Constant Switching Frequency Random PWM Techniques for Two-Level Inverter fed Induction Motor Drives

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Published in IJIRMPS (E-ISSN: 2349-7300), Volume 10, Issue 4, (July-August 2022)

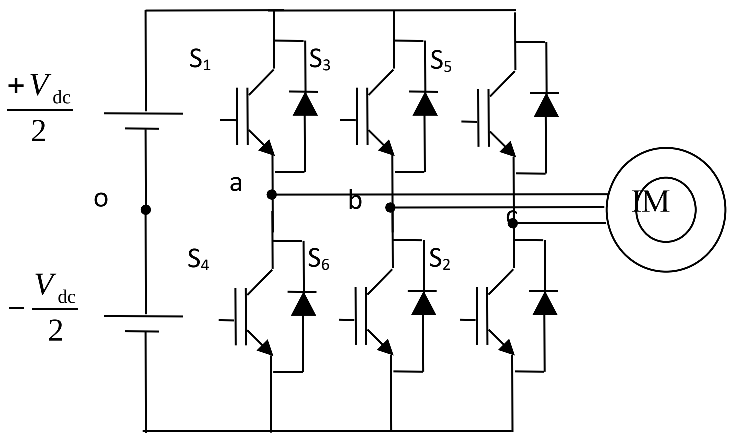
Abstract

Conventional PWM techniques generate acoustic noise because of high energy concentration around harmonics of switching frequencies. To reduce the acoustic noise the magnitude of harmonics around switching frequencies are to be reduced. In this paper three different types PWM techniques are proposed for the reduction of acoustic noise. The implementation of these PWM techniques is carried based on carrier comparison approach It is observed that carrier comparison approach is easy to implement when compared with space vector based PWM techniques. The performance evaluation of these PWM techniques are carrier out in MATLAB/Simulink and results are presented.

Keywords: Conventional PWM Techniques, Acoustic Noise, Space Vector

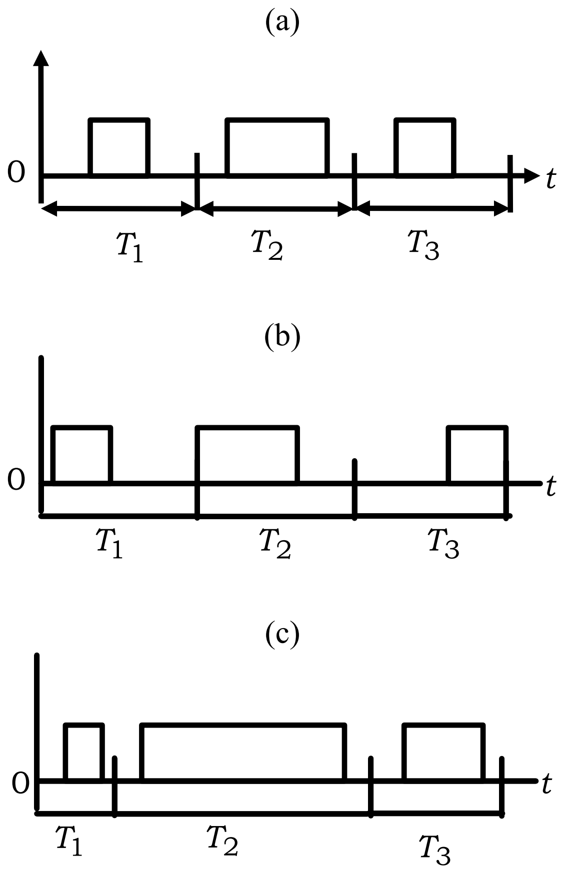
1. Introduction

Figure 1: Circuit Diagram of Two-level Voltage Source Inverter Fed Induction Motor Drive



To control of output voltage and frequency different PWM techniques are employed for the two-level voltage source inverters (VSI's) [1-6] shown in Figure 1. The realization of these PWM techniques are carried out based on carrier comparison approach and digital space vector approach [4]. Authors in [4] explained correlation between carrier comparison approach and digital space vector approach. Various continuous and discontinuous PMW techniques [5-6] were proposed to increase DC utilization, reduced current ripple and switching losses. But all the PWM techniques generate high amount energy at harmonics of switching frequencies, which results in acoustic noise.

