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Denoising of Power Quality Disturbance Based on Self-adapting Neural Fuzzy Control

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Abstract: In order to increase the accuracy of power quality disturbance detection in noising environment, this study puts forward a denoising algorithm of power quality disturbance based on self-adapting to neutral fuzzy control. It establishes a structure with double-input and single-output neural network fuzzy system. Meanwhile, it presents the principle of denoising and makes a simulation analysis on disturbance circumstances with colored noise such as harmonic wave, voltage sag, voltage swell, voltage interruption etc. The results indicate that the proposed algorithm can well remove the signal-disturbing noise in grid. The waveform is visual clarity; the process of analyzing and calculating is simple and fast; the data got from calculation is few, which make the disturbance denoising of power quality more practical.

Key words: Disturbance, colored noise, wavelet transform, self-adapting neural, power quality

INTRODUCTION

In the process of power quality disturbance detection, the existence of noise would affect the detection analysis. In order to improve the accuracy of power quality disturbance detection in noisy environment, the high frequency noise should be removed firstly when detecting the power quality disturbance (Li *et al*., 2008), so that the power quality disturbance can be better detected and analyzed (Xia, 2011).

At present, the methods used to denoise include Fourier transform denoising method, denoising method based on signal autocorrelation, denoising method based on wavelet transform, which includes wavelet denoising method based on threshold value and the wavelet denoising method based on module maximum (Huang *et al*., 2008), denoising method based on wavelet package transform, which includes the signal denoising method based on optimum wavelet package basis (Xue and Yang, 2004), self-adapting threshold value method based on wavelet package analysis (Idi and Kamarudin, 2012) and the denoising algorithm based on traditional threshold value wavelet package (Qin *et al*., 2010). Among this detecting method, the most frequently used is wavelet transform. The essence of wavelet transform is to develop the function into a linear combination of basic wavelet function, which meet certain conditions. Currently, wavelet transform method is widely used but it is both sensitive to all kinds of noise and weak signals (Shilbayeh and Alshamary, 2010). In reality, there is always mixed noise in power quality disturbance. Therefore, wavelet transform would be affected by noise inevitably. To solve the problem of noise disturbance in wavelet transform when denoising, this study makes some researches on power quality disturbance denoising problem by using the self-adapting neural fuzzy control algorithm (Jiasheng *et al*., 2012).

The establishment of self-adapting neural fuzzy control system: As shown in Fig. 1 is a structure of double input, single output neural network fuzzy system (Yue and Mao, 2002). It adopts multilayer feed forward neural network. Every layer completes a particular task and then passes the information to the next layer. The first layer finishes the task of receiving error and the error change etc. The second layer completes blur task, converting the input value into fuzzy volume which belongs to a certain fuzzy subsets.

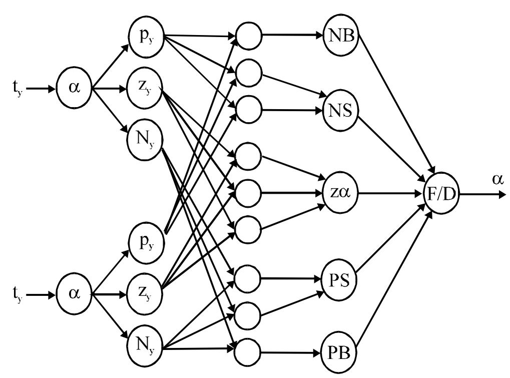

Fig. 1: The structure schematic drawing of fuzzy neural network system

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The third and fourth layers accomplish the fuzzy reasoning process. The third layer finishes the antecedent of the rule. The fourth layer fulfills the consequent of the rule, doing fuzzy reasoning and outputting fuzzy volume. The fifth layer finishes the process of clearing and finally outputs control volume.

The implication of self-adapting neural fuzzy control algorithm in the disturbance denoising of power quality: It will come across noises overlying in signals when detecting power quality disturbing signal. When such kind of noise is Gaussian white noise, we can use the method of linear filtering; when the noise is a colored one, we had better use nonlinear filtering (Zeng *et al*., 2001). In this study we employ self-adapting neural fuzzy system to construct a nonlinear filter.

We can regard colored noise as the result of white noise passing through the nonlinear movements. The aim of the signal we can get mixed with colored noise, the noise source components and signal filter is to eliminate noise and extract useful signal. Here, we use self-adapting neural fuzzy system to model for nonlinear movements and take advantage of self-adapting neural fuzzy system to recur colored noise. Then we can eliminate colored noise from measured signals to get useful signals. The fuzzy filtering principle of denoising is shown in Fig. 2.

