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Characterization Of Power Quality Assets Through Wavelets

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Abstract— ***Owing to very rapid growth in electronics and technology, it has become very essential to maintain power quality at the consumer end. Since power quality has vast no of assets, mainly important and frequently occurring disturbances are considered in this paper. Power quality is mainly defined by disturbances associated with voltage. However, the voltage disturbances can be classified based on the duration of occurrence and magnitude. In most of cases, it is very difficult to identify the type of disturbance which is very essential for the operation of the circuit breaker because the circuit breakers should be operated based on severity of the disturbance and its effect on the loads. Power quality (PQ) disturbance recognition is the foundation of power quality monitoring and analysis. Though many analyzing tools exist for characterizing the disturbances, wavelets provide a better methodology. Wavelets have an added advantage of providing time and frequency information of a given signal.***

Key Words- Power Quality, Sag, Swell, Wavelets

I. Introduction

The increased requirements on supervision, control and performance in modern power systems make power quality monitoring a common practice for utilities. Studies of power quality phenomena have emerged as an important subject in recent years due to renewed interest in improving the quality of the electric supply. New tools are required to extract all relevant information from the recordings in an automatic way.

It is well known that the main power quality deviations are caused by short-circuits, harmonic distortions, notching, voltage sags and swells, as well as transients due to load switching. In order to rectify such problems, firstly, they should be detected and identified. Nevertheless, whenever the disturbance lasts only for a few cycles, a simple observation of the waveform in a busbar may not be enough to recognize whether there is a problem or, even more difficult to identify the sort of the problem.

Switching phenomena results in oscillatory transients in the electrical supply, for example capacitors switching contributes considerably to power quality (PQ) disturbances. In addition, high power non-linear loads add to the generation of current and voltage harmonic components. Among the different voltage disturbances that are produced the most noteworthy and critical power quality problems are voltage sags. Short-term voltage drops (sags) can trip electrical drives or more sensitive equipment, leading to interruptions of vital production.

Power quality problems arise with the association of any deviation in voltage, current or frequency resulting into an undesirable performance of customer's equipment. PQ problems relate to the basic system design, system maintenance issues, ensuring equipment protection within customer facilities.

Consequently, power quality monitoring and classification has become an essential service which many utilities perform for their customers. The monitoring and analysis tools must be able to detect, identify, and localize the disturbances on the supply lines and make proper system decisions. However, there is still further scope for research work to identify and classify the power quality problems with very high accuracy so as to keep the losses minimum.

The wavelet transform is a mathematical tool like Fourier transform in analysing a signal that decomposes a signal into different scales with different levels of resolution. Santoso et al proposed wavelet transform technique for the detection and localization of the actual power quality disturbances. Heydt and Galli proposed wavelet techniques for the identification of the power system transient signals. Fuzzy logic control technique has been discussed by Hiyama et al to enhance power system stability using static VAR compensator.

A hybrid scheme using a Fourier linear combiner and a fuzzy expert system for the classification of transient disturbance waveforms in a power system has been presented by Dashetal. Olivier et al investigated the use of a continuous wavelet transform to detect and analyze voltage sags and transients.

Due to the absence of field results different power quality problems have been simulated in the MATLAB/SIMULINK environment. The PQ data thus obtained matches the field data. Subsequently, using the Wavelet toolbox of the MATLAB, multi signal decomposition on the captured signals is performed.

Owing to various reasons mentioned above an attempt has been made in the present paper to classify the most commonly occurring power quality disturbances using wavelet analysis, Multi-resolution signal decomposition (MSD) using wavelet transformation (WT) is used as a basis for feature vector for obtaining the training and testing data.

II. Power Quality

The most common problems, like harmonics, short term voltage variations (sags, swells and interruptions), long term voltage variations (under voltages, over voltages and interruptions), transients, unbalance, frequency variations and others, can cause several problems to the consumers which require high levels of power quality for their industrial processes or domestic use. Power quality studies are the necessary first step in order to determine what is wrong, so that precautionary measures can be taken to solve the problems. Because many of the commercially available equipments are either too expensive, or have too many limitations, it was decided to develop a new low-cost power quality monitor that could be an alternative to the equipment in the market. There are indications that the harmonic distortion in the power system is rising, but no conclusive results are obtained due to lack of large scale surveys.

