Power Quality Analysis of Short-Time Disturbance based on SPWVD

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Abstract—**Based on smoothed pseudo Winger-Ville time-frequency distribution (SPWVD), this paper has analyzed the power quality of the power grid voltage disturbance, and constructed SPWVD time-frequency distribution diagram, FFT spectrum of voltage, and the joint distribution of voltage time domain waveform. Also, the status of short time power quality can be revealed in real time. According to analyzing voltage frequency mutation, voltage sag, voltage swell and power failure, it reveals the validity and accuracy of voltage harmonic interference and harmonic energy distribution.**

Keywords-power quality; Wigner-Ville; time-frequency analysis; voltage disturbance

I. INTRODUCTION

As we all known, the requirements of power quality have become increasing for users. Therefore, it is very important to detect the voltage of power network. In the actual situation, due to a large number of perceptual load with random variation and all kinds of fault, voltage signals tend to appear all sorts of perturbation, such as sudden power interruption, voltage sag, sudden jump of voltage and so on. Because of these facts, the grid is very difficult to keep stable frequency and voltage, detecting each kind of perturbation of the grid to ensure load in the safe and stable operation is very important, which is known as electrical power quality problems.

Application of time-frequency analysis methods to describe the electric power quality is the main means of current research. Commonly used methods have short time Fourier transform (STFT) [1], which is more suitable for stationary random signal analysis. Although it is possible to roughly reflect the local spectral characteristics of the signal near this moment, this local stationary condition is usually not satisfied or only approximately satisfied. Wavelet analysis [2] has time frequency analysis function of non-stationary signal decomposition, but there is a problem on selecting the wavelet base and the time and frequency cannot be simultaneously with high resolution. To improve the accuracy of wavelet analysis detection, it is necessary to construct a wavelet base with strict frequency division and energy concentration. S transform [3] overcomes the shortcomings of STFT and the wavelet and inherits the advantages of the two, but there are some problems in the sampling point and window function to be correspondence [4]. Hilbert-Huang transform (HHT) [5] is the improvement of S transform. It has strong processing ability for non-linear, non-stationary signals, and can accurately obtain the time-frequency-energy distribution characteristics of signals, but there are boundary effects and it is suitable for narrow band signal. Neural network [6], such as artificial intelligence technology, mathematical morphology [7], and fractal theory [8] are also perturbation analysis for short term electrical power quality.

Wigner-Ville distribution is proposed in the study of quantum mechanics by E.Wigner in 1932 [9]. In 1948, Ville applied it in the field of signal processing [10], so it is called the Wigner-Ville distribution (WVD). However, Mark pointed out that the Wigner-Ville has a serious disadvantage, which exists the cross interference [11]. Classen and Mecklenbraker put forward to the properties and numerical calculation of Wigner-Ville distribution and other issues [12] in 1980, which just promoted the wide application of Wigner-Ville. The basic idea of Wigner-Ville distribution is that the one-dimensional signal is expressed in the form of two-dimensional time-frequency distribution of the energy density function, which accurately reveals the energy density and intensity of the time frequency of the harmonic perturbation in the signal.

Due to the combined representation of time and frequency, time-frequency analysis has a natural advantage over traditional analysis methods when dealing with non-stationary signals with complex frequency variations. As an excellent time-frequency analysis method, WVD is not only simple and effective compared to other joint time-frequency analysis methods. Moreover, it has high resolution, energy concentration and ability to track the instantaneous frequency, which can more clearly characterize the changes of the signal in the time-frequency domain. The WVD algorithm has high accuracy for the amplitude and frequency of the harmonics and harmonics of the grid under certain conditions, and can also judge the cross-disturbance signal of the power quality. It can effectively detect the short-time voltage fluctuations of sudden, non-stationary disturbances, the start and stop time and frequency information of power quality signals such as harmonics and interharmonics. In this paper, an improved algorithm for WVD of time-frequency signal analysis tools: smoothed pseudo Winger-Ville distribution (SPWV) is used to analyze the power quality of the power grid voltage disturbance.

