Suppressing Harmonics in Delta Modulation by Synchronization Hysteresis with the Reference Signal

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Abstract: The delta modulation used for controlling the speed of an induction motor has high peak of harmonic spectrum at low speed range causing acoustic noises in the induction motor. This paper proposes to suppress the harmonics by synchronizing the reference signal with the hysteresis windows for controlling the distribution of the switching frequency. As a result we can decrease the peak of harmonic spectrum. The simulation results show that the peak spectrum of harmonics can be reduced up to 60 %.

1. Introduction

Pulse-width modulation voltage source inverter (PWM-VSI) is now standard equipment for the speed control of induction machine. It operates normally with a fixed switching frequency which often causes acoustic noise in the induction machine. A frequency of the acoustic noise is centered at a multiple of the switching frequency and causes an irritable noise for the human being.

The noise problem can be solved by (1) increasing the switching frequency above 20 kHz so that human ears can not detect, (2) inserting filters between the inverter and induction machine and (3) random switching frequency or random positions which distribute the acoustic noises over a wide spectrum [1]-[3]. However, high switching frequency means high switch losses while inserting filter in low frequency range causes power losses and increase extra cost. Although the random switching frequency or random positions techniques work well with various kinds of PWM such as sine pulse-width modulation (SPWM) and space vector pulse-width modulation (SVPWM), it is not suitable for the delta modulation technique.

Delta modulation (DM) scheme, which was originally developed for communication systems, has been proposed as an alternative method for inverter switching control in AC drives [4]. It is a well established technique and offers a number of advantages including (1) simple electronic circuitry without external feedback from high power circuit, (2) inherent constant volts per hertz control for a preset frequency range, (3) smooth transition between the constant voltsper hertz and constant volts and modes of operation, (4) severe attenuation of low order harmonics, and (5) low commutation rates for high modulation. Naturally, the DM distributes switching frequency over a spectrum range following the reference sine. As a result, the acoustic noise is low when applying the DM while the induction machine is running at a high range of speed. However, this property only exists at high switching frequency which implies higher switching losses (more details in Section 2.) Also the acoustic noises are still quite high at low range of speed despite the high switching frequency. This leads us to propose a technique for reducing acoustic noise in delta modulation at low range of machine speed and low switching frequency. By means of adjusting the hysteresis, we can distribute the switching frequency around a specific frequency. Moreover, the distribution is synchronized with the sinusoidal signal used for controlling the motor speed.

2. Background and Basic Concept

Figure. 1(a) shows the basic block diagram of the delta modulation. Two basic components of the modulator are the quantizer comparator and the integrator. For inverter operation the input to the modulator is a sine wave, $x(t)$, and the output is the modulated wave, $v_o(t)$.

The integrator performs the function of signal estimation by low pass filtering the output modulated wave resulting in the estimated signal, $\tilde{x}(t)$. The estimated signal is compared with the sine wave to produce an error signal, $e(t)$. The error signal is quantized by the quantizer producing the modulated output which is the switching pattern for the inverter. The typical waveforms of the delta modulator driven by a sinusoidal reference are shown in Figure. 1 (b)-(d), it can be observed that the feedback signal approaches the reference within the hysteresis width $(\pm h)$.

The switching frequency can be varied by adjusting the integrator time and the hysteresis window following equation (1) (detail in [5]-[7]).

$$f_s = \frac{k.E}{4.h}\left[1 - \left(\frac{v_R\omega_r}{k.E}\right)^2 \cos^2 \omega_r t\right], \qquad (1)$$

where

k is the integrator time,

v_r is the peak amplitude of the reference signal,

E is the saturated output voltage,

h is the hysteresis window, and

ω_r is the angular frequency of the reference signal.

$$\frac{v_{o1}}{\omega_r} = R_1.C.v_r \qquad (2)$$

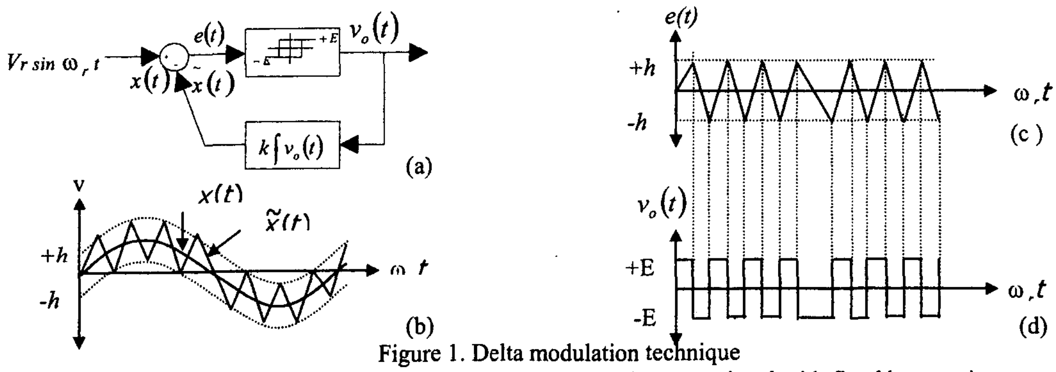

Figure 1. Delta modulation technique

(a) block diagram
(b) reference and feedback voltage
(c) error signal with fixed hysteresis
(d) PWM switching pattern