2.1 Power Quality Problems

2.1.1 Short Duration Voltage Variations

Voltage sag is a fundamental frequency decrease in the supply voltage for a short duration (5 cycles to 1 minute)

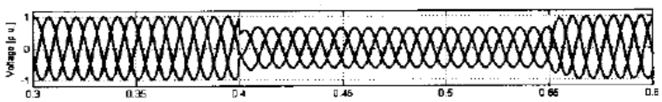

Fig.1 Balanced Voltage Sag

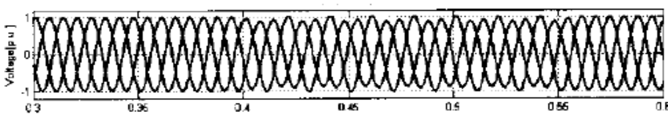

Fig.2 Unbalanced Voltage Sag

Voltage Swell is defined as increasing of fundamental frequency voltage for short duration.

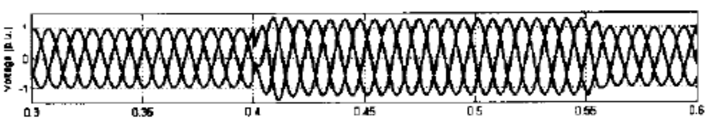

Fig.3 Balanced Voltage Swell

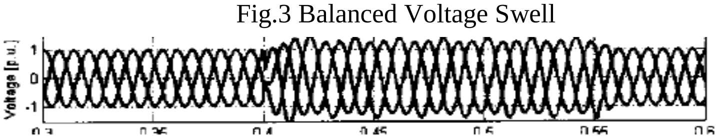

Fig.4 Unbalanced Voltage Swell

2.1.2 Long Duration Voltage Variations

These are the r.m.s variations in supply voltage at fundamental frequency for period exceeding one minute.

In a weak system the switching off of a large load or the energization of a large capacitor bank may result in an over voltage. The decrease in the supply voltage level to zero for more than one minute is called sustained interruption. Typical causes of sustained interruptions vary from place to place.

2.1.3 Voltage imbalance

This is the condition in which the voltages of the three phases of the supply are not equal in magnitude or equally displaced in time. The primary cause is the single phase loads in three phase circuits. These are however restricted to within 5%.Severe imbalance (greater than 5%) can result during single phasing condition when the protection circuit opens up one phase of a three phase supply.

2.1.4 Wave Form Distortion

Whenever fault occurs on power system we can't get pure sinusoidal voltage. The wave form is getting distorted from its original shape.

2.1.5 Voltage Fluctuations

These are systematic random variations in supply voltages. A very rapid change in supply voltage is called voltage flicker. This is caused by rapid variations in current magnitudes of loads such as arc furnaces in which a large inrush current flows when the arc strikes first causing a sag in the bus voltage. Other customers that are connected to the same bus face severe voltage drops.

2.1.6 Frequency variations

These variations are usually caused by rapid changes in the load connected to the system. The maximum tolerable variation in supply frequency is often limited within +5HZ or -5HZ from the nominal frequency of 50 or 60 HZ. The frequency is directly related to the rotational speed of the generators. Thus a sustained operation outside the tolerable frequency range may reduce the life span of turbine blades on the shaft.

2.2 Characterization of Disturbances

2.2.1 Sag/ Voltage sags

Decrease in voltage between 90 % and 10% of nominal voltage for a period of one-half cycle to one minute is treated as voltage sag.

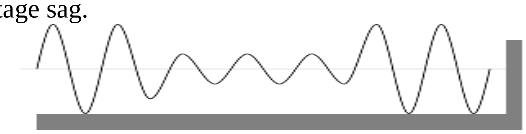

Fig.5 Voltage Sag

Under voltage is a decrease in voltage below 90% of its nominal value for more than one minute is treated as under voltage.

