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A Novel Active Current Disturbance Method Based on Discrete Wavelet Analysis

Wu Tiezhou*, Xiong Jinlong, Wu Xiaomin and Luo Meng

Hubei University of technology, Hubei collaborative Innovation Center for High-efficiency Utilization of Solar Energy, Wuhan, 430068, China
wtz315@163.com

Abstract

Islanding detection method of active current disturbances in three-phase photovoltaic-to-grid system makes the common connection point (PCC) voltage appear high frequency components on account of load variation, the surge current occurrence and other factors. This high frequency component cause islands misjudgment. Using Db10 wavelet to detect and analysis PCC's voltage high-frequency components on real-time based on the active current disturbances principle. And selecting an effective wavelet domain values as the voltage harmonic detection amount islanding detection. Islands simulation test is conducted in the case of the inverter output power and load input power to match, the test results show that this method can quickly detect islanding, and effectively prevent pseudo-island phenomenon of false positives.

Keywords: *Active current disturbances; Three-phase photovoltaic-to-grid system; Islanding detection; DWT*

1. Introduction

Three-phase grid inverter with the distributed generation system of island detection technology is becoming a hot research topic[1], in which P-U, Q-f power island detection method of a given curve has small detection blind-area, but its application object needed contains power control links, and detection time by power outside ring of effects; adapted phase offset method can detect fast without blind area, and has small normal grid frequency, yet based on the adaptive three-phase island phase shift need to be researched indeed; Sandia frequency deviation method[2] applied to three-phase constant power system detection performance attenuation occurs; Pertur-bation constant active current law does not give an analysis for the case of load mismatch, and continuous injection of active disturbance current makes the inverter has been in over-load or under-load run, which affects the life or efficiency of the inverter. Current periodic perturbation method [3] is often used to eliminate blind spots islanding detection; disturbance size and period features are on the grid voltage total harmonic distortion (THD) have an impact.

Most of three-phase system using active or reactive current perturbation methods[4] based on d-q coordinate system, which cause point of common coupling voltage amplitude and frequency beyond the normal range and determine the occurrence of islands. In engineering applications, excessive current amplitude perturbations affect power quality, too small may not be able to make the amplitude of PCC's voltage and frequency deviation from normal, resulting islanding detection in failure. It is necessary to quantify and optimize the design to ensure to detect the occurrence of islands in a relatively small current disturbance, meanwhile minimize the impact on power quality. Discrete Wavelet [3] is superior quality to the Fourier transform analysis for

*Corresponding Author

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non-stationary signals and transient signals, be better able to break down the fundamental, harmonics and other disturbances of labor-frequency signal voltage signal. This paper research on the active periodic current perturbation based on extraction of PCC voltage signal higher harmonic components by discrete wavelet transform and wavelet transform wavelet effective high-frequency signal as the detection threshold amount islanding detection feature.

2. Active Current Disturbance Methods

In the active current disturbance islanding detection method, the current disturbance does not cause breaker tripping problem in the normal grid when the system injecting appropriate current disturbances, but in the island, the current disturbance will cause the amplitude of the PCC's voltage significant changes, to determine the occurrence of island by OVP / UVP judgment. Distributed power grid islanding detection system is shown in Figure 1.The amplitude of PCC's voltage is U_{gm} for grid-connected inverters operation, while the switch S_1, S_2 is closed. When the switch S_2 is open, means the island occurring, inverter output current and *RLC* load determine the *PCC*'s voltage together, then the amplitude is shown *U*am=*Ri*d, i_d is a three-phase output current of the direct-axis component , and is the active current.

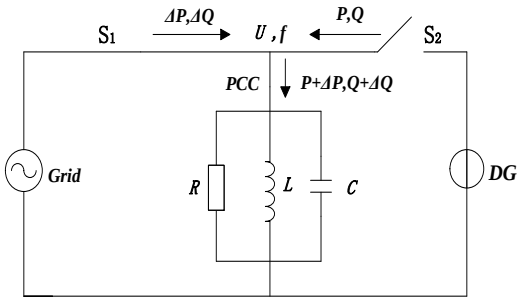

Figure 1. Distributed Power to Grid System

Figure 2 shows the three-phase active current disturbance detection principle: the inverter output current terminal sampling phase current ia, ib, ic and three-phase voltage ua, ub, uc, and the sampling phase current is supplied to the fundamental wave extractor to extract the corresponding control fundamental component, which is injected into a given current idref and iqref as the amount of interference given by the sampled current and voltage control, the output control signal is applied to PWM inverter control.

