

# Influence Research of Renewable Energy Application on Power Quality Detection

**Ge Beichang, Wu Xiao, Liu Yingying, Zhang Zhang, Yang Fan**

State Grid Tianjin Economic Research Institute, State Grid Corporation of China,  
Tianjin China

e-mail: zimo\_ge@163.com, wuxiao0117@126.com, lyypower@126.com,  
strongzhang1988@163.com, 870415059@qq.com

**Abstract.** With the development of renewable energy generation systems, it not only relieves energy shortages and environmental pollution problems, but also brings harmonic pollution, which is related with power quality detection. A modified harmonic and interharmonic analysis method is studied in this paper. By applying window interpolation, signal reconstruction, 5-point modified algorithm, and other signal handling methods, harmonic and inharmonic components are separated exactly, improving harmonic and interharmonic detection accuracy under new energy application, providing accurate signal basis and reference for further harmonic suppression and distribution network reconstruction scheme, and finally improving power quality.

## 1. Introduction

With the deterioration of energy shortage and environmental pollution, clean energy generation system sources, such as distributed photovoltaic power generation system, get support of national energy policy and social concern widely, for advantages of abundance, clear, and so on [1].

In recent years, photovoltaic power plants, wind power plants and other distributed energy system grow rapidly, transforming traditional distribution network with single power supply and radioactive network to be with multiple power supplies. Renewable energy power generation systems are combined with lots of non-linear electronic devices, injecting harmonics and interharmonics into distributed network, harming electrical equipments and grid safe operation [2].

Traditional FFT algorithm (fast Fourier transform, FFT) has advantages of less calculation, specific physical meaning, and good performance on integer harmonic analysis [3], [4]. However, due to interharmonics and fundamental frequency variation, it is difficult for FFT algorithm to realize synchronous sampling, causing spectrum leakage and fence effect. Although windowed interpolation FFT algorithm can release the effect, it also has limitations, which means that it is not suitable for harmonic and interharmonic analysis under energy application [5], [6].

Aimed at the above problems, a modified harmonic and harmonic analysis method, based on literature [7], is researched in this paper, effectively improving harmonics and interharmonic precision under renewable energy application. The algorithm researched in this paper not only can provide accurate harmonic and interharmonic characteristics, but also provides signal basis and reference for radioactive, relay protection and distribution network restructuring plan under renewable energy application.



## 2. Harmonic and Interharmonic Generation Mechanism Under Renewable energy Application

When power grid runs normally, the harmonics generated by power system are mainly divided into two aspects: harmonics generated by internal power supply systems and generated by electronic components of distributed power generation system.

The harmonics generated by the grid itself are dominated by harmonics of 1, 2, 3, 5, etc. Harmonic components generated by distributed generation system are complex. Especially when it faults, lots of interharmonics are generated for nonlinear actions of power electronic devices and control system [8].

Interharmonics may cause fundamental frequency variation, making traditional FFT algorithm difficult to realize synchronous sampling. It will cause large errors in the phase calculation, hugely influencing the power system stability under renewable energy application.

## 3. Harmonic and Interharmonics Detection Method Based on Modified 2-stage FFT Algorithm

### 3.1. Signal Expansion

For power system, signals are represented in the shape of sine [9]. For components containing both harmonics and interharmonics, the expression is as follows:

$$\begin{aligned} S(t) &= S_H(t) + S_J(t) = \sum_{h=1}^H S_h(t) + \sum_{j=1}^J S_j(t) \\ &= \sum_{h=1}^H A_h \sin(2\pi f_h t + \varphi_h) + \sum_{j=1}^J A_j \sin(2\pi f_j t + \varphi_j) \end{aligned} \quad (1)$$

Among them,  $A_h$ ,  $\varphi_h$  and  $f_h$  are amplitude, phase and frequency of the  $h$ th harmonic, and  $H$  is the highest harmonic frequency;  $A_j$ ,  $\varphi_j$  and  $f_j$  are value, phase, and frequency of the  $j$ th interharmonic,  $J$  is the number of interharmonics in the signal.

Spectral leakage and fence effect of fundamental and harmonics may affect the interharmonics detection effect, which can lower harmonic detection accuracy in turn [7].

In order to reduce the mutual interference between harmonics and interharmonics existed in actual signals, this paper researched a modified 2-stage FFT analysis method, which separates harmonic  $S_H$  and interharmonic  $S_J$  in signal, acquiring accurate signal characteristics under renewable energy application.