Figure 2: Pulse Pattern of (a) Conventional PWM Technique, (b) Pulse Position Modulation Technique, (c) Pulse Frequency Modulation Technique



To reduce the energy concentration around harmonics of switching frequencies either pulse position or pulse width or pulse frequency is varied randomly [7-13]. The pictorial representations of pulse pattern of such PWM techniques are shown in Figure 2. In Figure 2(a) the pulse pattern with conventional PWM is shown in which pulse width is different but the pulse frequency is same in the entire time period. In the pulse position modulation technique pulse frequency remains same but the pulse position is randomly placed as shown in Figure 2(b). In Figure 2(c) pulse frequency is varied over a wide range of frequencies. Among constant switching frequency [7-8, 13] and variable switching frequency PWM techniques [9-10, 13], constant switching frequency PWM schemes are gaining importance because of easier filter design. In constant switching frequency PWM techniques pulse position can be modulated in three different ways. One such method based on carrier comparison approach is discussed in [11-12]. Though the PWM technique have given better results but with the idea to getting best results higher commutations are introduced in this paper. The realization of such PWM techniques is discussed in the paper. The results are presented and evaluated using MATLAB/Simulink.

2. Pulse width Modulation Techniques

In carrier comparison approach to generate control signals for three-phase two-level inverter, three reference signals as given in (1) are compared with carrier signal. The intersection point of reference signals with carrier signal defines the switching instants. The realization of conventional sinusoidal

PWM using carrier comparison approach is shown Figure 1. The switching logic used for the generation of control signals is given in Table 1.

$$\begin{aligned} Va\,ref &= Vm \times \cos(\omega t) \\ Vb\,ref &= Vm \times \cos(\omega t - 120) \\ Vc\,ref &= Vm \times \cos(\omega t - 240) \end{aligned} \quad (1)$$

Figure 3: Realization of Conventional Sinusoidal PWM

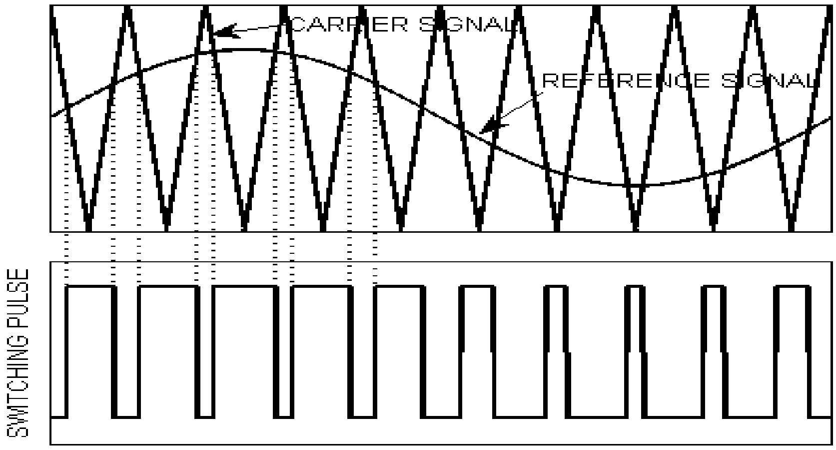


Table 1: Switching Logic

Condition	**Switching State**
If $V_a > V_t$	S1 = ON S4 = OFF

The control signals obtained by the using the switching fashion as shown in Figure 3 generate output voltage with high ripple and poor DC utilization [5-6]. As the neutral point of the induction motor is isolated a zero sequence signal can be added to the reference signals given in (1) to improve the DC-utilization. The general equation for the generation of zero sequence signal is given (2).