Fig.6 Under Voltage Sag

Typical voltage sag, as measured by the PQMS, is presented in Fig.7.

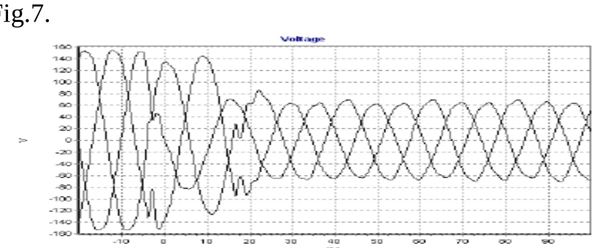

Fig.7 Typical Voltage sags

Voltage sags are caused by:

1. Energization of heavy loads.
2. Starting of large IM (Induction Motors)
3. Single LG(Line to Ground) faults
4. Load frequency from one power source to another.

2.2.2. Swell

A swell is the increase in RMS voltage level to 110% -180% of nominal for one- half cycle to one minute.

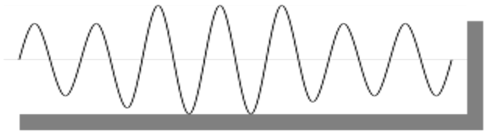

Fig.8 Voltage Swell

Over voltage is an increase in voltage above 110% of nominal for more than one minute.

Reasons of cause - Load Rejection
Effects -Overheat of electronic equipments
Possible Solution -Power conditioner

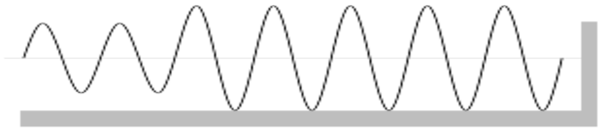

Fig.9 Over Voltage Swell

Causes of Voltage swells

1. Switching off of a large load
2. Energization of a capacitor bank
3. Voltage increase of the unfaulted phase during a single LG fault

III. Description of Wavelets

Most of the signals in practice are TIME - DOMAIN signals. But in many applications, the most distinguished information is hidden in the frequency content of the signal. Sometimes both frequency and time related information may be required. Mathematical transformations are applied to signals to obtain further information from those signals that is hidden and is not readily available in their raw format. Transforms widely used in signal analysis are:

1. Fourier transforms
2. Short time Fourier transforms
3. Wavelet transforms

3.1 Fourier Analysis

It is the analysis, which breaks down a signal into constituent sinusoids of different frequencies and infinite duration. Another way to think of Fourier analysis is as a mathematical technique for transforming our view of the signal from time-based to frequency-based.

Fig.10 Fourier analysis

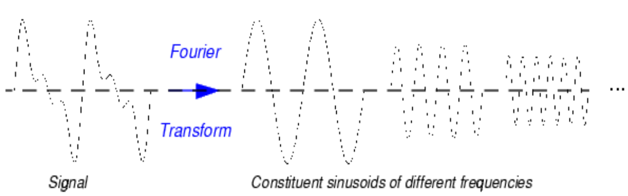

Fig.11 Breaking the signal into sine waves of different amplitudes using FT

For many signals, Fourier analysis is extremely useful because the signal's frequency content is of great importance.

3.2 Short-Time Fourier Analysis

There is only a minor difference between STFT and FT. In STFT, the signal is divided into small enough segments, where these segments (portions) of the signal can be assumed to be stationary. For this purpose, a window function "w" is chosen. The width of this window must be equal to the segment of the signal where its stationary is valid.

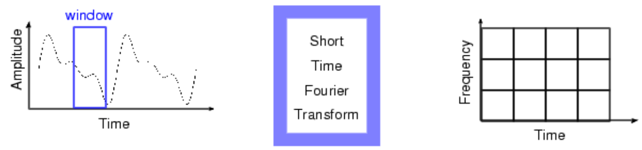

Fig.12 Short Time Fourier analysis

3.3 Wavelet Analysis

Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information. Wavelet analysis does not use a time- frequency region, but rather a time-scale region.