This work is supported by Natural Science Foundation of Shanghai under the Project Grant No.14ZR1418500 and 14ZR1418400.

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II. THE PROBLEM OF CROSS TERM IN WIGNER-VILLE

The WVD is the bilinear time-frequency transform which was first proposed to account for quantum corrections to statistical mechanics by Eugene Wigner. The WVD is defined as:

$$W_x(t,f) = \int_{-\infty}^{\infty} x(x+\frac{\tau}{2})x^*(x-\frac{\tau}{2})e^{-j2\pi f\tau}d\tau \qquad (1)$$

The WVD is not linear, that is, the WVD of two superposed signals are not equal to the sum of two WVD respectively. When $S(t)=S_1(t)+S_2(t)$, its WVD is

$$WVD_S(t,f)=WVD_{S1}(t,f)+WVD_{S2}(t,f)+2\mathrm{Re}\{WVD_{S1S2}(t,f)\} \qquad (2)$$

Where the cross term is

$$WVD_{S1S2}(t,f)=\int s_1(t+\frac{\tau}{2})s_2^*(t-\frac{\tau}{2})e^{-j2\pi f\tau}d\tau \qquad (3)$$

One cross term is created by two component signals and it is the complex number in frequency while in time domain, it is the oscillation mode with twice amplitude. When there are m component signals, m(m-10/2) cross terms would be generated. Their amplitudes carry a lot of energy resulting in the loss of practical value of the WVD. In Fig. 1, we can see the sudden change of the simulation grid voltage frequency waveform and the time-frequency distribution of the WVD shown in Fig. 2 where the middle line is created by cross term and the brown area indicates the strong energy.

III. THE ELIMINATION OF CROSS TERM IN WIGNER-VILLE

In order to take full advantage of the WVD to decompose signals, the phenomenon of cross term must be eliminated. Constructing a two-dimensional filter $\phi(\tau,v)$ with time and frequency window as the kernel function, it must meet the constraint condition

$$\psi(f,v)=\int_{-\infty}^{\infty}\phi(\tau,v)e^{-j2\pi\tau f}d\tau=0,\forall|f|\neq\frac{|v|}{2} \qquad (4)$$

Where the kernel function is

$$\varphi(t,\tau)=\int_{-\infty}^{\infty}\phi(\tau,v)e^{j2\pi tv}dv=0,\forall|t|\neq\frac{|\tau|}{2} \qquad (5)$$

When a WVD with one-dimensional time window kernel function is called pseudo Wigner-Ville distribution (PWVD) which could restrain the time domain component of cross term. The PWVD of s(t) could be

$$PWD_x(t,f)=\int_{-\infty}^{\infty}x(t+\frac{\tau}{2})x^*(t-\frac{\tau}{2})h(\tau)e^{-j2\pi ft}d\tau \qquad (6)$$

Meanwhile, the Fig. 3 shows the cross term of the PWVD and we can find that the cross term of the PWVD has been weakened compared with the WVD. Based on the PWVD, we put the frequency window kernel function in it and get smoothed pseudo Wigner-Ville distribution (SPWVD)

$$SPWD_x(t,f)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}x(t-u+\frac{\tau}{2})x^*(t-u-\frac{\tau}{2})h(\tau)g(u)e^{-j2\pi ft}d\tau du \quad (7)$$

Where $h(0)=G(0)=1$. The separable kernel function $\phi(u,v)=g(u)H(v)$ restrains the cross term in time or frequency domain by controlling the smoothing scale of windows which can eliminate the disturbances of cross term completely and the result is revealed in Fig. 4.

