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PWM Techniques For The Reduction Of Harmonic Magnitudes At Multiples Of Switching Frequencies

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Abstract: Conventional constant switching frequency random PWM techniques generate high amount of harmonics at the multiples of switching frequencies. This high magnitude of harmonics causes acoustic noise, vibration and electromagnetic interference to the nearby systems. In this paper a three different types of random variable switching frequencies PWM techniques were discussed and these PWM techniques are able to reduce the magnitude of harmonics at multiples of switching frequencies. As the switching frequencies are varied in a limited range (±500 Hz) filter design also becomes easy. The performance evaluation of these PWM techniques is carried out in MATLAB/ Simulink and results are presented.

Key words: PWM techniques, harmonics, switching frequencies.

I. Introduction

The circuit diagram of conventional two-level voltage source inverter fed induction motor drive is shown in Fig.1. Vao,Vbo,Vco are called as pole voltages, Vab, Vbc,Vca are called as line voltages. For the control of output voltage and frequency different pulse width modulation (PWM) techniques are employed [1-6]. The realization of PWM techniques is carried out based on carrier comparison approach and space vector approach [4-6]. Because of easy implementation and non usage lengthy calculations, carrier based PWM techniques are gaining importance [5-6].

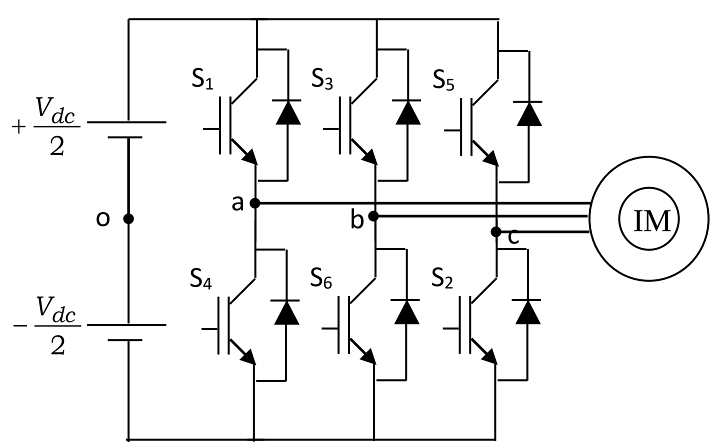


Fig. 1 Circuit diagram of two-level voltage source inverter fed induction motor drive.

Based on carrier frequency selection, PWM techniques are classified as constant switching frequency and variable switching frequency schemes [7-12]. Conventional constant switching frequency PWM techniques [4-6] show superior performance in terms of good quality of output voltage but because of constant switching frequency it is observed that much amount of energy is concentrated at multiples of switching frequencies. This high magnitude of harmonics at switching frequencies causes acoustic noise or humming noise, vibration and electromagnetic interference [13].

In order to reduce noise, vibration and electromagnetic interference different random PWM techniques are gaining importance. In literature constant switching frequency random PWM techniques like pulse position modulation schemes and pulse width modulation schemes were proposed [7-9]. But the magnitudes of reduction in harmonics at multiples of switching frequencies are small. With variable switching frequency PWM techniques [10-12] harmonic magnitudes can be reduced but filter design becomes complex. But with variation of switching frequencies with a band of 1 kHz, design issues become easier. Hence in this work two different types of variable switching frequency PWM techniques were discussed. In these PWM techniques switching frequency is varied in a band of ±500 Hz of base frequency.

II. Conventional carrier based PWM techniques

Majority of PWM techniques discussed for two-level inverter can be implemented based on scalar carrier comparison scheme or space vector scheme. In this paper much focus is applied on scalar based carrier comparison scheme. In carrier comparison scheme reference signal is compared with high frequency carrier signal. The intersection point of these two gives the switching instants. Hence to generate control signals for three-phase two-level voltage source inverter as shown in Fig.1, three reference signals are compared with high frequency carrier signal. The three reference signals can be mathematically expressed as in (1).

$$\begin{aligned} V_{a,ref} &= \cos(\omega t) \\ V_{b,ref} &= \cos(\omega t - 120) \\ V_{c,ref} &= \cos(\omega t - 240) \end{aligned} \tag{1}$$

The realization of carrier comparison scheme to a phase is shown in Fig. 2. In similar way to generate control signals for the remaining phases, phase shifted reference signal ($V_{b,\,mod}$ and $V_{c,mod}$) is compared with a common carrier signal.

