WAVELET-BASED VOLTAGE MAGNITUDE CALCULATION TO AUTOMATICALLY CLASSIFY POWER QUALITY PROBLEMS

Wattana TRONGPANICH
Provincial Electricity Authority,
Bangkok 10900 – Thailand
E-mail address : wattana_t@pea.co.th

Chamanuch WACHIRAPAN
Provincial Electricity Authority,
Bangkok 10900 – Thailand
E-mail address : chamanuch@pea.co.th

ABSTRACT

This paper presents a wavelet-based technique for calculating the magnitude of a voltage signal for classifying power quality problems. The paper also shows a comparison between the proposed method and other methods such as Root Mean Square (RMS), Orthogonal Component and Peak Value Method. These methods were tested with a signal from a simulation of Provincial Electricity Authority (PEA) substation in the PSCAD/EMTDC program, IEEE Power Quality Event Characterization Working Group (P1159.2) and real signals measured at a PEA 115/22 kV substation. All techniques were then implemented in a Matlab program. The results show that the proposed wavelet-based technique is superior to other conventional techniques.

I. INTRODUCTION

For the past decade, power quality (PQ) has become an outstanding issue in power systems due to increasing utilization of nonlinear power electronic loads and voltage-sensitive computer-controlled and microprocessor-based equipment. PQ events include voltage sags, swells, switching transients, notches, flickers, harmonics, etc. Classification of power quality problems is essential for protecting a power system. Magnitude can be used to classify power quality events such as transients, voltage swell, voltage sag, overvoltage, undervoltage and interruption following as shown in Fig 1. [1] Therefore voltage magnitude calculation is essential for monitoring PQ problems and the result can indicate magnitude characterization as a function of time. The magnitude of a voltage can be determined in a number of ways. Most popular methods to obtain the magnitude are Root Mean Square (RMS), Orthogonal and Peak Voltage Method. [2]

The Wavelet Transform (WT) was introduced at the beginning of the 1980s and it has been applied in a wide variety of research areas such as signal analysis, image processing, data compression and denoising, and numerical solution of differential equations. In the last decade, WT techniques have been proposed in the literature as a new tool for monitoring and analysing PQ problems.

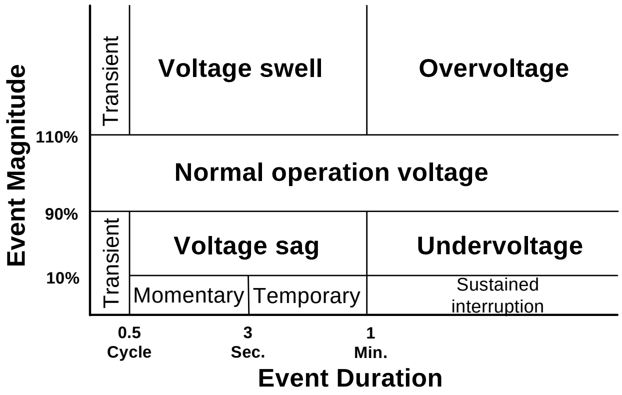

Fig. 1 Durations of voltage magnitude events as used in IEEE Std.1159-1995.

In this paper, the WT is applied to calculate the voltage magnitude for classifying PQ events. Firstly, A brief introduction to the WT is given. The following paragraphs propose wavelet-based voltage calculation for classifying PQ problems. Next, the method is implemented in a Matlab program and tested with test signal from three sources. Finally, the result is compared with the result of RMS value, Orthogonal Component and Peak Voltage Methods.

II. WAVELET TRANSFORM

WT is a mathematical tool for transforming data from time-domain to time-frequency domain. Like the Fourier transform, the WT demonstates time-frequency information of data. Unlike the Fourier transform, it has various basis functions. The basic concept in WT is to select a proper wavelet function and then perform analysis using shifted and dilated versions of a chosen wavelet. Therefore, the WT can be chosen with very desirable frequency and time characteristics as compared to Fourier techniques which has only sine/cosine basis functions. There are two types of WT; the continuous wavelet transform (CWT) and the discrete wavelet transform (DWT). The principles of the DWT needed in this paper will be briefly reviewed. [3]

The DWT moves a time domain discretized signal into its corresponding wavelet domain. This is done through a process called "sub-band codification" by Finite Impulse Response (FIR) digital filter techniques. In signal processing theory, to filter a given signal $f(n)$ means to make a convolution of this signal. This is illustrated in Fig. 2 : the $f(n)$ signal is passed through a low-pass digital filter ($h(n)$) and a high-pass digital filter ($g(n)$). After that, half of the signal samples are eliminated. This is indicated by the symbol $(\downarrow 2)$ in Fig 2.

