Short Time Disturbance Detection Using DCT Analysis In Distribution System

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This paper introduces DCT (discrete cosine transform) into short time disturbances detection. DCT coefficients of sampled signal about short time power quality disturbances (voltage sag, voltage swell and voltage interruption) in serious noises can be extracted through DCT transform, and a difference sequence can be extracted through DCT coefficients, then disturbance characteristics can be detected. Simulation results show that this method has a simple process, and can realize signal detection in heavy noises, and the detection results have a high precision.

1 INTRODUCTION

Overfull usage of large scale power transformer, electronic apparatus and other nonlinear load bring negative influence to power quality, however, industry automation, intelligent devices such as microprocessor and electronics would be easily influenced by power quality disturbance. Correlative department should monitoring power quality continuously so as to take appropriate measures to improve power quality. So detection and analysis of short time power quality disturbance is very important. Many experts and scholars at home and abroad varied power quality disturbance using DWT [1~5]. However wavelet transform is sensitive to signal noises, and it can not detect or mistake point of divergence when noises are serious or the disturbance starts ends in the zero point of signal. Literature [6] put forward that detect voltage sag, voltage swell, voltage interruption using DB1 wavelet analysis to avoid influence form noises. Nevertheless higher precision results are wanted.

This paper introduces DCT into short time power quality disturbances detection. Disturbance can be detected through DCT coefficients, and its characteristics can be calculated through different sequence. This method can obtain comparative high precision results when signal is in heavy noises.

2 FUNDAMENTAL OF DCT

2.1 Basic idea

Wavelet packet can part frequency axis into different intervals so that it is especially adaptive to signals those have different behaviour in different frequency interval. However if signal $f$ changes along with time axis, analysing $f$ in block basis is more appropriate. Block basis part time axis into intervals so that it is adaptive to change of $f$ along with time, while amplitude of short time power quality disturbance such as voltage sag, voltage swell and voltage interruption would change during disturbance so that we can try analysing this kind of signal using DCT.

From Fourier series we know any signal $f \in C^\infty$ can be decomposed into some orthogonal cosine functions. So we always can decompose signal using cosine block basis. However cosine block basis are computed through parting beeline into non-cut rectangle windows, which would produce gaps when multiplying a signal, that is, it would produce great coefficient in high frequency. In order to avoiding the flaw it is necessary to adopt smooth windows. So we can get local cosine basis.

Discrete local cosine basis $g_{p,a,n}$ is normative orthogonal basis in $l^2(Z)$, it is defined as following:

$$g_{p,a,n} = \frac{2}{l_p} \cos \left[ \pi(k + \frac{1}{2}) \frac{n - a_p}{l_p} \right]_{0 \leq k < l_p, a_p \in Z}$$

Typical wave of $g_{p,a,n}$ is as in Figure 1.

In formula (1) $g_p[n]$ is discrete smooth window, $p \in k$ mean time and frequency respectively, $l_p$ which can vary length of time interval $p$, $a_p$ is the left extreme point of time interval $p$.

$$e_{i,k}[n] = \frac{2}{l} \cos \left[ \pi(k + \frac{1}{2}) \frac{n + \frac{1}{2}}{l} \right]_{0 \leq k < l}$$

is discrete IV cosine basis.

Local cosine basis can be shown as covers in time-frequency plane. High concentricity in time and frequency in every local cosine are approached by Heisenberg rectangle, as shown in Figure 2.

Fig.1 Local cosine function

Fig.2 Heisenberg box of local cosine vector

Time-frequency scope of local cosine basis $g_{p,a,n}$ is as following,
Making \( f \) a DCT is to compute product between signal \( f \) and local cosine basis \( g_{p,k}[n] \), i.e. compute \( \langle f, g_{p,k} \rangle \).

Calculation formula of DCT IV coefficient is,

\[
C_{p,k} = \langle f, g_{p,k} \rangle = \sum_{n=0}^{N-1} h_p[n] \frac{2}{l_p} \cos \left( \frac{\pi}{l_p} \left( n + \frac{1}{2} \right) \right)
\]

In this formula \( h_p \) is the replicate of \( f \), which is product between smooth window \( g_{p}[n] \) and \( f \).

### 2.2 Application in analysis of short time power quality disturbance

Here short time power quality disturbance include voltage sag, voltage swell and voltage interruption. Voltage sag is a electromagnetism disturbance during which virtual value of fundamental wave drops to 0.1~0.9 pu, Voltage swell is a electromagnetism disturbance during which virtual value of fundamental wave goes up to 1.1~1.8 pu, voltage interruption is a electromagnetism disturbance during which supplied voltage or load current drops below 0.1 pu and duration is less than 1 min.

Obviously DCT is a linear orthogonal transform, DCT coefficient \( C_{p,k} \) represent projection of signal at time \( p \), frequency \( k \) on local cosine basis. Generally, normal voltage wave can be consider as sine wave. If parting signal equally every fundamental period \( T \), DCT coefficients would repeat value every fundamental period. Once disturbance happens at certain time-frequency interval, the same change would take place accordingly on DCT coefficient. Separating coefficients at disturbance frequency from \( C_{p,k} \), finally realizing detection and analysis.

Compare DWT, DCT has some characteristics, which are very appropriate to analysis of power quality disturbance. At first, DCT coefficients consider every whole time interval so that its amplitude is decided by signal itself and nearly has nothing to do with noises. Namely DCT coefficients are robust to noises, and can get satisfying detection results in serious noises. Furthermore, the relation between DCT coefficients and signal sampling points is one to many, which can decrease dimension of signal and greatly decrease calculation in data rerunning. Apply to this paper it is easily to extract a difference sequence from DCT coefficients, which can realize accurate location of signal disturbance.

