Application of Wavelets and Auto-Correlation-Function For Cancellation of High-Frequency EMI Noise

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Abstract **–** This paper presents a wavelet transforms and auto-correlation function based approach for the high-frequency switching noise cancellation. The noise is extracted by wavelet multi-resolution analysis. The enough features of signal in frequency and time domains are obtained by using arguments and magnitudes of complex wavelet transform as well as main frequency evaluation of auto-correlation function. The simulation results showed that the high frequency noise could be detected and reconstructed accurately and the average noise attenuation is larger than 20dB. This new method provides a multi-level process and multi-level description method for disturbance identification and cancellation.

I. INTRODUCTION

To achieve electromagnetic compatibility (EMC) compliance, filtering approaches are commonly used. Many practical forms of active EMI filters (AEF) have been reported [1-8]. In voltage canceling filters, a voltage is introduced in series with the noise voltage to cancel it [1, 3, 6]. In current canceling filters, a cancellation current is injected at a node traversed by the noise current [2, 4, 5]. Feed-forward filters achieve noise reduction by measuring a noise component and injecting its inverse [1,4], while feedback filters operate to suppress the noise with high gain feedback control [2, 3 ,6 ,7]. Hybrids of these filter types are also possible [5, 8].

Unfortunately, although the basic concept has been known for some time, there seems to be no change in the noise identifying approach. The existing technique is an analogue method, which uses a band-pass filter to identify a certain bandwidth noise signal. The design of the analogue filter has to incorporate at least a 6th-order filter to ensure a reasonable roll-off frequency. The main disadvantage with this method is that the sensor thus derived has magnitude and phase errors. The phase error normally reaches more than 100°, which is unacceptable for EMI filter applications.

Complex wavelet has been widely used as a time-frequency analysis algorithm for signal processing. Often the wavelet transform of a real signal with complex wavelet is plotted in modulus-phase form, rather than in real and imaginary representation. In the complex wavelet transform analysis, the modulus maxima and the phase crossings point out the locations of sharp signal transitions. Nevertheless, the phase information reveals isolated singularities in a signal more accurately than does the modulus [9-11]. Also, using the phase information, different kinds of transition points of the analyzed signal, i.e. local maxima and inflection points, can be distinguished.

This paper proposes a multi-level process and multi-level description method for disturbance identification and cancellation. In this work, a wavelet-based method incorporated with autocorrelation function is used in the active EMI filter to perform the following tasks: detecting the switching noise, feature extraction and reconstruction of the disturbed signal, canceling the disturbance. The paper has the following structure: section II treats the wavelet bases and deals with the implementation of digital active EMI filter. Some results provided by simulations are given in Section III. Finally, Section IV presents the conclusions.

II. IMPLEMENTATION OF DIGITAL ACTIVE EMI FILTER

Given a time-varying signal $f(t) \in L^2(R)$, wavelet transform can be seen as the computation of coefficients that are inner products of the signal and family of wavelet basis functions. From this function, one can obtain a family of time-scale waveforms by translation and scaling,

$$\mathrm{WT}(f(t);a,b) = \int_{-\infty}^{+\infty} f(t)\psi_{a,b}^{*}(t)\mathrm{d}t \qquad (1)$$

where $\psi(t)$ is the wavelet function that can be also deemed a band-pass function, and $\psi^*(t)$ is the complex conjugate of $\psi(t)$. This function can be dilated through the control parameter of a and time-shifted by the parameter of b, in which the factor of $1/\sqrt{a}$ is to ensure the energy preservation.

The complex Gaussian wavelet is chosen as the mother wavelet in this approach. Since the Gaussian

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wavelet looks more like a switching noise generated by parasitic oscillation in geometric shape especially when its shape control parameter is adjusted to be a small value. According to the "matching mechanism" of wavelet transform, the better the wavelet function matches the signal in geometric shape, the more accurate the feature of the signal can be represented by wavelet coefficients. The complex Gaussian wavelet is defined from the derivatives of the Gabor wavelet and is given by,

$$\psi_n(x) = C_n \frac{\mathrm{d}^n}{\mathrm{d}t^n}(e^{-j\omega t}e^{-t^2}) \qquad (2)$$

where n denotes the order, $\mathrm{d}/\mathrm{d}t$ is the symbolic derivative and C is a normalizing constant, which depends of n. This wavelet can be easily turned into analytic wavelet by canceling its negative frequencies by means of the Hilbert transform. The frequency response is then,

$$\psi_n(x) = K_n \xi^n e^{-\frac{\xi^2}{2}} \chi(0,\propto)(\xi)\,. \qquad (3)$$

where $\chi(0,\infty)(\xi)$ denotes the Heaviside step function, which is equal to 1 when $\xi > 0$ and to 0 otherwise. K_n denotes normalization constant. The parameter n gives different numbers of vanishing moments of wavelets. When performing wavelet singularity analysis, the number of vanishing moments is very important, as it provides an upper bound measurement for singularity characterization.