Fig.13 Wavelet Analysis

A wavelet is a waveform of effectively limited duration that has an average value of zero. Compared to sine waves, the basis of Fourier analysis, which do not have limited duration (they extend from minus to plus infinity) and are smooth and predictable, wavelets tend to be irregular and asymmetric.

Fig.14 Sine Wave and a Wavelet wave

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.

Just looking at pictures of wavelets and sine waves, it can be observed that signals with sharp changes might be better analyzed with an irregular wavelet than with a smooth sinusoid.

Wavelet is denoted by the symbol Ψ (t).

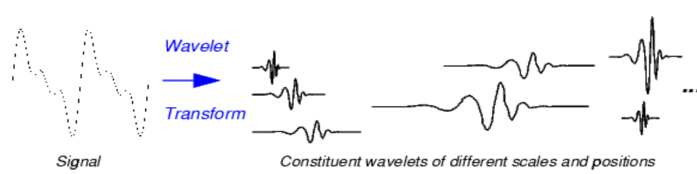

Fig.15 Breaking the signal into wavelets of different amplitudes using WT

IV. RESULTS

4.1 Power System Network

In this paper, we consider single source feeding to 0.8 MW and 0.4 MVAR load through a transmission line of 200 Km length at 5 KV. Here the test system has been simulated for normal loading condition, sag, swell and interruption. The MATLAB test system shown in fig.16.

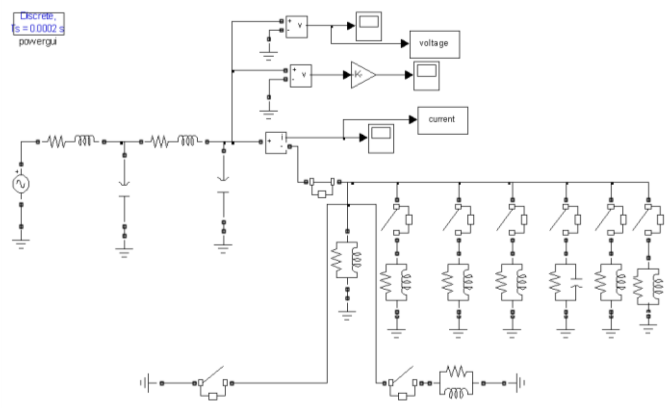

Fig.16 Matlab Test System

4.2 Specifications of Test System

Table: 1 Ratings of the test system

Source Values	Voltage = 4.6 kV	Frequency = 50Hz
Transmission Line Parameters	Resistance = 2.56 Ω Inductance = 20mH Capacitance = 0.86μF	
Auxiliary Loads Parallel RC Load	Active Power = 0.34MW Active Power = 0.18MW Active Power = 0.3 MW Active Power = 0.36MW Active Power = 0.38MW Active Power = 0.06MW	Q_L Power = 0.16 MVAR Q_L Power = 0.06 MVAR Q_L Power = 0.14 MVAR Q_L Power = 0.17 MVAR Q_L Power = 0.19 MVAR Q_L Power = 0.6 MVAR
Breaker Resistance	0.01 Ω	
Snubber Resistance	1 M Ω	
Total length of transmission line	200 KM	
Breaker Timings	[0.06 0.1]	

These are the specifications used to simulate the test system using MATLAB SIMULINK. The above network had simulated in MATLAB using Simulink blocks with the given specifications mentioned above.

4.3 Wavelet Algorithm

4.3.1 With Continuous Wavelet Transform

As the initial step, continuous wavelet transform is applied for power quality analysis. The given signal is first simulated with sampling frequency of 5 KHZ. The voltage signal values are then applied to Continuous wavelet transforms. Wavelets coefficient is a correlation of the wavelet energy and signal energy over a fixed scale. For n-level decomposition, there are n+1 possible ways to decompose or encode the signal.

$$W_f (a, b) = \int f (t)\ \Psi (at+b)\ dt$$

Where f (t) is the function to analyze, Ψ is the wavelet, and [Ψ (at+b)] is the shifted and scaled version of the wavelet at time b and scale a.

