DISCRETE WAVELETS TRANSFORM TECHNIQUE APPLICATION IN IDENTIFICATION OF POWER QUALITY DISTURBANCES

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ABSTRACT

Poor power quality may cause many problems for affected loads, such as malfunctions, instabilities, short equipment lifetime, and so on. Poor quality electric power is normally caused by power-line disturbances, such as lightning impulses, interruptions, voltage swell, voltage sag, harmonic distortion, and flicker, and this results in failure or misoperation of end-user's equipment. In order to improve power quality, the sources and causes of such disturbances should be identified and localized before appropriate mitigating actions can be taken. In the paper the Discrete Wavelet Transform (DWT) Technique with Multiresolution Analysis (MRA) capability is used to identify and classify various power disturbance types simulated with the help of Alternative Transient Program - ElectroMagnetic Transient Program (ATP-EMTP). The analysis conducted and results obtained show the merit of methods in use and prospective applications of wavelet technique to power disturbances assessment.

I. INTRODUCTION

Diverse power disturbances are in existence in power systems: capacitor bank switching, voltage sag, voltage swell, interruption, flicker, harmonics, lighning impulse, fault due to short-circuit, inrush current on no-load transformer energization…, and power quality of the system may be greatly affected. Therefore, researches in the field of analysis, recognition, and classification of power disturbances in an effort to mitigate their negative impacts on power quality have drawn much interests by many authors in recent years [1]–[6]. For most of these researches, signal patterns such as pure sine wave, sag, swell, harmonics, flicker, capacitor switching, interruption… are created in Matlab package, then inputted to Matlab's Wavelets Toolbox for wavelets coefficients calculation. In [5], wavelets technique was used to extract information of interest from obtained power disturbance signals, then energy distribution by Parseval theorem calculated corresponding to various decomposition levels of a variety of disturbances are inputted to neural networks or neuro-fuzzy classifiers for recognition and classification purpose. In this paper, various practical power disturbances further to previously mentioned phenomena, pertaining to capacitor bank switching in power grid, such as isolated capacitor bank switching, capacitor bank back-to-back switching, capacitor bank magnification, prestrike, restrike, are analyzed in the well known transient phenomena analysis software ATP-EMTP (Alternative Transient Program). Simulated power disturbance results are then converted to Matlab-compatible format, then analyzed by Matlab Wavelets Toolbox with Discrete Wavelet Transform (DWT) by Daubanchie "db4" wavelet function. Energy distribution of the distorted signals per Parseval's theorem was calculated and plotted in function of decomposition levels to extract interesting features. As a result of this analysis important remarks and conclusion are made to recognize and classify different disburbances.

II. POWER QUALITY DISTURBANCES SIMULATION BY ATP-EMTP

Following are various power quality disturbances simulations performed with the help of ATP-EMTP:

1. Capacitor bank switching: simulations were made with various switching phenemena of a power capacitor bank into a 110kV grid.

1.1 Isolated capacitor bank switching (*Fig.1*)

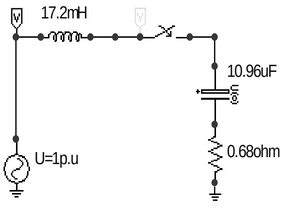


Fig.1a Simulation circuit

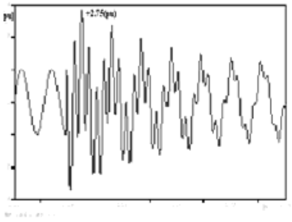
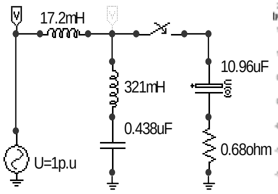


Fig.1b Voltage wave

Overvoltages depend heavily on switching timing and a value of 1.89 p.u may be reached when closing to capacitor bank with power wave in the maximal peak.

1.2 Voltage magnification (*Fig.2*): a bank of 20 MVAR is closed onto the primary side of 110/22 kV transformer of 10 MVA, X= 0.1 pu, with a capacitor bank of 2 MVAR on the secondary side. Potential side effect of adding power factor correction capacitors at the customer location is that they may increase the impact of utility capacitor switching transient on end-user equipment, magnification voltage occur when $L_1xC_1=L_2xC_2$ and current magnification value amplitude is very high.



