Measurement of power quality disturbances

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***Abstract* - In the power quality analysis non-stationary nature of voltage distortions require some precise and powerful analytical techniques. Poor electric quality can result in malfunctioning of the devices and may have expensive consequences. To improve the quality of electric power, sources of disturbances must be recognize and controlled. For this recognition and control here the technique used is Discrete Wavelet Transform (DWT).**

***Index Terms* - Power quality, Wavelet transform, Discrete wavelet transform, Multi resolution analysis, Application, Conclusion.**

I.INTRODUCTION

It is well known to any scientist and engineer who work with a real world data that signals do not exist without noise, which may be negligible (i.e. high SNR) under certain conditions. However, there are many cases in which the noise corrupts the signals in a significant manner, and it must be removed from the data in order to proceed with further analysis. One such significant area is the Electric Power Quality. One of the important issues in power quality (PQ) problems is to detect and classify disturbance waveforms automatically in an efficient manner. In the emerging power systems, power quality (PQ) issues have attained considerable attention in the last decades due to increased penetration of power electronics based loads and/or microprocessor based controlled loads. On one hand these devices introduce power quality problem and on other hand these devices mal-operate due to the induced power quality problems. A PQ problem can be defined as being “Any power problem manifested in voltage, current and/or frequency deviations that result in failure or mal-operation of customer equipment”. The disturbance in voltage, frequency and/or current may lead to serious damage to the load equipment.

II.POWER QUALITY MONITORING AND DISTURBANCES

Power Quality is a determination of the quality of the voltage in a circuit. Measurement of power quality requires a set of standards with which you can establish the quality of the incoming supply. Power Quality examines the voltage quality by defining power quality events. Incomplete quality. Information comes from the instantaneous changing load factors influence quality as they vary over time.

Power Quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. The complexity of the system to move electric energy from the point of production to the point of consumption combined with variations in weather, generation, demand and other factors provide many opportunities for the quality of supply to be compromised.

III.SOURCES OF POWER QUALITY

Power Quality problems can be traced into three main origins, they are

- Upstream supply
- Internal distribution
- Internal loads.

IV.EFFECT OF POOR POWER QUALITY

- Increased currents & losses in the system
- Lower Energy efficiency
- Failure of equipment and Mal-function of equipment
- Poor operational efficiency

V.BENEFITS OF POWER QUALITY MONITORING

- Direct Benefits: Energy Savings, Release of blocked capacity, Reduced temperature rise, Increased reliability, Reduced mal-function of equipment(e.g. Drives, Relays)
- Indirect Benefits: Penalty savings, Tax benefits, compliance to standard and benefits regulations.
- Other benefits: Understanding PQ and reliability, Identifying problem conditions, Information services, Enhanced quality of delivery.

VI.POWER QUALITY DISTURBANCES

A PQ problem can be defined as being "Any power problem manifested in voltage, current and/or frequency deviations that result in failure or mal-operation of customer equipment". IEEE defined power quality disturbances into seven categories based on wave shape:

- Long-Duration Voltage Variations
  - Interrruption
  - Overvoltages and undervoltages
- Voltage Dips (Sags) & Voltage Swells
- Voltage Fluctuation

6.1 Long-Duration Voltage Variations

This category includes disturbances with a large spectrum of possible durations, including very long durations, and with less clear definitions than those in the coming categories. Generally interruptions, under-voltages, over-voltages, and rapid voltage changes can be considered in this type.

6.1.1 Interruption

An interruption is an event defined in the Swedish Standard as a state during which the RMS value of the voltage at the supply terminal is below 5 % of its reference value. For three-phase systems the voltage must be below this limit in all three phases to constitute an interruption, otherwise the event is classified as a voltage dip, or an under-voltage if it persists long enough.