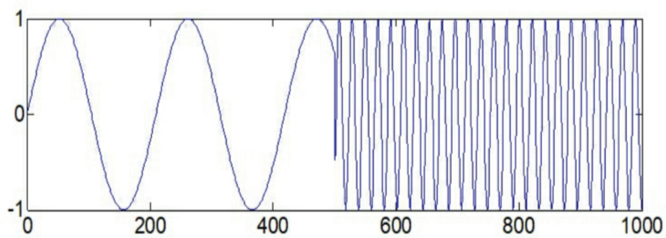

Figure 1. The signal of mutation frequency

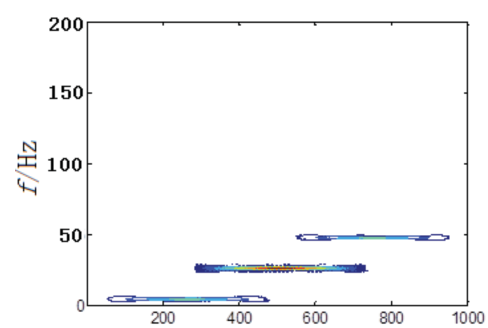

Figure 2. The cross term of the WVD

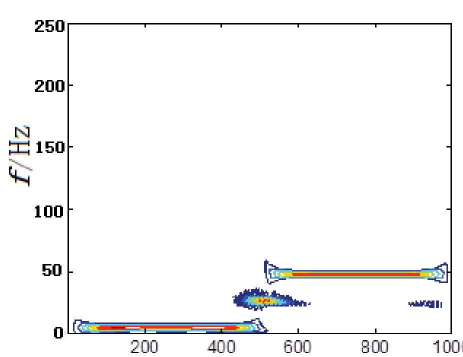

Figure 3. The cross term of the PWVD

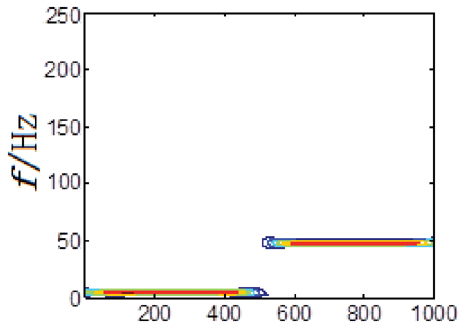

Figure 4. The cross term of the SPWVD

Similarly, Fig. 5 is the joint distribution of mutation frequency signal in FFT, time domain waveform and SPWVD where accurately shows the position and time of mutational site and the brown area indicates the strong energy.

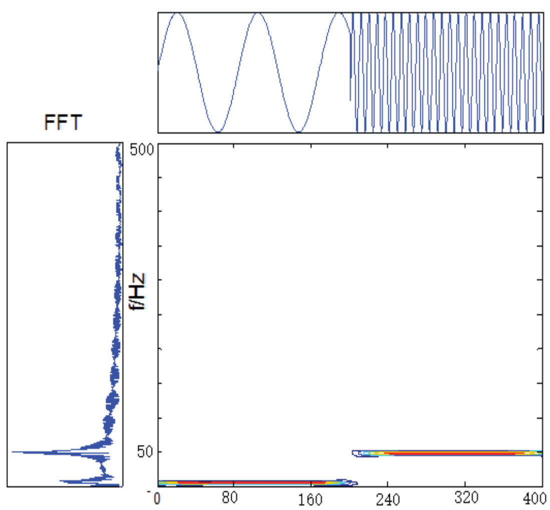

Figure 5. The joint distribution of mutation frequency signal

IV. Application Examples

In recent years, with the large number of applications of sensitive devices, the problems caused by power quality disturbances have received increasing attention. Dynamic power quality problems mainly include voltage swell, voltage sag and power failure. These problems often cause high-precision equipment failures, which have become an important cause of modern production processes, causing great losses to the power supply department and users.

A. Voltage swell

Voltage swells disturbances often occur on non-faulty phases in the event of a single-phase earth fault in a three-phase circuit. Fig. 6 shows the SPWVD joint distribution of voltage in 200~400 time period. From the time frequency distribution of two-dimensional energy, the energy of voltage frequency f=50Hz in 200~400 time period has a significant increase.

B. Voltage sag

Voltage sags in IEC standards have clear definition, but national standard has no this definition. At present, there only has the voltage concave, collapse and subsidence. IEEE sets for 10% - 90% voltage collapse sag in the duration 102ms as voltage sag standard, because it is enough to cause damage for sensitive load equipment in this time period. In the distribution network, when the induction motor starts, or a short-circuit fault, switching operation, switching of the transformer or capacitor bank, etc., can cause voltage sag. Short-time voltage sag (amplitude drop greater than 10%, duration greater than 100ms) may cause computer system turbulence, speed control equipment trip (amplitude drop greater than 15%, duration 8ms) and mechanical and electrical equipment misoperation.

