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Feature Extraction of Power Quality Waveforms and Energy Coefficient Analysis Using Integer Lifting Wavelet Transform

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Abstract: This study advances a novel method for power quality monitoring by using Integer Lifting Wavelet Transform (ILWT). ILWT based wavelet uses time domain for its integer calculation and could lessen calculation complexity due to its structure, compared with Modified Wavelet Transform (MWT) which depends on floating point coefficients. The whole method is tested over sample disturbances like voltage sag, voltage swell and harmonics. Energy analysis of approximation and detailed coefficients indicates that the proposed method is superior to MWT.

Key words: Power quality, power system disturbances, integer lifting wavelet transform, lifted wavelet energy, lifting wavelet transform

INTRODUCTION

To improve the quality of the power supply detection of the disturbance must be done accurately. The power quality events should be detected, localized and classified accurately so that proper mitigation measures could be applied.

In the recent years, Hui Liu *et al.* proposed to employ the lifting wavelet scheme and wavelet entropy for power quality analysis (Liu *et al.*, 2008; Li *et al.*, 2008), applied lifting wavelet of Daubechies to detect strange characteristics of the power signal, many contribution has presented in articles based on Artificial Intelligence (AI) tools such as artificial neural network (Yilmaz *et al.*, 2007; Santoso *et al.*, 2000; Borras *et al.*, 2001), fuzzy logic (Elmitwally *et al.*, 2001), adaptive neuron-fuzzy (Calderbank *et al.*, 1998), genetic algorithm (Daubechies and Sweldens, 1998), expert systems (Sweldens, 1997), wavelet transform (Santoso *et al.*, 2000; Borras *et al.*, 2001; Elmitwally *et al.*, 2001) and others are surveyed by Ibrahim and Morcos (2002). But in many cases, the extracted wavelet features is not optimal or the classifier has not ability to deal with time and frequency ranges of power quality events. In this study, a novel and optimal vector comprises of integer elementary based fast lifting wavelet transform is presented and applied the lifted wavelet energy analysis for approximation/detail coefficients. The accuracy rate is improved using integer lifted wavelets along with the statistical differentiation of the various power signal disturbances.

Basic lifting scheme: The lifting scheme is a technique for both designing wavelets and performing the discrete wavelet transform. Actually, it is worthwhile to merge these steps and design the wavelet filters while performing the wavelet transform. This is then called the second generation wavelet transform. The technique was introduced by Wim Sweldens. The basic idea of lifting is the following: if a pair of filters (h, g) is complementary that is it allows for perfect reconstruction then for every filter s the pair (h', g) with allows for perfect reconstruction.

Fast lifting wavelet transform: Using the lifting scheme, arrived at a universal discrete wavelet transform which yields only integer wavelet and scaling coefficients instead of the usual floating point coefficients.

MATERIALS AND METHODS

Polyphase matrix is a matrix of Laurent polynomials and demanded that its determinant be equal to 1 for that the filter pair (h, g) is complementary. The lifting theorem (Uytterhoeven *et al.*, 1997) states that any other finite filter g^{new} complementary to h is of the form:

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$$g^{new}(z) = g(z) + h(z)s(z^2) \quad (1)$$

where, $s(z^2)$ is a Laurent polynomial. This can be seen very easily if g^{new} in polyphase form (Sweldens, 1997) and assemble the new polyphase matrix as:

$$P^{new}(z) = \begin{pmatrix} h_e(z) & h_e(z)s(z) + g_e(z) \\ h_o(z) & h_o(z)s(z) + g_o(z) \end{pmatrix} = P(z)\begin{pmatrix} 1 & s(z) \\ 0 & 1 \end{pmatrix} \quad (2)$$

It can be easily verified with the determinant of the new polyphase matrix which is also equals 1. Similarly, applying the lifting theorem to create the filter $\tilde{h}^{new}(z)$ complementary to $\tilde{g}(z)$:

$$\tilde{h}^{new}(z) = \tilde{h}(z) + \tilde{g}(z)\tilde{s}(z^2) \quad (3)$$

with the new dual polyphase matrix given by:

$$\tilde{P}^{new}(z) = \begin{pmatrix} \tilde{h}_e(z) + \tilde{g}_e(z)\tilde{s}(z) & \tilde{h}_o(z) + \tilde{g}_o(z)\tilde{s}(z) \\ \tilde{g}_e(z) & \tilde{g}_o(z) \end{pmatrix} = \begin{pmatrix} 1 & \tilde{s}(z) \\ 0 & 1 \end{pmatrix}\tilde{P}(z) \quad (4)$$

It is called primal lifting, lifting the low-pass subband with the help of the high-pass subband. Figure 1 shows the effect of primal lifting graphically.