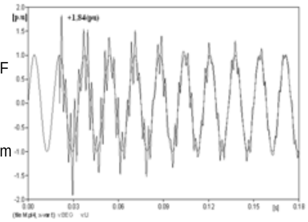
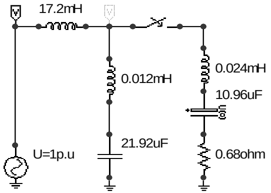


Fig.2a Simulation circuit   Fig.2b Voltage wave

1.3 Back to back Capacitor Switching (*Fig. 3*)



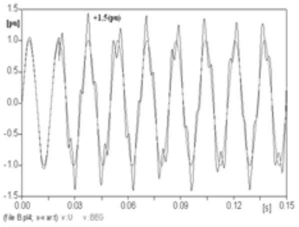
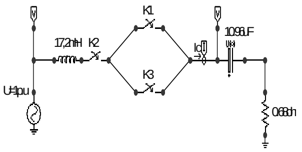


Fig.3a Simulation circuit   Fig.3b Voltage wave

Overvoltage amplitudes of 1.5 pu may be reached when a capacitor bank is switched into other parallel banks already in operation in high voltage network.

1.4 Prestrike Capacitor Switching (*Fig.4*)



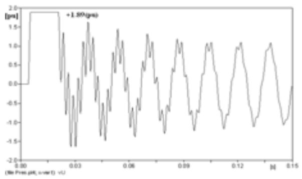
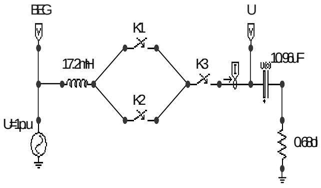


Fig.4a Simulation circuit   Fig.4b Voltage wave

During closing process, electrical field between the two contacts of circuit breaker attains such a value that incurs insulation breakdown. This phenomenon of prestrike happens well before capacitor closing, and voltage amplitude can reach 2.6 pu.

1.5 Restrike Capacitor Switching (*Fig. 5*):

During breaking process, the voltage difference between circuit breaker contacts may reach to a value of 2 pu in excess of insulation withstand. An overvoltage of 3 pu may be reached during the first restrike, and second, third restrike may happen. In second restrike voltage amplitude can reach a value as high as 6.4pu.



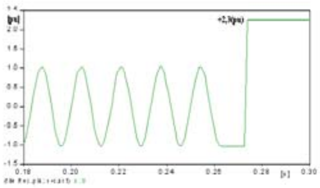
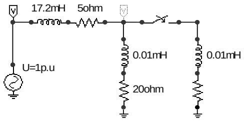


Fig.5a Simulation circuit   Fig.5b Voltage wave

2. Voltage Sag (*Fig.6*)



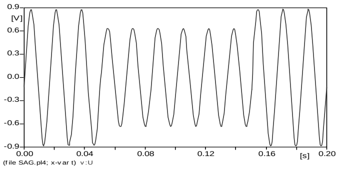
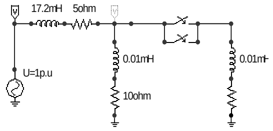


Fig.6a Simulation circuit   Fig.6b Voltage wave

A sag is a decrease to 0.1~0.9 pu in RMS voltage at the line frequency for duration from 0.5 cycles to one minute. Voltage sag is normally caused by system faults, energization of heavy loads and starting of large motors.

3. Voltage Swell (*Fig.7*)



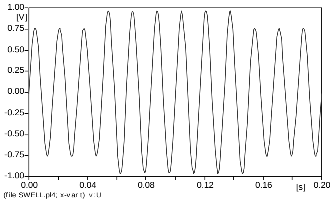


Fig.7a Simulation circuit   Fig.7b Voltage wave

A swell is defined as an increase to 1.1~1.8pu in RMS voltage at the line frequency for duration from 0.5 cycles to one minute. Swell are usually associated with system fault conditions.

4. Voltage Interruption (*Fig.8*)

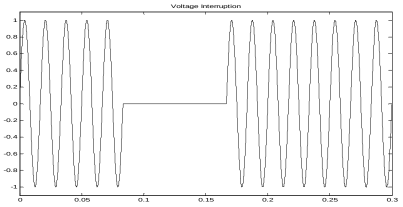


Fig.8 Voltage wave

An interruption occurs when the supply voltage or load current decrease to less than 0.1pu for a period of time not exceeding one minute. Interruption can be caused by power system faults, equipment failures and control malfunctions.

5. Flicker Voltage (*Fig. 9*)

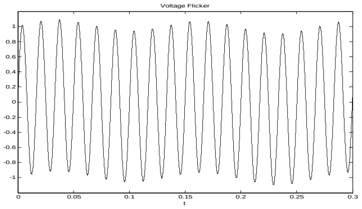


Fig.9 Voltage wave

Flicker are systematic variations of the voltage envelope or series of random voltage changes, the magnitude of which does not normally exceed the voltage ranges specified by ANSI C84.1 -1982 of 0.9 to 1.13pu.