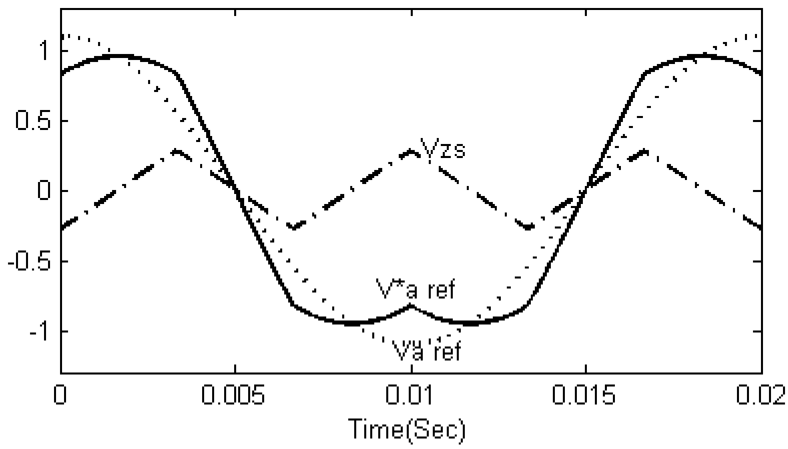
$$V_{zs} = \frac{V}{2}(2k_o - 1) - a_o V_{max} + (k_o - 1) V_{min} \quad (2)$$

$$V^*_{i_{ref}} = V_{i_{ref}} + V_{zs} \quad (3)$$

where i = a, b, c

In (2) where V_{max} and V_{min} are maximum and minimum of reference signals given in (1). V_{dc} is the normalized DC Voltage and k_o is the constant. By selecting different values for k_o various new continuous and discontinuous modulating signals can be generated. The general expression for generation of new reference signals is given in (3). Old reference signal ($V_{i\,ref}$), zero sequence signal and new reference signal ($V^*_{i\,ref}$) obtained by choosing k_o as 0.5 is shown in Figure 4. When the continuous modulating signal (new reference signal) shown in Figure 4 is compared with high frequency carrier signal, such PMW technique is called as continuous PWM (CPWM).

Figure 4: Old Reference Signal, Zero Sequence Signal and Continuous Modulating Signal



3. Random PWM Techniques

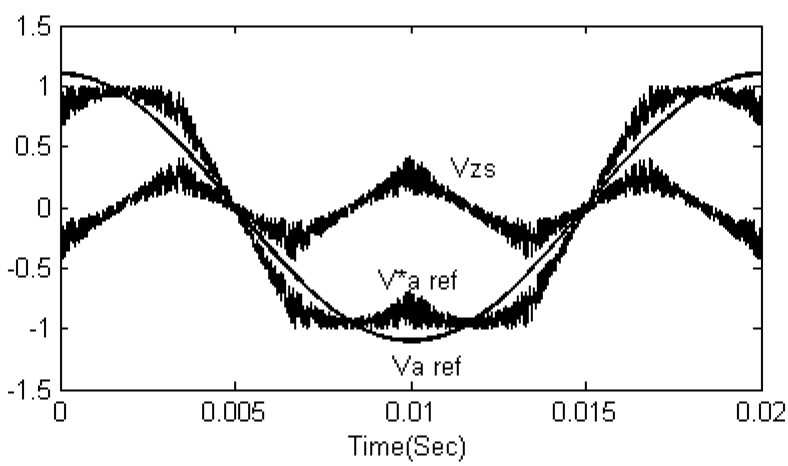
With the switching fashion employed in CPWM technique reduce current ripple and improves the DC utilization. But because of constant switching frequency employed to carrier signal, in the harmonic spectra it is observed that much amount of energy is concentrated at the multiples of switching frequencies. To reduce the magnitude of harmonics different random PWM techniques were identified.

(a) Random Reference PWM (RR-PWM)

In this type of PWM pulse position and pulse width is randomly varied by introducing the random ness in the reference signal. This type of reference signal is also called as random reference signal and it can be generated in similar way as continuous modulating signal.

To generate three phase random reference signal, consider three reference signals and zero sequence signal as given in (1) and (2). In zero sequence signal, instead of choosing k_o as 0.5 (0.5 to generate continuous new reference signal) k_o is chosen randomly between 0 and 1. The resulting random modulating signal is shown in Figure 5. It is observed from the modulating signals shown in Figure 4 and Figure 5 is the continuous modulating signals are smoothly varying signals where random modulating signals contains abrupt variations. When such type of modulating signals is compared with high frequency carrier signal, gives rise to RR-PWM.

