Application of Chaotically Frequency Modulated SVPWM for EMC Enhancement of Closed-loop Motor Drives

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Abstract —In this paper, a chaotically frequency modulated pulse-width-modulation (PWM) scheme is proposed and applied to enhance the electromagnetic compatibility (EMC) for the closed-loop induction motor drive. The key is to develop chaotic-amplitude frequency modulation (CAFM) to modulate the switching frequency of PWM in such a way that the resulting chaotic PWM can offer the features of low peaky electromagnetic interference (EMI), well designed spectrum and good operating performance for the motor drive. Both simulation and experimental results are given to verify the validity of the proposed strategy.

I. INTRODUCTION

The variable speed electric drive systems are widely used in some industrial applications such as the propulsion system for electric vehicles, the starter/generator system for aerospace applications, etc [1]. However, the variable speed motor drive with fixed switching frequency suffers from the problem of conducted electromagnetic interference (EMI), which results from the high-frequency switched voltages of the inverter as shown in Fig. 1. In order to mitigate the conducted EMI, various approaches have been proposed: multilevel converter topology, soft switching, filter, and variable switching frequency modulation. Among them, the random or chaotic switching frequency techniques require no additional hardware and filter design. Besides, they offer continuous spectrum with wideband and easy implementation for motor drives. Compared to random signals, chaotic signals were verified to show better spectra performance, and achieve the uniformly distributed noise [2]. In addition, the generation of chaotic signals is much easier and cheaper than that of truly random noise.

In [3], the chaotic pulse-width-modulation (PWM) is created by using chaotically amplitude-modulated rectangular signals; whereas in [4], the chaotic PWM is based on chaotically frequency-modulated signals. However, both of them are only applied to the open-loop induction motor drive and they are based on sinusoidal PWM. Actually, to the best of authors' knowledge, the chaotic PWM technique applicable to the closed-loop induction motor drive is absent in literature.

The purpose of this paper is to propose and implement the new chaotically frequency modulated PWM scheme to the high-performance vector controlled induction motor drive. The key is to use the Logistic map to chaoize the amplitude of frequency modulation (FM). Then, by using this chaotic-amplitude FM (CAFM) to modulate the PWM, the CAFM-PWM is realized, which is in turn applied to a vector-controlled induction motor drive. The proposed chaotic PWM motor drive offers the definite advantages of low EMI level, well designed spectrum, and good operating performance for the motor drive. Furthermore, this chaotic PWM can afford different switching patterns by online tuning the parameter of chaotic map.

II. PROPOSED CHAOTIC PWM STRATEGY

Firstly, a standard FM is used to modulate the switching frequency of the conventional PWM in the way as:

$$f_v = f_{sw} + \Delta f \sin(2\pi f_m t) \qquad (1)$$

where f_v is the real switching frequency, f_{sw} is the fixed switching frequency of the conventional SVPWM, Δf is the deviation frequency, f_m is the modulating frequency, and $\Delta f \sin(2\pi f_m t)$ is the amplitude of FM. With the standard FM, the switching harmonic peaks around nf_{sw} of the conventional SVPWM are broken into some lower discrete harmonics around $nf_{sw} \pm kf_m$ in the SVPWM spectrum. Thus, the peaky EMI level is reduced.

Secondly, the chaotic series $\{\xi_i\} \in (0,1)$ is generated by the Logistic map, namely $\xi_{i+1} = \kappa \xi_i (1-\xi_i)$ is used to chaoize Δf so that the amplitude of FM in (1) is modified as $\xi_i \Delta f \sin(2\pi f_m t)$. By tuning the control parameter κ in the Logistic map, the fixed-frequency PWM (FF-PWM), the standard frequency modulated PWM (FM-PWM), and CAFM-PWM can be implemented on line. It should be noted that the voltage spectra around nf_{sw} can be well designed within the sideband of [$nf_{sw} - n\Delta f - f_m$, $nf_{sw} + n\Delta f + f_m$] under the condition that f_{sw} is much larger than the operating frequency f_{ref} of the motor drive.