6. Harmonics (*Fig.10*)

Harmonics is defined as a steady-state deviation from an ideal sine wave of line frequency principally characterized by the spectral content of the deviation.

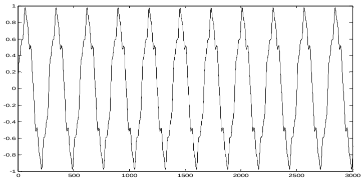


Fig.10 Voltage wave

III. APPLICATION OF DWT TECHNIQUE AND EXPRIMENTAL RESULTS:

1. Multi-Resolution Analysis technique: The first main characteristic in DWT is the Multi-Resolution Analysis (MRA) technique that can decompose the original signal into several other signals with different levels (scales) of resolution (*Fig.11*). From these decomposed signals, the original time-domain signal can be recovered without losing any information.

The recursive mathematical representation of the MRA is as follows:

$$u_J = w_{J+1} \oplus u_{J+1} = w_{J+1} \oplus w_{J+2} \oplus \cdots \oplus w_{J+n} \oplus u_{J+n} \quad (1)$$

Where:

u_{J+1}: approximated version of the given signal at scale J+1

w_{J+1}: detailed version that displays all transient phenomena of the given signal at scale J+1

$\oplus$: denotes a summation of two decomposed signals

N : is the decomposition level

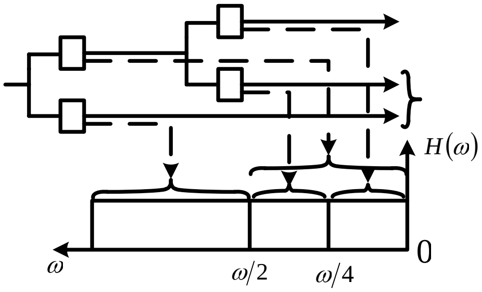


Fig.11: Two decomposed/reconstructed levels of DWT

2 Parseval's theorem in the DWT Technique:

$$\frac{1}{N}\sum_{k=1}^{N}(x[k])^2 = \frac{1}{N}\sum_{k=1}^{N}|u_J[k]|^2 + \sum_{j=1}^{J}\left(\frac{1}{N}\sum_{k=1}^{N}|w_j[k]|^2\right) \quad (2)$$

With x[k] is a discrete input, k = 1…N

The first term on the right of (2) denotes the average power of the approximated version of the decomposed signal, while the second term denotes that of the detailed version of the decomposed signal. The second term giving the energy distribution features of the detailed version of distorted signal will be employed to extract the features of power disturbance.

3.Detailed Energy Distribution:

As seen in (2), the energy of the distorted signal can be partitioned at different resolution levels in different ways depending on the power-quality problem. Therefore, the coefficient of the detailed version at each resolution level will be examined to extract the features of the distorted signal for classifying different power-quality problems. The process can be represented mathematically by:

$$P_j = \frac{1}{N}\sum_{k=1}^{N}|w[k]|^2 = \frac{\|w_j\|^2}{N} \quad (3)$$

Energy is normalized:

$$P_j^D = (P_j)^{1/2} \quad (4)$$

In this paper, a 13-level decomposition of each discrete distorted signal will be performed to obtain the detailed version coefficients $w_1 \sim w_{13}$. Simultaneously, with formulas (3)-(4), each detailed energy distribution ($P_1^D \sim P_{13}^D$)can be obtained.

4. Duration and Amplitude of Transients

In general, when a transient disturbance occurs, the stable power signal will generate a discontinuous state at the start and end points of the disturbance duration.

Employing the DWT technique to analyze the distorted signal through three-level decomposition of the MRA will cause the wavelet coefficients w_3 at the start and end points of the disturbance to generate severe variation. Therefore, we can easily obtain the start time t_S and end time t_E of the disturbance duration from the variations in absolute wavelet coefficients w_3 and calculate the disturbance duration t_T:

$$t_T = \left| t_E - t_S \right|$$

Amplitude A is max value of the discrete input in disturbance duration.

5. Experimetal results

We can categorize three properties of energy distribution of the given distorted signals:

❖ When Sag or Swell or Interruption occurs, P_7^D and P_8^D will show great variations. The difference of them:

- Interruption has amplitude A between 0.0p.u and 0.1p.u.

- Voltage sag has amplitude A between 0.1p.u and 0.9p.u.

- Voltage swell has amplitude A between 1.1p.u and 1.8p.u.

❖ When the voltage suffers a transient disturbance of the high-frequency elements such as capacitor switching and harmonic distortion, P_3^D, P_4^D and P_5^D will show obvious variations. The difference of them:

- Capacitor Switching has the disturbance duration t_T.