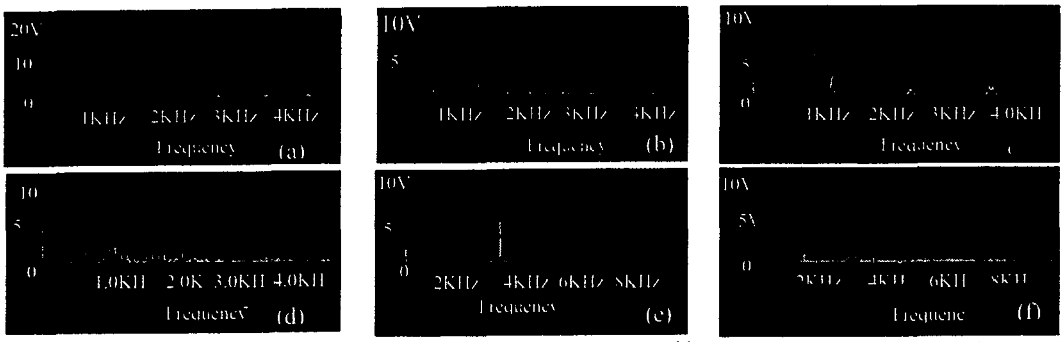

Figure. 2 Spectrum output voltage delta modulation , E =12 v, V_r = 8 v, k = 312.5, rang speed = 1 - 76 Hz

(a),(b) 10,50 Hz h = 1 v (c),(d) 10,50 Hz h = 0.5 v

(e),(f) 10,50 Hz h = 0.1 v

Since the range of the motor speed (i.e. the range of ω_r) depends on the integrator time from equ. (2), it is fixed according to a required range of ω_r. Assuming that the integrator time (k) is fixed, we can vary the switching frequency by adjusting the hysteresis window (h). As shown in Figure. 2, the higher hysteresis window, the lower switching frequency, and the distribution of the switching frequency depends on both the hysteresis window and the ω_r. At high ω_r as shown in Figure. 2 (b), (d), and (f), the switching frequency is already well distributed. However, at low ω_r as shown in Figure. 2 (a), (c), and (e), the switching frequency is still concentrated at the maximum switching frequency despite the higher switching frequency (Figure. 1. (f)).

To solve the problem at low ω_r, we propose to vary the hysteresis window according to the reference signal.

3. Propose Scheme

To control the hysteresis window by the angular frequency ω_r, the synchronization is inserted into the basic block of the DM as shown in Figure. 3.

As a result, the switching frequency will swing following the ω_r. The practical circuit for synchronization hysteresis delta modulator is shown in Figure.. 4.

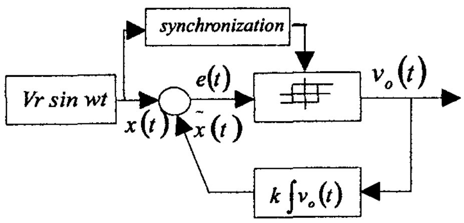

Figure. 3. Block diagram of the proposed scheme.

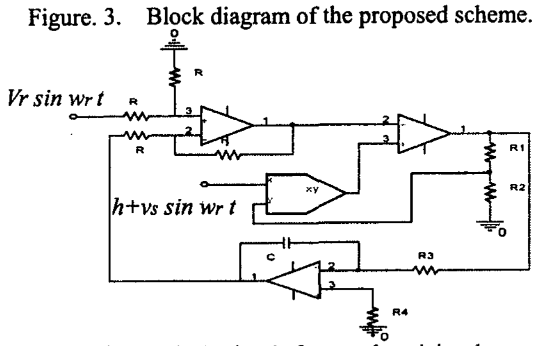

Figure. 4. A circuit for syschronizing hysteresis DM

From equation (1), we propose to adjust the hysteresis window by the following equation.

$$H = h + v_s \sin\omega_r t, \quad (3)$$

where v_s is used to control the distribution of switching frequency.

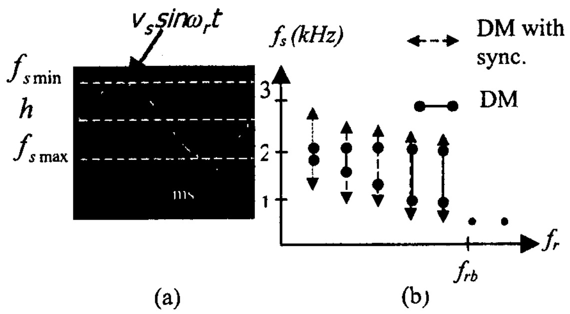

Figure.5: (a) the hysteresis window varies follow reference sine and (b) the distribution of switching frequency

Figure. 5 (a) shows that hysteresis window is varied follow reference sine in which $f_{s\,min}$ and $f_{s\,max}$ are controlled by v_s. Figure. 5 (b) shows the distribution of switching frequency. Notice that at low reference frequency, the switching frequency has wide distribution.