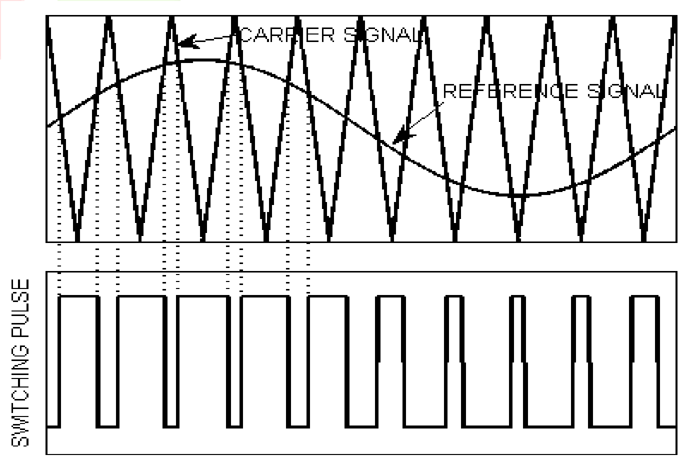


Fig. 2 Realization of carrier comparison scheme.

The carrier comparison scheme discussed in Fig. 2 generates the output voltage with poor DC utilization, high magnitude of harmonics and high ripple. Hence the reference signals and carrier signals need be modified. The circuit configuration shown in Fig. 1 is three-phase three wire system, zero sequence current will not flow through the phase windings. So addition of zero sequence signals to the reference signals will not affect the zero sequence currents. Hence the new reference signal ($V_{i\ mod}$) is obtained by adding a zero sequence signal to the old reference signal as in (3). The expression for zero sequence signal is considered as in (4)[ ]. Here V_{dc} is the normalized DC bus voltage, ko is the constant value between 0 and 1, V_{max} and V_{min} are the instantaneous maximum and minimum values of the old reference signal. By choosing different values between 0 and 1 for ko, various continuous and discontinuous reference signals can be generated. The continuous reference signal with ko=0.5 is shown in Fig. 3.Along with continuous new reference signal, zero sequence signal and old reference signals are also shown in Fig. 3.

$$V^{*}_{i\ ref} = V_{i\ ref} + V_{zs} \quad \text{where} \quad i = a,b,c \tag{3}$$

$$V_{zs} = \frac{V_{dc}}{2}(2k_o - 1) - k_o V_{\max} + (k_o - 1)V_{\min} \tag{4}$$

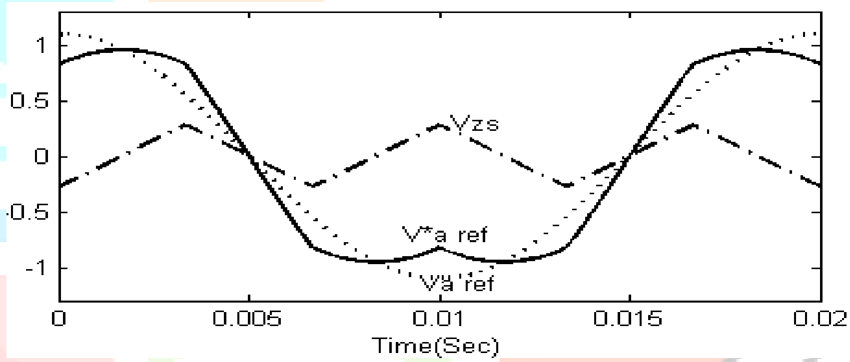


Fig. 3 Old reference signal, zero sequence signal and Continuous new reference signal

The continuous new reference signal as shown in Fig. 3 is compared with high frequency carrier signal, to generate the switching instants (continuous PWM or CPWM). The pulse pattern with such type of PWM technique (CPWM) improves the DC utilization and reduces the current ripple but generate high magnitude of harmonics at multiples of switching frequencies because of employing constant switching frequencies to the carrier signal.