- Harmonic distortion has no the disturbance duration t_T.

❖ When the voltage suffers a transient disturbance of the low-frequency elements such as voltage flicker, P_9^D , P_{10}^D and P_{11}^D will show obvious variations.

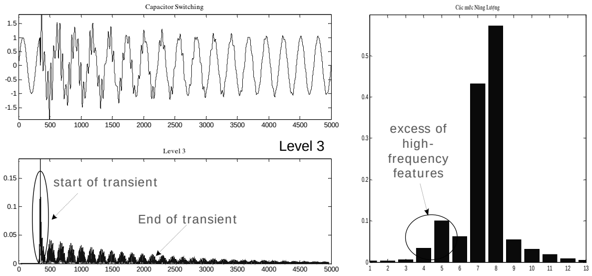


Fig. 14. DWT and energy distribution diagram of voltage magnification of capacitor switching

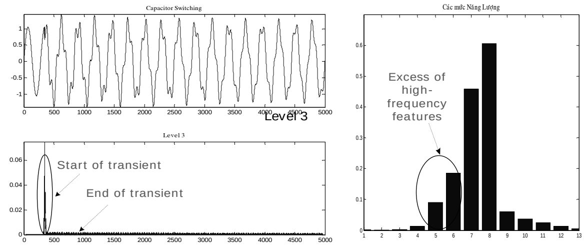


Fig. 15. DWT and energy distribution diagram of back to back capacitor switching

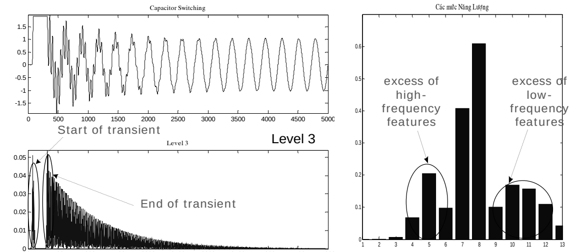


Fig. 16. DWT and energy distribution diagram of prestrike in capacitor switching

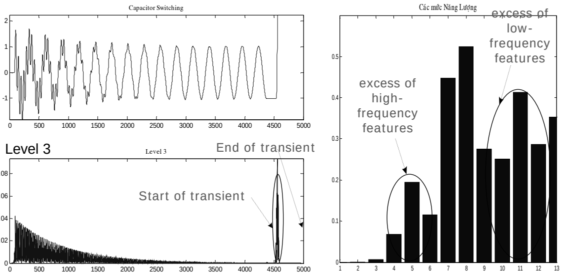


Fig. 17. DWT and energy distribution diagram of restrike in capacitor switching

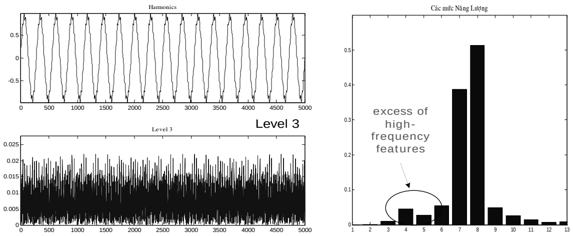


Fig. 18. DWT and energy distribution diagram of harmonics

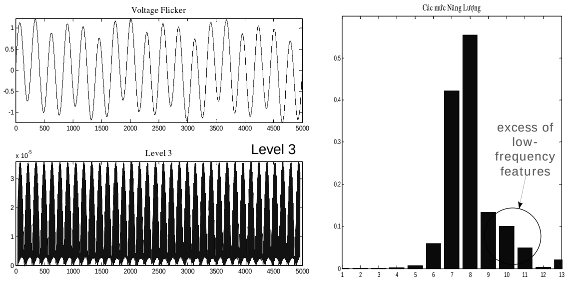


Fig. 19. DWT and energy distribution diagram of flicker

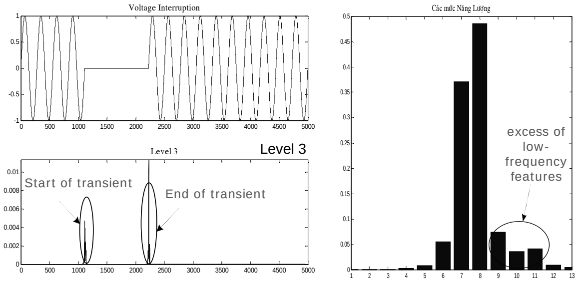


Fig. 20. DWT and energy distribution diagram of interruption

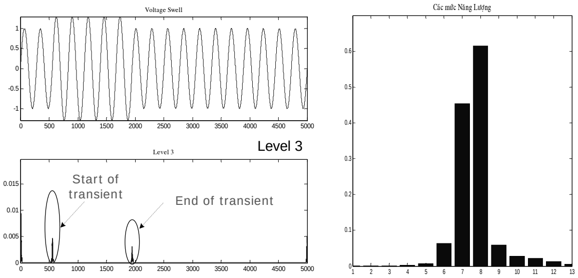


Fig. 21. DWT and energy distribution diagram of voltage swell

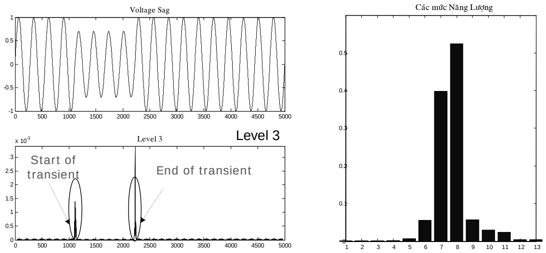


Fig. 22. DWT and energy distribution diagram of voltage sag

Based on energy distribution diagram, exact transient time in transient processes could be recognized. From *Table 1* and *Fig. 12 to Fig. 22* it is clearly shown that pure sine wave and waves of similar nature, such as sag, swell are characterized by energy distribution, basically focused in levels of 7 and 8, while capacitor switching transients (isolated bank, back-to-back, voltage magnification, prestrike and restrike) and harmonics by levels 4, 5, 6. Flicker and interruption are characterized by energy distribution of levels 9, 10,11.

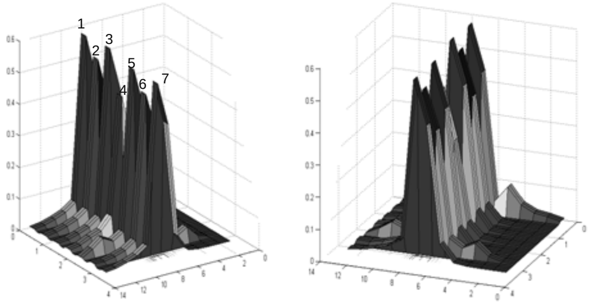
Thus, following remarks are made:

- Capacitor switchings and Harmonics are of high-frequency features.