Figure 5: Old reference Signal, Zero Sequence Signal Random Modulating Signal



(b) Random Carrier PWM (RC-PWM)

In this type of PWM technique instead of using one carrier signal, two carrier signals (positive triangular signal and negative triangular signal) are used for the generation of control signals. Though PWM techniques use both carrier signals, but at any instant only one carrier signal used for the generation of control signal. The selection among the two carrier signals is carried out randomly. The illustration of carrier selection scheme is shown in Figure 6. From Figure 6, it is observed that both positive and negative carrier signals are fed as inputs to carrier selector, along with these random generator output is also given as input. At any instant random generator generates 0 or 1. If random generator generates 1, then carrier selector selects positive carrier signal and if random generator generates 0, then carrier selector selects negative carrier signal. Hence the output of carrier selector is blend of positive and negative carrier signal. This resulting random carrier signal is compared with continuous modulating signal shown in Figure 4. The PWM technique with continuous modulating signal and random carrier signal is called as RC-PWM technique. The simulation results obtained during random carrier selection is shown in Figure 7.

Figure 6: Illustration of Random Carrier Selection Scheme

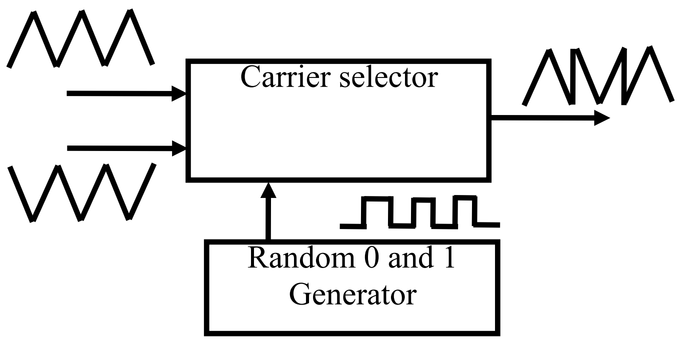
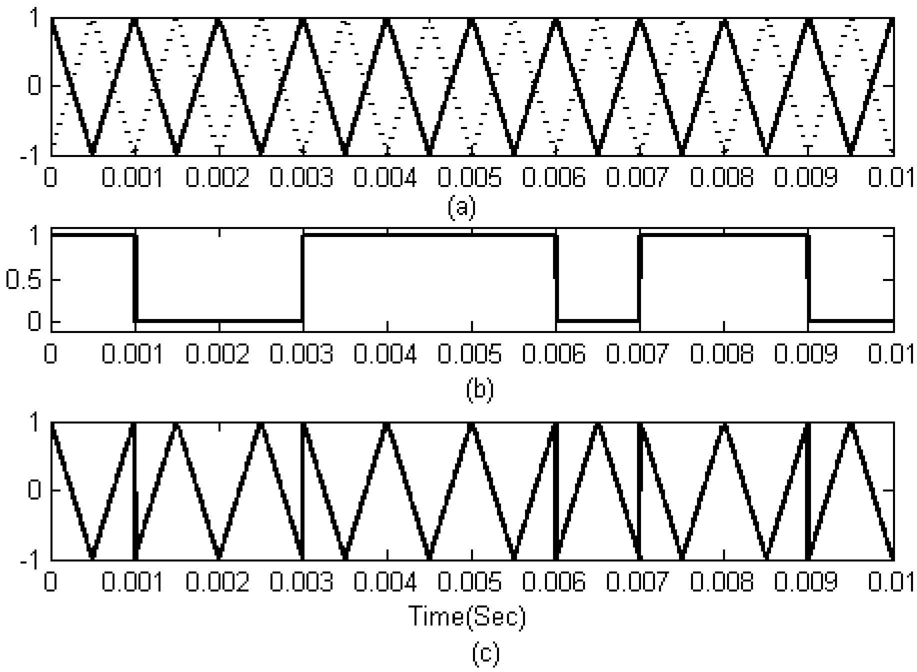


Figure 7: Simulation Results (a) Input Positive and Negative Carrier Signals (b) Random Generator Output (c) Out of Carrier Selector



From Figure 7, it is observed that during time period 0 to 0.001 random generator output is 1 hence positive carrier is selected. During time period 0.001 to 0.003 random generator output is 0 hence negative carrier is selected. In similar way during reaming time periods based on random generator output positive and negative carrier is selected.

