Methods of de-noising the low frequency electromagnetic data

WANG Yan(王 艳)

(*Guangdong Electric Power Design Institute, Guangdong 510663, China*)

Abstract: The quality of the low frequency electromagnetic data is affected by the spike and the trend noises. Failure in removal of the spikes and the trends reduces the credibility of data explanation. Based on the analyses of the causes and characteristics of these noises, this paper presents the results of a preset statistics stacking method (PSSM) and a piecewise linear fitting method (PLFM) in de-noising the spikes and trends, respectively. The magnitudes of the spikes are either higher or lower than the normal values, which leads to distortion of the useful signal. Comparisons have been performed in removing of the spikes among the average, the statistics and the PSSM methods, and the results indicate that only the PSSM can remove the spikes successfully. On the other hand, the spectrums of the linear and nonlinear trends mainly lie in the low frequency band and can change the calculated resistivity significantly. No influence of the trends is observed when the frequency is higher than a certain threshold value. The PLSM can remove effectively both the linear and nonlinear trends with errors around 1% in the power spectrum. The proposed methods present an effective way for de-noising the spike and the trend noises in the low frequency electromagnetic data, and establish a research basis for de-noising the low frequency noises.

Key words: spike; trend; low frequency electromagnetic data; de-noising; preset statistics stacking method (PSSM); piecewise linear fitting method (PLFM)

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0 Introduction

Deep resources exploration requires research on the techniques in the low frequency electromagnetic detection, among which the removal of the low frequency noise is one of the key problems that need to be improved[1-4]. Literatures have reported that the stacking or polarized stacking method (PSM) can remove effectively the regular noises such as the white noises, sferics, earth noises, drifts and periodic noises[5]. However, for the spikes and the trend noises which significantly affect the low frequency data[6,7], the PSM fails to de-noise. Therefore, new approaches are needed to remove these noises.

However, the removal of the spikes and trends in low frequency electromagnetic data is scarcely reported till the present. Hardware methods have been reported for de-noising the spikes[7,8], but such a method is prone to distort the useful signal. Furthermore, the hardware method is relatively expensive. Strack[6] reported that the alternative stacking method can suppress the spikes effectively but without details for the execution. In addition, the statistics method was used to remove the gross spikes in the car field[9]. For de-noising the trend noise, a report has been only found in the field of electrochemical measurements in the corrosion field, such as the linear fitting method and the polynomial fitting method[10-13]. However, linear fitting to nonlinear noises will bring additional noises, and the polynomial fitting curve begins to vibrate as the highest power value increases. In this paper, a preset statistics stacking method (PSSM) is proposed to remove the spikes, while the piecewise linear fitting method (PLFM) is used for de-noising the linear and the nonlinear trends.

1 Spikes and PSSM

Spike noises may be caused by natural sources such as lightening and by many different cultural sources such as water pumps, electric fences, trains, factories and vehicles passing by the receiver. The amplitude of the spikes is either far above or far below the average signal level as shown later, which will severely distort the results. Once this noise is recorded but not recognized, the observers can not judge the availability of the data directly and therefore bring difficulties for later processing.

The PSSM is based on the principle of average and statistics de-noising methods. This method aims to

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Corresponding author: WANG Yan(wyan99@jlu.edu.cn)

remove the high and low amplitude noises in the low frequency electromagnetic data. The procedure of the coupled methods consists of the following steps: 1) The same curve will be sampled by N times, and the samples are $x_1, x_2, \cdots, x_N$. Sort the data of the same sampling time in an ascending order by the amplitude; 2) Preset a value ($0 < M < 0.5$), reject $M \times N$ data from both ends of the series; 3) Calculate the average μ and the standard deviation δ for the remained data; 4) Re-inspect the sorted data. Those satisfying the formula $| x_i - \mu | \leqslant \delta$ are selected for averaging, and the final averaged results are the data after de-noising the spikes.

2 Trends and PLFM

Trend noises or drifts can be caused by mismatch and error of components, instability of the test electrode during the electromagnetic measurement period. Trend noises display in two manners, relatively linear and nonlinear. Fig. 1(a) shows the measured linear trends in the electrode caused by the concentration changes. Fig. 1(b) gives the measured nonlinear trends curve with the temperature changes.