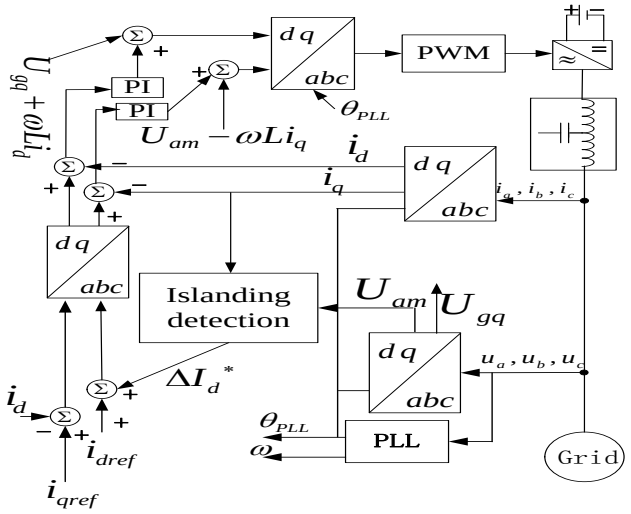

Figure 2. Main Circuit for Islanding Detection

In IEEE Std.929-2000, the operating condition of over/under voltage protection (OVP/UVP) for islanding detection is Uam≫1.1Ugm or Uam≪0.88Ugm, and islanding detection of active current flow chart shown in Figure 3.This article assumes that the offset of voltage is α=Uam/Ugm, when α∉(0.88, 1.1), the OVP/UVP is operated. If α∈[1.0,1.1), minimum injection disturbance current is $\Delta I_{d1}^{*} = \left(1.1\alpha^{-1} - 1\right) I_d$ for making PCC's voltage trigger overvoltage protection to detect the island; If α∈(0.88,1.0), to make PCC's voltage trigger undervoltage protection to set minimum injection disturbance current $\Delta I_{d2}^{*} = \left(0.88\alpha^{-1} - 1\right) I_d$. The relationship between the the minimum ΔI_d which can trigger islanding protection and α is shown in Figure 4.