The self-adaptive neural fuzzy system is used to approach colored noise. Its input is noise u(k) and u(k-1). And the output of the training data originally should be colored noise but cannot get it directly. So we can use measurement signals x(k) = s(k)+f (u(k), u(k-1)) to replace it. Because we suppose the useful signal s(k) has no relation to noise. The training of self-adaptive neural fuzzy system tries to make the output close to x(k) which can modeling for the unknown nonlinear function f(u(k), u(k-1)) but can do nothing to the signal s(k). Therefore, finally what we can get is the approximate colored noise. And we can eliminate colored noise from measurement signal.

Suppose useful signal is a power quality disturbance signal s(k) and colored noise is produced by white noise after going through the followed nonlinear function:

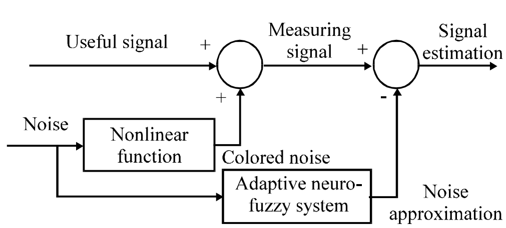

Fig. 2: Diagram of denoising principle

$$d(k) = f(u(k), u(k-1)) = \frac{4u(k-1)\times \sin(u(k))}{1+u^2(k-1)} \quad (1)$$

The input of self-adaptive neutral fuzzy system employs u(k) and u(k-1) and each variable adopts two campaniform membership functions. We use self-adaptive neutral fuzzy controlling algorithm to design a fuzzy filter to eliminate colored noise in signals.

Stimulation and results analysis: In order to show the validity of this algorithm, the algorithm mentioned in this study is applied to several situations of power quality disturbance signals with noise in Matlab 7.0, for example.

Computational example 1: The useful signal is harmonic wave: If the input signal s(k) is a voltage harmonic signal, we can suppose its mathematical model is:

$$s(k) = \sin(20\pi t)+0.5\sin(40\pi t) \quad (2)$$

The sampling time is 1 msec. In Fig. 3a, it is the voltage harmonic signal with colored noise. The noise approximate signal after self-adaptive neutral fuzzy controlling filter wave is showed in Fig. 3b. In Fig. 3c, it presents a voltage harmonic signal without noise in it. In Fig. 3d, it is the harmonic estimated signal after denoising. Observing Fig. 3a, we cannot figure out the measured signal is a grid voltage with harmonic wave. After using the removing system constructed by self-adaptive neutral fuzzy system to denoise, we can find out the measured signal is a grid voltage with harmonic wave clearly, which is showed in Fig. 3d and is very close to Fig. 3c.

Computational example 2: The useful signal is a voltage sag: If the input signal s(k) is a voltage sag signal, its mathematical model is as follows:

$$s(t) = A[1-B\,(u(t-t_2)-u\,(t-t_1))]\sin(\omega t) \quad (3)$$

The sampling time is 1 msec. In this equality, ω = 100π, B = 0.5:

$$u(t) = \begin{cases} 1, t \geq 0 \\ 0, t < 0 \end{cases}$$

and the following is similar. t_2-t_1 is the duration of voltage sag. T<t_2-t_1<4T, t_1 is the starting time of voltage sag and t_2 is the ending time. In simulation, supposing A = 1, t = t-0.1, t_1 = t_2 = 0.04, Fig. 4 can be gotten after simulation (Chen, 2010).