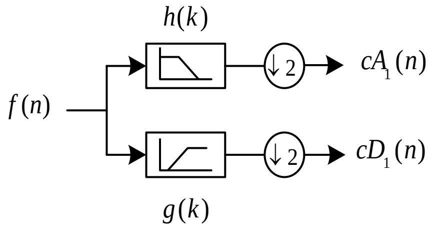

Fig. 2 Sub-band codification scheme of a signal

At the end of the first level of signal decomposition (as illustrated in Fig. 2), the resulting vectors are the level 1 wavelet coefficients of approximation and of detail. In fact, for the first level, these wavelet coefficients are called $cA_1(n)$ and $cD_1(n)$ respectively. The decomposed orthogonal voltage signal components are calculated by:

$$cA_1(n) = \sqrt{2}\sum_{k=0}^{N-1} f(n).h(2n-k) \quad (1)$$

$$cD_1(n) = \sqrt{2}\sum_{k=0}^{N-1} f(n).g(2n-k) \quad (2)$$

Next, in the same way, the calculation of the approximated $(cA_2(n))$ and the detailed $(cD_2(n))$ version associated with level 2 is based on the level 1 wavelet coefficient of approximation $(cA_1(n))$. The wavelet adopted in this method was the "Daub4" ,which is shown in Fig. 3

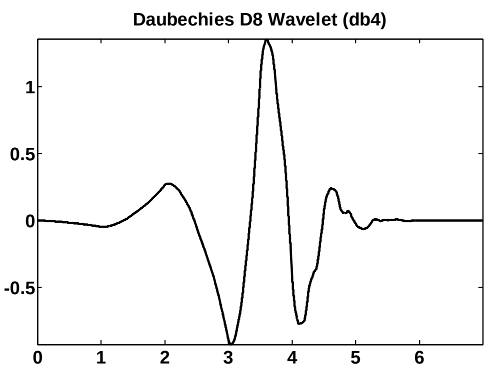

Fig. 3 Daub4 wavelet

III. THE PROPOSED TECHNIQUE PRINCIPLE

In monitoring PQ problems, voltage waveforms are initially sampled into time sequences like $\{v_n, n = 1, 2, ...\}$, where $n = 1$ corresponds to the beginning of the sample process. The voltage magnitude characterization should be calculated from the sampled time sequence. A data window is required for applying digital signal processing techniques. Here it is assumed that the length of a sliding data window is N samples which are typically one cycle. The proposed algorithm was developed and implemented in the Matlab program, through five steps, as follows [4]:

Step 1 : Read a measured voltage signal waveform from first data window and then construct a reference waveform R(t) as follows :

$$\mathrm{R}(t) = \sin(2 \times \pi \times f \times t) \quad \text{p.u.} \quad (3)$$

where f is a fundamental frequency and t is the sampling time of the measured signal.

Step 2 : Performing DWT level 2 on these two signals (Measured signal and reference). The result gives the corresponding detail and approximation coefficients of measured signal and reference. Let A_{mes} and A_{ref} be vectors that present the approximation coefficients of measured signal and reference respectively.

Step 3 : Calculate the phase angle between A_{mes} and A_{ref} which will be the angle between the fundamental component of the measured signal and the reference from equation (4).

$$\theta = \cos^{-1}\left(\langle A_{ref}, A_{mes}\rangle / \left(|A_{ref}||A_{mes}|\right)\right) \quad (4)$$

where $|A_{mes}|$ and $|A_{ref}|$ are the magnitudes of A_{mes} and A_{ref} respectively and $\langle A_{ref}, A_{mes}\rangle$ is the inner product between A_{mes} and A_{ref} .

Step 4 : Construct the comparative signal $F_1(t)$ using equation (5).

$$F_1(t) = \sin\left(2 \times \pi \times f \times t + \theta / 180^{\circ} \times \pi\right) \quad \text{p.u.} \quad (5)$$

where θ is obtained from equation (4)

Step 5 : $F_1(t)$ is calculated by DWT level 2. Let A_1 be vectors that present the approximation coefficients of $F_1(t)$. Then, calculate the signal magnitude x from (6).

$$|A_1| : 1\,\text{p.u.} = |A_{mes}| : x \quad , \quad x = \frac{|A_{mes}|}{|A_1|} \quad (6)$$

Step 6 : Move data window and then repeat step 1.

IV. SIMULATION RESULT

For this research, a techniques mentioned were tested in a Matlab program and the test signals obtained in three ways. The first is a 115/22 kV substation simulation of PEA in Thailand by using the PSCAD/EMTDC program. The second is using real signals measured at a PEA 115/22 kV substation. The signals provided by IEEE Power Quality Event Characterization Working Group (P1159.2) are the third way [5].

A. Testing with waveforms obtained from a simulation of a PEA substation

The PSCAD/EMTDC simulation of a PEA 115/22 kV substation was used to test these algorithm. The details of the substation are shown in Fig. 4 and more details can be found in [6].