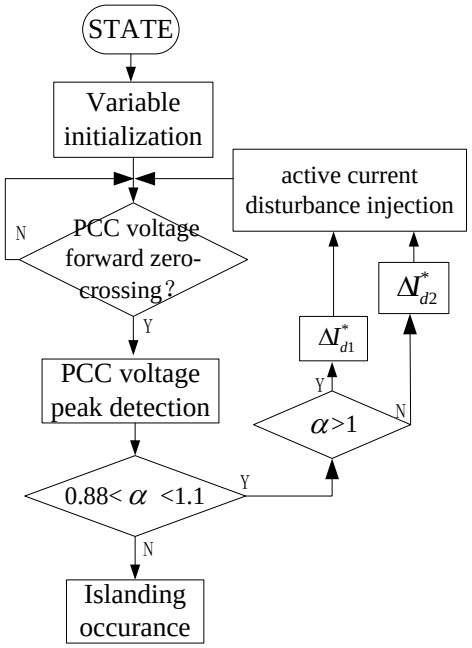

Figure 3. Fundamental Current-Based Islanding Detection Flowchart

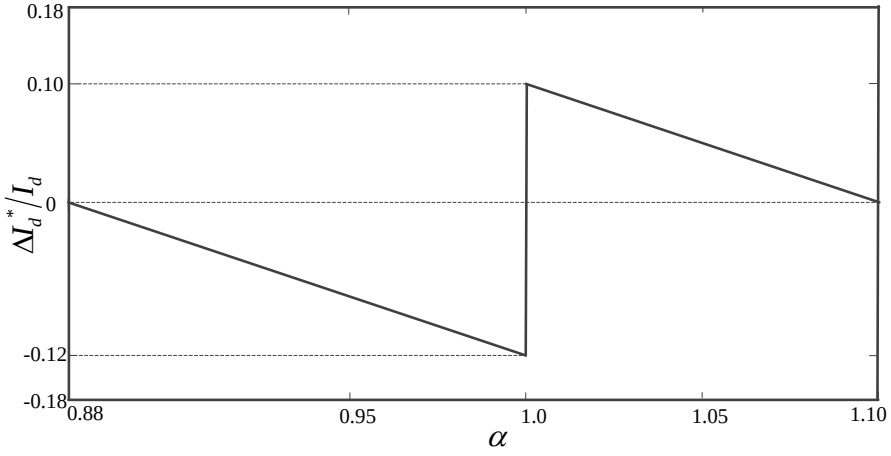

Figure 4. Relevance of the minimum ΔI_d to α

3. Wavelet Transform and Wavelet Basis Selection

3.1. Wavelet Transform

Wavelet multi-scale decomposition analysis can decompose harmonic current signal into different frequency signals and hold real-time tracking of harmonic changes, of which are all high frequency harmonics, low frequency of the fundamental. Reading the voltage and frequency signal from the distributed generation system, amplifying frequency signal for the sake of the less instantaneous content, and identifying the voltage and frequency high-frequency component using Daubechies wavelet transform is abnormal or not. PCC voltage and frequency of the signal through the discrete wavelet transform of the sampling circuit was subjected to quantitative analysis, artificial high-frequency harmonics filtering process introduced, it will improve the low and high frequency characteristics of the signal as an active fundamental extractor enter the amount, according to the voltage and frequency of the test results to help identify and detect network system operation and protection of islands determine accuracy.

Wavelet filtering process for the sampling current can effectively reduce the pressure on the analysis of the digital extractor, and get a good fundamental component. In the application, the wavelet basis function selection determines the wavelet decomposition, the inappropriate choice of the mother wavelet will be greatly affected its application results. When power system failure runs, the voltage waveform of which characterize in superimposed multi-harmonic signals. It can be selected as a test signal square wave signal when choosing wavelets.

3.2. Wavelet Basis Selection

Wavelet multi-scale decomposition for the given original signal to de-noise, filter and reconstruct to obtain the reconstructed signal, and to select the appropriate wavelet function basis for the degree of similarity of the reconstructed signal with the original signal. In this paper, S_1 is the square wave test signal, S_2 is the reconstructed signal after wavelet multi-scale decomposition process, taking into account the overall S_1 and S_2 and the local bias may exist to formula (1) as the error calculation method, assuming $\lambda 1$ overall bias factor, $(1-\lambda 1)$extreme deviation factor, and $\lambda 1 \geq 0$.

$$e = \frac{\lambda_1 \sqrt{\rho(S1, S2)^2 / N} + (1-\lambda_1)\left(\max\left(\left|S1 - S2\right|\right)\right)}{\sqrt{\rho(S1, S2)^2 / N}} \quad (1)$$

And, $\rho(S1, S2) = \sqrt{\sum_{i=1}^{N} (S_{1i} - S_{2i})^2}$, N is for Signal length.

Table 1 shows the test results remodeling factor low frequency, high frequency, and 60Hz harmonics by square wave test signal. The test results show db10 wavelet function has a significant effect well under test.

Table1. Remodeling Factor Calculated at Low /High Frequency Narrowband, and 60Hz Harmonics

Wavelet function	Low-frequency	high-frequency	60Hz harmonics
Haar	0.1653	0.2691	0.2186
mexh	0.1652	0.2713	0.2453
db4	0.1674	0.2731	0.2372
db10	0.1742	0.3084	0.2593
sym2	0.1733	0.2723	0.2175
sym3	0.1672	0.3104	0.2364

3.3. Wavelet Domain Value Selection

According to the national standard requirements for harmonics, power system harmonic analysis generally be about 60 harmonics, thus setting harmonic frequency sampling resultant signal is 3 kHz, the sampling frequency f_s actual is 10 kHz. This selection based on db10 compactly supported wavelets, choosing level of 7 layers to make better band division. It is clear to see the development trend of the original signal in the reconstruction of the low-frequency coefficients of wavelet decomposition for 7 Order of discrete wavelet decomposition.

Wavelet analysis for islanding detection splitting off instantly by major power grids, real-time measurement of voltage and frequency at the PCC and acquired by discrete wavelet decomposition voltage 7 Order discrete wavelet decomposition sequence, corresponding to the scale coefficients and wavelet sequences under different orders in the quantized voltage signal characteristics at different scales to determine the coefficient of islands is generated. Figure 5 is a flow chart of wavelet-based islanding detection improved, after adding the active current disturbances, monitor PCC terminal voltage changes and its voltage stratified on real-time, compare voltage waveform of rated load with the active current disturbance, after setting the threshold voltage of a valid judgment stratification factor peak current caused by such factors. Discrete wavelet coefficients by their corresponding low (high) pass filter for filtering the signal obtained. After the power off, the occurrence of islands is characterized by observing the coefficient variation and the duration time.