For applying wavelets to the required signal initially give the command as wavemenu in matlab command window. Then it opens a pallet which is shown in fig.17.

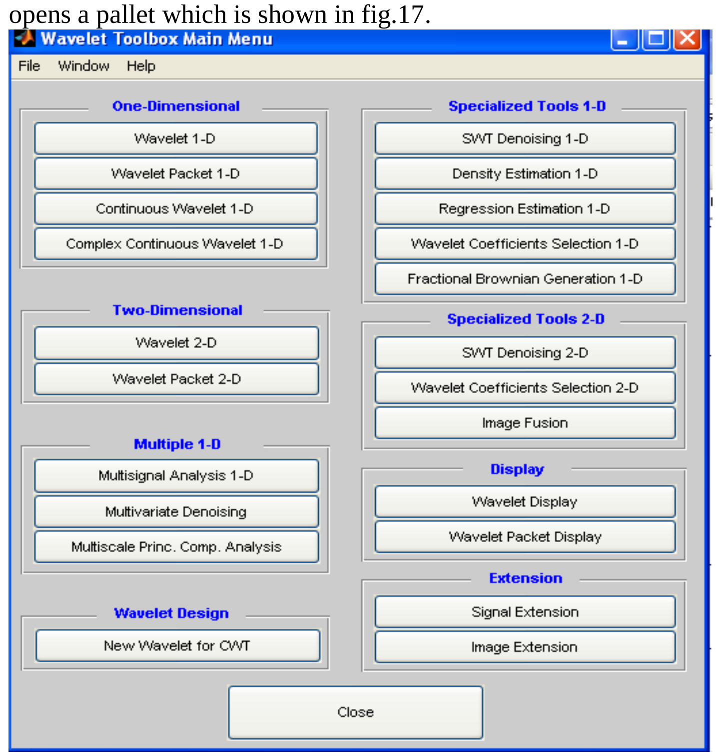

Fig.17 Wavelet Toolbox Main Menu

For applying of Discrete wavelet transform like on One-Dimensional wavelet 1 –D. Then load the signal and select the type of wavelet, number of levels and then apply to continuous Wavelet Transform.

4.3.1.1 Algorithm for Continuous Wavelet Transform

Step1: Start

Step2: Create the disturbance signal.

Step3: Measure the source voltage for with sampling time Ts=0.0002s.

Step4: Categorize source voltage signal into number of samples depending on number of cycles of disturbance.

Step5: Load the voltage signal and apply CWT for 4 levels.

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Step6: If the level is increased the frequency is half of the previous level.

Step7: If the signal is represents color means it has high strength, dark color means no signal.

Step8: Depending on the color coding
For normal voltage:-equal strength
Voltage sag: - less strength
Voltage swell: - high strength
Voltage interruption: - no signal

Step9: End

Case 1: Normal balanced condition

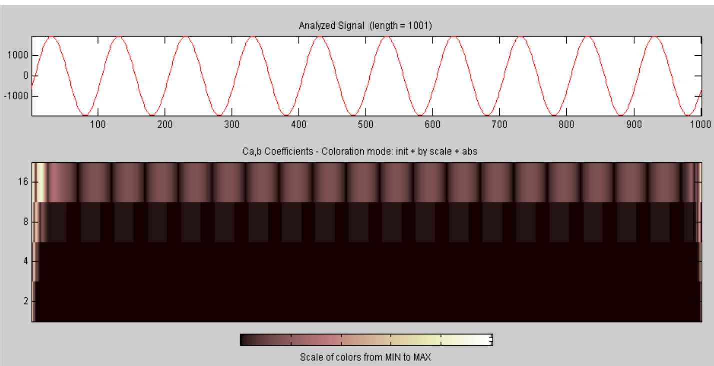


Fig.18 Continuous wavelet for normal voltage

Wavelet decomposition is done with sampling frequency of 2000HZ. At scale 2, the signal is entirely dark indicating there is no 2000Hz frequency component in the given signal. Energy at this frequency is very less. At scale 16, the signal is showing light colour means at that particular level frequency is matching with the input signal frequency. Higher the scale more is the accuracy. If the signal is present, there will be energy transfer from one half cycle to other indicated by square boxes in the figure. In the above fig.18 all the square boxes are identical. So the energy distribution of the total signal is same.