Thirdly, the proposed CAFM-PWM scheme is applied to the closed-loop motor drive with vector control, and the control block is shown in Fig. 2. The sampling rate of the current controller varies with the switching frequency of the CAFM-SVPWM inverter while the sampling rate of the speed controller is kept to be a constant value. Due to the variable sampling rate, the PI parameters in the current controller are updated during each sampling interval.

III. RESULTS

For experimental verification, an IGBT-based voltage source inverter is constructed to supply a 220V-1.5kW-

1430rpm induction motor drive. Different PWM schemes are implemented digitally by using a single-chip TMS320F240 microcontroller. The Givi Misure EN600C-10000PPR encoder is used to measure the rotor speed and the LEM LA25-NP current sensor is used to measure the armature current. The LeCroy WR6100A digital storage oscilloscope with a special spectrum analyzer module is used to measure the voltage spectra.

Firstly, the stator current spectra of the proposed CAFM-SVPWM under different values of κ, namely κ=0, κ=2, κ=3.2, and κ=4, are measured as shown in Fig. 3. It can be observed that the conventional FF-PWM is obtained when κ=0. When κ=2, the distinct peak is broken into several smaller peaks, and the peaks become more and smaller when κ=3.2. The continuous spectrum is provided when the chaotic PWM is implemented under κ=4 finally.

Secondly, the measured spectrum is compared between the conventional FF-PWM and the proposed CAFM-PWM in Fig. 4 and 5. It can be observed the high peaks exist in the voltage spectrum and current spectrum with FF-PWM as shown in Fig. 4(a) and 5(a), respectively. Meanwhile, the peaky EMI is reduced effectively with the proposed CAFM-PWM in Fig. 4(b) and 5(b).

Thirdly, the operating performance of the proposed CAFM-PWM based closed-loop induction motor drive. As shown in Fig. 6, when i_d^* is changed with four steps (0.5A → 1A → 0.5A → 0.75A), i_q can quickly track the changes (0.58A → 0.25A → 1A → 0.33A). The starting process of the induction motor drive with the proposed CAFM-PWM also shows good operating performance in Fig. 7.

REFERENCES

[1] K. T. Chau, Y. B. Li, J. Z. Jiang, and C. Liu, "Design and analysis of a stator-doubly-fed double-salient permanent-magnet machine for automotive engines," *IEEE Trans. on Magn.*, Vol. 42, no. 10, pp. 3470-3472, 2006.

[2] A. Ashtari, G. Thomas, W. Kinsner, and B. C. Flores, "Sufficient condition for chaotic mpas to yield chaotic behavior after FM," *IEEE Trans. on Aerospace and Electronic Systems*, vol. 39, no. 1, pp. 202-210, 2003.

[3] M. Balestra, A. Bellini, S. Callegari, R. Rovatti, and G. Setti, "Chaos-based generation of PWM-like signals for low-EMI induction motor drives: analysis and experimental results," *IEICE Transactions on Electronics*, vol. E87-C, pp. 66-75, 2004.

[4] Z. Wang, K. T. Chau and C. Liu, "Improvement of electromagnetic compatibility of motor drives using chaotic PWM," *IEEE Trans. Magn.,* vol. 43, no. 6, pp. 2612-2614, 2007.

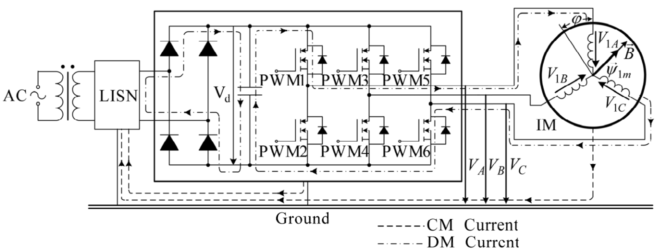

Fig. 1. Conducted EMI in voltage source converter fed motor drives.