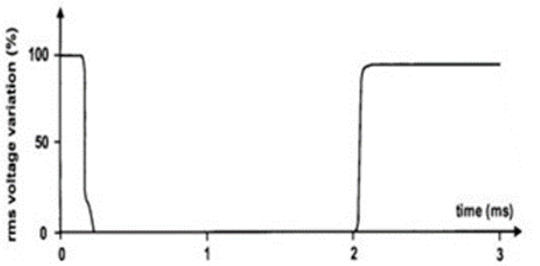

Figure 1: Short interruption due to a fault

6.1.2 Over-voltages & Under-voltages

An overvoltage can be defined as any voltage between one phase conductor and ground or between phase conductors having a peak value exceeding the corresponding peak of the highest voltage allowed for adjacent equipment.
The effects of under-voltages are usually increasing currents drawn by motors, increased reactive power demand, and voltage instability. For over-voltages common effects also include increased reactive power demand and voltage instability, as well as heightened stress on insulation.

6.2 Voltage Dips (Sags) & Voltage Swells

These types of disturbances have durations of between 10ms (0.5 cycles) and 1min. This duration is measured from the crossing of the start threshold to the crossing of the end threshold. Voltage dips are much more common than voltage swells.

Voltage Dips (Sags)

The starting threshold is equal to 90% of the reference voltage for voltage dips(called voltage sags in America). The end threshold is usually set 1 - 2 % of the reference voltage above the start threshold. As previously mentioned, if all phases drop below 5 % of the reference voltage or the duration exceeds 1 min the event will be re-classified as an interruption or an under-voltage respectively. Main causes of voltage dips include energizing of heavy loads (e. g. arc furnaces), starting of large induction motors, single line-to-ground, line-line and symmetrical faults, and transference of load from one power source to another.

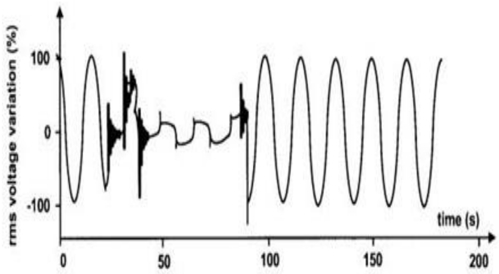

Figure 2: Voltage dip

Effects of voltage dips mainly include voltage instability and malfunctions in electrical low-voltage devices, uninterruptible power supplies, and measuring and control equipment. Also, problems in interfacing with communication signals can arise.

Voltage Swells

For voltage swells the start threshold is equal to 110 % of the reference voltage according to the Swedish Standard. The end threshold is usually set 1 - 2 % of the reference voltage below the start threshold. In other words, the duration of a voltage swell is measured from when one phase rises above 110 % of the reference voltage until all three phases have again fallen below 108 % - 109 % of the reference voltage. If the event persists longer than 1 min it will be re-classified as an overvoltage.

Main causes of voltage swells include energizing of capacitor banks, shutdown of large loads, unbalanced faults, transients and power frequency surges. The effects of voltage swells are largely the same as for voltage dips.

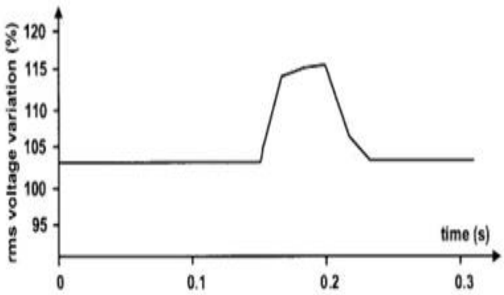

Figure 3: Voltage swell in the phase-to-phase voltage

6.3 Voltage Fluctuations

Voltage fluctuations are defined as a series of voltage changes or a cyclic variation of the envelope of the voltage. These voltage changes are commonly between 90 - 110 % of the reference voltage and are considered steady-state disturbances. Main causes of voltage fluctuations are startup of drives and drives with rapidly changing load or load impedance, as well as operation of arc furnaces, pulsed-power outputs.