### 3.2. Harmonic Analysis in modified 2-stage FFT Algorithm

*Fundamental wave analysis using dual - spectral interpolation FFT method with hanning-window.*

Sample signal  $S(t)$  ( $t_s$  duration) with the fixed sampling rate  $f_s$ , then obtain the  $N$ -point discrete sequence  $S(n)$ .  $S(n)$  is analyzed by dual-spectral interpolation FFT algorithm with Hanning-Window, obtaining fundamental frequency  $f_0$ . Sample number  $N=f_s \cdot t_s$ , sample interval  $T_s=1/f_s$ .

Amplitude of fundamental wave in power signals is much larger than that of harmonics and interharmonics. And by adding window interpolation method, spectrum leakage and fence effect are further inhibited. So the obtained fundamental frequency  $f_0$  meets the precision requirement, ensuring further synchronization accuracy.

*Signal reconstruction with cubic spline interpolation.* According to the calculated fundamental frequency  $f_0$ , the original sampling sequence  $S(n)$  is reconstructed by cubic spline interpolation method, obtaining a new  $N$ -point equal interval sequence, denoted as  $Sr(n)$ . The sample frequency of the reconstructed sequence  $Sr(n)$  is  $f_s' = n_1 \cdot f_0$ , and the sample interval is  $T_s' = 1/f_s'$ .  $n_1$  is a positive integer, satisfying requirements for simultaneous sampling.

A suitable interpolation algorithm is a key factor in signal reconstruction. The cubic spline interpolation is a smooth curve passing through a series of shape points, with low computational

complexity and high reconstruction accuracy [10]. In this paper, cubic spline interpolation is used for signal reconstruction.

*Harmonic analysis of reconstructed signals.* The reconstructed sequence  $S_r(n)$  satisfies synchronous sampling requirement of fundamental and harmonics. However, due to the uncertainty of interharmonic period, it is difficult to realize simultaneous sampling for interharmonics, and to eliminate the interference between harmonics and interharmonics. Based on literature [7], harmonics of reconstructed sequence are analyzed by odd frequency point interpolation method in this paper.

In this paper, the reconstructed sampling sequence is analyzed by 5-point modified algorithm with Rectangular-Window, acquiring amplitude  $A_h$ , phase  $\varphi_h$  and frequency  $f_h$  of fundamental wave and harmonics. The reconstruction sequence  $S_r(n)$  is a synchronous sampling sequence, effectively inhibits spectral leakage between fundamental wave and harmonics; Rectangular-Window owns the narrowest main lobe, which can avoid the spectrum interference between harmonics and interharmonics; 5-point modified algorithm is good at suppressing spectral interference, effectively solving the spectral interference problem between harmonics and interharmonics. Through the odd frequency point interpolation method, frequency spectrum leakage, spectrum aliasing and fence effect problem are well solved, acquiring accurate fundamental wave and harmonic parameters.

### 3.3. Inharmonic Analysis in Modified 2-stage FFT Algorithm

*Obtaining of interharmonics from the original signal.* Through subtracting the fundamental wave and harmonic components  $S_H(n)$  from the original sampling signal  $S(n)$ , interharmonic components  $S_I(n)$  are obtained. The specific steps are as follows: According to the fundamental and harmonic components obtained in 2.2, the structure of the fundamental and harmonic components is expressed as:

$$\begin{aligned} S_H(t) &= A_h \sin(2\pi f_h t + \varphi_h), \\ t &= 0, Ts, 2Ts, \dots, (N-1)Ts \end{aligned} \quad (2)$$

$S_H(n)$  is a N-points sequence. Interharmonic component  $S_I(n)$  is obtained by subtracting  $S_H(n)$  from  $S(n)$ .

*Interharmonics analysis based on 5-point modified algorithm with Rectangular-Window.* Considering spectral aliasing influence for interphonic detection, 5-point modified algorithm based with Rectangular-Window is used to analyze the separated interharmonics signal, obtaining exact interharmonic amplitude  $A_j$ , Phase  $\varphi_j$  and frequency  $f_j$  parameters. Compared with the traditional 2-stage FFT algorithm, the 5-point modified algorithm not only suppresses the effects of spectral aliasing, spectral leakage and fence effect, but also avoids the cumulative error and high computational complexity of peak search method.

### 3.4. A Modified 2-stage FFT Algorithm

In this paper, the process of modified 2-stage FFT algorithm for harmonic and interharmonic analysis is shown in Figure 1.

Compared to traditional 2-stage FFT algorithm, 5-point modified algorithm with Rectangular-Window is used in this paper, solving mutual interference problem between harmonics and interharmonics, and improving detection accuracy.

