A Characteristics Study of Delta-Sigma Modulated Inverter with Sampling Interval Jitter Component

Atsushi Hirota
National Institute of Technology,
Akashi College
Akashi, Japan

Saad Mekhilef
Electrical Department
University of Malaya
Kuala Lumpur, Malaysia

Mutsuo Nakaoka
Electrical Department
University of Malaya
Kuala Lumpur, Malaysia

Abstract—Switching power converters are widely used because of its saving energy feature. Pulse width modulated (PWM) inverter causes large switching noise peaks on the carrier frequency. But delta-sigma modulated inverter does not induce large noise component and this makes an advantage of avoiding EMI problems. Although delta-sigma modulator operates on the assumption that the sampling interval is uniform, it is necessary to examine the influence of the sampling interval variation.

This paper examines the sampling interval jitter component effect on the output voltage characteristics of delta-sigma modulated inverter. From the investigation, it is plain that the low frequency harmonic components increase in compliance with jitter rate.

Keywords—sampling interval; jitter rate; noise component; delta-sigma; full bridge inverter

I. INTRODUCTION

Aiming to saving energy and accurate power control, switching power converters are widely used. To control switches of power converter, PWM scheme, which varies the switch control pulse width, is generally used. This method compares the reference signal to carrier triangle wave every carrier interval, large switching noise components arises on the carrier frequency. On the contrary, delta-sigma modulated inverter does not raise large noise component and this feature can avoid EMI problems. Incidentally, delta-sigma modulation circuit works according to the sampling interval and makes switch control signal, it is considered that the circuit is affected by the variation of the sampling interval.

This paper studies the effect about the output characteristics of delta-sigma modulated inverter with sampling interval jitter. As a result, it is clarified that the low frequency harmonic components increase according to jitter ratio. But it also evident that unlike PWM measure, no large switching noise component does not appear as for delta-sigma modulated inverter.

II. FUNDAMENTALS OF DELTA-SIGMA MODULATION

When using switching power converter, it is necessary to generate the switch turn-on or turn-off signal from the analog reference signal. Recently, to produce the switch control pattern, PWM technique is widely used. But this method induces large switching noise peak components. On the contrary, when delta-sigma modulation circuit is introduced to generate switch control signal, large switching noise component does not appear, and this is an advantage of noise problem.

The quantum error noise is induced in the stage in which the analogue reference signal is converted to the switch control signal. Fig. 1 represents the quantum error noise characteristics. The error noise of PWM method spreads uniformly over the frequency axis, the noise character changes in case of delta-sigma modulator [1], [2]. As illustrated in Fig. 1, when the sampling frequency is enough higher than the reference signal frequency, the error noise around the reference signal is suppressed, and increased high frequency error noise can be removed by low-pass filter. The output signal of delta-sigma modulation circuit is used as switch control signal, and then low noise switching operation is implemented.

Fig. 2 depicts the block diagram of delta-sigma modulation circuit. The circuit consists of a comparator and one sample delay element. The difference between the comparator input and the output is feedbacked to the input side with one sample delay. If the comparator input exceeds the threshold value, the comparator outputs +1, and the other case, the comparator outputs -1 [3]. The relation of the input signal sequence \( x_i \), the output signal sequence \( y_i \), and the error noise sequence \( e_i \) is expressed in

\[
y_i = x_i + (e_i - e_{i-1})
\]

The output signal is composed of the input signal and the difference of the error noise sequence, and the error noise character changes.

![Quantum error noise characteristics](image-url)
III. ANALYZED FULL BRIDGE TYPE INVERTER

Though delta-sigma modulator works based on the uniform sampling interval [4],[5], a disturbance factor, for example clock signal imprecision, may change the sampling term. In this paper, the influence on the inverter output voltage by jitter rate of sampling interval is analyzed.

Fig. 3 shows the full bridge type inverter investigated in this paper. When the reference signal is positive, the inverter outputs positive value or zero, and in the reference signal is negative term, the inverter outputs negative value or zero. Fig. 4 illustrates the relation between the jitter rate and the sampling interval of delta-sigma modulator. The influence of the output voltage caused by sampling jitter component is studied. The pseudo noise is used to the jitter signal. The spectrum of the jitter component is as shown in Fig. 5. The dotted line represents when the jitter ratio is 10(%), and the dashed line represents the jitter component is 30(%). This signal value takes zero to 10. The value is transferred into the sampling interval variation. Some specific components arise, this pattern does not affect the results because of its high frequency value.

IV. ANALYTICAL RESULTS

About the full bridge type inverter, the analyses are carried out. Under the condition that the fundamental reference frequency is 60(Hz), the sampling frequency is 61.44(kHz) and the inverter input voltage is 100(V), the jitter rate changes and the output voltage characteristics are investigated.

Fig. 6 represents the output voltage waveform and its spec-
trum in the case of the reference amplitude is 30(V) without jitter component. The output voltage is controlled according the reference signal. Observing this figure, large noise component is not appearing. And from the FFT analysis, it is found that the fundamental component is 30(V).

The output voltage spectra with jitter rates of 10(%) and 30(%) are as shown in Fig. 7. According to increasing the jitter component, low harmonic components increase.

The results of the reference amplitude 30(V), 50(V) and 70(V) are expressed in Fig. 8. In this figure, the solid line represents without jitter case, the dotted line illustrates the jitter rate is 10(%), and the dashed line shows the jitter ratio is 30(%) respectively. In the all cases, the low harmonic components increase according to the jitter rate growth.

Next, the sampling frequency is changed to 15.36(kHz) and Fig. 9 shows the output voltage spectrum about the reference value is 50(V). The solid line shows without jitter, the dotted line represents jitter rate is 10(%) and dashed line depicts jitter rate is 30 (%) respectively. Same as the former case, the low frequency components increase in accordance with the sampling jitter ratio.

To compare the delta-sigma modulated inverter with PWM controlled inverter from the viewpoint of switching noise, the switching noise component of the PWM inverter is examined. Fig. 10 depicts the output voltage spectra of PWM controlled
From these results, it is clarified that the low harmonic components increase according to the jitter rate growth. The low harmonic components are difficult to remove by using low pass filter. But as for delta-sigma modulated inverter, large noise component like PWM inverter does not come out. This advantage is kept in spite of sampling jitter component.

V. CONCLUSIONS

This paper mentioned about the influence on the output voltage characteristics of delta-sigma modulated inverter with sampling interval jitter. Full bridge inverter was treated and the output voltage characteristics were examined. As a result, the low harmonic component increased according the jitter rate growth. But unlike PWM controlled inverter, large switching noise component does not appear and it was an advantage from the view of switching noise problem.

REFERENCES


Fig. 10. Output voltage spectrum of PWM inverter: (a) reference 30 (V) (b) reference 50 (V).

inverter with the reference amplitude are 30(V) and 50(V). Unlike the delta-sigma modulated inverter, large noise components appear on the carrier frequency, and this causes EMI problem on other electrical equipment.