Case 2: For Voltage sag

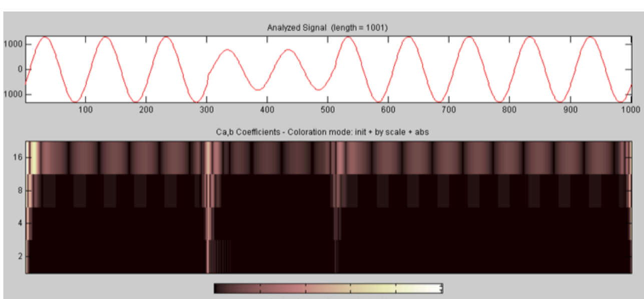


Fig.19 Continuous wavelet for Sag

For analyzing the voltage sag through continuous Wavelet Transform, first load the input signal. The width of all square boxes is not equal, it is clearly observed in the above fig.19. Between 300 to 500 samples there is an energy deviation. Especially at scale 16 it is clearly observed. For sag the voltage magnitude is deceased. So the width of the boxes is also less when compared with the balanced waveform. Higher the scale more is the accuracy.

Case 3: For Voltage Swell

The basic definition of swell is voltage magnitude is high when compared with the balanced voltage. At initial load the characterizing voltage swell and then apply to Continuous Wavelet Transform.

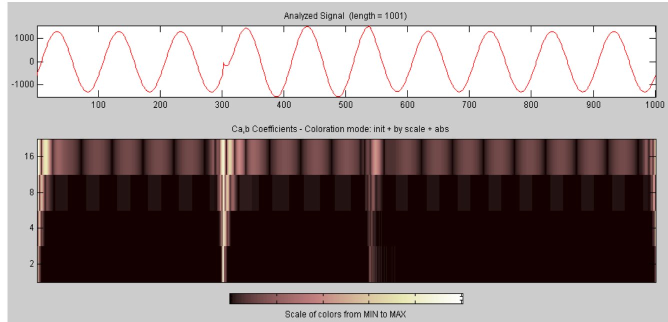


Fig.20 Continuous wavelet for swell

The width of boxes at scales 8 and 16 indicates energy distribution for each half cycle. Between 300-550 samples, the width of box is increased compared to other samples. This increased width indicates abnormal energy distribution; large width indicates swell. There is a deviation in energy at scale 8 and 16; width of the box (300-550 samples) is more indicating magnitude is high. Hence swell.

Case4: For Voltage Interruption

According to definition of Interruption the voltage magnitude is zero. Except between the samples 300 to 500 remaining at all samples boxes are there. Dark color in scale 16 between the 300 to 550 samples indicates there is no signal, hence interruption.

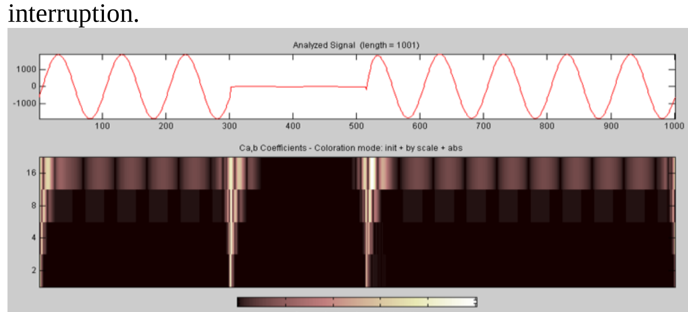
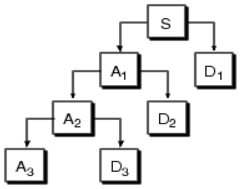


Fig.21 Continuous wavelet for interruption

4.3.2 With Discrete Wavelet Transform (DWT)

In the pre-processing voltage signals are captured during a power quality problem. Due to the absence of field results different power quality problems have been simulated in the MATLAB/SIMULINK environment. The PQ data thus obtained matches the field data. Subsequently, using the Wavelet toolbox of the MATLAB, multi signal decomposition on the captured signals is performed. Depending on the selected resolution levels, the PQ signal is decomposed into a number of wavelet levels.

