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A new detection approach of transient disturbances combining wavelet packet and Tsallis entropy

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ABSTRACT

Tsallis entropy owns additivity property for different independent subsystems, which will not produce the frequency aliasing and energy leakage in comparison with Shannon entropy and wavelet transform. Singular value decomposition can simply obtain the hidden information of data. In this paper, we propose a new detection approach of transient disturbances, which combines wavelet packet, Tsallis entropy and singular value decomposition. Through the introduction of Tsallis entropy and wavelet packet, the definition of wavelet packet Tsallis entropy (WPTSE) and calculation method are given. The key parameters during the course of detection, including wavelet decomposition levels, window width, and nonextensive parameter of Tsallis entropy, are respectively discussed in detail. The detection plan of transient disturbances with WPTSE is proposed. The experimental results show that the precision of proposed detection approach is high. It owns the anti-noise ability, and the influences of the disturbance parameters are very small. In the end, the comparisons show that the detection performance of WPTSE is better than that of wavelet transform and EEMD (ensemble empirical mode decomposition). The PSCAD/EMTDC and real-life signals also demonstrate its feasibility and validity.

1. Introduction

Increasing interest in power quality (PQ) has evolved over the past decade [1]. Voltage sag, swell, interruption, impulsive, and oscillation are common transient PQ disturbances, which can cause a series of problems to the sensitive electronic equipment. Voltage deviation degree and duration are two main indicators which can characterize the transient voltage events. In order to detect transient PQ disturbances more accurately, different methods are proposed such as time-domain methods [2–6], frequency-domain methods [7–10], time–frequency domain methods [10–19], and mathematical statistics methods [20,21]. Among these methods time–frequency domain methods are most common and useful. Wavelet transform (WT), Hilbert–Huang transform (HHT) and the related improved algorithms are the most commonly used time–frequency domain method for the time location [22–28]. WT and its improved algorithms have good features in many aspects, but they are sensitive to the singularity of the signal, and the selection of mother wavelets and parameters has great impact on the result. Currently, the literatures about WT are mostly based on simulated signals. There is little evidence can prove that these methods are applicable to complex real-life signals. HHT is suitable for non-stationary signal analysis [29]. Ensemble empirical mode decomposition (EEMD) based HHT is applied to detect the transient disturbances, and proved to be effective in simulated signals [30,31]. However, endpoints effect and mode mixing are two basic problems of HHT. The use of improved methods such as EEMD can reduce the impact of these problems, but the improved methods have some limitations and they are suitable only for some specific signals. Therefore, it is necessary to propose a new efficient and stable method based on the existing methods.

Spectral entropy based on Shannon entropy is one kind of tools as analysis index on complexity or uncertainty of signal or system. Wavelet transform is capable of revealing aspects of data that other signal analysis techniques may miss, and it satisfies the analysis need of transient signals. The combination of wavelet transform and entropy is proposed in [32], which is applied to analyze electroencephalogram signal. It is used in fault classification in power system [33]. However, Shannon entropy is built based on Boltzmann–Gibbs (BG) entropy in thermodynamics and BG entropy is extensive [34]. Hence, Shannon entropy is extensive, too. Some experiments show the decomposition and coefficients of disturbance signals are nonextensive [35].

More high-frequency information can be obtained with wavelet packet transform than wavelet transform, which can supply more information for the transient disturbances detection [36–39].

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However, the translation sensitivity of traditional wavelet transform directly influences the detection precision. In addition, the noise can directly influence the detection performance. If the wavelet transform is only used to detect the PQ disturbances, the detection performance cannot be efficiently ensured.

The nonextensive entropy owns additivity property for different independent subsystems, which will not probably produce frequency aliasing and energy leakage with Shannon entropy and wavelet transform. Singular value decomposition is one of typically feature extracting and representation methods, which can simply obtain the hidden information of data. Through the above analysis, it is clear that wavelet packet, non-extensive entropy and singular value decomposition theory each has some good properties. But when they are used to transient power quality detection individually, the result is not always satisfied. Wavelet packet Tsallis entropy (WPTSE) is the combination of wavelet packet, non-extensive entropy and singular value decomposition, which takes full advantages of the three methods. In this paper, WPTSE is applied to the detection of transient power quality disturbances. The choice of the parameters and the detection plan are discussed in detail.

This paper is structured as follows: Section 2 provides the introduction Tsallis entropy and wavelet packet, and gives the definition of wavelet packet Tsallis entropy (WPTSE) and calculation method. Section 3 presents and analyzes the detection parameters choice on WPTSE. Section 4 gives the detection plan with WPTSE. Section 5 gives the experimental results, analyzes the influences of transient disturbance parameters, and makes some discussions. Section 6 gives the comparison with WT and EEMD, and verification with real PSCAD/EMTDC signals.