III. Variable switching frequency random PWM techniques

To reduce the magnitude of harmonic around the multiples of switching frequencies Random PWM techniques are gaining importance. In literature random PWM techniques are classified as constant switching frequency random PWM techniques and variable switching frequency PWM techniques. In this paper much focus is given to variable switching frequency random PWM techniques.

(a) Variable switching frequency random PWM (VSF-RPWM) technique:

In these types of random PWM techniques carrier signal frequency is varied over a wide band of frequencies (fs±500 Hz). The block diagram illustrating variable switching frequency random PWM (VSF-RPWM1) is shown in Fig. 4. In the Fig. 4 random frequency generator block randomly generates a frequency of ±500 of base switching frequency (5000 Hz). Based in this frequency, carrier signal generator block generates variable switching frequency carrier signal. In this VSF-RPWM1 the output, variable switching frequency carrier signal is compared with continuous modulating signal to generate control signals.

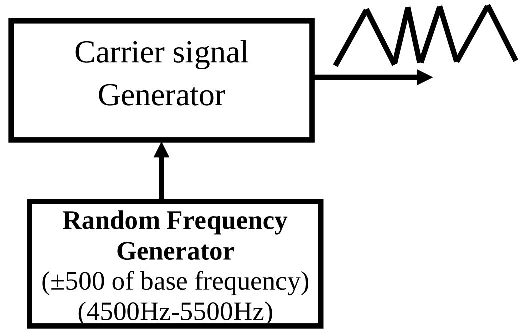


Fig. 4 Block diagram illustrating variable switching frequency carrier signal generation scheme

(b) Random carrier selection and random variable switching frequency PWM (RCVSF-PWM) technique:

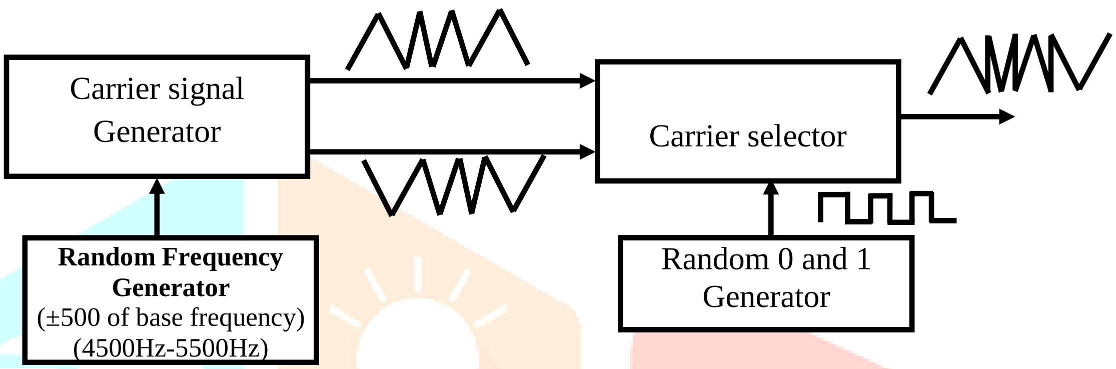
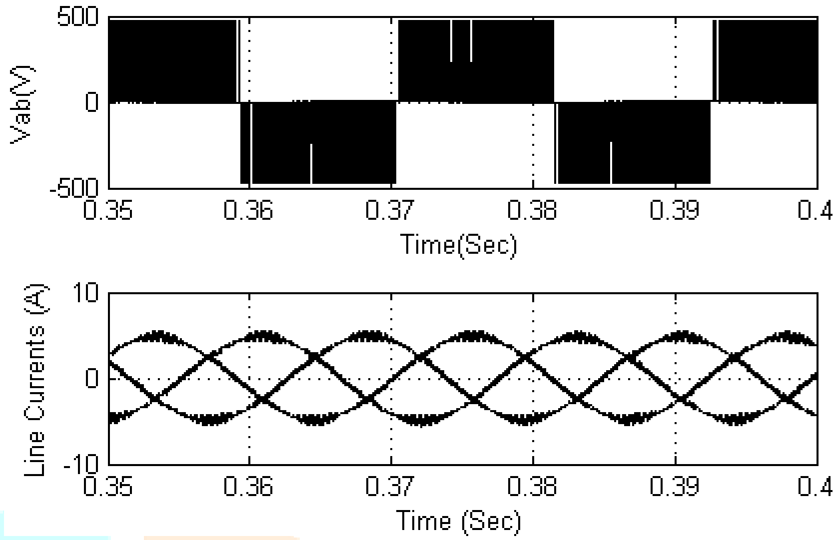