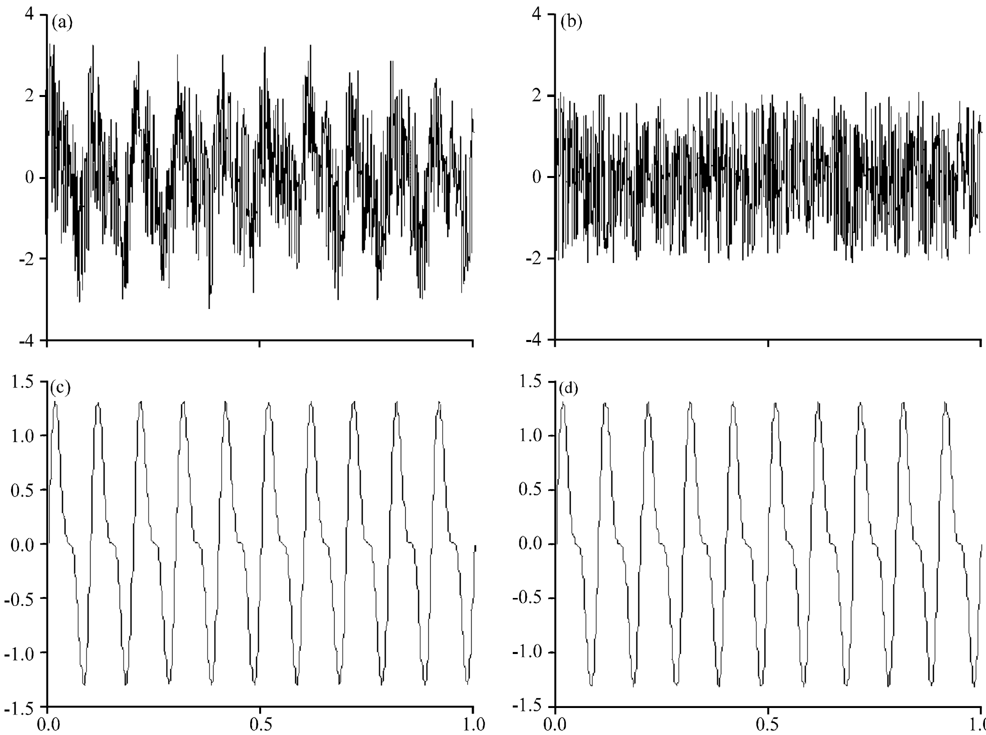

Fig. 3(a-d): Denoising of voltage harmonic wave with noise, (a) Measuring signal, (b) Fuzzy approximation of the noise, (c) Signal and (d) Signal estimation

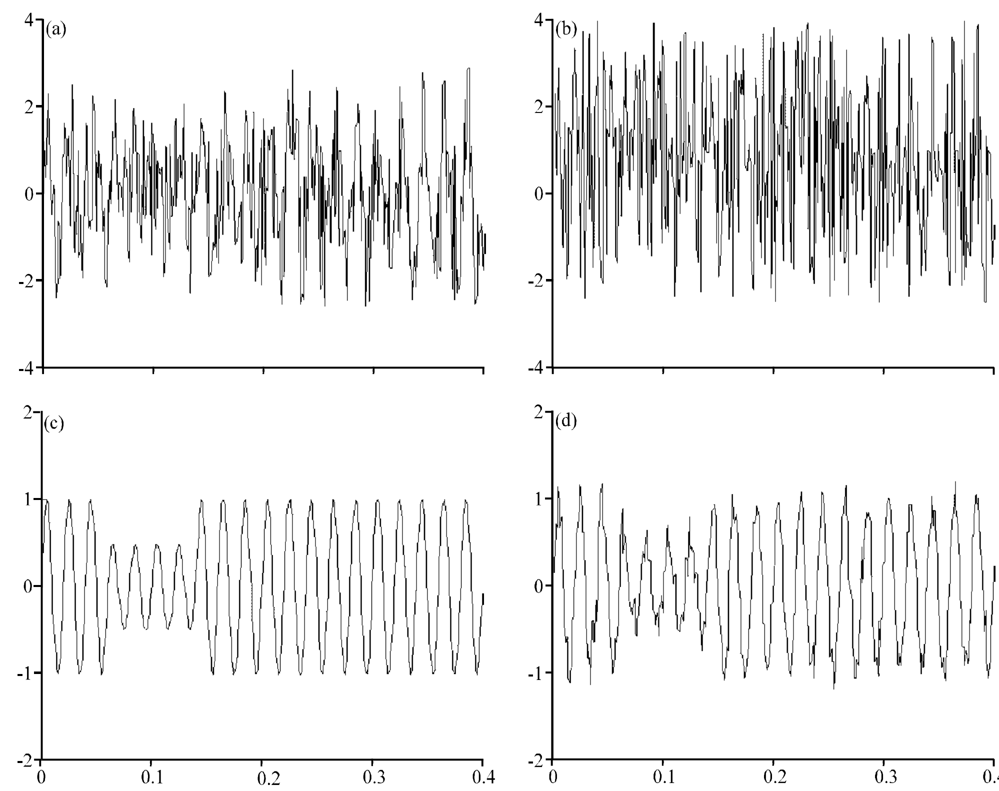

Fig. 4(a-d): The denoising of voltage sag with noise, (a) Measuring signals, (b) Fuzzy approximation of the noise, (c) Signal and (d) Signal estimation

