Proceedings of the Institute of Acoustics

ELECTROMAGNETIC NOISE SOURCES IN ELECTRIC MOTORS FED BY NON-SINUSOIDAL SUPPLIES.

S.J.E. Yang

Heriot-Watt University, Department of Electrical and Electronic Engineering, Edinburgh

1. INTRODUCTION

The use of power electronic devices for variable speed electrical drives has increased rapidly in recent years. One major problem associated with the use of power electronics is the acoustics noise emission from electric motors due to the voltage/current harmonics introduced by power electronic devices such as thyristors, MOSFETs and IGBTs (isolated gate bipolar transistors).

A number of papers [1,2,3] investigated electric motor noise and vibration problems related to current harmonics which are even and odd multiples of the fundamental frequency. Giessler and Sattler [4] described the effects of switching frequency of the power electronic device on induction motor noise emission. However, little information is available about the effects of switching frequency on electromagnetic forces causing noise and vibration.

This paper describes the effects of switching frequency of the power electronic device on current harmonics and electromagnetic forces in an electric motor fed by a PWM (pulse width modulation) inverter.

2. CURRENT HARMONICS AND FLUX WAVES

The non-sinusoidal current waveform in an electric motor fed by an inverter with PWM could contain the following frequency components:

(a) The fundamental frequency, f_1;

(b) The odd and even harmonics of the fundamental frequency i.e. if_1, where i is an integer;

(c) The switching frequency of the power electronic device, f_s and its harmonics, kf_s; and

(d) The sum and difference of (b) and (c), $kf_s \pm if_1$.

Fig. 1 gives an example of the current spectrum for a 3-phase induction motor fed by a PWM inverter using IGBTs. The switching frequency of the IGBTs was 10 kHz.

Taking into account the mmf waves due to the current harmonics of the fundamental frequency and the current components related to the switching frequency, the air gap radial flux density waves can be expressed as [5].

$$B(\phi,t) = \sum B_{mi,\omega i}\cos(m_i\phi-\omega_i t-\varphi_{mi,\omega i})$$

$$= \lambda[F_1\cos(p\phi-\omega_1 t) + F_2\cos(p\phi-2\omega_1 t-\varphi_2)$$

$$+F_3\cos(p\phi-3\omega_1 t-\varphi_3) + F_4\cos(p\phi-4\omega_1 t-\varphi_4)$$

$$+F_5\cos(p\phi-5\omega_1 t-\varphi_5) + \sum_{i=6}^{\infty} F_i\cos(p\phi-i\omega_1 t-\varphi_i)]$$

$$+\lambda\{F_s\cos(p\phi-k\omega_s t-\varphi_s)$$

$$+\sum_{i=1}^{\infty}\sum_{k=1}^{\infty} F_{ik}\cos[p\phi-(k\omega_s \pm i\omega_1)t-\varphi_{ik}]\} \qquad (1)$$

where m_i is the coefficient of ϕ, ω_i is the coefficient of t, ϕ is the mechanical angle with respect to a reference position, F_i is the amplitude of the mmf wave, λ is the permeance, φ is the phase angle, p is the pole pair number of the motor, ω_1 is the fundamental angular frequency, and ω_s is the switching angular frequency of the power electronic device.

3. ELECTROMAGNETIC FORCES

The radial electromagnetic forces acting on the inner surface of the stator are given by

$$\sigma_{ra}(\phi,t) = \frac{B^2(\phi,t)}{2\mu_0} \qquad (2)$$

where μ_0 is the permeability of free space.

Substituting Eqn(1) into Eqn(2), it can be shown that the radial electromagnetic forces are

$$\sigma_{ra}(\phi,t) = \sum \hat{\sigma}_{mi,\omega i}\cos[(m_{i,a}\pm m_{i,b})\phi-(\omega_{i,a}\pm\omega_{i,b})t-\varphi_{mi,\omega i}] \qquad (3)$$

where $m_{i,a}$ and $m_{i,b}$ are any two coefficient of ϕ in Eqn(1) and $\omega_{i,a}$ and $\omega_{i,b}$ are the two corresponding coefficients of t in Eqn(1).

