltage signal at bus-13, similar to the previous section, where the wind turbine is connected, is being measured and taken offline for processing. When there is an AG fault in the line connected between bus-13 and bus-14, this signal is collected at the bus. Of course, both the voltages at the buses are affected. But, for study the voltage signal at bus-13 is taken into account in order to know the effect of fault as well as wind turbine on the voltage. With its detection results by detail and approximate coefficient of Haar wavelet the voltage signal is presented in Figure 6. As seen that the fault occurs at about 60 secs in the signal and the corresponding detection in the detail and approximate coefficients of Haar wavelet are reflected in figure. The instant fault occurrence is clearly detected from the detail coefficient with a sudden increase and oscillation of magnitude and when the fault is cleared, the voltage and its coefficients become normal.

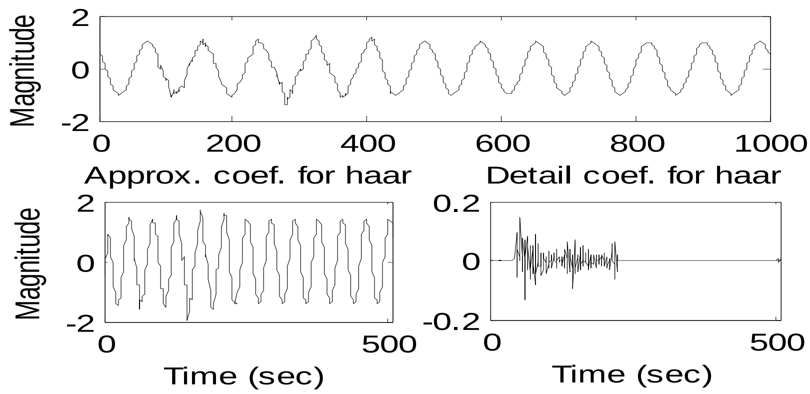

Figure 6: AG Fault Detection at Bus-13 using Wavelet Transform

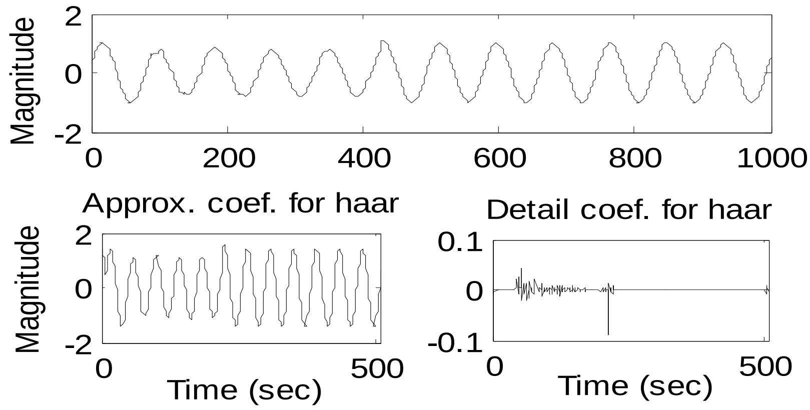

Figure 7: AB Fault Detection at Bus-11 using Wavelet Transform

Similarly, the detection results for a AB fault in the connected line near bus-11 is shown in Figure 7. The variation which is also being detected by the wavelet coefficients is represented by the voltage signal. As soon as the fault is cleared, the signal as well as the coefficient comes to the normal operating conditions.

Simulation Result of Wavelet Packet Transform

The detection of power quality events using wavelet transform as well as wavelet packet transform is described by this section. By switching load operation different types of PQ disturbances are created in the considered grid-connected PV system. At point of common coupling the voltage signal is retrieved and is being passed through the wavelet packet as well as wavelet transform. The detection results as shown in Figures.8-11, clearly shows that the voltage swell as well as voltage sag disturbances in PV system is nicely detected by both wavelet and wavelet packet transform.