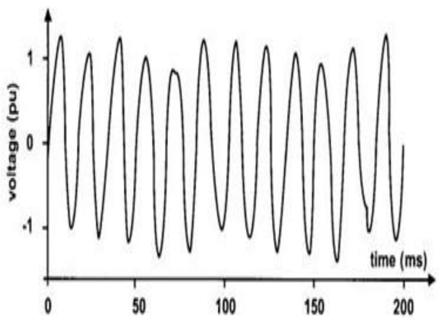

Figure 4: Voltage fluctuations caused by arc furnace operation

This category includes disturbances with a large spectrum of possible durations, including very long durations, and with less clear definitions than those in the coming categories. Generally interruptions, under-voltages, over-voltages, and rapid voltage changes can be considered in this type.

VII. DETECTION USING WAVELET TRANSFORM

Wavelets are functions that satisfy certain requirements. The very name wavelet comes from the requirement that they should integrate to zero, waving" above and below the x-axis. Other requirements are technical and needed mostly to insure quick and easy calculation of the direct and inverse wavelet transform.

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. The resulting wavelets, called daughter wavelets, are localized both in time and frequency. Thus, wavelet transform provides a local representation of signal in both time and frequency unlike Fourier transform which gives a global representation of signal in terms of frequency.

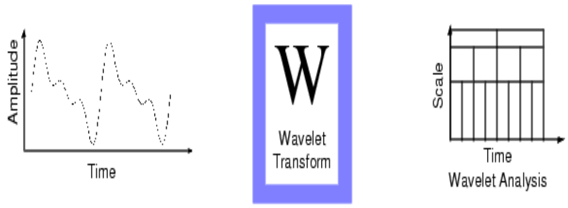

Figure 5: Wavelet Transforms

7.1 Discrete Wavelet Transform

Although the DWT is merely one more tool added to the toolbox of digital signal processing, it is a very important concept for data compression. A wavelet, in the sense of the DWT is an orthogonal function which can be applied to a finite group of data. Functionally, it is very much like the Discrete Fourier Transform, in that the transforming function is orthogonal, a signal passed twice through the transformation is unchanged, and the input signal is assumed to be a set of discrete-time samples.

7.1.1 Scaling and shifting

Scaling a wavelet simply means stretching (or Compressing) it. The parameter scale in the wavelet analysis is similar to the scale used in maps. As the case of maps, high scales corresponding to a non detailed global view, and low scales correspond to a detail view. Similarly, in terms of frequency, low frequencies correspond to global information of the signal, where as high frequencies correspond to detailed information of hidden pattern in the signal.

7.2 Multi Resolution Analysis (MRA)

The foundations of the DWT go back to 1976 when Croiser, Esteban, and Galand devised a technique to decompose discrete time signals. Crochiere, Weber, and Flanagan did a similar work on coding of speech signals in the same year. They named their analysis scheme as subband coding. In 1983, Burt defined a technique very similar to subband coding and named it pyramidal coding which is also known as multiresolution analysis. Later in 1989, Vetterli and Le Gall made some improvements to the subband coding scheme, removing the existing redundancy in the pyramidal coding scheme. Subband coding is explained below. A detailed coverage of the discrete wavelet transform and theory of multiresolution analysis can be found in a number of articles and books that are available on this topic, and it is beyond the scope of this tutorial.
The MRA was introduced by Mallat Define Vj; j 2 as a sequence of linear subspaces. The MRA can be described through a nested subspaces spanned by a single scaling function ϕ together with its translates and dilates $\phi(2^{mt}-k)$

$$V_1 \in V_2 \in V_3 \text{........ i.e } V_j \in V_j + 1 \qquad (3.1)$$

From above Equation we can see that, as j goes to infinity, V_j enlarges to become all energy signals (L2), as j goes to negative infinity V_j shrinks down to only zero. For every j ∈ Z, define W_j to be the orthogonal complement of V_j in V_j +1, then

$$V_j + 1 = V_j \oplus W_j \text{ and } W_j \perp W_j^{|} \qquad (3.2)$$

The above Equations 3.1 and 3.2 can be visualized in figure 3.3. In MRA, any time series x(t) can be completely decomposed in terms of the approximations, provided by scaling functions ϕ and the details, provided by the wavelets ψ where

$$\psi\text{mn}=2^{-\frac{m}{2}}\psi(2^m t-n) \qquad (3.3)$$

$$\phi\text{mn}= \ 2^{-\frac{m}{2}}\psi(2^m t-n) \qquad (3.4)$$

The approximation are the low frequencies components of the time series and the details are the high-frequency components. MRA leads to a hierarchical fast scheme.