(c) Random Reference and Random Carrier PWM (RRRC-PWM)

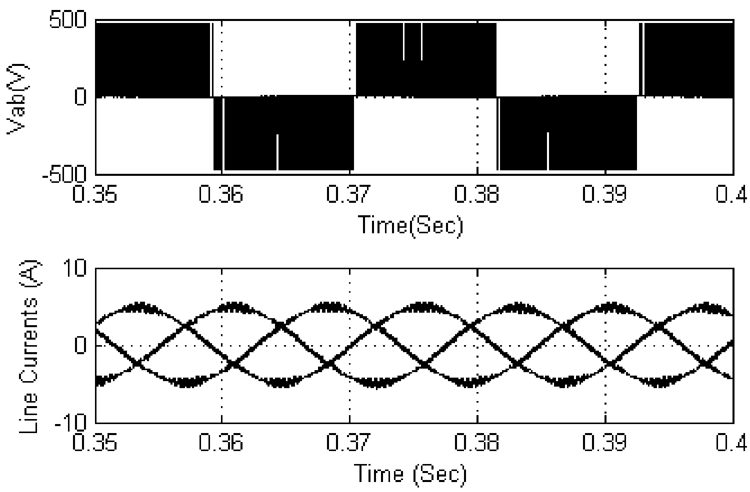
To reduce magnitude of harmonics in this type of PWM technique the random ness is introduced in both generation of modulating signal and selection of carrier signal.

4. Results and Discussion

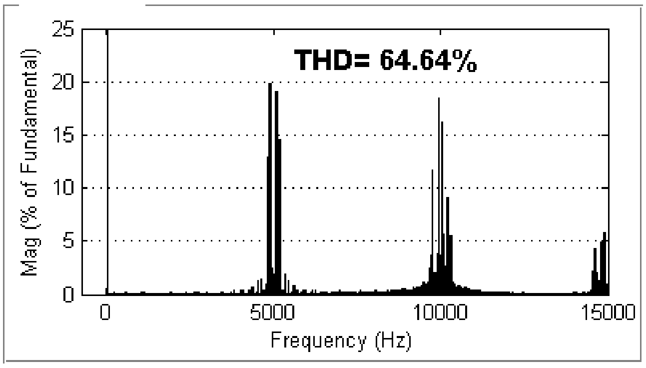
To validate the performance of proposed random PWM techniques simulation studies are carried in MATLAB/Simulink environment. In simulation studies v/f control was employed for the speed control of inverter fed induction motor drive. The specifications of induction motor are 4 Hp, 400 V, 50 Hz, 1430 rpm. 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 of voltage source inverter fed induction motor drive at modulation index M = 0.81 with SVPWM, RRPWM RCPWM and RRRCPWM are shown in Figure 8(a) to Figure 11(a). As the induction motor drive is employed with two-level voltage source inverter it is observed that the line voltage plot has three different levels of V_{dc}, 0 and $-V_{dc}$. The three phase line currents are shown under no load conditions.

Figure 8: Simulation Results of SVPWM 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)



(b)



(c)

