The study and design of inter-harmonic detection device based on quasi-synchronous technique in power system

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Abstract

On the basis of analyzing the characteristics of harmonic signals, the inter-harmonic detection algorithm of quasi-synchronous sampling is introduced in this paper. This algorithm pre-processes the original sampled signal and separates all the harmonics and inter-harmonics of the reconstructed signal with designed comb FIR filters, to restrain the mutual interference between them, and finally achieve accurate measurement of harmonic and inter-harmonic in power system. At last, the validity of this algorithm is verified with harmonic and inter-harmonic signal generated from standard signal source.

Keywords: quality of electric energy, inter-harmonics, quasi-synchronization, comb FIR filter

1 Introduction

With higher demand on power quality, the inter-harmonics in power quality monitoring is more and more concerned. Nevertheless, due to the uncertainty of inter-harmonic frequency and much smaller amplitude with respect to fundamental and harmonic waves, the spectrum leakage in the process of harmonic signal sampling may cause serious impact on inter-harmonic measurement, or even annihilating of inter-harmonic signal in serious case.

Thus, the current sophisticated algorithms for harmonic detection (such as FFT, etc.) can hardly locate inter-harmonics in the spectrum accurately, and even mistake spectrum leakage or noise interference as inter-harmonics [1, 2].

It is difficult to achieve the desired complete synchronous sampling in practice considering the fluctuation of fundamental wave and non-integer ratio between harmonic frequency and fundamental frequency in actual electric power signal. However, in actual asynchronous sampling process, the reciprocal serious interference among sub-harmonics and neighbor inter-harmonics on the spectrum can influence final measure results. Therefore, the harmonics and inter-harmonics of signal must be first separated, then, their respective parameters are calculated and the parameters of harmonics and inter-harmonics are obtained accurately.

In order to reduce mutual interference between harmonics and inter-harmonics, the quadratic measurement can be adopted to increase accuracy, i.e. the entire measurement process is divided into two stages: first, the harmonic component is extracted from original signal and parameters are calculated; then, the various parameters of inter-harmonics are calculated. In this method, because the harmonics interference has been wiped out before calculating parameters of inter-harmonic signal, so the accuracy of inter-harmonic measurements can be effectively increased [3].

The method of reducing mutual interference through separating harmonics and inter-harmonics of signal, can increase the accuracy to some extent, but the ignorance of inter-harmonics' influence on harmonics when harmonic signals are extracted directly and subtracting them from original signal makes this method incomplete. Due to the mutual interference between harmonics and inter-harmonics, a better way to calculate their parameters should be to separate them precisely from the original signal before calculating their respective parameters [4, 5].

Undoubtedly use comb filter can be ideal separation between the harmonic and harmonic signal, but the comb filter is suitable for the synchronous sampling signal processing, in order to enable it to application in asynchronous sampling condition, must be the actual asynchronous sampling signal accurate synchronization processing to meet the needs of a comb filter for synchronous sampling.

2 Detection model of quasi-synchronous sampling and inter-harmonic

Synchronous sampling requires that the number of signal cycles T_0 contained N sample sequences must be integer, namely: $N \cdot T_S = P \cdot T_0$.

Wherein, T_S is the sampling period; for synchronous sampling, P is an integer; in the asynchronous sampling, P is not an integer. And comb filter requires p to meet integer condition, T_S can be adjusted to make the equation take holds, set the adjusted quasi-ampling period λ_s satisfies [6]:

$$\lambda_s = \frac{P \cdot T_0}{\mathrm{K}}, \tag{1}$$

wherein, K is the sampling points in P sampling periods, usually an integer. According to Equation (1), quasi-sampling period λ_s can be calculated. Then the interpolation

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calculation is carried out among K sampling points with equal interval λ_s, a group of new signal sample sequence $K\lambda_s$ with a total length of K can be obtained. P sampling periods are contained in this sequence, so it is the desired quasi-synchronous sampling sequence, and DFT operation or some other operations applied will not result in spectral leakage.

In this case, by simply setting the space width of comb filter according to different situations (usually the fundamental frequency), the harmonic and inter-harmonic signal components can be separated from signal.

3 Measurement of fundamental frequency from inter-harmonic signal

In accordance with IEC61000-4-7, due to the uncertainty of inter-harmonic frequency, at least 10 cycles of fundamental signal sequence are analysed in order to obtain a more accurate calculation value of fundamental cycle. Meanwhile, in order to ensure that the sample sequence after the reconstruction is no shorter than the sum of the length of both the comb filter and the analysis window, 20 cycles of sample sequence will be taken and it's mean value will be operated to obtain a more accurate value of the fundamental cycle [6-8].

$$T^*_{MEAN} = \frac{1}{20}[(k_{n+20} - k_n)T_s + (I_{n+20} - I_n)] . \quad (2)$$

Quasi-sampling period is: $\lambda_s = \frac{20T^*_{mean}}{L^*}$.