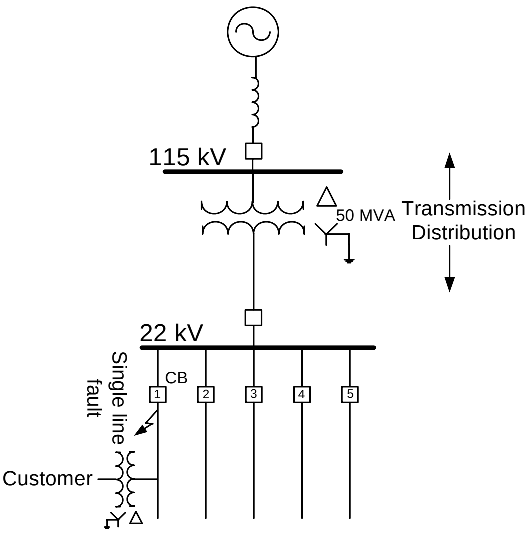

Fig.4 The diagram of a PEA 115/22 kV substation

Fig.4 shows a simulation of a single line to ground fault which occurs at phase A about 13 kilometers from the substation. The phase C voltage waveform is measured on the low voltage side of the substation during the fault. It is a voltage swell type and Its swell duration is 0.04 second. (0.135 - 0.195 s.) as shown in Fig.5. The test waveform has a 50 Hz fundamental frequency. The sampling frequency used to measure is 12,800 Hz. The value is in per unit format. Data length is 0.1 second.

Fig.6 shows the result of the wavelet-based method obtained from calculating the PSCAD/EMTDC simulation waveform. It shows that the swell duration is about 0.0526 seconds (0.1376 – 0.1902 s.). The swell magnitude is 1.6 per unit.

Table 1 shows the comparison of the test waveform results measured by the wavelet-based method and other conventional method. It shows that the wavelet-based method indicates magnitude and duration of voltage swell better than other methods because it has a lower percentage error than other methods.

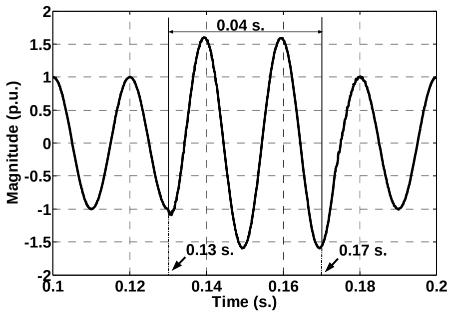

Fig. 5 Test waveform obtained from the PSCAD/EMTDC simulation of a PEA 115/22 kV substation

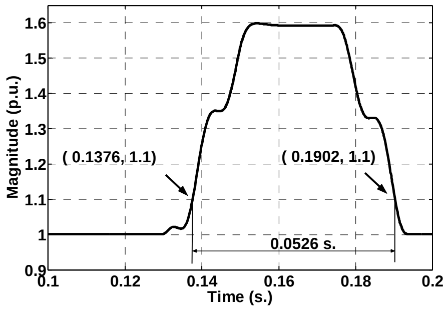

Fig. 6 The result of the wavelet-based method used to measure the PSCAD/EMTDC simulation waveform

Table 1. A comparison of the swell waveform results measured by the wavelet-based method and other methods

Method	Duration (s.)	Error (%)	Magnitude (p.u.)	Error (%)
Wavelet	0.0526	31.50	1.5988	0.075
Orthogonal	0.0539	34.75	1.5977	0.144
RMS	0.0526	31.50	1.5978	0.138
Peak voltage	0.0551	37.75	1.6015	0.094

B. Testing with waveforms provided by the IEEE Power Quality Event Characterization Working Group (P1159.2)

Test waveforms provided by the IEEE Power Quality Event Characterization Working Group (P1159.2) are recommended for testing designed algorithms or in other research in the power quality community.

For this testing, the test waveform is a voltage sag as shown in Fig.7. It has a 60 Hz fundamental frequency and was measured with a sampling frequency of 15,360 Hz. The value is in per unit format. Data length is 0.1 second. Sag duration is about 0.035 seconds (0.03 – 0.065 s.).

Wavelet-based voltage magnitude characterization of the test waveform are plotted in Fig.8. It shows that the sag duration is about 0.0356 seconds (0.0354 – 0.0710 s.).