2. Tsallis entropy and wavelet packet

2.1. Tsallis entropy

Wavelet entropy is the combination of wavelet transform and Shannon entropy. Tsallis wavelet entropy, with nonextensive features, is the expansion of the Shannon entropy. It can better characterize the signal, and it is applied to the detection and classification of power system signals. The discrete expression of Tsallis entropy is [34]

$$S_q = k\frac{1-\sum_{i=1}^{W} p_i^q}{q-1}\left(\sum_{i=1}^{W} p_i = 1;\ \ q \in R\right) \quad (1)$$

where k is the Boltzmann constant, W is the total number of microscopic possibilities of the system, q is the nonextensive parameters, p_i is the probability of status i.

For different systems, if the proper q is chosen for the calculation of Tsallis entropy, the information measurement can be flexibly and definitely expressed. When $q \to 1$, Tsallis entropy is equal to Shannon entropy, which can describe the system with extensivity property [40,41]. Tsallis entropy adopted to analyze random complicated signals is the continuation of Shannon entropy. After the multi-scale decomposition of wavelet for random complicated signals, the decomposition coefficients at each scale will own nonextensivity. For the wavelet transform, the frequency aliasing and energy leakage may be produced, which results into the loss of extensivity property for Shannon entropy. In the light of the reason, Tsallis entropy will replace Shannon entropy in the paper. If the proper nonextensivity parameter q is adopted and Tsallis entropies are calculated with wavelet coefficients along the time, we can obtain the time–frequency characteristics of transient disturbances based on the variety of entropy values.

2.2. Wavelet packet

When Mallat algorithm of discrete wavelet transform is used to decompose the signals, the high-frequency resolution of signals is very low. For most random complicated signals, the high-frequency transient features are very important to analyze the signals, which will strongly influence the calculation of signal entropy and result into the inaccurate representation for the signal complexity. Wavelet packet can efficiently overcome the disadvantage and improve the high-frequency analysis ability of complicated signals. The discrete wavelet packet recursive decomposition is listed as follows.

$$\begin{cases} d_{i,2j}(t) = \sqrt{2}\sum_k g(k) d_{i-1,j}(2t-k) \\ d_{i,2j-1}(t) = \sqrt{2}\sum_k h(k) d_{i-1,j}(2t-k) \\ d_{0,0}(t) = x(t) \end{cases} \quad (2)$$

where $x(t)$ is the original signal, $h(k)$ is high-pass filter, $g(k)$ is low-pass filter, and $d_{i,j}(k)$ is the reconstruction signal of wavelet packet decomposition at the ith level for the jth node.

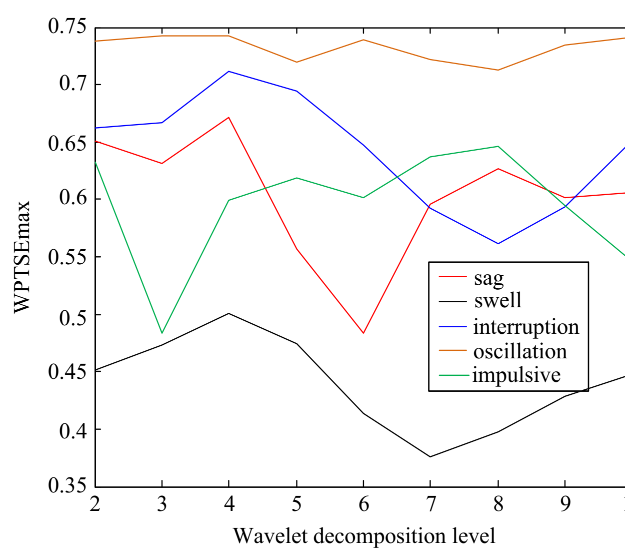

Fig. 1. The maximum of wavelet packet Tsallis singular entropy and wavelet decomposition levels.

Table 1
Parameters of five transient PQ disturbances.

Disturbance	Parameters setting
Swell	Swell amplitude: γ=0.5, start and end time: t_1=0.115 s, t_2=0.214 s
Sag	Sag amplitude: γ=0.55, start and end time: t_1=0.16 s, t_2=0.22 s
Interruption	Interruption amplitude: γ=1, start and end time: t_1=0.12 s, t_2=0.174 s
Impulsive	Impulsive amplitude: γ=1, start and end time: t_1=0.1225 s, t_2=0.1239 s
Oscillation	Oscillation amplitude: γ=0.15, relative coefficient: μ=25, attenuation coefficient: c=5, start and end time: t_1=0.1162 s, t_2=0.1286 s