The reconstitution of sampling results after Newton interpolation is:

$$P(m) = x(g_u T_s) + \tau_m \Delta f_0 + \frac{\tau_m(\tau_m - 1)}{2!}\Delta^2 f_0 + \cdots + \frac{\tau_m(\tau_m - 1)\cdots(\tau_m - 4 + 1)}{4!}\Delta^4 f_0 . \quad (3)$$

4 The design of equiripple comb FIR filter

Comb filters are generally divided into FIR and IIR filters. In the same filter performance parameters requirement, although IIR filter has lower order, its nonlinear and stability of phase characteristics does not meet the requirements of the inter-harmonic measurement; therefore, comb FIR filter will be chosen [9].

Supposing FIR filter with order Mi, if Mi is odd, then the transfer function can be expressed as:

$$H(z) = \sum_{m=0}^{2K} h(n) z^{-m} = z^{-K}[h(K) + 2\sum_{K=1}^{2K} h(K-m)\frac{1}{2}(z^m + z^{-m})] . \quad (4)$$

According to the first species of Chebyshev polynomials $T_n(\omega) = \cos(n \cdot \arccos(\omega))$, $\omega \in [-1,1]$ $\omega = \left(z + z^{-1}\right)/2$, then:

$$T_n(\omega) = \frac{z^n + z^{-n}}{2} , \quad (5)$$

$z = e^{j\omega}$.

The transfer function can be reduced as

$$H(z) = z^{-k} \sum_{m=0}^{k} a(m) T_m(\omega) . \quad (6)$$

Considering the impact of the filtering effect and filter order on the computational efficiency, design parameters of comb FIR filter with inter-harmonic detection algorithm will be selected. As mentioned earlier, first, the sample sequence with length of 20 fundamental cycles is selected; after reconstructing the sampling sequence, fundamental cycle is determined as 50.1 Hz, and sampling points 102. Then, the filter order of Chebyshev polynomial series is obtained through experiment. The amplitude-frequency response of designed comb FIR filter is shown as Figure 1 [10-12].

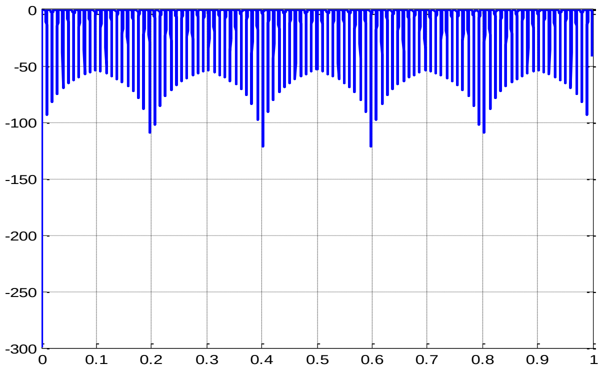

FIGURE 1 Amplitude-frequency Response of Comb FIR

In the harmonic measurement, impulse response effect needs to be considered, the impact of the filter impulse response is shown in Figure 2 [13, 14].

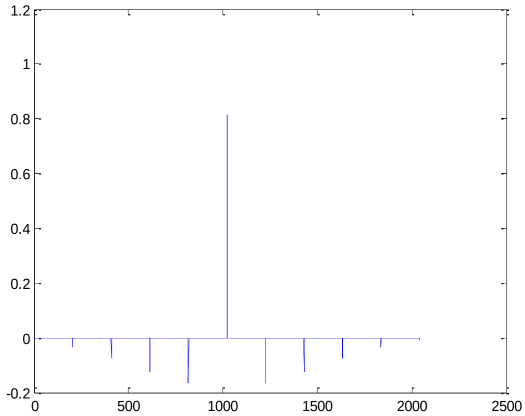

FIGURE 2 Impulse Response of Comb FIR Filter

5 Hardware structure diagram of harmonic and inter-harmonic analyzer

Hardware Structure Diagram of Harmonic and Inter-harmonic Analyser are shown in Figure 3. Three parts are mainly included: data sampling module, the data processing module data management module [15] based on DSP and ARM.

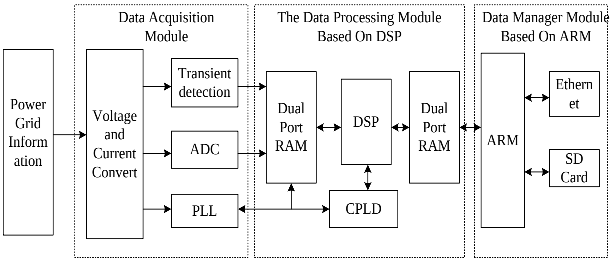

FIGURE 3 Hardware Structure Diagram of Harmonic and Inter-harmonic Analyzer

Among them, the data sampling module includes voltage and current transmitter, PLL, analog to digital converter (ADC) and transient detection and other components, which is mainly responsible for collecting original signal; data processing module is in charge of processing the collected power system voltage, current data, and transient information, meanwhile calculating power quality parameters, which is the core part of analyzer; data management module implements the function of data storage, management, human-computer interaction and supporting network communication.