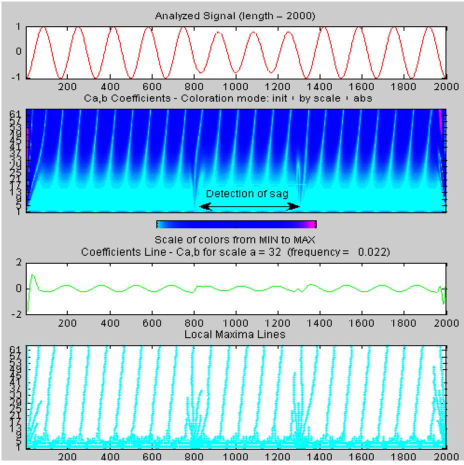

Figure 8

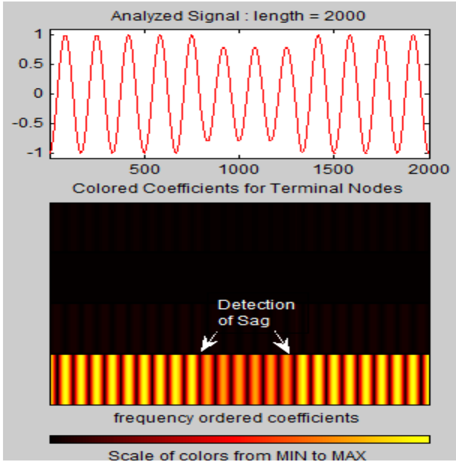

Figure 9

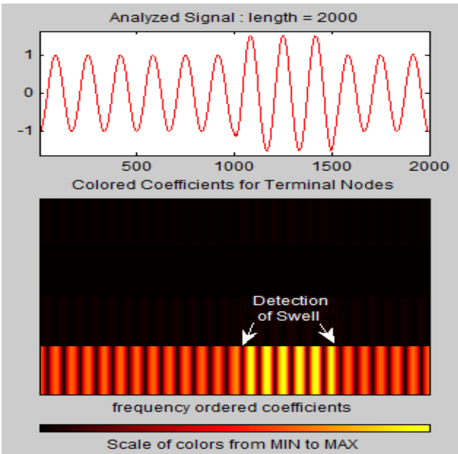

Figure 10

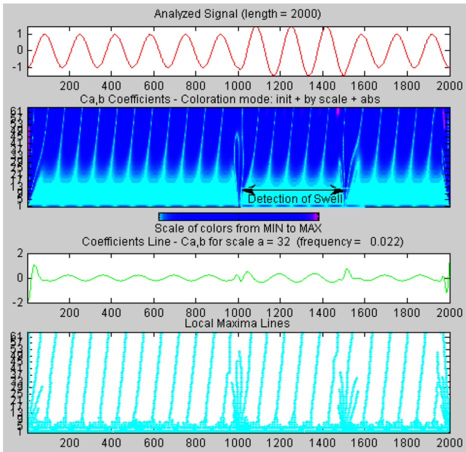

Figure 11

Table 1

PQ Disturbance	Mean	Standard Deviation	RMS Value	Entropy
Sag	4.1314e-06	0.6749	0.6747	4.8492
Swell	2.4869e-06	0.8100	0.8098	4.4993
Normal	0.0428	0.7281	0.7279	4.1527

The results reflect that wavelet packet transform because of the detail decomposition of various frequency range shows better detection performance. In addition, performance indices such as RMS value, mean, standard deviation and entropy are calculated so that threshold values can be selected based on which the type of power quality disturbance can be identified. The values are presented in Table 1.

4. Conclusion

In this paper we have studied different power quality problems in grid when connected to the photovoltaic system. Various power quality problems such as sag, swell in voltages are created by switching loads on the PV system and the waveform is collect from the point of common coupling .This recorded wave is passed through the wavelet and wavelet packet transform for the detection of the abnormalities and analysis. Due to MRA the transformation able to analyse the disturbance.

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