Thus, the frequency values of these force waves related to the switching frequency are given by:

$$f = kf_s\pm(i_a\pm i_b)f_1 \qquad (4)$$

where k, i_a and i_b are independant integers.

4. NOISE

Taking k=1 or 2, i_a= 1 or 2 and i_b = 1 or 2 in Eqn(4), the forces related to the switching frequency contain the following frequency components: f_s, $f_s\pm f_1$, $f_s\pm 2f_1$, $f_s\pm 3f_1$, $2f_s$, $2f_s\pm f_1$, $2f_s\pm 2f_1$ and $2f_s\pm 3f_1$. Fig. 2 shows an example of the noise spectrum at 1m for a 3-phase induction motor fed by a PWM inverter with IGBTs at a switching frequency of 10008 Hz.

It is seen that all components derived from Eqn(4) with k,i_a and i_b values of 1 or 2 are important discrete frequency components. Table 1 gives the sources of these discrete frequency components.

Eqn(4) suggests that by using a high switching frequency, certain important noise components can be shifted to frequencies higher than 20 kHz, the limit of human audible range. Therefore, the use of high switching frequency is beneficial for noise reduction [6].

However, the use of high switching frequency could cause considerable electromagnetic interference problems. The electromagnetic interference could affect the accuracy of noise measurement and analysis. Furthermore, the high switching frequency of the power electronic device could contaminate the mains, which in turn could affect the operation of all instrumentation connected to the mains.

5. CONCLUSIONS

(1) For PWM variable speed drives with power electronic devices operating at a switching frequency of f_s, the electromagnetic forces causing motor noise

emission contain discrete frequency components at $kf_s \pm (i_a \pm i_b) f_1$, where k, i_a and i_b are independent integers, and f_1 is the fundamental frequency.

(2) The use of high switching frequency can shift certain important noise components to frequencies higher than 20 kHz, resulting in low noise emission. However, care should be taken to ensure that the accuracy of the noise measurement and analysis instrumention is not affected by high frequency electromagnetic interference.

6. REFERENCES

[1] S.J. YANG & P.L. TIMAR, "The effect of harmonic currents on the noise of a three-phase induction motors",IEEE Transactions, PAS-99, No.1,pp307-310(1980).

[2] S. WILLIAMSON, D. PEARSON & A.M. RUGEGE, "Acoustic noise and pulsating torgues in a triac-controlled permanent-split-capacitor fan motor", Proc IEE, 128, pt B, pp201-206(1981).

[3] A. BOUGARA & M. MCCORMICK, "Analysis of noise production in a small fan units driven by P.S.C.motor", Proceedings ICEM,pp41-46(1988).

[4] F. GIESSLER & P.K. SATTLER, "Magnetic noise of induction machines by inverter supply", Proceedings ICEM, pp611-616(1988).

[5] S.J. YANG, "Low Noise Electric Motors", Oxford University Press, 1981.

[6] T.INOUE, T. NISHIMURA, M. NAKOKA & T. MARUHASHI, "Reduction of acoustic noise in induction motor driven by three phase PWM chopper using IGBT", Proceedings of second EPE,pp847-852(1987).