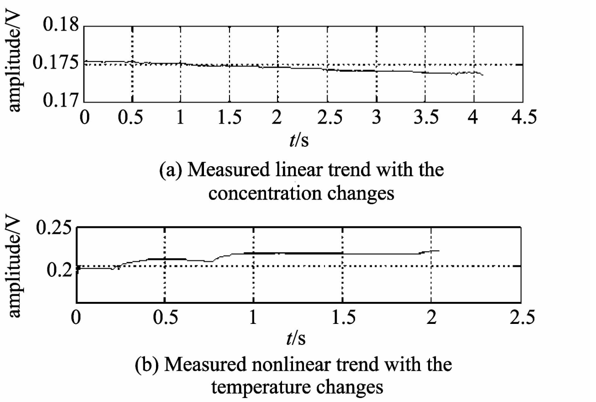

Fig. 1 Signals with drifts

The spectrum of the trends mainly focuses on or near the zero frequency, which will greatly affect the measurement and extraction of the low frequency signals. The inaccurate electric field value may lead to wrong inversion results in such as CSAMT (controlled source audio-frequency magneto-tellurics) exploration, in which the apparent resistivity is calculated by the ratio of electric field and magnetic field.

Because the curve characteristics of the trends are near linear or piecewise linear, if the trends can be fitted with a method, this kind of noise will be removed from the useful signal. The PLFM is proposed based on the features of the trends.

The basic principle of the PLFM is that: the linear equation $y = a_i + b_i x$ will be assigned to the ith period of data, in which its slope change is smaller than ε (a positive, small and arbitrary integer) at the ith time period. And then the parameters a_i and b_i are calculated by the least squares method. For different time periods, different linear equations will be fit for the measured data until the last period.

3 Results

3.1 Removal of the spikes

White noise and spikes (Fig. 2(a)) are added to the original signal and then are used to test the efficiency of spikes de-noising. For the purpose of comparison, the spikes are removed by the average methods, the statistics rejection method (3δ and δ) and the PSSM. All the simulations are performed at Matlab 7.0 environment. The results of the spikes de-noising are illustrated in Fig. 2(b−d) and Fig. 3.

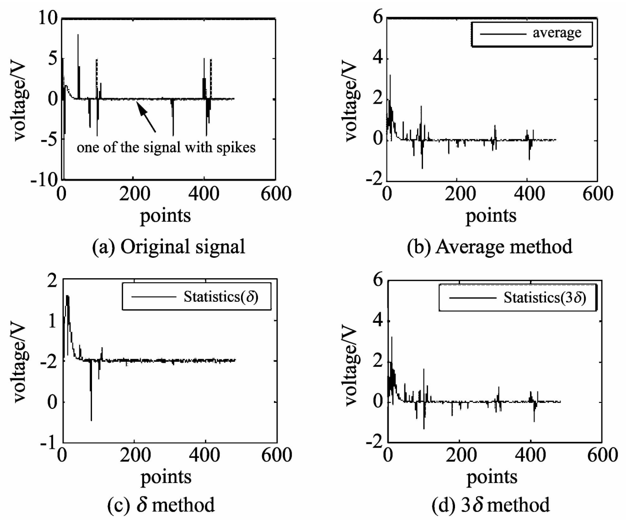

Fig. 2 Original signal and results after other de-noising methods

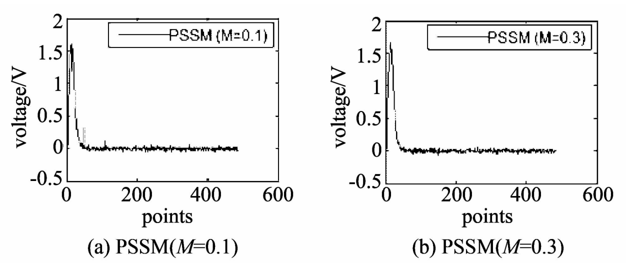

Fig. 3 Results after PSSM

It can be seen that the average and the 3δ methods can remove to some extent the spikes. However, the effects are very poor. The δ remove the spikes better than the foresaid methods, but cannot remove most of the spikes from the original data either.

With the PSSM, if $M = 0.1$, the spikes are removed significantly (Fig. 3(a)). If $M = 0.3$, the spikes are rejected perfectly (Fig. 3(b)). Therefore, the PSSM can remove the spikes effectively. The spikes are removed better with the larger value of M, which depends on the degree of the spikes. M is equal to zero for the condition when the statistic average method is valid. In general, the maximum M is smaller than 0.4.

3.2 Removal of the trends

The noise data used to study the validity of the PLFM method in the trends de-noising are generated by CSAMT method. Four different slopes are simulated for the trends. White noise is also added to the data to better simulation near the reality. The power spectrums for the useful signal have been calculated from the original signal, noise signal and noise removed signal. The results are shown in Fig. 4 and are listed in Table 1.

