Intelligent Data Acquisition and Information Process Technologies and Their Applications. Part II
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International Frequency Sensor Association (IFSA).

Digital Sensors and Sensor Systems: Practical Design
Sergey Y. Yurish

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Jacob Y. Wong, Roy L. Anderson

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Compression of Power Quality Data Based on Improved DCT Transform

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Abstract: Compression is the preprocessing work before power quality event data transmission and analysis. In this paper segmented discrete cosine transform (DCT) was used for power quality signal compression. For transient power quality event, such as short duration voltage variation, wavelet transform was used to detect the singularity of the signal firstly. Then the signal was divided into segments by singularities and DCT was performed following. The simulation results show that for stable power quality data, the compression effect of DCT is better than that of wavelet transform. And for short duration voltage variation signal, the compression effect of segmented DCT is better than that of direct DCT. Finally the experiment result was presented to prove the effection of above method. Copyright © 2013 IFSA.

Keywords: Power quality, Short duration voltage variation, Data compression, Wavelet transform, Segmented DCT.

1. Introduction

Compression is the preprocessing work before transmission or analysis of the power quality (PQ) data. The storage of PQ event data is becoming an important issue. As we all know that the frequency range of power quality disturbance is very large. Frequency of voltage fluctuation and flicker caused by arc furnace is lower than 25 Hz, while frequency of pulse transient caused by lightning impulse is high above several Mega-Hz. The power quality monitoring device with 1 MHz to 4 MHz sampling frequency is necessary for recording high frequency transient disturbance. This implies a dramatic need of data compression in terms of storage [1]. In addition, sampled data may be sent to remote control center to analysis and process, which brings enormous stress to channel capacity. Compression – method of reducing the bandwidth or storage capacity needed for analysis and processing is of great importance to power quality monitoring.

There are two parts of compression: lossless compression and lossy compression. According to the principle of information theory, signal is considered as the combination of redundancy and information. The purpose of lossless compression is to reduce redundancy of data, where there is none information losing which is called as entropy coding. Contrariwise, there is information loss in lossy compression which can be called as entropy compression. Transform coding is kind of lossy compression. Original data are transformed to a compact orthogonal space firstly by a certain transforms, and then some coefficients of the transform are discarded according to a certain criterion, finally, the reconstructed signal is achieved by the invert transform. Usually, lossless coding technology is used after lossy transform coding, which would obtain better compression effect. Wavelet transform (WT) has many applications in PQ disturbance data detection and compression [2-5]. PQ data are sinusoidal signal of voltage or current. We
know that the orthonormal basis of discrete cosine transform (DCT) is sinusoidal signal, also. According to the principle of similarity, DCT would be more effective than that of WT in energy concentration characteristics [6]. What’s more, DCT transform is a set of real-value orthogonal transform, thus the calculation quantity is smaller than that of complex FFT algorithm.

In this paper segmented DCT was used in PQ data event compression. Harmonic is stable PQ signals only including sinusoidal signal (fundamental and harmonic signal). DCT was used directly for harmonics signal. Short duration voltage variation (SDVV) is transient PQ signal with high frequency transient disturbance, which can not to be considered stable in the whole long time. So the compression effect using DCT does not act well. Taking account of the problems above, WT was used to detect the singularity of the signal. Then signal was divided into segments by singularities and DCT was performed following. The simulation and experiment results show that the compression effect of segmented DCT is better than that of DCT for SDVV signal.

2. The Principle of DCT

Let \( X = (x_1, x_2, ..., x_N) \) is a column that consists of \( N \) samples, \( A \) is a matrix of \( N \times N \), then
\[
Y = AX
\]
(1)

Defining a linear transformation of \( X \), \( A \) is called the kernel matrix of the transform.

The kernel matrix of DCT is
\[
A = \frac{2}{\sqrt{N}} \left[ c(k) \cos \left( \frac{2m+1)k \pi}{2N} \right) \right]_{k,m=0,1,L,N-1}
\]
(2)

That is
\[
Y_k = \frac{2}{\sqrt{N}} \sum_{n=0}^{N-1} x(n) \cos \left( \frac{2m+1)k \pi}{2N} \right),
\]
(3)

where
\[
c(k) = \begin{cases} 
  1 & k = 0 \\
  \frac{1}{\sqrt{2}} & k = 1,2,L,N-1 
\end{cases}
\]
(4)

Thus, when samples are real, the DCT of samples are real, too.

3. Compression based on DCT

There are two kinds of PQ: stable PQ and transient PQ. The characteristics of stable PQ are waveform distortion, which include harmonics, voltage fluctuation and flicker, voltage unbalance and notch.

The characteristics of transient PQ are spectrum and duration, which include transient resonance, transient pulse, voltage sag and swap. Different characteristic would be taken into account to get better compression effect.