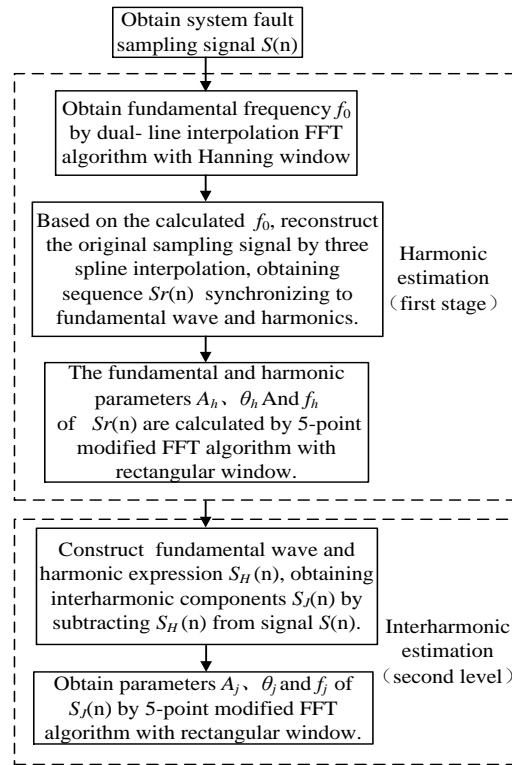


Figure 1. Flowchart of modified 2-stage FFT scheme.

#### 4. Simulation and Experiment

Suppose that the sampling signal containing multiple harmonic and interharmonic components is:

$$\begin{aligned}
 S(t) = & 200\sin(f \cdot 2\pi t - 23.1^\circ) + 4.5\sin(2f \cdot 2\pi t + 115.6^\circ) + 7\sin(3f \cdot 2\pi t + 59.3^\circ) + \\
 & 5\sin(5f \cdot 2\pi t + 78.7^\circ) + 3\sin(7f \cdot 2\pi t + 92.5^\circ) + 0.6\sin(23 \cdot 2\pi t + 73.8^\circ) + 0.3\sin(84 \cdot 2\pi t + 53.7^\circ) \\
 & + 0.2\sin(175 \cdot 2\pi t + 113.4^\circ) + 0.1\sin(189 \cdot 2\pi t - 23.3^\circ)
 \end{aligned} \quad (3)$$

Considered fundamental wave fluctuations, set the fundamental frequency to be 49.8Hz. Harmonics are 1th, 2th, 3th, 5th and 7th. Interharmonics have frequencies of 23, 84, 175 and 189 Hz.

IEC 61000-4-7 recommends 10 basis-cycle window (50 Hz system) to analyze power system signals [11]. Therefore, this paper also uses 10 basis-cycle window. The specific steps are:

- Discrete sampling signal. Sampling frequency  $f_s=10\text{kHz}$ , sampling window length  $t_s=0.2\text{s}$ . Discrete the sampling signal to obtain the original sampling sequence  $S(n)$  with  $N=2000$  points and sampling interval  $T_s=10^{-4}\text{s}$ .
- Estimate fundamental frequency. The  $S(n)$  is analyzed by dual - line interpolation FFT algorithm with Hanning-Window. The fundamental frequency  $f_0=49.799976\text{Hz}$  and the error is  $-4.8908\text{E}-5\%$ .
- Synchronize sampling signal. Based on the calculated fundamental frequency  $f_0$ , the original sampling sequence  $S(n)$  is reconstructed by cubic spline interpolation method, to obtain sequence  $S_r(n)$ , synchronous for fundamental and harmonics.
- The sampling points of  $S_r(n)$  are 2000, and the sampling interval  $T_s'=1/49.799976/2000\text{s}$ .

- Harmonic analysis of reconstructed sampled signal. Analyze the quasi-synchronous sampling signal  $S_r(n)$  with 5-point modified algorithm with Rectangular-Window, which can suppress interference between harmonics and interharmonics, acquiring accurate amplitude  $A_h$ , phase  $\varphi_h$  and frequency  $f_h$  of fundamental wave and harmonics.
  - As can be seen from Table 1, detection errors of 2th harmonic are the largest, respectively be 0.0016%、-0.00298° and 0.000256%. In general, detection of all fundamental and harmonics obtains high accuracy.
  - Structure fundamental wave and harmonics expression as  $s_h(t)$ . Subtract  $S_H(t)$  from the original signal  $S(n)$ , obtaining interharmonic sequence  $S_I(t)$ .
  - Interharmonic analysis. Analyze  $S_I(t)$  by use of 5-point modified algorithm with Rectangular-Window, restraining spectrum leakage and aliasing, and obtaining accurate interharmonic parameters, amplitude  $A_j$ , phase  $\varphi_j$  and frequency  $f_j$ .
- It can be seen from Table 1 that the biggest detection error of 175 Hz is 0.5128%, - 2.49611° and 0.040205%, respectively.