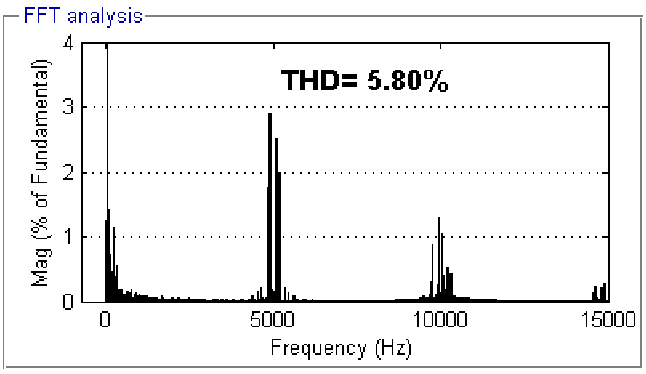
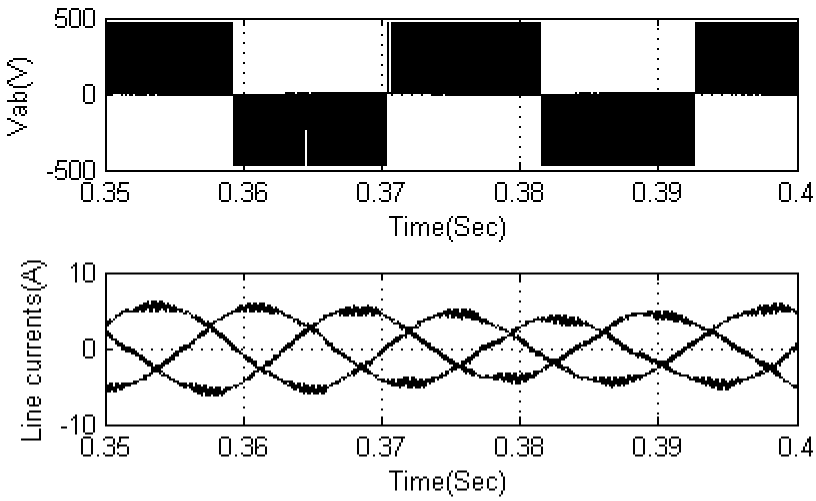
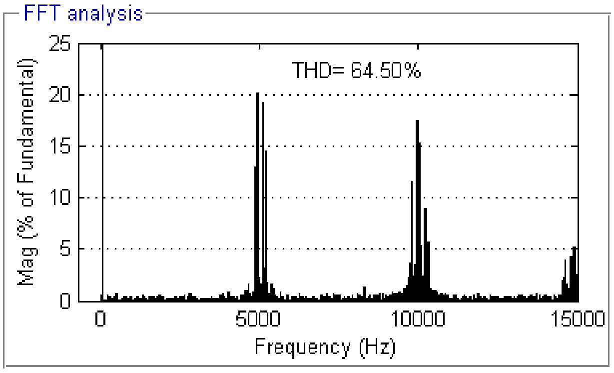


Figure 9: Simulation Results of RRPWM based Inverter Fed Induction Motor Drive (a) Line Voltage and Three Phase Line Current (b) Harmonic Spectrum of Line Voltage (c) Harmonic Spectrum of Line Current

(a)



(b)