3. Spectrum Analysis

Figure. 6. (a-c) sketches harmonic spectrum at a low reference speed corresponding to fixed hysteresis window at *h*, varied hysteresis window with positive half of the reference sine wave, and varied hysteresis window with the negative half of the reference sine wave, respectively. The resulting equivalent harmonic frequency distribution can be predicted in Figure. 6 (d).

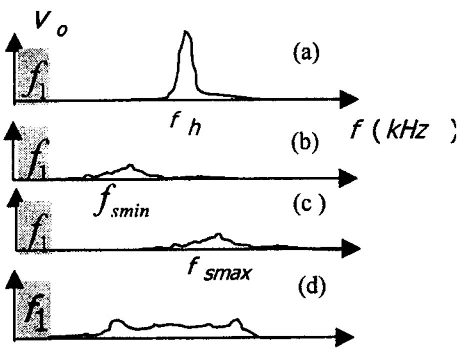

Fig 6. Sketched harmonic spectrum

4. Simulation Results

In this section we show the PSPICE simulation results comparing between fixed hysteresis delta modulation and the proposed delta modulation (varied hysteresis DM). Figure. 7 shows spectrum output voltage at speed range of 1-76 Hz,, E = 12 v, *Vr* = 8 v, *k* = 312.5, *h* = 0.3, *Vs* =0.15 v.

5. Discussions

From the spectrum in Figure. 7, the power of the acoustic noise are illustrated in Table 1, the propose technique shows to decrease peak spectrum of harmonic. However, the peak spectrum of harmonics are still concentrated at *fsmin* and *fsmax.*

TABLE 1
Show Peak Spectrum

Frequency of Reference sine (Hz)	Fixed Hysteresis Voltage (v)	Propose Voltage (v)
10	12 (2 kHz)	2.5 (1.5 kHz)
20	9 (1.75kHz)	2.5 (1.5kHz)
30	5 (1.8-2kHz)	4(1.5kHz)
40	4 (1.9-2 kHz)	3 (1.8-2 kHz)
50	4 (1.9-2k Hz)	2.5 (1.2kHz)

6. Conclusions

The problem of acoustic noises caused by peak harmonic spectrum of output voltage in delta modulation is solved by synchronizing the hysteresis widow of the DM to the reference signal. and the simulation results show a promising reduction of the noises. We are currently conducting the experiment to measure the actual acoustic noises in induction motor to confirm proposed technique.

References

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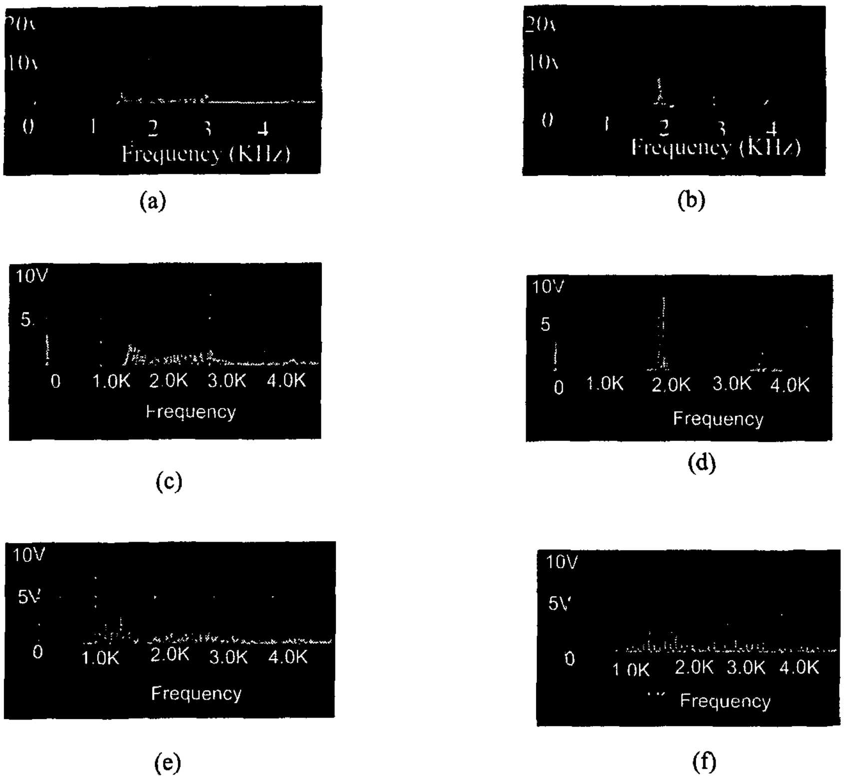

Figure. 7 Spectrum of output voltage, whreras (a), (c) and (e) corresponds to the proposed delta modulation at 10, 20 and 50 Hz, and (b), (d) and (f) corresponds to the fixed hystetresis delta modulation at 10,20 and 50 Hz