Build wavelet domain value test circuit model in Matlab/Simulink environment, including photovoltaic inverter unit input DC voltage of 600V, the output power of 50kw, and network interface filter inductance L = 0.5mH, C = 3.174μF, other test circuit parameters is seen in Table 2.

Table 2. Wavelet Threshold Test Parameter

RLC load				grid		
R (Ω)	*L* (*m*H)	*C* (*m*F)	*Q*	U_m (V)	*i* (A)	*f* (Hz)
2	3.24	3.174	1.8	380	20	50

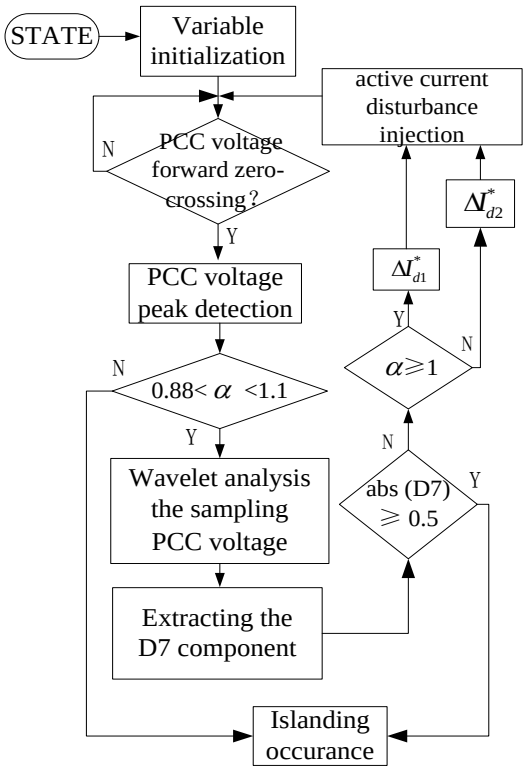

Figure 5. Improved Wavelet-Based Islanding Detection Flowchart

Figure 6 shows the voltage on the PCC wavelet coefficients stratified sampling in the negative-sequence current component of the grid disturbance. After the grid is disconnected, to synchronize the sampling decomposition the voltage of PCC is shown in Figure 7.

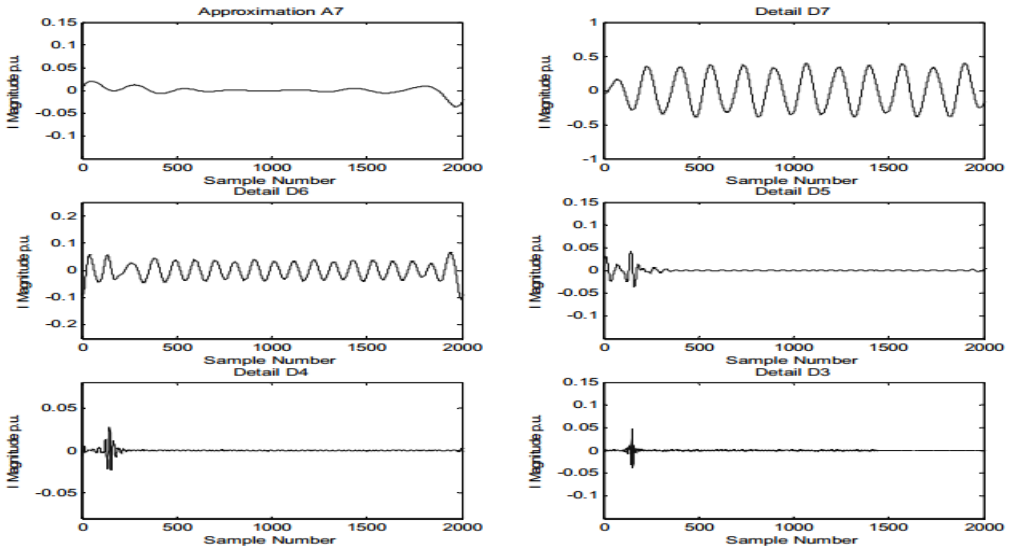

Figure 6. DWT Decomposition of PCC Undervoltage

Before and after the occurrence of island, off the grid and active current common point PCC voltage disturbances will bring change to make D3, D4 peak amplitude increases rapidly, and D7 wavelet coefficients also change accordingly, when the magnitude of the change in the amount of within two sampling periods exceeds a preset threshold 0.5, we can determine that the island effect, and then to the distributed and network control section sends a signal to stop the inverter system islanding operation.