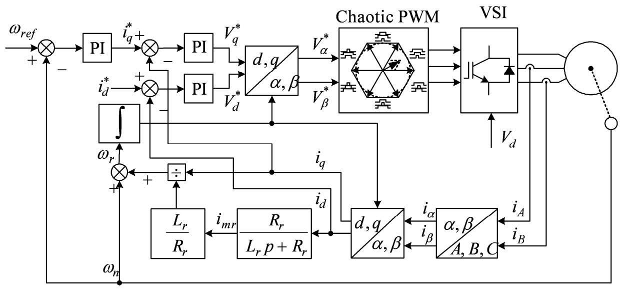

Fig. 2. Block diagram of the vector controlled induction motor drive.

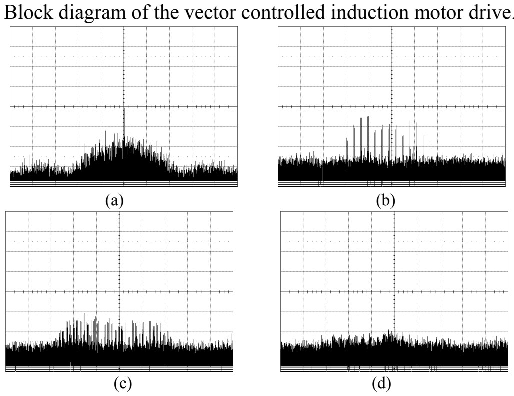

Fig. 3. Measured spectrum of stator current (X: 1kHz/div; Y: 10dB/div): (a) $\kappa = 0$; (b) $\kappa = 2$; (c) $\kappa = 3.2$; (d) $\kappa = 4$.

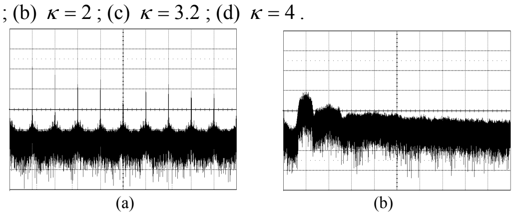

Fig. 4. Measured spectrum of output voltage (X: 10kHz/div; Y: 20dB/div): (a) FF-PWM; (b) CAFM-PWM.

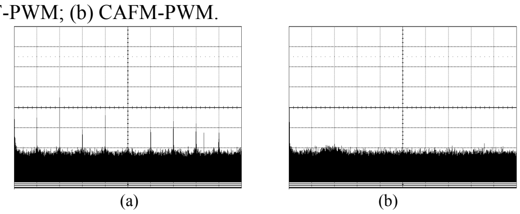

Fig. 5. Measured spectrum of stator current ((X: 10kHz/div; Y: 10dB/div)): (a) FF-PWM; (b) CAFM-PWM.

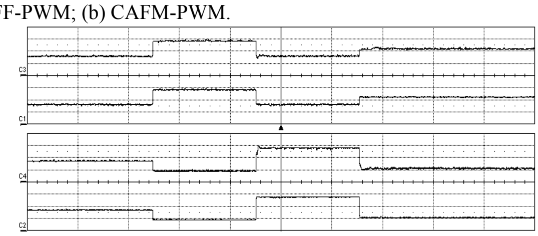

Fig. 6. Measured dynamical response of current controller (X: 1s/div, Y: 0.4A/div, C1: i_d^*, C2: i_q^*, C3: i_d, C4: i_q).

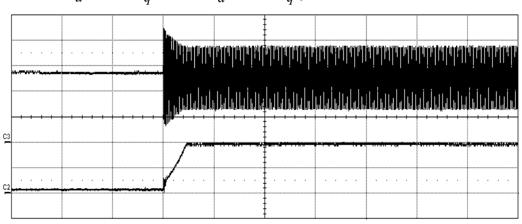

Fig. 7. Measured starting process of the CAFM-PWM based motor drive (Upper: Stator current, X: 5s/div, Y: 0.4A/div; Lower: Rotor speed, X: 5s/div, Y: 72rpm/div)