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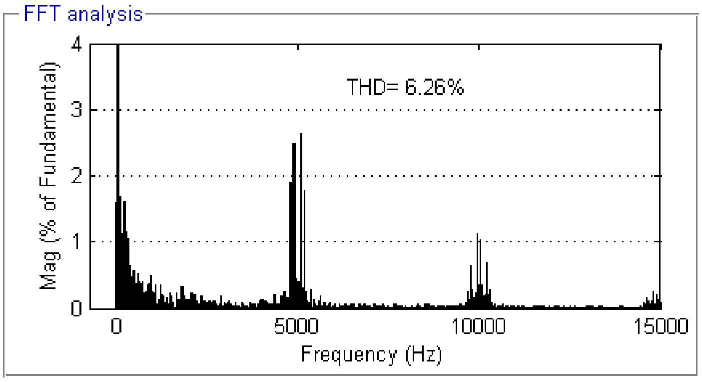
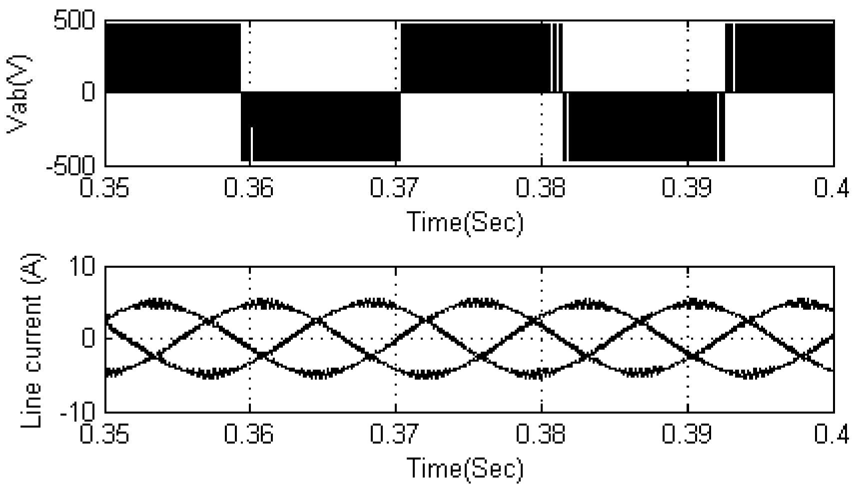
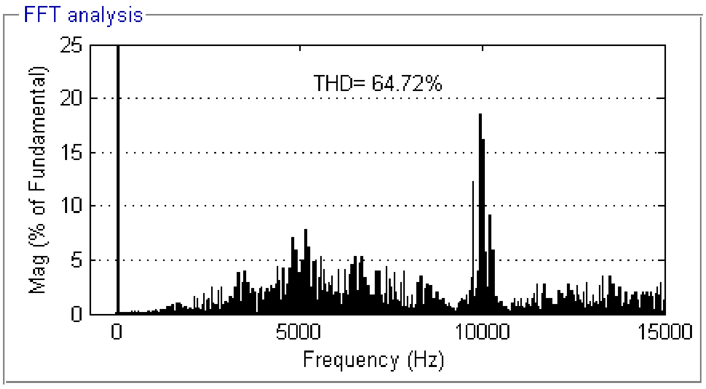


Figure 10: Simulation Results of RCPWM based Inverter Fed Induction Motor Drive (a) Line Voltage and Three Phase Line Current (b) Harmonic Spectrum of Line Voltage (c) Harmonic Spectrum of Line Current

(a)



(b)



(c)

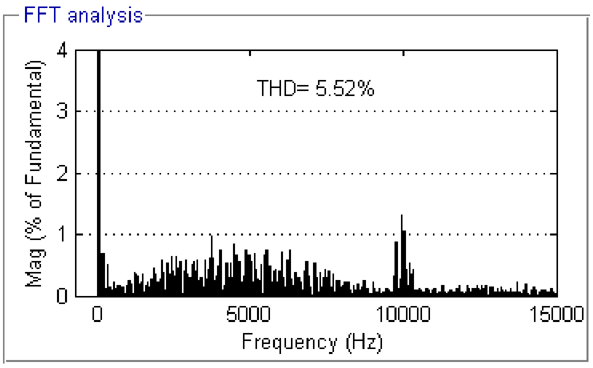
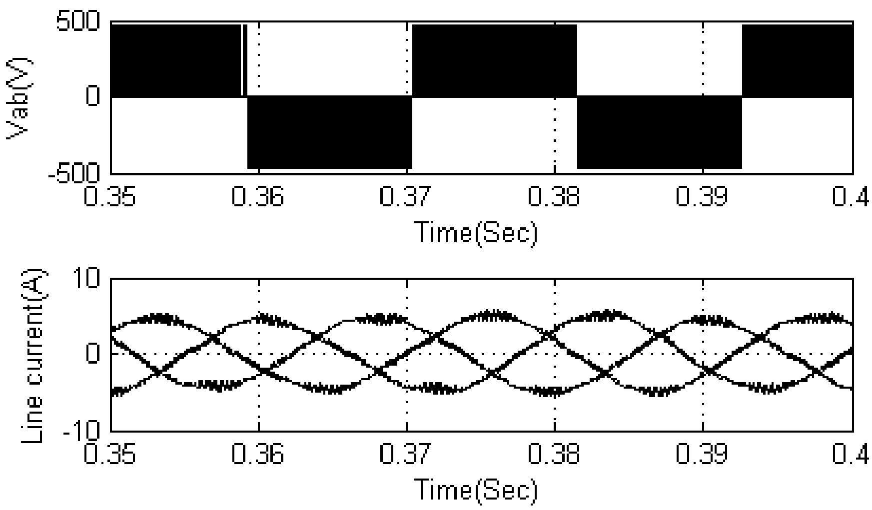
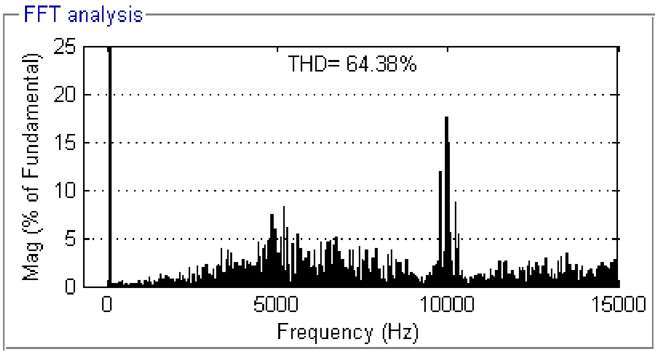