TABLE I. ANALYSIS RESULTS AND ITS RELATIVE ERRORS OBTAINED BY THE MODIFIED 2 STAGE FFT METHOD

Analog signal parameters			Analysis Results and Errors by Modified 2-Stage FFT Algorithm					
Amplitude (A)	Phase (degree)	Frequency (Hz)	Amplitude(A)	Error (%)	Phase (degree)	Error (degree)	Frequency (Hz)	Error (%)
200	-23.1	49.8	200.00016	8.00E-05	23.09912207	0.000877933	49.79997635	-4.75E-05
4.5	115.6	99.6	4.50007585	0.001685549	115.5970165	0.002983468	99.59974407	0.000256961
7	59.3	149.4	7.000006806	9.72E-05	59.29950322	0.000496776	149.4000221	1.48E-05
5	78.7	199.2	4.999995719	-8.56E-05	78.69994557	-5.44E-05	249.0000014	5.77E-07
3	92.5	349	2.999990299	0.000323366	92.49999027	-9.73E-06	348.6000003	7.68E-08
0.6	73.8	23	0.600041793	0.006965558	73.82929977	0.029299772	22.99918117	0.003560111
0.3	53.7	84	0.300009971	0.003323582	53.71358186	0.013581864	83.99967662	0.000384975
0.2	113.4	175	0.201025666	0.512833066	110.9038863	2.496113707	175.0703589	0.040205067
0.1	-23.3	189	0.100000116	0.000116094	23.29887904	0.001120958	188.9999701	-1.58E-05

## 5. Conclusions

The modified 2-stage FFT algorithm researched in this paper, considers the interference between harmonics and interharmonics, applies window interpolation, signal reconstruction, 5-point modified algorithm, and other signal handling methods, achieving high accuracy in harmonics and interharmonic detection, providing accurate signal basis and reference for further researches under renewable energy application, such as harmonic suppression scheme, distribution network reconstruction plan, evaluation index of power quality, adaptability of clean energy enhancing scheme, and so on.

But the algorithm needs data window of ten fundamental wave periods, showing bad performance in quick detection. The way to compress detection data window, which can realize quick detection and analysis, will be researched in further study.

## 6. References

- [1] Wang Chengshan, WANG Shouxiang. Study on some key problems related to distributed generation systems [J]. Automation of Electric Power Systems, 2008, 32(20): 1-4,31.
- [2] ISHIKAWA T. Grid-connected photovoltaic power systems: survey of inverter and related

- protection equipments [R]. Tokyo, Japan : Report IEA-PVPS Task , 2002.
- [3] XUE Hui, YANG Rengang. Precise algorithms for harmonic analysis based on FFT algorithm[ J ] . Proceedings of the CSEE , 2002, 22( 12) : 106 - 110
  - [4] ZHANG Fusheng, GENG Zhongxing, GE Yaozhong. FFT algorithm with high accuracy for harmonic analysis in power system[J] . Proceedings of the CSEE, 1999, 19( 3) : 63 - 66.
  - [5] Pang Hao, Li Dongxia, Zu Yunxiao, et al. An improved algorithm for harmonic analysis of power system using FFT technique[J]. Proceedings of the CSEE, 2003, 23(6): 50-54.
  - [6] Dariusz B, Andrzej B. Improvement of accuracy of power system spectral analysis by coherent resampling[J]. IEEE Transactions on Power Delivery, 2009, 24(1): 1004-1013.
  - [7] Hui Jin, Yang Honggeng. An approach for harmonic/inter-harmonic analysis based on the odd point interpolation correction [J]. Proceedings of the CSEE, 2010, 30(16): 67-72(in Chinese)
  - [8] HAO Jiangtao, LIU Nian, XING Jinyu, et al. Study on interharmonic of power system[ J ] . Electric Power Automation Equipment, 2004, 24( 12) : 36 - 39.
  - [9] Mai R K, Fu L, Dong Z Y, et al. Dynamic Phasor and Frequency Estimators Considering Decaying. DC Components[J]. IEEE Transactions on Power Systems. 2012, 27(2): 671-681.
  - [10] Jin Weigang, Liu Huijin. A New Algorithm for Interharmonics Measurement Based on Time Domain Sampling and Reconstruction by Cubic Spline Interpolation[J]. Power System Technology, 2012, 36(7):74-80.
  - [11] Hui J, Yang H, Xu W, et al. A Method to Improve the Interharmonic Grouping Scheme Adopted by IEC Standard 61000-4-7[J]. IEEE Transactions on Power Delivery. 2012, 27(2): 971-979.