The joint distribution from Fig. 7 shows that the energy of voltage frequency f=50Hz in 200~400 time period has a significant decrease. Brown color represents the strong energy.

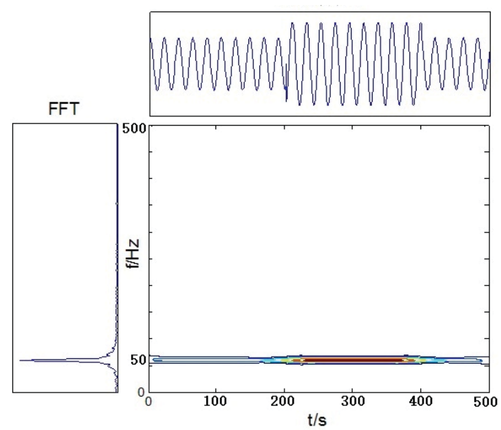

Figure 6. The joint distribution of voltage swell

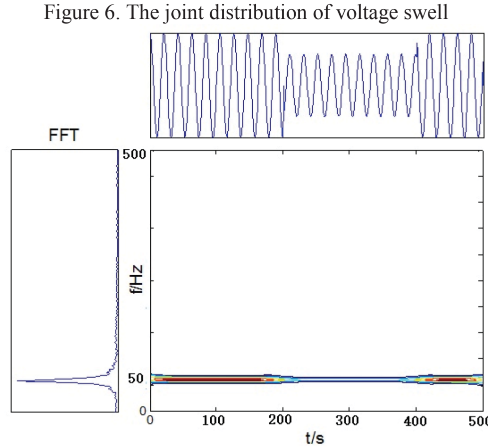

Figure 7. The SPWVD joint distribution of voltage sag

C. Burst power failure

Fig. 8 is the joint distribution of SPWVD during the period of sudden power outage. From the time frequency distribution of the two-dimensional signal energy, the voltage of voltage frequency f=50Hz in 200~400 time period is basically disappeared. So it can be considered that the start time of the burst failure is t=200, and the time of recovery is t=400, which is consistent with the time domain diagram of the original voltage.

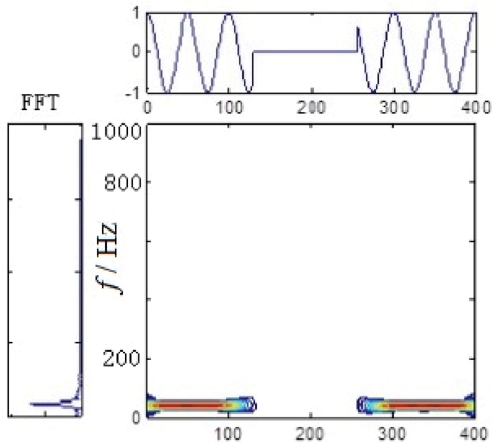

Figure 8. The SPWVD joint distribution of burst power failure

V. CONCLUSION

By Using the analysis of the smoothed pseudo Winger-Ville distribution (SPWVD) on Grid voltage, frequency mutation, voltage sag, voltage swell and the perturbation from network voltage sudden power lost show clearly on the time-frequency map. the brown part is the intensity of grid energy. The deeper the brown, the stronger the energy. Through the joint distribution of the voltage of FFT and SPWVD, the instant, duration, the voltage harmonic component and the energy of voltage disturbance can be seen directly. Considering of the complexity of the voltage disturbance in the actual grid, SPWVD can identify the information of disturbance component in the power quality within a short time. The prediction of long-time power quality disturbance has still not been solved in theory. In the future, the focus of the research is how to classify and predict the power grid disturbance automatically, improve the function and precision of power quality detection.

ACKNOWLEDGMENT

This work is supported by Natural Science Foundation of Shanghai under the Project Grant No. 14ZR1418500 and 14ZR1418400.

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