Figure 11: Simulation Results of RRRCPWM based Inverter Fed Induction Motor Drive (a) Line Voltage and Three Phase Line Current (b) Harmonic Spectrum of Line Voltage (c) Harmonic Spectrum of Line Current

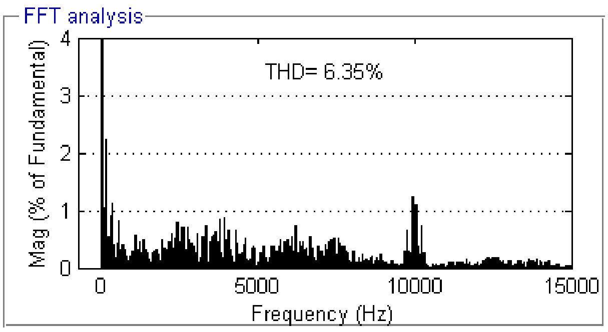
(a)



(b)



(c)



Along with line voltage and line currents, their harmonic spectrums are also shown in Figure 8 to Figure 11. In general, with random PWM techniques total harmonic distortion may increase or decrease when compared with conventional PWM techniques [7-13]. This is because THD depends on pulse position and pulse width. It is observed from the harmonics spectrums shown in Figure 8 to Figure 11 that with CPWM technique magnitude of harmonics at multiples of switching frequencies (5 kHz, 10 kHz, 15 kHz, ...) is high. With the introduction of random ness in modulating signals (RRPWM technique) it is observed that there is only very small reduction in magnitude of harmonics (5 kHz, 10 kHz, 15 kHz, ...). With the introduction in of random ness in selecting carrier signals (RCPWM and RRRCPWM) it is observed from Figure 10 and Figure 11, that there is reduction in harmonic magnitude at odd multiples of switching frequencies (i.e at 5 kHz, 15 kHz, ...) but still considerable amount of harmonic magnitudes can be observed at even multiples of switching frequencies (i.e. 10 kHz, 20 kHz, ...).

High magnitude of harmonics at multiples of switching frequencies causes the acoustic noise, vibration and electromagnetic interference to the nearby electronic systems. The intensity of these effects will be high with the lower order multiples of switching frequencies. It is observed that the magnitude of lower order harmonics of switching frequencies are reduced with RCPWM and RRRCPWM techniques. Hence the acoustic noise, vibration and electronic magnetic interference are reduced with RCPWM and RRRC PWM.

5. Conclusion

In this paper, three different types of random PWM techniques were presented for two-level voltage source inverter fed induction motor drive. This PWM techniques were presented based on simple scalar approach where there is no need to calculate sector number and reference voltage magnitude.

Among the three random PWM techniques (RRPWM, RCPWM and RRRCPWM) it is observed that RCPWM and RRRCPWM techniques have shown superior performance in reducing magnitude of harmonics at lower order harmonics of switching frequencies. Hence the acoustic noise, vibration and electronic magnetic interference are reduced with RCPWM and RRRC PWM.

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