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Wavelet Based Real Time Power Disturbances Monitoring

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Abstract:
This paper describes a Discrete Wavelet Transform to detect and classify different types of power quality disturbances like voltage sag, voltage swell and voltage momentary interruptions with the help of Discrete wavelet transform (DWT). In discrete wavelet transform analysis given disturbance signal is decomposed into other signals which represent an approximate coefficient and the detailed coefficient of the original signal. In this Simulink model, wavelet multi-resolution analysis technique was used to decompose the voltage signal into various approximate and detailed signals. A unique feature from the 1st and 6th level detailed coefficients are obtained as criteria for detecting and classifying different types of power disturbances.DWT coefficients based approach for the energy contents in the different frequency zone are proposed. The proposed detection algorithm provided meaningful detection for various power disturbances. The real time simulation performed for the power quality disturbances by using real time simulator OPAL-RT (OP4510).

Keywords: Power disturbances**,** Discrete Wavelet Transform **(**DWT), real time simulation, hardware in loop (HIL)

I. INTRODUCTION

The quality of electric power has become an important issue for electric utilities and consumers. The consumers, in particular, are the party who face a major detrimental effect of their load due the PQ problem or technically define as power disturbances. These disturbances have degraded the performance and efficiency of consumers' loads; especially power electronics load. The subject of PQ encompasses most area of power engineering starting from generation to the endusers In seeking relief, electric power utilities and consumers turn to inspect, monitor, record and analyze of the electric power to determine the problem and the correct mitigation technique in order to mitigate the occurrences of the disturbance Now a days, electrical power quality has become an important issue.

For the higher efficiency and the good performance of the electrical equipment, demand of the clean power is increased. Reason behind this is the increasing use of microelectronic processors in various types of equipment such as computer terminals, programmable logic controllers (PLCs), diagnostic systems, etc. Most of the devices among then are sensitive to the disturbances of supplied power. Electrical power quality is nothing but maintaining sinusoidal waveform power distribution bus voltages at rated voltage magnitude and frequency. Wide frequency spectrum is cover up by the power quality disturbances in electrical power system. It's in the range of a few Hz in case of flickers to a few kHz in the case of transients. On the other hand, electric power quality disturbances can be consider as any deviation, distortion, or departure from a sinusoidal voltage waveform at rated magnitude and frequency. Utility and the customer are interconnected to each other with the help of power distribution system. Therefore any disturbance generated on the generator side propagates on the customer side. In the same manner, disturbance generated at any customer side will affect the power quality of other customer since they are interconnected. As per the IEEE-519 and IEC-61000 by limiting the harmonics current drawn by the customer, the voltage distortion can be kept within the acceptable range [1][2].

Instead of building actual prototype it's cost effective to model and simulate the simulation in simulating tools. It is challenging to implement actual prototype to identify early defects in the system which may be time and cost consuming. In actual industrial practice it's common to test the simulation of system in the real time environment before actual hardware implementation. Real time simulation for wavelet based power disturbances monitoring system is performed in the real time simulator OPAL-RT (RT-LAB), supported by MATLAB environment. For this purpose OP4510 is used [3].

II WAVELET TRANSFORM ANALYSIS

Now-a-days with the advent of the digital techniques, onsite and online monitoring of power quality disturbance is possible. For the detection of PQ disturbances recently the wavelet transform (WT) has emerged as a powerful tool. Wavelet function which used as the basis function in wavelet transform scales itself according to the frequency under analysis. Since the scheme uses wavelet as basic function in WT instead of an exponential function used in FT and STFT it gives better results [4][5].

Signal is decomposed into different frequency levels and presented as wavelet coefficients by using WT. Continuous wavelet transform (CWT) and discrete wavelet transform (DWT) are employed on the basis of the type of signal.