For inter-harmonic detection, it needed to separate harmonics from inter-harmonics with comb FIR filter, which is a relatively large amount of data processing, and due to the power quality analyser's high requirements of accuracy, the high-performance TMS320C6713 DSP chip produced by TI will be chosen as the arithmetic unit to improve system performance.

In order to achieve inter-signal synchronization between phase position and frequency, a phase locked loop (PLL) circuit is used to automatically adjust the sampling frequency so, as to correspond to the synchronous measurement.

6 Experimental results

In order to carries on the analysis comparison, using the device on the analog signal test and analysis. The experiment uses FLUKE 6100A standard electrical power to produce a distorted signal as a test signal. The actual output signal is as shown in Equation (7):

$$x(t) = 10sin(49.9\omega t) + 0.6sin(99.8\omega t + 0.3) + 0.05sin(149.7\omega t - 0.15) + 0.2sin(75.5\omega t) + 0.05sin(154.5\omega t) . \quad (7)$$

In the above Equation, the first three are the fundamental wave and second and third harmonics, the last two are inter-harmonics. The fifth inter-harmonic and third harmonic frequency are closer, and are prone to mutual interference, which can cause some difficulties to accurate measurement of inter-harmonics. The specific waveform is shown in Figure 4:

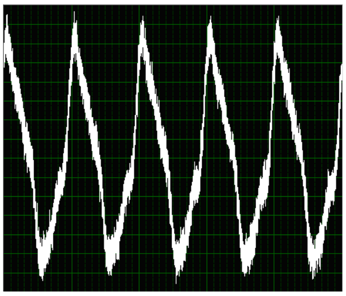
FIGURE 4 The measured signal waveform

Under the proposed IEC standard, the analysis window length should be 200 ms (approximately 10 cycles). The sampling frequency of inter-harmonic and harmonic analyser is the fixed value of 10240 Hz, which is 200 times of fundamental wave (about 50 Hz) in order to avoid aliasing, while ensuring high harmonic detection accuracy.

In addition, the analyser can upload the collected original signal to a computer to facilitate the comparison with a variety of other algorithms and calculation results. In this experiment the original signal is compared with the FFT and second-level WIFFTA methods. The results are in Tables 1-3.

TABLE 1 Results of different algorithm - FTP

Actual value		**FFT**			
		Frequency		*Amplitude*	
Frequency	*Amplitude*	*Measured value*	*Deflection*	*Measured value*	*Deflection*
49.9	10	50	0.1	9.99	0.01
99.8	0.7	100	0.2	0.75	0.05
149.7	0.05	150	0.3	0.07	0.02
75.5	0.1	75	0.5	0.15	0.05
154.5	0.05	-	-	-	-

TABLE 2 Results of different algorithm - Two-level WIFFTA Method

Actual value		**Two-level WIFFTA Method**			
		Frequency		*Amplitude*	
Frequency	*Amplitude*	*Measured value*	*Deflection*	*Measured value*	*Deflection*
49.9	10	49.9	0	9.99	0.01
99.8	0.7	99.78	0.02	0.7	0
149.7	0.05	150.9	1.2	0.07	0.02
75.5	0.1	75.48	0.02	0.11	0.01
154.5	0.05	156.9	2.4	0.02	0.03

TABLE 3 Results of different algorithm - Quasi-synchronous sampling algorithm

Actual value		**Quasi-synchronous sampling algorithm**			
		Frequency		*Amplitude*	
Frequency	*Amplitude*	*Measured value*	*Deflection*	*Measured value*	*Deflection*
49.9	10	49.9	0	10.0	0
99.8	0.7	99.8	0	0.7	0
149.7	0.05	149.68	0.02	0.05	0
75.5	0.1	75.5	0	0.1	0
154.5	0.05	154.65	0.15	0.04	0.01

7 Conclusions

Judging from the analysis, traditional FFT method is affected by spectral leakage, and accurate parameters of harmonics and inter-harmonics cannot be obtained; though the secondary WIFFTA method is with higher accuracy in the measurement, it cannot effectively suppress mutual interference between Inter-harmonics and harmonics. Therefore, the accuracy of measurement will be affected, in case of serious mutual interference. In the three times measuring results for harmonics and 154.5 Hz inter-harmonics, both frequency and amplitude errors are relatively large. Yet, the present method, which provides better stability and accuracy, even in the case of serious mutual interference, and in which the accuracy of sub-harmonic measurement is able to meet the requirements, is significantly superior to the other two methods.

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