The other way that is lifting the high-pass sub band with the help of the low-pass sub-band and then it is called dual lifting. For dual lifting the equations become:

$$h^{new}(z) = h(z) + g(z)t(z^2) \quad (5)$$

$$P^{new}(z) = \begin{pmatrix} h_e(z) + g_e(z)t(z) & g_e(z) \\ h_o(z) + g_o(z)t(z) & g_o(z) \end{pmatrix} = P(z)\begin{pmatrix} 1 & 0 \\ t(z) & 1 \end{pmatrix} \quad (6)$$

And:

$$\tilde{g}^{new}(z) = \tilde{g}(z) + \tilde{h}(z)\tilde{t}(z^2) \quad (7)$$

$$\tilde{P}^{new}(z) = \begin{pmatrix} \tilde{h}_e(z) & \tilde{h}_o(z) \\ \tilde{g}_e(z) + \tilde{h}_e(z)\tilde{t}(z) & \tilde{g}_o(z) + \tilde{h}_o(z)\tilde{t}(z) \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \tilde{t}(z) & 1 \end{pmatrix} \quad (8)$$

Dual lifting can be graphically displayed as in Fig. 2. Each time, apply a primal or dual lifting step. All the samples in the stream are replaced by new samples and at any time it needs only the current streams to update sample values. In other words, the whole transform can be done in-place, without the need for auxiliary memory. The transformed data also takes the same place as the input data. This in-place property makes the lifting wavelet transform very attractive for use in embedded applications where memory and board space are still expensive.

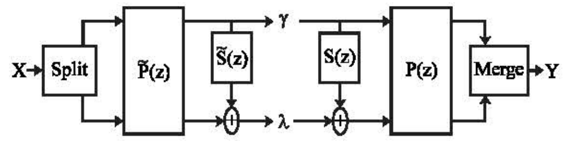

Fig. 1: Primal lifting, the low-pass sub-band is lifted with the help of the high-pass sub-band

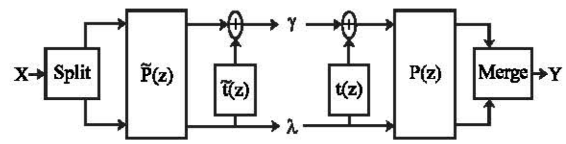

Fig. 2: Dual lifting, the high-pass sub-band is lifted with the help of the low-pass sub-band

It is proven that for long filters the lifting scheme cuts computation complexity in half, compared to the standard iterated FIR Filter Bank algorithm. This type of wavelet transform has already a complexity of N in other words, much more efficient than the FFT with its complexity of Nlog(N) and lifting speeds things up with another factor of two. Hence, it is called as fast lifting wavelet transform of FLWT (Uytterhoeven *et al.*, 1997).

Integer lifting wavelet transform: In classical transforms, including the non-lifted wavelet transforms, the wavelet coefficients are assumed to be floating point numbers. This is due to the filter coefficients used in the transform filters which are usually floating point numbers. In the lifting scheme, it is easy to maintain integer data, although the dynamic range of the data might increase. This is possible in the lifting scheme has to do with the easy invertibility property of lifting. The basic lifting step is rewritten as (Sweldens, 1997):

$$x^{new}(z) \leftarrow x(z) + s(z)y(z) \quad (9)$$

Because the signal part y(z) is not changed by the lifting step, the result of the filter operation can be rounded and written as:

$$x^{new}(z) \leftarrow x(z) + \lfloor s(z)y(z) \rfloor \quad (10)$$

where we have used $\lfloor \cdot \rfloor$ to denote the rounding operation. It is fully reversible to:

Table 1: Reconstruction of approximation and detailed coefficients error

Type of waveforms	Modified Wavelet Transform (MWT)	Integer Lifting Wavelet Transform (ILWT)
Sine wave	5.5e-016	0
Voltage sag	5.5e-016	1.1e-016
Voltage swell	5.5e-016	1.1e-016
Harmonics	5.5e-016	1.1e-016

Table 2: Compression of power quality events using integer elementary lifted wavelet transform

Sample waveform	Retained energy using lifting	Zero coefficients using lifting
Sine wave	100.00	78.68
Voltage sag	100.00	74.90
Voltage swell	100.00	61.21
Harmonics	90.43	90.48

Table 3: Energy coefficient comparison of power quality waveforms using integer lifted wavelet transform

Sample waveforms	Ea	MWT	ILWT
Sine wave	Ea	94.20	96.82
Voltage sag	Ea	93.80	95.99
Voltage swell	Ea	94.60	96.94
Harmonics	Ea	93.50	95.38

$$x(z) \leftarrow x^{new}(z)-\lfloor s(z)y(z) \rfloor \tag{11}$$

and this shows the important feature of integer lifting: irrespective of rounding operation is used the lifting operation will always be reverse.

RESULTS AND DISCUSSION

Reconstruction of approximation and detailed coefficients obtained from proposed approach proves the algorithm efficiency in Table 1.

Compression of various power quality waveforms are carried using integer elementary fast lifting wavelet transform algorithm. The result shows that the retained energy coefficients and zero crossing coefficients after compression of signals are of good percentage in Table 2.

Unfortunately, the integer elementary fast lifting wavelet transform based power quality waveform decomposition and reconstruction turns out with output such that the energy coefficient calculation is not superior to conventional wavelet transform. It is denoted that the energy of approximation coefficients as Ea in percentage and energy of detailed coefficient vectors as Ed in Table 3.

CONCLUSION

The experimental simulations have verified the effectiveness of the proposed algorithm for transient and steady harmonics signals. ILWT calculation complexity is greatly lower than classical wavelet-domain. So, the ILWT method is an attractive algorithm, not only from the convergence performance point of view but from the computational complexity point of view as well. The disadvantage of such a transform is that large coefficients may be represented by small values. The hardware is to be implemented to validate the simulation results.

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