CWT based decomposition is adopted for continuous time signal and DWT based decomposition is employed for discrete time signal [6]. Since all the signals shown in this work are discrete in nature hence DWT based decomposition is used herein this part of the work different PQ disturbances such as Voltage Sag, Voltage Swell, Voltage Interruption are generated using MATLAB and then decomposed using decomposition algorithm of WT. On that basis point of actual disturbance is located and type of disturbance is detected.

A) Continuous wavelet transform (CWT):

$$CWT(a,b) = \int_{-\infty}^{+\infty} x(t)\Psi^{*}a,b(t)dt \quad a>0 \qquad (1)$$

Where,

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}}\Psi\left(\frac{t-a}{b}\right) \quad a>0 \text{ and } \quad -\infty < b < +\infty$$

Where $x(t)$ is the signal to be analyzed, $\psi a,b(t)$ is the mother wavelet shifted by a factor (b),scaled by a factor (a), large and low scales are respectively correspondence with low and high frequencies, and * stands for complex conjugation.

B) Discrete Wavelet Transform (DWT):

CWT generates a huge amount of data in the form of wavelet coefficients with respect to change in scale and position. This leads to large computational burden. To overcome this limitation, DWT is used. In other words, in practice, application of the WT is achieved in digital computers by applying DWT on discretized samples. The DWT uses scale and position values based on powers of two, called dyadic dilations and translations.. To do this, the scaling and translation parameters are discreted as $a=a0m$ and $b=nb0a0m$, where $a0>1$, $b0>0$, and m, n are integers, then the DWT is defined as:

$$DWT(m,n) = \int_{-\infty}^{+\infty} x(t)\Psi^{*}m,n(t)\,dt \qquad (2)$$

Where $\Psi_{m,n}(t) = a_0^{-m/2}\Psi((t-na_0^m b_0)/a_0^m)$

is the discretized mother wavelet. The DWT, based only on subsamples of the CWT, makes the analysis much more efficient, easy to implement and has fast computation time, at the same time, with the DWT, the original signal can be recovered fully from its DWT with no loss of data. As long as the sampling frequency is chosen properly continuous-time signal can be represented in a discrete form. This is done by using the sampling theorem also known as Nyquist theorem [7]. The sampling frequency used to turn the continuous signal into a discrete signal must be twice as large as the highest frequency present in the signal (Oppenheim & Schafer, 1989). For implementation of the DWT, an approach can be developed called as Multi-Resolution Analysis technique. By using this approach the signal can be decomposed, then this signal passed through the high pass filter and low pass filter with various cut off frequencies at different levels [8]. In case of discrete wavelet transform analysis the low frequency content is called the approximate coefficient (A) and the high frequency content is called the detailed coefficient (D). This procedure can be repeated for decomposition of the approximate coefficient obtained at each level until the desired level is reached as shown in Fig.1.

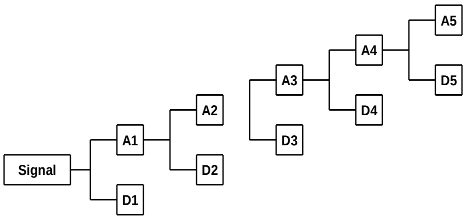


Figure.1. Decomposition tree for DWT

III PROPOSED METHOD TO DETECT POWER DISTURBANCES

The wavelet transform coefficients characterized as the signal energy, these coefficients are used to measure the voltage disturbance magnitude in distorted signal. For real time application of wavelet transform as a power disturbances monitoring tool, it is essential to detect disturbances in minimum time. Therefore, distorted signal is processed through time window of fixed frame length(size). Length of the frame is the number of sample points of discrete data signal included, for which energy has to be calculated. The time window moves forward along the signal and hence energy is calculated for each frame. Frame length decides the response time of the method.The developed detection method of power quality disturbance is based on the discrete wavelet transform and evaluation of wavelet energy. In this proposed method, the sampled signal is used as input for analysis. After decomposition of the signal for required level, the wavelet energy is calculated as shown in Fig.4.