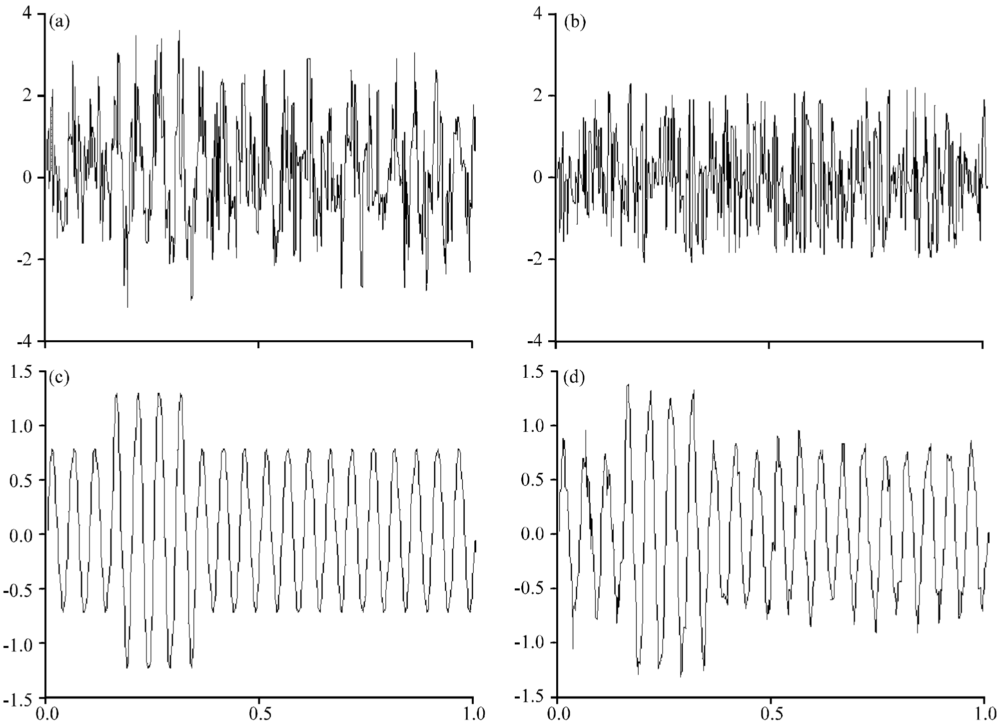

Fig. 5(a-d): The denoising of voltage swell with noise, (a) Measuring signals, (b) Fuzzy approximation of the noise, (c) Signal and (d) Signal estimation

Figure 4a is the voltage sag signal with colored noise. Figure 4b is the noise approximate signal after controlling filter wave by self-adaptive neutral fuzzy. Figure 4c is a voltage sag signal without noise. Figure 4d is the estimated signal after denoising. Observing Fig. 4a, we can not find out the voltage sag disturbance. After using removing system constructed by the self-adaptive neutral fuzzy system to denoising, we can see there is sag disturbance happening in 0.06-0.14S, which is presented in Fig. 4d and is very close to Fig. 4c.

Computational example 3: The useful signal is a voltage swell: If the input signal s(k) is a voltage swell one, its mathematical model is shown in function (3). The sampling time is 1 ms, $\omega = 100\pi$, B is the voltage rising range, B = 0.7, t_2-t_1 is the duration of voltage swell, $T<t_2-t_1<4T$, t_1 is the starting time of voltage swell and t_2 is the ending time. In simulation, supposing A = 1, t = t-0.1, $t_1 = t_2 = 0.04$, we can get Fig. 5 after simulation.

Figure 5a is the voltage swell signal with colored noise. Figure 5b is the noise approximate signal after controlling filter wave by self-adaptive neutral fuzzy. Figure 5c is a voltage swell signal without noise. Figure 5d is the estimated signal after denoising. Observing Fig. 5a, we can not find out that it is a voltage swell disturbance with noise. After using removing system constructed by the self-adaptive neutral fuzzy system to denoising, we can see there is swell disturbance happening in 0.06-0.14S, which is presented in Fig. 5d and is very close to Fig. 5c.

Computational example 4: The useful signal is voltage interruption: If the input signal s(k) is a voltage interruption signal, its mathematical model is as shown in function (3). The sampling time is 1 ms, ω = 100, B = 0.995,t_2-t_1 is the duration of voltage interruption. $T<t_2-t_1<2T$,t_1 is the voltage interruption starting time and t_2 is the ending time. In simulation, supposing A = 1, t = t-0.1, $t_1 = t_2 = 0.04$, we can get Fig. 6 after simulation.