In wavelet analysis, a signal is split into an approximation (low pass filter output) and a detail (high pass filter output). The approximation is then itself split into a second-level approximation and detail, and the process is repeated. The information contained in the coefficients of details and approximations is very useful for further processing. The wavelet decomposition is shown in fig.22.



$$S = A_1 + D_1$$
$$= A_2 + D_2 + D_1$$
$$= A_3 + D_3 + D_2 + D_1$$

Fig.22 Wavelet Decomposition

4.3.1.1 Algorithm for Discrete Wavelet Transform

Step1: Start

Step2: Create the disturbance signal.

Step3: Measure the source voltage for disturbance signal.

Step4: Categorize source voltage signal into number of samples depending on number of cycles of disturbance.

Step5: Apply DWT for each cycle of source voltage for 6 levels

With Ts=0.0002s

Step6: Obtain sum of detail coefficients of 6th level.

Step7: If ∑VD6 is same for all cycles, set ∑VD6=Reference Value (471).

If ∑VD6 >Ref; hence Swell

∑VD6 <Ref; hence Sag

∑VD6 =0; hence Interruption

Step8: End

The wavelet indices for sag, swell and interruption with respect to normal voltages is shown in the fig.23.

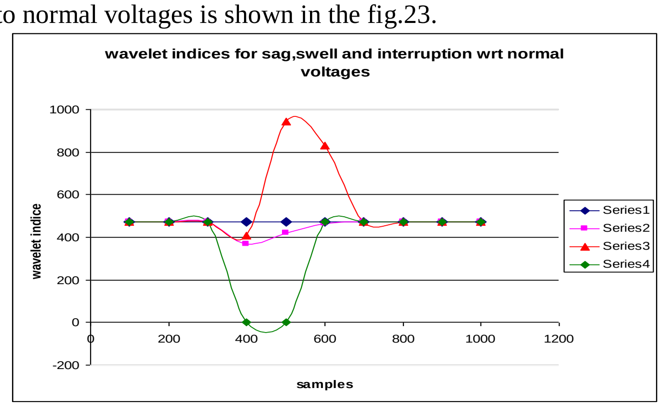


Fig.23 Wavelet indices for sag, swell and interruption wrto normal voltages

In the graph, y axis is wavelet indices and x axis is no. of samples. In the graph the blue color line indicates the threshold value of the sine wave with balanced load. By using the above code the reference value for normal voltage is 471. Except the samples between 300 to 500 remaining at all samples it follows the balanced voltage graph. The pink color graph is below the threshold line. So it is sag signal. The reference value for this voltage sag is 382. The yellow color graph is above the threshold line. So it is swell. The reference value is 730.For green color graph voltage magnitude is zero. So it is interruption.

Comparison of Continuous and Discrete Wavelets

The continuous Wavelets are more redundant than the discrete wavelets. The continuous wavelet transform does not separate the high frequency component and low frequency component from a given signal hence cannot provide more information regarding disturbance. On the other side, discrete wavelets uses low pass and high pass filters for decomposition of a given signal. Hence, provide more information with respect to disturbance.

Continuous wavelet transform is based on color coding, if signal has light color indicate the high strength dark color means no signal. Whereas discrete wavelet transform uses the sampling frequency for decomposition and information.

V. Conclusions

This paper presented classification of power quality problems with continuous and discrete wavelet transform. Though both the methods can distinguish the various problems associated with power quality, discrete wavelets is better method. Discrete wavelets provide more information with respect to problems. Algorithm is presented for characterization of disturbance.

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