### 3 SIMULATION ANALYSIS

#### 3.1 Analysis of signal disturbance in noise

Actual voltage would always introduce noises, that is to say sampling signal are comprise original signal and noises. Especially power system fault would arise serious noises, which make SNR at a very low level. Here sampling frequency of simulation signal is 6.4 kHz, sampling duration is 10 fundamental periods, SNR is about 25dB.

![Fig.3 voltage sag sampling signal and its analysis](image1)

Figure 3~5 are three short time power quality disturbance sampling signals and its analysis, which are all disturbances at fundamental frequency. Analysing those signals using DB1 wavelet detection precision could only reach 5 ms. Suppose sampling frequency is \( f_s \), sampling duration is \( T_d \), fundamental frequency is \( f_1 \), fundamental period is \( T_1 \). So sampling number is \( N = \frac{1}{f_1}T_d \), according to literature [6], in order to extract disturbance at fundamental frequency it is necessary to decompose signal to scale \( j \), satisfying

\[
2^j = \frac{f_1}{2f_s}
\]

According to down sampling we can but get

\[
N_j = \frac{N}{2^j} = 4f_sT_d
\]

low frequency coefficients, then get

\[
\frac{A_f}{T_d \cdot T_1} = 4 \text{ coefficients every fundamental period, here}
\]
detection precision only reach $T_i/4$.

DCT can part time axis at will, can adjust length of time interval according to detection requirement. Here there are 128 sampling points every fundamental period, we part time axis every 16 sampling points, then every fundamental period we can get 8 DCT coefficients, so detection precision can reach $T_i/8$. Making sampling signal DCT we can get a $80 \times 60$ two-dimension coefficients matrix $C$, which covers the whole time-frequency range. As before voltage sag, swell and interruption are all disturbances at fundamental frequency, so extract corresponding DCT coefficients sequence $C_T(m)$ (absolute value) from $C$, as shown in Figure 3-5(b). $C_T(m)$ is period waveform, its period is 4, which corresponding half a fundamental period. When disturbances occurs, the same change would reflect in $C_T(m)$. Furthermore, noises robustness of DCT coefficients could greatly resist influence from noises. From these figures we can see that even in strong noises DCT coefficients amplitude still on normal course and normal course, then we can get

$$\text{disturbance amplitude}.$$

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In order to make the results more palpable and clearer, it is necessary to define a difference sequence, 

$$\text{diff}(k) = C_T(m) - C_T(m-4) \quad (3)$$

as shown in Figure 3-5(c). Actually it is to detection disturbances through comparing DCT coefficient and its in-phase points a period ago in turn. If disturbances duration is less than a period, there are two corresponding changes in these figures, one is original plot, the other is opposite mirror image plot. Here disturbances duration equal to the length of original plot; other if disturbances duration is more than a period, then disturbances duration equal to distance between the two point singularity. Here three short time power quality disturbances mentioned above all belong to the second type. For voltage sag in Figure 3, it is obviously the first point singularity occurs at 17th difference coefficient, which corresponds the starting time, the second point singularity occurs at 49th difference coefficient, which corresponds the ending time. As the same, we can analysis voltage swell and voltage interruption. On the other hand, as DCT is linear and orthogonal transform, amplitude of DCT coefficients is in proportion to amplitude of signal, so disturbances amplitude can be calculated. After deciding disturbances time, computing ratio of the maximum between disturbances course and normal course, then we can get disturbance amplitude.

### 3.2 Simulation results comparison

Analyzing three kinds disturbances using DB1 wavelet and DCT separately, simulation results are shown in table 1.

<table>
<thead>
<tr>
<th>Type</th>
<th>Index</th>
<th>DWT Value</th>
<th>DCT Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>start time/s</td>
<td>0.04219</td>
<td>0.04500</td>
</tr>
<tr>
<td></td>
<td>end time/s</td>
<td>0.12183</td>
<td>0.12200</td>
</tr>
<tr>
<td></td>
<td>amplitude/V</td>
<td>0.67500</td>
<td>0.67190</td>
</tr>
<tr>
<td>sag</td>
<td>start time/s</td>
<td>0.07813</td>
<td>0.08500</td>
</tr>
</tbody>
</table>

The first method is DB1 wavelet analysis raised by Literature [6]. Here it detects signal disturbances by extracting low frequency coefficients in scale 5. The second method is DCT analysis, and here every time interval takes 16 sampling points. From table 1 we can see that the second method can locate disturbances more accurately due to higher time resolution while detection accuracy of disturbances amplitude is almost equal. So DCT analysis decreases detection accuracy greatly.

### 4 CONCLUSION

This paper introduces DCT into detection of power quality disturbances. This method realizes characteristic detection of disturbances in strong signal noises through DCT coefficients and the difference sequence extracted from corresponding DCT sequence, which make use of linearity and orthogonal of DCT and noises robustness of DCT coefficients. The advantage of this method is that it can realize short time power quality disturbances detection in strong noises, and detection accuracy is higher than DB1 wavelet analysis, and it can get good accuracy to most of the disturbances characteristic.

Furthermore, as data size of DCT coefficients is small, retreatment of the data is easy. So we can consider defining class eigenvector using DCT coefficients, and class and identify all kinds of disturbances. This is the next work we can do.

### 5 REFERENCE


[7] Stephane Mallat. A Wavelet Tour of Signal Processing,