Fig. 5 Block diagram illustrating random carrier selection and random variable switching frequency PWM technique

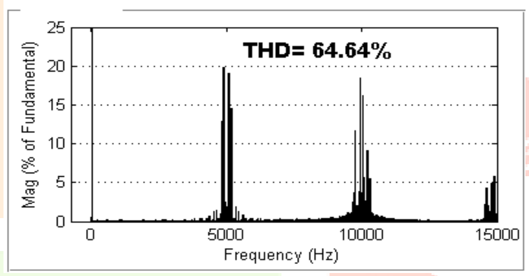
In this type of PWM technique instead of using one random variable switching frequency carrier signal, two sets (positive and negative carrier signals) of random variable switching frequency carrier signals are used. The selection among positive and negative variable switching frequency carrier signals is done randomly. The block diagram illustrating the RCVSF-PWM is shown in Fig. 5. In the Fig.5 carrier signal generator generates both the carrier signals (positive and negative carrier signals) with randomly variable switching frequency. These two signals are fed as inputs the carrier selector. Based on random generator, carrier selector randomly selects positive and negative carrier signal. The output carrier selector will be blend of positive and negative variable switching frequency carrier signals. The blended carrier signal (positive and negative carrier signals) is compared with continuous modulating signal to generate control signals.

IV. Results and discussion

To evaluate the performance of these PWM techniques simulation studies are carrier out on v/f controlled induction motor drives. The specifications of induction motor are 4 Hp, 400 V, 50 Hz, 1430 rpm. An input DC voltage of 470 V is employed for the voltage source inverter and switching frequency of 5 kHz is employed in generating control signals. The simulation results of line voltage and three-phase line currents at M=0.81 with CPWM, VSF-RPWM and RCVSF-PWM are shown in Fig. 6(a) to Fig. 8(a). It is observed that with all the PWM techniques, the line voltage has three different levels $-V_{dc}$, $0, V_{dc}$, Though the voltage levels created are same because of change in carrier signals position of voltage level is changed. This change in position of voltage level affects the harmonics. Along with the line voltage and line currents their harmonic spectrum are also shown in Fig. 6 to Fig. 8. With CPWM technique both in voltage and current spectrum it is observed that much amount of harmonic magnitudes can be observed at the multiples of switching frequencies (5 kHz, 10 kHz , 15 kHz …….). But with VSF-RPWM and RCVSF-PWM the harmonic magnitudes at multiples of switching frequencies (5 kHz, 10 kHz , 15 kHz …….) are reduced. The reduction is much better with RCVSF-PWM technique. As the magnitude of harmonics at multiples of switching frequencies (5 kHz, 10 kHz , 15 kHz …….) are reduced but remaining harmonic magnitudes may increase or decrease. This can be observed from the harmonic spectrums. Because of increase in harmonics the total harmonic distortion of line voltage and line currents are high with VSF-RPWM and RCVSF-PWM techniques when compared with CPWM technique.



(a)