The algorithm consists of following four steps:

- Forming a frame
- Decomposition of frame into required level
- Evaluating DWT coefficients
- Calculation of wavelet energy

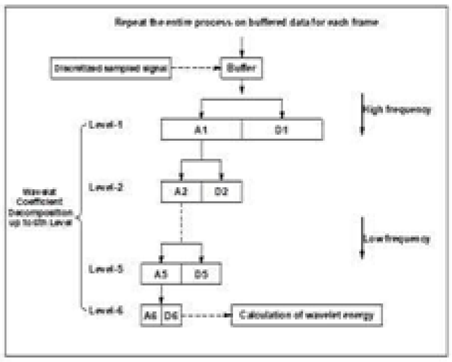


Figure.2. Calculation block of Wavelet Energy

For calculation of wavelet energy coefficients the above number of step used are shown in Fig.2. The important parameters which need to be decided are type of wavelet transform, mother wavelet function, sampling frequency, buffer size and decomposition level. For 6^{th} level signal decomposition, a fixed length of frame of sample points 512 is used to obtained fast response of time. According to Nyquist theorem the sampling frequency has to be selected and 6^{th} level is the level of signal decomposition.

IV. WAVELET ENERGY

In wavelet domain, the signal is analysed into the approximate coefficient and detailed coefficient. Therefore, energy is dissipated by the signal as approximate and detailed coefficient and can be calculated mathematically by following equation(3). Parseval's theorem states that: 'In time domain the energy contain function is equal to the addition of all energy concentrated in different resolution levels of wavelet energy transformed signal of the same function.'

$$\sum_{n=1}^{N}[x(n)]^2 = \sum_{n=1}^{N}[a_j(n)]^2 + \sum_{j=1}^{J}1\sum_{n=1}^{N}[d_j(n)]^2 \qquad (3)$$

Where x (n) is the signal in time domain, N is the total

$\sum_{n=1}^{N}[a_j(n)]^2$ is the total energy of approximate coefficients of signal concentrated at j^{th} level.

$\sum_{j=1}^{J}1\sum_{n=1}^{N}[d_j(n)]^2$

is the total energy of detailed coefficients of signal concentrated from levels j=1 to j=J and is the total energy of the signal in discrete time domain.

V. CHOICE OF MOTHER WAVELET

For detecting and classifying the different types of power disturbances, the choice of mother wavelet plays an important role. Daubechies mother wavelet with 4,6,8 and 10 filter coefficient works well in most power disturbances detection cases. The original signal to be decomposed is multiplied with the selected mother wavelet to obtain the scaled and translated version of the original signal at different levels. There are several mother wavelets such as, Daubechies Morlet, Haar, Symlet etc. exists in wavelet library but literatures revealed that for power quality analysis Daubechies wavelet gives the desired result. Again the Daubechies wavelet has several orders such as Db2, Db3, Db4, Db5 Db6, Db7 Db8, and Db10etc. Based on the detection problem, the power qualities disturbances can be classified into two types, fast and slow transients. In the fast transient case the waveforms are marked with sharp edges, abrupt and rapid changes, and a fairly short duration in time. In this case Daub4 and Daub6 give good result due to their compactness. In slow transient case Daub8 and Daub10 shows better performance as the time Interval in integral evaluated at point n is long enough to sense the slow changes.

A. Investigation of Power disturbances using DWT

The power disturbances like voltage sag, voltage swell and voltage momentary interruptions are simulated for each case, change in wavelet energy is plotted. The signal specifications

is as follows:

T=0.2sec
Fs=10 kHz
F=50Hz
No. of Cycles=10
No. of Sample points/cycle=200,

Duration of Power Quality Disturbances=200ms (between 600ms to 800ms sampling points)

To detect the power quality issues, signal is decomposed upto 6th level. Daubechies4 (Db4) mother wavelet function is used due to its good time localization characteristics.