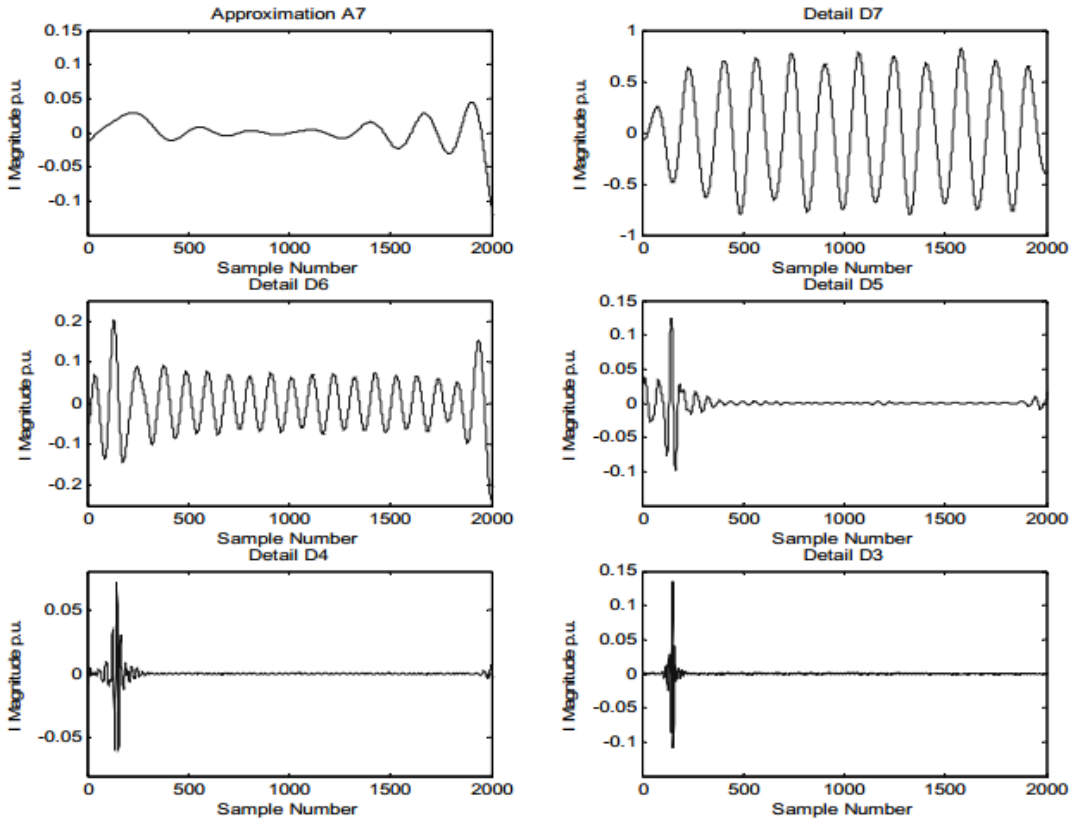

Figure 7. DWT Decomposition of PCC Overvoltage

4. Three-Phase Single-Islanding Detection Test

4.1. Test Model

Considering IEEE.std.1547 provisions worst case that the grid system output power and load power matching, RLC parallel load parameters: R = 2.95Ω, L = 3.750mH, C = 2740.2μF, quality factor Q_f = 2.5, resonance frequency f_r = 50Hz. The simulation time is set to 1.5s, using ode23tb simulation solver for solving the three-phase circuit breaker switch off analog islands in the 0.6s at the occurrence of active current improved its Matlab/Simulink environment disturbance islanding detection method PCC frequency waveform in the simulation results shown in Figure 8 and Figure 9.