- Flickers and Interruptions are of low-frequency features.

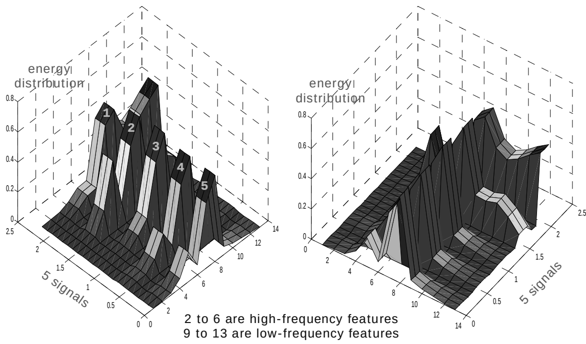
- Sag, Swell are similar to ideal sine wave in terms frequency characterization feature.

- Level 3 of DWT could be used to extract precise transient timing of distorted signals.



1:Capacitor Switching 2:Voltage Sag 3:Voltage Swell 4:Interruption
5:Voltage Flicker 6:Harmonic Distortion 7:Pure sine

Fig. 23. Differences in energy distribution of fundamental distorted signals.



2 to 6 are high-frequency features
9 to 13 are low-frequency features

1:Isolated capacitor switching **2**:Magnification capacitor switching **3**:Back to back capacitor switching **4**:Prestrike capacitor switching **5**:Restrike capacitor switching

Fig. 24. Differences in energy distribution of capacitor bank switching types.

Fig. 23 and *Fig.24* show differences in energy distribution of power disturbances, in particular of capacitor bank switching transients.

IV. CONCLUSION

This paper performed simulations on ATP-EMTP of a variety of power quality disturbances other than traditional ones. Integration of ATP-EMTP and Matlab Wavelet Toolbox result in detailed analysis using DWT technique to extract interesting features of distorted signals. From the carried-out research based on energy distribution of decomposed levels important remarks were made in terms of frequency characterization of particular disturbance waves. Numerical experiments achieved with informative results have shown the merit of the proposed method as a valuable tool in power quality assessment. Further researches in the direction of using advanced recognition and classification technique such as neural networks, fuzzy logic, or neuro-fuzzy, as well as using real distorted signals retrieved from digital recording instruments will be carried out in future papers to improve the capability of the method.

V. REFERENCES

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