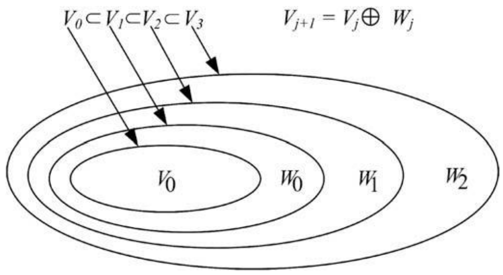

Figure 6: Nested Subspace of MRA

The wavelet function serving as high pass filter with filter coefficients g(n), generates the detailed version of the distorted signal, while the scaling function associated with low pass filter with filter coefficient h(n), generates the approximated version of the distorted signal as shown in Figure3.5 Thus, by using MRA high frequency transients can be easily analyzed in presence of low frequency components such as non-stationary and non-periodic wide-band signals. MRA can be implemented by a set of successive filter banks as in Figure 3.5.

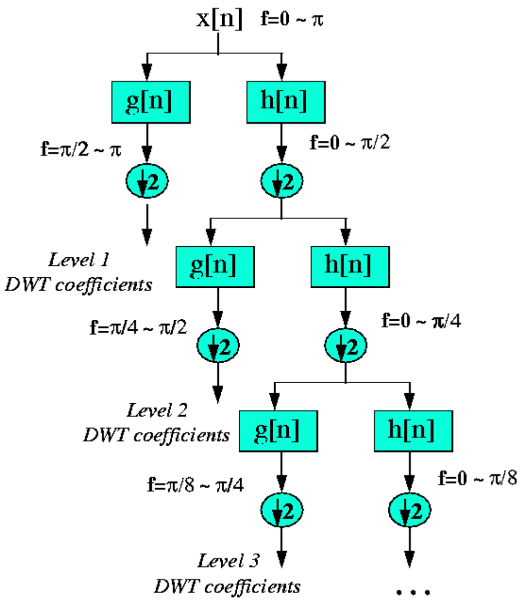

Figure 7: Filter Bank Realization

VIII. ADVANTAGES OF WAVELET TRANSFORM

- One of the main advantages of wavelets is that they offer a simultaneous localization in time and frequency domain.
- The second main advantage of wavelets is that, using fast wavelet transform, it is computationally very fast.
- Wavelets have the great advantage of being able to separate the fine details in a signal.
- Very small wavelets can be used to isolate very fine details in a signal, while very large wavelets can identify coarse details.

IX. APPLICATIONS

- Compression of digital images.
- Denoising in electric drives.
- Power system protection and high impedance fault detection.
- On-line monitoring of high voltage equipment.
- Transmission line surge detection and location management.
- Pattern and speech recognition.

X. CONCLUSION

The power quality disturbances like voltage sag, voltage swell, flicker, fluctuation, notch and, harmonics are identified and classified. Detection of Noise was done with the help of feature extraction using Multi Resolution Analysis (MRA). The most important part of the work is to locate the fault being accurately done. After the process of detection, the results were verified using the wavelet toolbox .Using this method to detect the disturbed voltage waveforms of arbitrary sampling rate and number of cycles. Even the visual observations can state the occurrence and the duration of disturbance very easily. Hence we can conclude that the wavelet MRA can effectively detect any type of PQD at a faster rate. S-transform uniquely provides frequency resolution while maintaining a direct relationship with the Fourier spectrum and provides accurate results of analyzing power quality signals for variable window lengths and detects the PQD accurately.

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XII. REFERENCES

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