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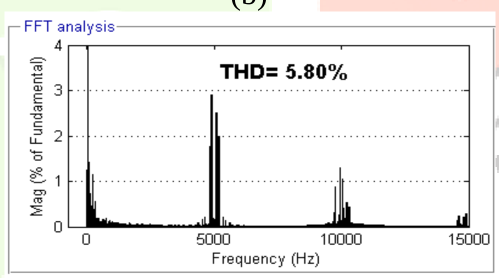
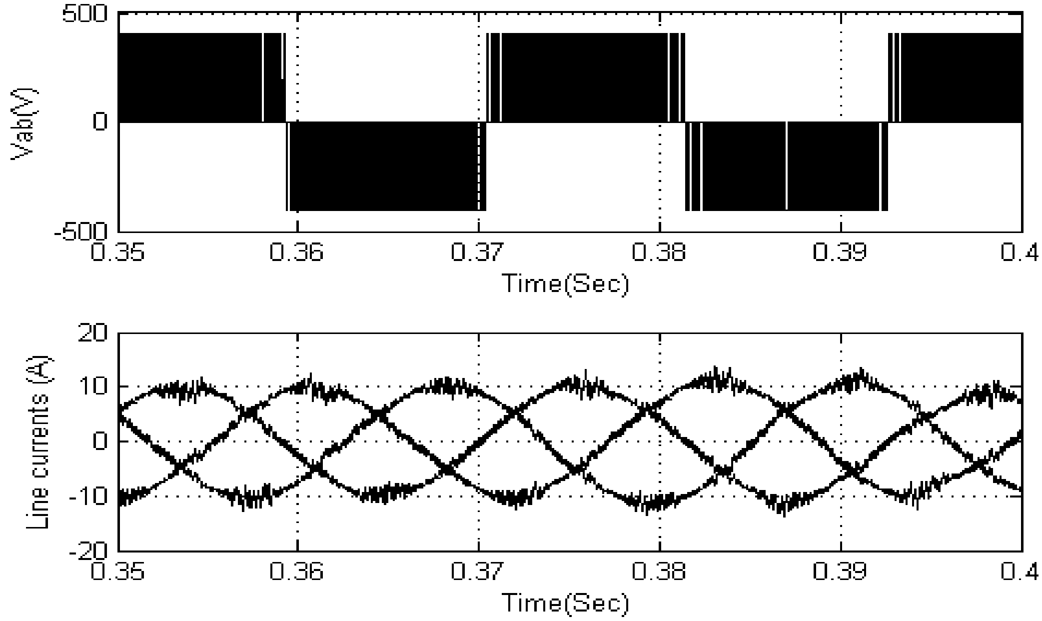
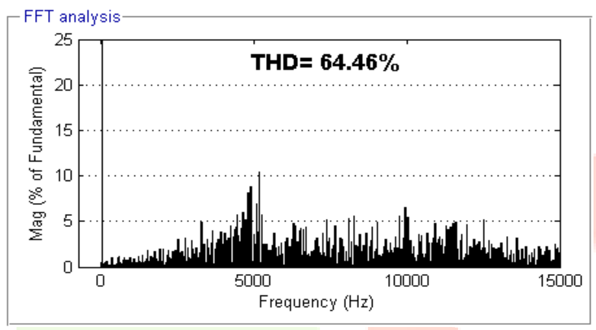


(c)

Fig. 6 Simulation results of CPWM based inverter fed induction motor drive (a) line voltage and three phase line current (b) Harmonic spectrum of line voltage (c) Harmonic spectrum of line current.



(a)



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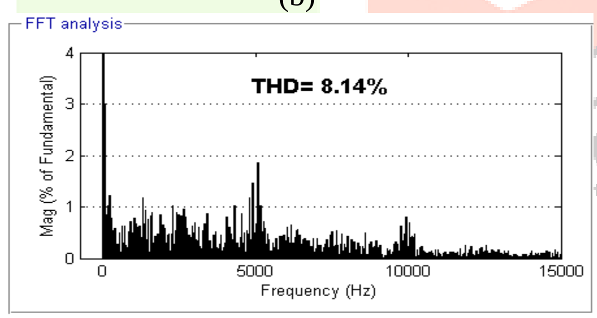

(c)

Fig. 7 Simulation results of VSF-RPWM based inverter fed induction motor drive (a) line voltage and three phase line current (b) Harmonic spectrum of line voltage (c) Harmonic spectrum of line current.