VI. REAL TIME SIMULATION USING OPAL-RT

Opal-RT is leading testing equipment use for the hardware-in-loop and software-in–loop testing for various electromechanical, power electronics and electrical power system [9]-[10]. Opal-RT is used for validating results of system simulation which is to be tested in real time. Simulation model of small power system, which includes 3 phase source and load, with wavelet based monitoring technique is developed as shown in Fig. Fundamental frequency of power system is 50 Hz. Three phase fault is introduced and controlled by external switch through hardware in loop simulation.

Db4 wavelet function is applied for up to 6th level decomposition. Hence, buffer size of 512 bit is taken accordingly. Sampling frequency and frame length is an important parameter for wavelet coefficient depends on the nature of signal and its degree of distortion.

Fig. shows the real time simulation model of power disturbances monitoring system developed in MATLAB. The disturbance is created by applying fault block in the MATLAB simulation model.

Figure.3. OP4510 Hardware

The simulation model developed in MATLAB is as shown in Fig 6 to study the performance of wavelet tool for analyzing the different voltage waveforms with different types of disturbance and distortion such as voltage sag, voltage swell and voltage interruption.

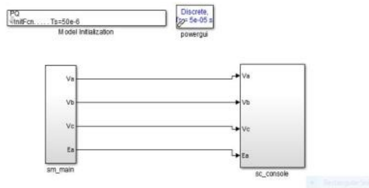


Figure. 4. Simulation model for analyzing types of disturbance in the signal through DWT

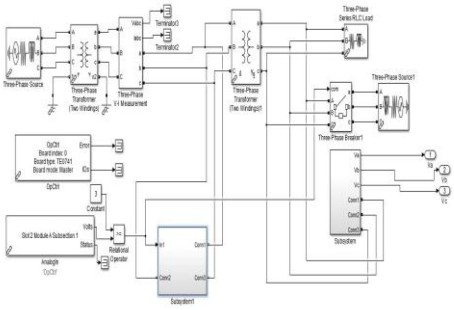


Figure.5. Main system

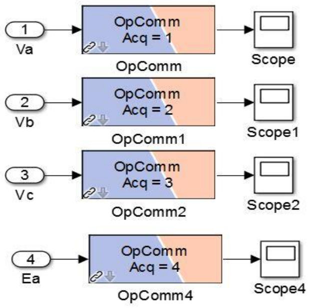


Figure.6. Console System

The schematic diagram of hardware-in-loop system shown in fig.4. Fig. 5 and Fig.6 shows the main and console system of the complete system. The real time simulation results are taken from the real time simulator(OP4510) and presented, from Fig.7 to Fig.11(c).

VII. OPAL-RT RESULTS

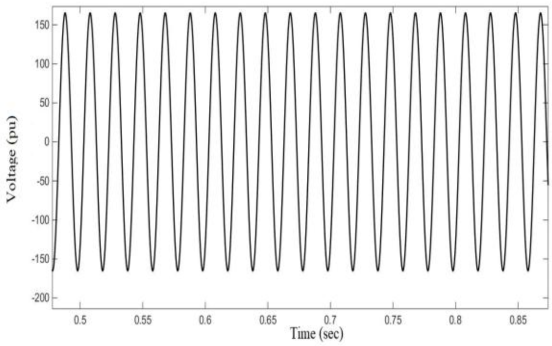


Figure.7.

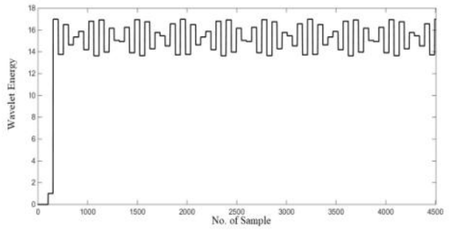


Figure. 8

Figure.7. and Fig.8 shows Normal Voltage waveform with its equivalent wavelet energy.