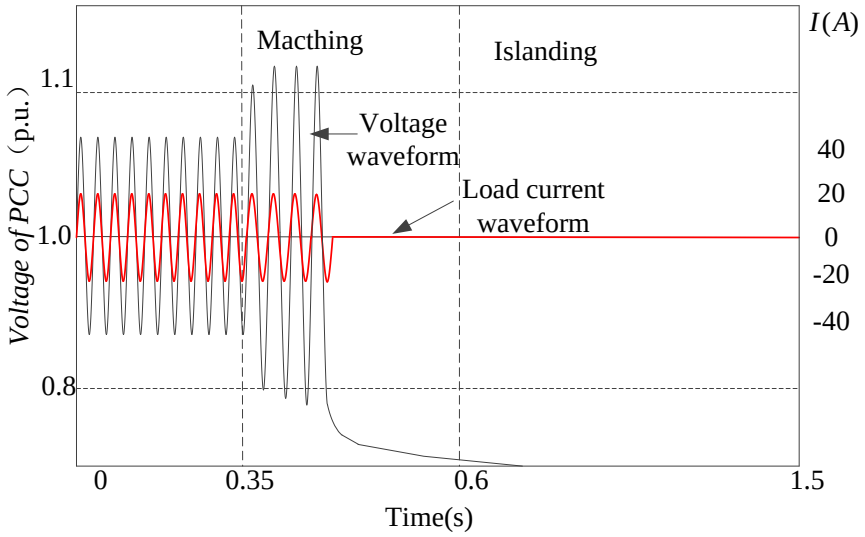

Figure 8. Waveform of Active Current Disturbance

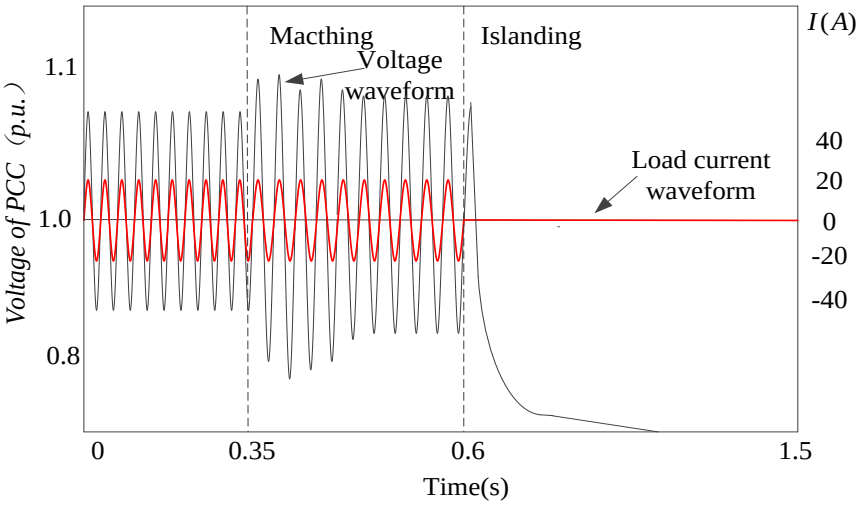

Figure 9. Waveform of Active Current Disturbance Based on Wavelet Analysis

4.2. Test Analysis

The active current disturbances islanding detection shown in Figure 8, when the load power matches with inverter output power, PCC voltage amplitude fluctuation is small and within the allowable voltage range, voltage period after 0.35s second voltage fluctuation becomes large, the load current value 0.45s is zero, the voltage has a sharp decline, the active current islanding detection device operates, but this time not yet out of the grid plan, indicating that the active current islanding detection misuse.

In Figure 9, the wavelet analysis to improve the active current disturbances based islanding detection; PCC voltage amplitude despite continued volatility in a relatively short period of time beyond the voltage range, the load current waveform has been stable. After the power off, can rapidly detect the islanding signals and respond within IEEE.std.1547 detection time. Fluctuations in the amount of harmonic detection based on wavelet transform method reaches a given threshold islanding detection, accurate feature quantity extracted to an island, to avoid affecting the local load and harmonic fluctuations may be caused, at the same time effectively identify pseudo-island phenomenon.

5. Conclusion

In this paper, to extract the PCC voltage harmonic components by the discrete wavelet transform, and to value effective Layer 7 high-frequency signal domain as current perturbation detect characteristic amount for islanding detection judgment. Compared with pure active current perturbation method, this method can reduce the disturbance of current injection frequency, and narrow islands judgment cycle appropriately. In case of power matching to analysis voltage waveform, we can reduce the chance of false positives islands, and have no significant effect the power quality.

Acknowledgment

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Author

Wu Tiezhou (1966-), male, professor, mater tutor, Research direction: signal analysis and system integration.