Figure 6a is the voltage interruption signal with colored noise. Figure 6b is the noise approximate signal after controlling filter wave by self-adaptive neutral fuzzy. Figure 6c is a voltage interruption signal without noise. Figure 6d is the estimated signal after denoising. Observing Fig. 6a, we can not find out that it is a voltage interruption disturbance with noise. After using removing system constructed by the self-adaptive neutral fuzzy system to denoising, we can see the measured signal is a grid voltage with interruption obviously, which is presented in Fig. 6d and is very close to Fig. 6c.

From the above simulation examples we can see that although there are burrs in signal estimation, it can wipe

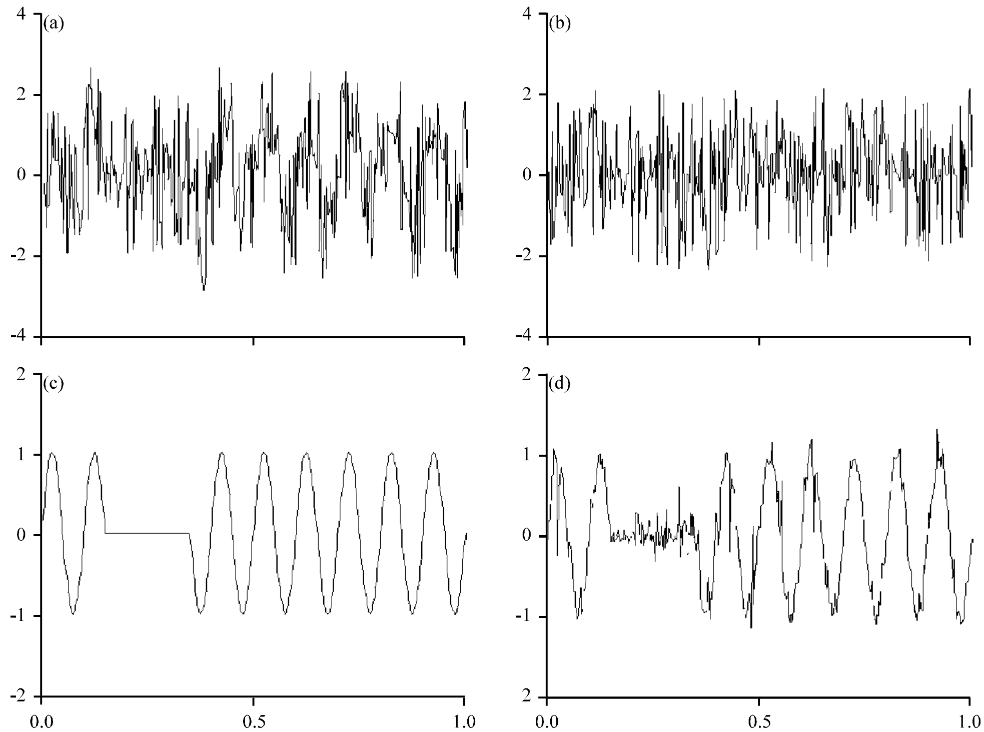

Fig. 6(a-d): The denoising of voltage interruption with noise, (a) Measuring signals, (b) Fuzzy approximation of the noise, (c) Signal and (d) Signal estimation

off the noise in grid disturbance signals and the wave form can be percept directly and clearly. What's more, it can play a good preprocessing role in power quality disturbance detection and provides convenience for the analyzing of power quality disturbance detection.

CONCLUSIONS

In order to improve the accuracy of power quality disturbance detection in noisy environment (Salem *et al*., 2007), this study proposes to make use of self-adaptive neutral fuzzy control algorithm for disturbance denoising tentatively. Simulation experiments demonstrate that this method can remove the noise in power quality disturbance such as voltage sag, voltage swell, voltage interruption and harmonic wave efficiently. It solves the problem that wavelet transform is disturbed by noise in the process of denoising (Zhang *et al*., 2004). In practical applications, this method has many advantages. For example, the waveform is intuitive and clear, the analyzing and calculation are simple, the speed is fast and the amount of data got from calculation is small. All of these make it more practical in the denoising of power quality disturbance.

The types of disturbance with noise studied in this study are limited and do not include the circumstance of several disturbances happen at the same time. And there exists certain errors between estimated signal and ideal signal. How to make the estimated signal closer to ideal signal will be the issue needed to be studied for the next step.

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