3.1. Compression of stable PQ event data

A typical stable PQ disturbance is harmonic. Let voltage signal with harmonics and inter harmonics under 40 dB white Gaussian noise is
\[
x(n) = \cos(100\pi n T_s + \frac{\pi}{3}) + 0.03\cos(110\pi n T_s + \frac{\pi}{5}) + 0.2\cos(500\pi n T_s + \frac{\pi}{10}) + 0.1\cos(700\pi n T_s) + 0.05\cos(360\pi n T_s + \frac{\pi}{2})
\]

Sampling frequency is \( f_s = 6400 \) Hz. And sampling number is 1024, that is to say, 8 periods. The waveform of \( x(n) \) was shown in Fig. 1(a), and DCT coefficients was shown in Fig. 1(b). It can be seen that most of DCT coefficients are small, which is beneficial to data compression.

There are several ways of measuring the distortion due to compression. Compression ratio (CR) and percentage of mean square error (MSE) are two of them.

CR is defined as:
\[
CR = \left(1 - \frac{S_{\text{new}}}{S_{\text{old}}} \right) \times 100\% ,
\]
(5)

where \( S_{\text{new}} \) is the amount of data after compression, and \( S_{\text{old}} \) is the amount of data before compression.

MSE is defined as:
\[
MSE = \frac{\sum_{k=1}^{N-1} (x(k) - y(k))^2}{\sum_{k=1}^{N-1} x(k)^2} \times 100\% ,
\]
(6)

where \( x(k) \) is the original signal; and \( y(k) \) is the reconstructed signal.

When CR is selected to be 87.5 %, then only 128 samples would be retained and 896 smallest samples must be set to zero. The original, reconstructed waveform of the data and the error between them were shown in Fig. 2. The compression performance of DCT and WT was compared here. While PQ data were compressed using Daubechies-4 wavelet transform, three-level decomposition is used. This made 1/8 of the transform samples coming from approximation coefficients. When detail coefficients were discarded, the CR is 87.5 %, too. The MSE of DCT is 0.9165, while the MSE of WT is 1.13894. The reconstructed errors of DCT and WT were shown in Fig. 2 (b), (d), respectively. It can be seen that under the same CR, the MSE of DCT was smaller than that of WT. That is to say, the compression performance of DCT is better than that of WT for harmonics.
Fig. 1. Waveform of harmonics signal and its DCT transform: (a) Waveform of harmonics signal with 40 dB white noise; (b) DCT transform of harmonics signal.

Fig. 2. Error when CR is 87.5 % of harmonic signal: (a) Original signal and its DCT reconstructed; (b) Error between original data and reconstructed data after DCT; (c) Original signal and its WT reconstructed; (d) Error between original data and reconstructed data after WT.

3.2. Compression of Stable PQ Event Data

Typical transient PQ disturbance is SDVV. The fundamental frequency of SDVV data is 50 Hz, sampling frequency is $f_s = 6400$ Hz, and sampling number is 1024. Between 150 and 400 samples, voltage sag with amplitude of 0.6 p.u. happens; and between 600 and 900 samples, voltage swell with amplitude of 1.5 p.u. happens.

CR was selected to be 87.5 % as above. Original data and reconstructed data using DCT were shown in Fig. 3. The MSE was 2.1432. It can be seen that the compression performance of direct DCT was bad. At the discontinuity point of SDVV event, peaks of reconstructed coefficients appeared. The reason lies in that DCT is frequency domain analysis, which is unfit for nonstationary signal.

3.3. PQ Event Data Compression based on Segmented DCT

SDVV signal is one of some kinds of signals that existing singularity points in begin-end time, which can be detected as the modulus maximum of WT detail scales [7-10]. In this paper, modulus maxima of the first detail signal of Db4 WT are extracted, and the positions where weak signal singularity occurs can be found, which are considered as the begin-end time of SDVV signal.
Reconstructed approximation coefficients and detail coefficients waveform of single-scaling decomposition were shown in Fig. 4. Db4 WT was used here. Singularity points of signal in reconstructed detail coefficients could be seen easily. The modulus maxima happen at 149, 301, 400, 601, 799, 901 sample points, which were much near the real singularity points.

According to the analysis above, we can get the method of PQ data compression based on segmented DCT transform. Firstly detail coefficients of wavelet are extracted to judge the existing of singularity point. If no singularity point exists, DCT is performed directly; and if singularity points exist, signal would be segmented by singularity points and segmented DCT and its reconstruction are performed separately. Using the segmented DCT method presented above, the MSE of SDVV signal is 0.7325 when CR is selected to be 87.5 %. Comparing the errors of Fig. 3 (b) and Fig. 5 (b), it can be seen that segmented DCT method reduces the reconstructed error at singularity point.

4. Compression of Real PQ Event

Real PQ event data with 32000 samples were shown in Fig. 6. The frequency is 6400 Hz. Also, we let CR = 87.5 %, and get MSN = 0.7913. The signal to noise ratio (SNR) is 42.0328. From the example it can be seen that the reconstructed signal remain the characters of original signal, and the method presented here is effective.
5. Conclusions

PQ event data compression using segmented DCT is discussed here. The simulation and experiment results show that the compression effect of segmented DCT is better than that of WT for harmonic signal and short duration voltage variation signal. However, the CR is fixed in this paper, which is not flexible for performance. One of the next works is how to select the compression.

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