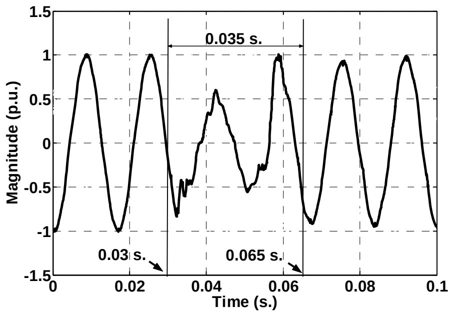

Fig. 7 Test waveform obtained from IEEE(P1159.2)

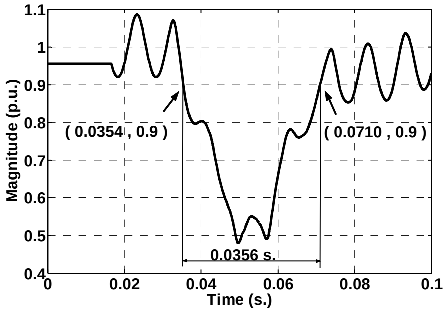

Fig. 8 The result of the wavelet-based method used to measure IEEE(P1159.2) waveform

C. Testing with real waveforms measured at a PEA's 115/22 kV substation

Fig 9 show the test waveform which is a voltage sag. It has 50 Hz fundamental frequency and was measured with a sampling frequency of 15,360 Hz. The value is in per unit format. Data length is 0.1 seconds. Sag duration is about 0.06 seconds (0.135 – 0.195 s.).

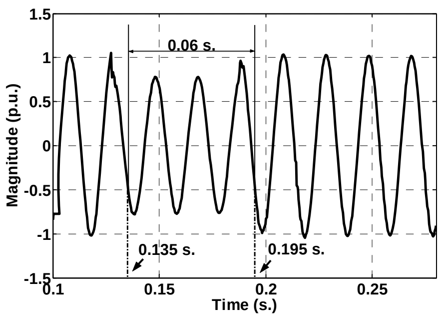

Fig. 9 Test waveform obtained from a PEA substation

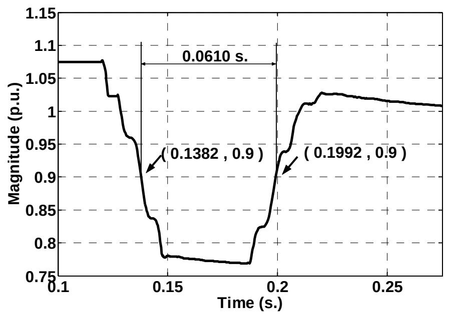

Fig. 10 The result of the wavelet-based method used to measure PEA waveform

Wavelet-based voltage magnitude characterization on the test waveform are plotted in Fig.10. It shows that the sag duration is about 0.0610 seconds (0.1382 – 0.1992 s.).

Table 2 shows the comparison of the test waveform result measured by the wavelet-based method and other methods. It shows that the wavelet-based method indicates the duration of the voltage sag better than other methods because it has a lower percentage error than other methods.

Table 2. A comparison of the IEEE and PEA sag waveform results measured by all methods

Test signal / Method	IEEE (P1159.2)		PEA measured signal	
	Duration (s.)	Error (%)	Duration (s.)	Error (%)
Wavelet	0.0356	1.710	0.0610	1.67
Orthogonal	0.0392	12.00	0.0616	2.67
RMS	0.0385	10.00	0.0610	1.67
Peak voltage	0.0230	34.29	0.0507	15.50

V. CONCLUSIONS

The wavelet transform is applied for calculating voltage magnitude in this paper. The result obtained is magnitude characterization which is compared with the result of the most popular methods such as RMS value, Orthogonal Component and Peak Voltage Method. The wavelet-based method can measure magnitude and duration of PQ events better than other conventional methods.

VI. REFERENCES

[1] M.H. Bollen, 2000, *Understanding Power Quality: Voltage Sags and Interruptions*, Wiley-IEEE Press, New York, USA., 19-22.

[2] W. Trongpanich, T. Bunyagul , 2005, "The Method of Calculating Voltage Magnitude For Monitoring Power Quality Problem", *Proceedings of the 28th Electrical Engineering Conference*, THAILAND, vol.1, 645-648.

[3] T.K. Sacker, C. Su., 1998, "A Tutorial on wavelets from an electrical engineering perspective I Discrete wavelet techniques", *IEEE Transaction on Antennas and Propagation Magazine.* vol. 40, 49-68.

[4] W. Trongpanich, A. Tantanuwat, T. Bunyagul , 2006, "Wavelet-based Voltage Magnitude Calculation for Voltage Sag Analysis", *Proceedings of the 29th Electrical Engineering Conference*, THAILAND, vol.1, 469-472.

[5] L. Morgan, 1999, "IEEE Power Quality Event Characterization : Fault related Sag Test Waveforms", *Available at* http://grouper.ieee.org//groups/1159/2/

[6] A. Tantanuwat, T. Bunyagul, Y. Vachiratarapadorn , 2006, "Experience on Resistance and Inductance Grounding in Distribution System: A Case of PEA", *Proceedings of the 2005 Electrical Engineering /Electronics, computer,Telecommunications and Information Technology (ECTI) International Conference*, THAILAND, vol.2, 571-574.