Therefore, the amplitude (WTM) and phase (WTPH) of wavelet transform can be calculated by use of the following equations,

$$WMT = \sqrt{\mathrm{Re}[\psi(x)]^2 + \mathrm{Im}[\psi(x)]^2}\,, \qquad (4)$$

$$WTPH = \arctan(\mathrm{Im}[\psi(x)]/\mathrm{Re}[\psi(x)])\,. \qquad (5)$$

That is, the complex wavelet bases are capable to deliver instantaneous amplitude of signal as well as instantaneous phase angles. As these new variables contain more information about the signal analyzed, alternative feature extraction with scalogram and phase spectrum can be derived.

The noise source is a 500W switching mode power supply (SMPS) with 100 kHz switching frequency. The original noise current at the AC input side of the equipment is recorded from a digital oscilloscope Tektronix 3012. Wavelet EMI detection and cancellation is simulated through Matlab 6.5 and the flow diagram is shown in Fig.1.

Compared with conventional analogue noise detection method, the high-frequency switching noise could be separated accurately by means of wavelet transform. The disadvantage of spectrum leakage and fence effect appeared in the classical method are overcome with ease. However, the delay effect of signal must be considered carefully. As we know, the switching noise always contains a main frequency signal that concentrates most of the noise energy. Therefore, if the main frequency of the noise could be estimated successfully, and combined with the above-mentioned amplitude and phase message, the compensation signal could be injected at the right time.

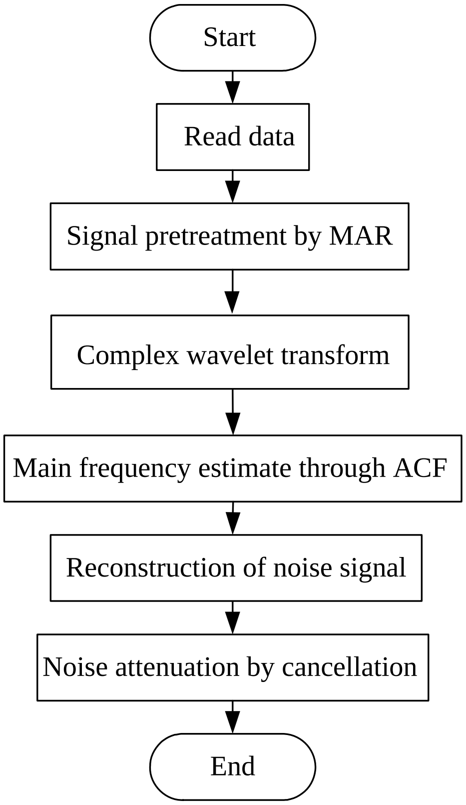


Fig. 1. Flow diagram for the proposed approach.

This paper use auto-correlation function to estimate the main frequency of switching noise. Auto-correlation function showing the relationship of a signal with a time shifted version of itself. The auto-correlation function is defined as,

$$r_X(m) = E\{x^*(n)x(n+m)\} \qquad (6)$$

where $x(n)$ is a real continuous signal. If N is the number of data and for each fixed lag m, the estimation of correlation function is,

$$\hat{r}_X(m) = \frac{1}{N-|m|}\sum_{n=0}^{N-1-|m|} x_N(n)x_N(n+m)\,. \qquad (7)$$

III. ANALYSIS RESULTS

Since the high frequency noise is sampled with some harmonics, certain pretreatment should be down to the original signal to get rid of low frequency harmonics. Figure 2 shows coefficients of high frequency noise signal through wavelet filter. The result of complex wavelet analysis is shown in Fig. 3. The characteristic features of high-frequency parasitic oscillating noise are exposed in those figures. From Fig. 3 (b), we found the modulus coefficient changes from maximum to minimum, indicates the regular change of oscillation amplitude. The abscissa of the scalogram plots time in samples, and the ordinate plots the frequency scale of the dilation of wavelet in samples of its time period.