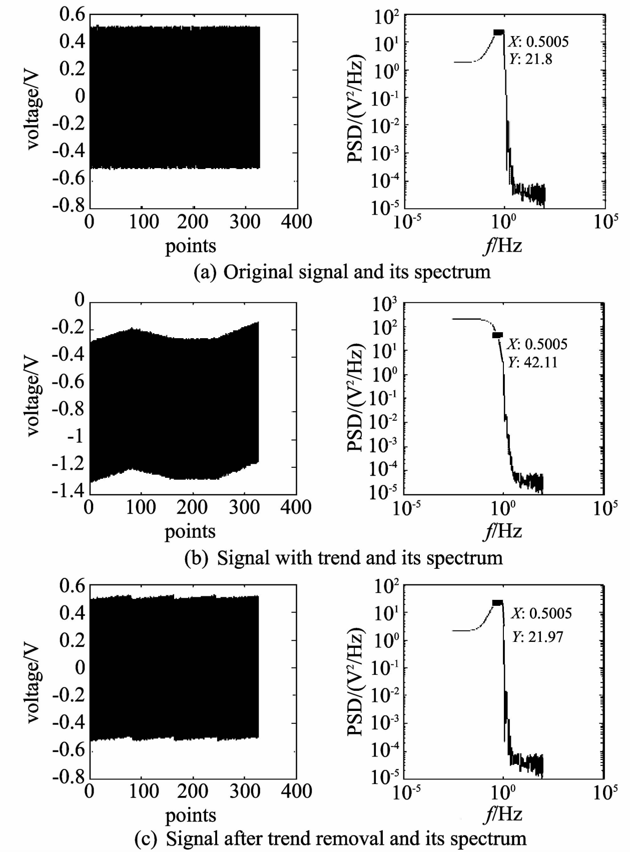

Fig. 4 Results before and after the piecewise linear fitting to the trend noise

Fig. 4(a) shows a useful signal with a frequency of 0.5 Hz while are sampled by a frequency of 200 Hz. The computed power spectrum in the original signal is 22 V^2/Hz. When there are trends in the data, the computed power spectrum changes to 37.23 V^2/Hz (Fig. 4(b)). It should be noted that this noise only influences the signal with a frequency below 0.5 Hz while no big effects are observed for signal with a frequency higher than 0.5 Hz. Fig. 4(c) shows the results after de-noising the trends by PLFM. It can be seen that the computed power spectrum at 0.5 Hz is equal to 22.17 V^2/Hz, which is quite similar to that computed from the original signal. Similar conclusion can be drawn from Table 1.

Table 1 PSD values with or without de-noising

F[1]/Hz	200	200	100	100	20	20
S[2]/Hz	1	0.5	0.1	0.05	0.02	0.01
1PSD1[3]/(V^2/Hz)	22	21.8	26.87	43.57	26.64	43.53
PSD2[4]/(V^2/Hz)	23.1	42.11	111	132.7	110	132.2
PSD3[5]/(V^2/Hz)	22	21.97	26.76	42.16	26.54	42.09
Error[6]/%	0	0.78	0.4	3.4	0.03	3

1. Sampling rate; 2. Signal frequency; 3. PSD of the original signal; 4. PSD of the signal with drifts; 5. PSD of the signal after noise removal

The error for the computed power spectrum in Table 1 is approximately 1%. Therefore, the PLFM can remove effectively the trends in the low frequency electromagnetic data.

It should be noted that the accuracy of the computed power spectrum is affected by the sampling frequency. Much higher sampling frequency leads to larger computed errors in the power spectrum for the lower frequency signal. For example, if a useful signal with a frequency of 0.4 Hz while are sampled by a frequency of 500 Hz, the computed error in the power spectrum is up to 7.3% for the PLSM. Therefore, the sampling frequency should be chosen carefully during the experiment.

4 Conclusion

The simulations of removing the spikes and trends in the low frequency electromagnetic data have been presented. The PSSM and PLFM have been proposed to remove the noise. The magnitudes of the spikes are either higher or lower than the normal values which lead to distortion of the useful signal. Classical average and statistics methods cannot remove the spikes effectively. However, the PSSM can remove the spikes perfectly with higher flexibility. The spectrums of the trends mainly lie in low frequency band and change the power spectrum of the useful signal at lower frequency. However, no influence can be observed when the frequency is larger than a certain threshold value. The trend noise can be removed effectively by the PLFM with errors around 1% in the power spectrum.

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