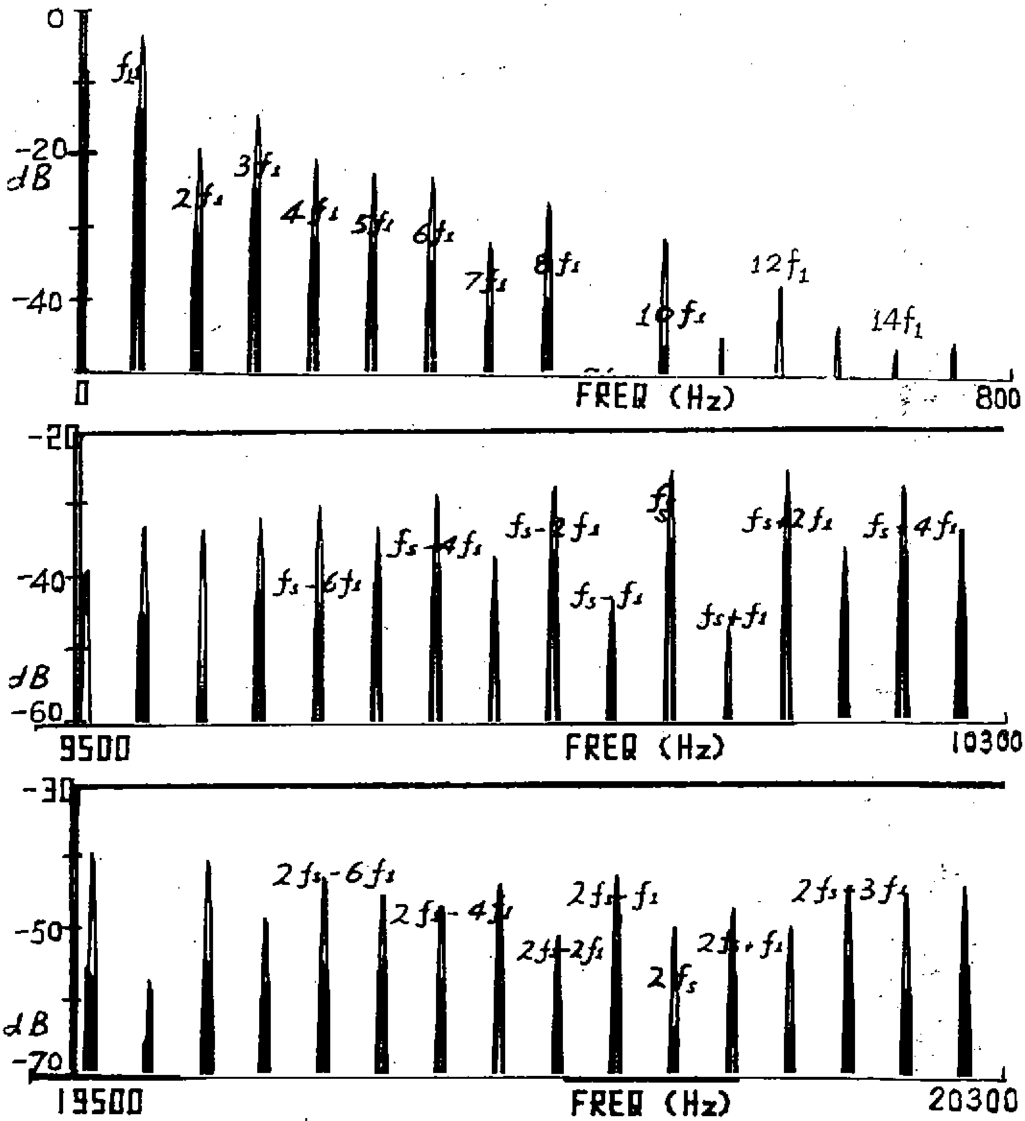

FIG. 1
CURRENT SPECTRUM

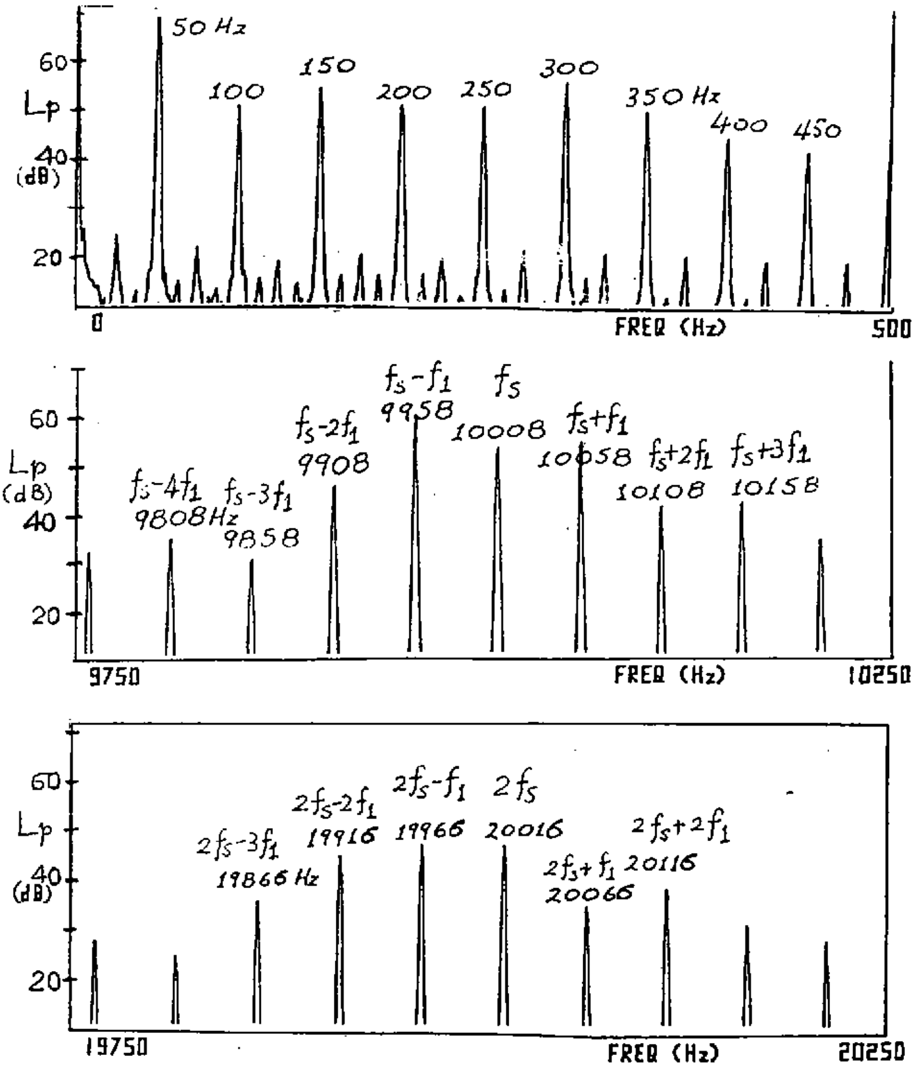

FIG. 2
SOUND SPECTRUM

TABLE 1

Sources of Important Noise Components for a 3-phase Induction Motor fed by a PWM Inverter.+

Frequency (Hz)	Sources f_1	$2f_1$	$3f_1$	$4f_1$	f_s	$2f_s$	Remarks
50	✓	✓					$2f_1-f_1$
100	✓		✓				$3f_1-f_1$, f_1^2
150	✓	✓					$2f_1+f_1$
200	✓		✓				$3f_1+f_1$
250	✓			✓			$4f_1+f_1$
9808				✓	✓		f_s-4f_1
9858			✓		✓		f_s-3f_1
9908		✓			✓		f_s-2f_1
9958	✓				✓		f_s-f_1
10008	✓	✓	✓	✓	✓		$f_s=f_s\pm(i_a-i_b)f_1$ *
10058	✓				✓		f_s+f_1
10108		✓			✓		f_s+2f_1
10158			✓		✓		f_s+3f_1
19916		✓				✓	$2f_s-2f_1$
19966	✓					✓	$2f_s-f_1$
20016	✓	✓	✓	✓		✓	$2f_s=2f_s\pm(i_a-i_b)f_1$ *
20066	✓					✓	$2f_s+f_1$
20116		✓				✓	$2f_s\pm2f_1$

\+ Operating at a fundamental frequency of 50Hz and a switching frequency of 10008Hz.

* $i_a=i_b$