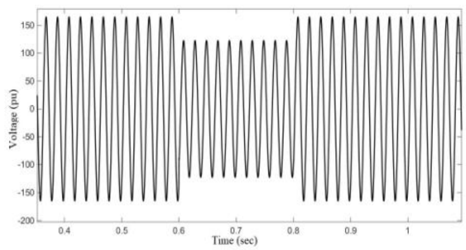
1) Voltage Sag

Voltage sag is defined as the decrement of the nominal rms voltage between 0.1 p.u. to 0.9 p.u. The duration of the voltage sag can be from 0.5 cycles to 1 minute. The general term for voltage sag is also known as the short duration decrease of the voltage. If the decrease of the voltage is longer then 1-minute, under voltage term is used. Generally, voltage sag is divided into three classes based on the duration of the occurrences. The classes are instantaneous sag, momentary sag and temporary sag. The expression used to simulate voltage sag is as follows:

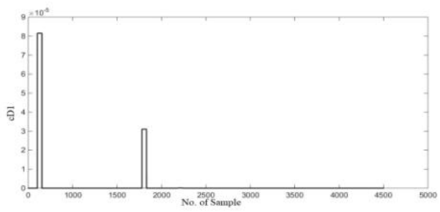
Y=n(t)*sin(2-pi*50) (4)

Where,

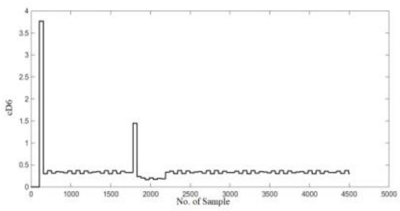
n(t)={1 t ϵ [0,0.6s]U[0.8s, 2s] and 0.5t ϵ [0.6, 0.8s]}



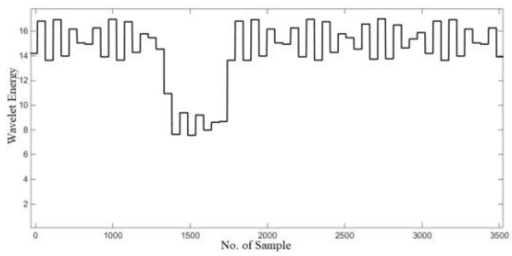
(a)



(b)



(c)



(d)

Figure.9 (a), (b) (c) and (d) shows Voltage Sag waveform with detailed coefficient (cD1), detailed coefficient (cD6) and its equivalent wavelet energy.

2) Voltage Swell

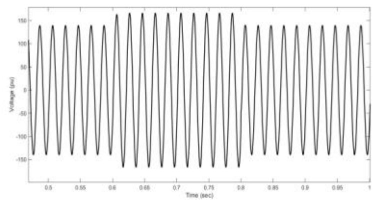
Voltage swell is defined as the increment of the rms voltage between 1.1 to 1.8 p.u. The frequency of the voltage swell occurrences is low compared to the voltage sag. Coincidently, the duration of voltage swell is the same as voltage sag, which is between 0.5 cycles to 1 minute. The factor that caused voltage swell is the starting of large motor, light system loading and incorrect tap setting of the transformer. The swell is also divided into three main classes namely; instantaneous swell, momentary swell and temporary swell. Like voltage sag, if the duration of increasing voltage exceed 1 minute, overvoltage term is preferable. Installing fast acting tap changers in the system can mitigate voltage swell. The consequences of this event are over heating of DC regulators and higher iron loss in most machines applications. The expression to simulate voltage swell is as follows:

The expression to simulate voltage swell is as follows-

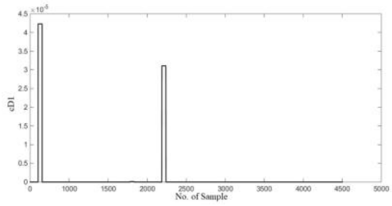
y=n(t)*sin(2*pi*50*t) (5)