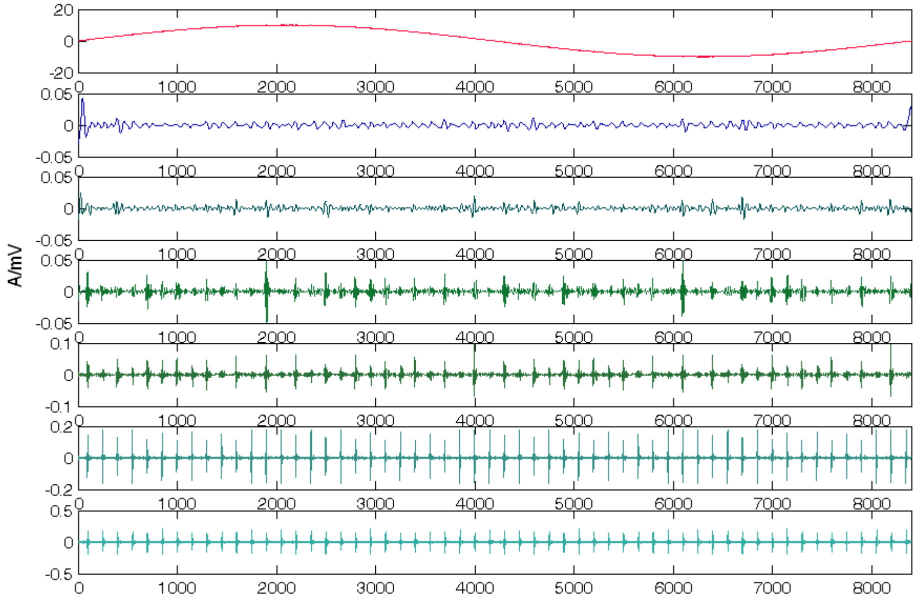
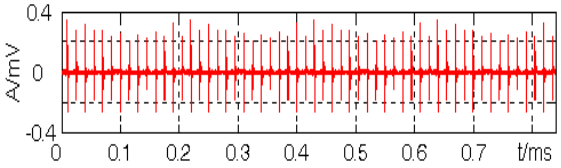
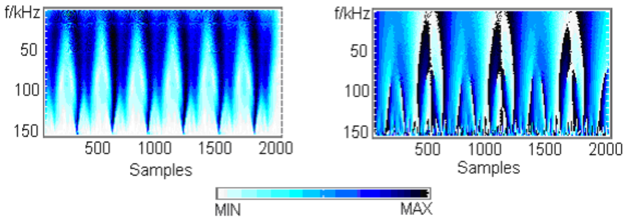


Fig. 2. Coefficients of switching noise through wavelet filter.



(a) Switching noise.



(b) Scalogram spectrum. (c) phase spectrum.

Fig. 3. Complex wavelet analysis.

At the highest scale (the highest y-axis values), the time window is very short, and the boundary distortion appeared. At lower scales, the frequency localization is more apparent and characterized by regularly spaced dark to bright transitions, indicates that impulses is present at different intervals. Fig. 3 (c) is the phase spectrum and angle coefficient of noise signal; they are also the characteristic feature that distinguished this approach from other wavelet detection method. Each narrow stripe in the phase spectrum represents the cycle corresponding to time zone of the signal. With the increase of frequency, the narrow stripe will split automatically until its width matches the cycle of a certain frequency. This example demonstrates the tracking of a changing frequency due to the zooming nature of the scale mother functions and the ability to discriminate frequencies created by parasitic oscillation.

Figure 4 is the reconstructed noise signal. It is found that the reconstructed one reflects the basic feature of the original signal perfectly. Figure 5 is the error between the two signals. The maximum absolute error is no more than 2%.

When the reconstructed noise signal is rejected into the original high frequency noise, the results are shown in

Fig. 6. The simulation results showed that the average noise attenuation is larger than 20dB.

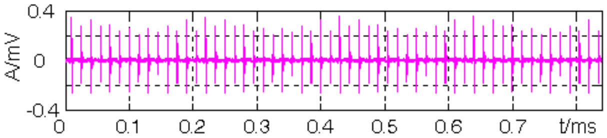


Fig. 4. Reconstructed noise signal.

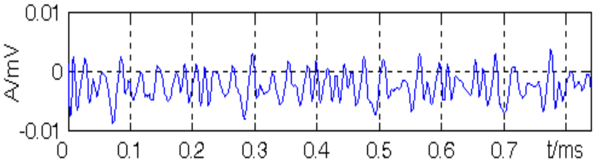


Fig. 5. Error between original signal and reconstructed signal.

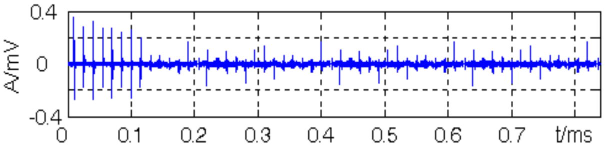


Fig. 6. Noise signal after active EMI cancellation.

IV. CONCLUSIONS

This paper has presented a new method technique possesses the advantages of complex wavelet transform and auto-correlation function for the high-frequency switching noise cancellation in power electronics equipments. The simulation results have shown that the satisfactory performance has been achieved. Therefore, it is reasonable to believe that the proposed method will be widely adopted and extensively applied to the attenuation of switching noise signals.

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