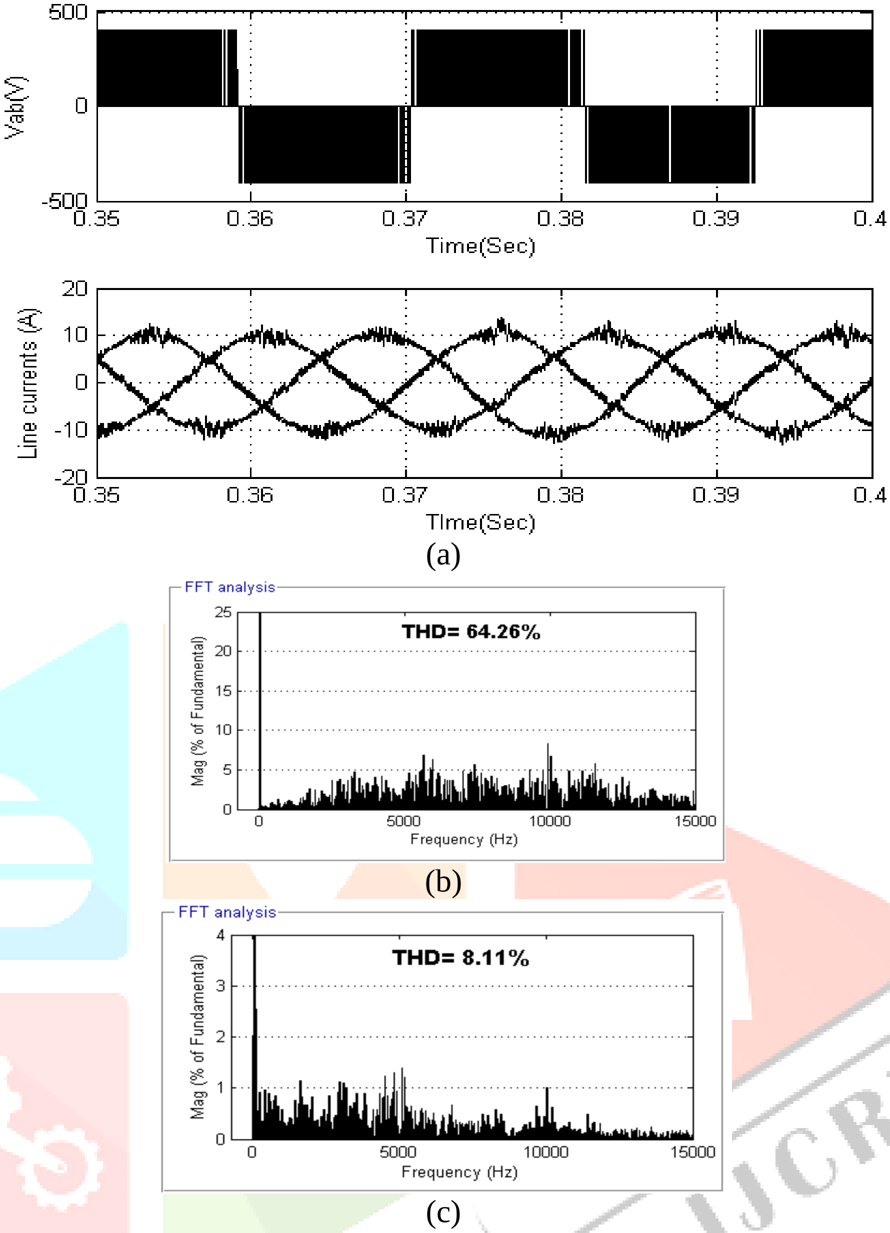

Fig. 8 Simulation results of RCVSF-PWM based inverter fed induction motor drive (a) line voltage and three phase line current (b) Harmonic spectrum of line voltage (c) Harmonic spectrum of line current.

V. Conclusion

In this paper two different types of variable switching frequency PWM techniques were discussed for two-level voltage source inverter fed induction motor drive. The implementation of these PWM techniques were discussed based on carrier comparison approach where there is no need to calculate sector or reference voltage magnitude information. Hence carrier based implementation is simple to implement.

With conventional constant switching frequency PWM techniques it is observed that much amount of harmonics are present at multiples of switching frequencies. With the proposed variable switching frequency PWM techniques (VSF-RPWM and RCVSF-PWM) magnitude of harmonics are reduced. This leads to reduction in acoustic noise, vibration and electromagnetic interference with the nearby systems.

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