Where

n(t)={1 t ϵ [0,0.6s] U [0.8s, 2s] and 1.4t ϵ [0.6, 0.8s]}



(a)



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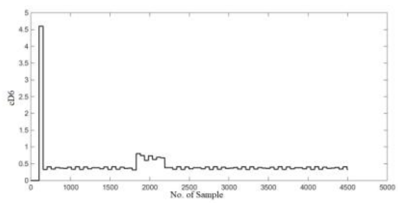
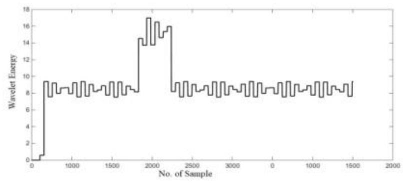


(c)



(d)

Figure.10. (a), (b) (c) and (d) shows Voltage Swell waveform with detailed coefficient (cD1), detailed coefficient (cD6) and its equivalent wavelet energy.

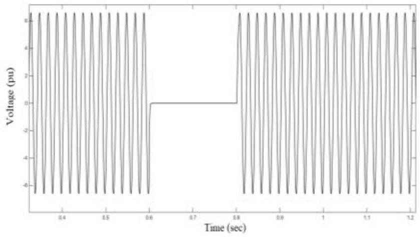
3) Voltage Interruption

Interruption is defined as the decrement in rms voltage less that 0.1 p.u. Most of the interruption occurs after the voltage sag. The interruption is resulted from the loose connection, severe fault and reclosing of circuit breaker. For the reclosing of circuit breaker action, transient phenomen followed by interruption can be observed. The interruption results in nuisance tripping and misoperation of the overall system. Interruptions show that the voltages are almost zero and nomore supply available into the system.The expression used to simulate voltage interruption is:

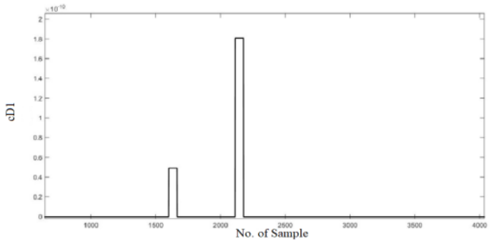
y=n(t)*sin(2*pi*50*t) (6)

Where

n(t)={1 t ∈ [0, 0.6s] ∪ [0.8s, 2s] and 0 t ∈ [0.6s, 0.8s]}



(a)



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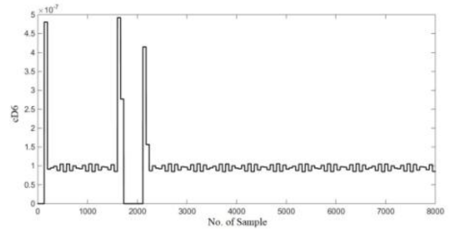

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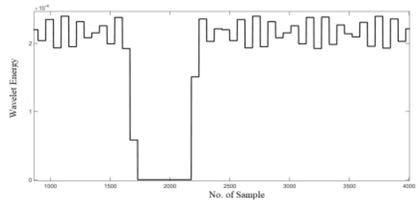

(d)

Figure.11.(a), (b) (c) and (d) shows Voltage Interruption with detailed coefficient (cD1), detailed coefficient (cD6) and its equivalent wavelet energy.

VIII CONCLUSION

DWT is a very useful mathematical tool for analysis of the distorted signal. In this paper, we can monitor the various power disturbances through wavelet energy distribution of a signal mapped in time and frequency domain by using DWT. In a time window have been studied the power disturbances such as voltage sag, voltage swell and voltage momentary interruptions. Based on real time simulation, it can be concluded that the proposed detection algorithm provides meaningful detection and classification of the various types of power disturbances. The novelty of work for power disturbances monitoring and verification, is done with RT lab and results are verified. The real time execution of it in OPAL-RT hardware. By using this method we can also classify and detect some other power quality issues like notch, frequency variations, flickers and harmonics.

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