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Performance of Random PWM Techniques for Induction Motor Drive

S. Nithya Lavanya, T. Bramhananda Reddy, M. Vijay kumar

Abstract – Conventional PWM techniques generate high magnitude of harmonics at and around harmonic of switching frequencies. This high magnitude of harmonics causes acoustic noise, vibration and electromagnetic interference to the nearby systems. In this paper different types of variable and constant switching frequency random PWM techniques were discussed to reduce the magnitude of harmonics at multiples of switching frequencies. In variable switching frequency random PWM techniques, frequencies are varied in a limited range (±500 Hz) hence filter design also becomes easy. The performance evaluation of these random PWM techniques is carried out in MATLAB/ Simulink without filter circuit between inverter and induction motor.

Index Terms— Constant switching frequency, Pulse Width Modulation (PWM), Random PWM, Variable Switching frequency

1. INTRODUCTION

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 Fig. 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.

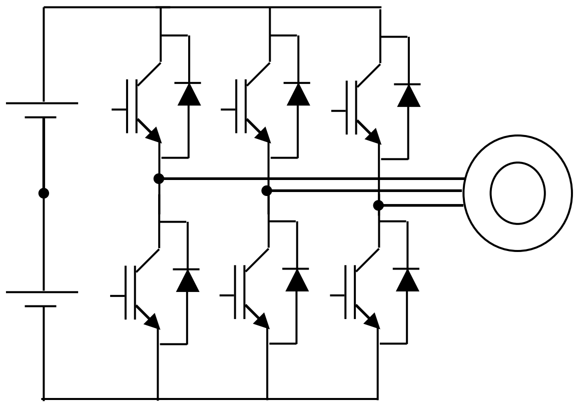

Fig. 1 Circuit diagram of two-level voltage source inverter fed induction motor drive.

In order to reduce acoustic noise, vibration and electromagnetic interference different PWM techniques are gaining importance. In these PWM techniques 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 Fig. 2. In Fig. 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 Fig. 2(b). Hence such PWM techniques are called as constant switching frequency random PWM techniques. In Fig. 2(c) pulse frequency is varied over a wide range of frequencies. Hence such PWM techniques are called as variable switching frequency random PWM techniques.

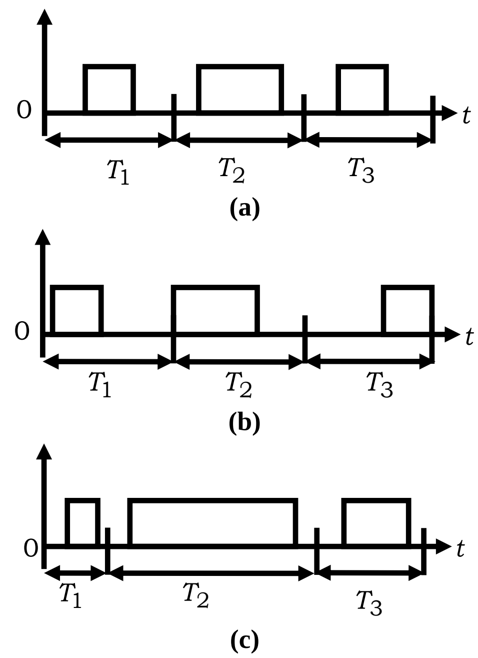

Fig. 2 Pulse pattern of (a) conventional PWM technique (b) pulse position modulation technique (c) pulse frequency modulation technique

Among constant switching frequency [7-8, 13] and variable switching frequency PWM techniques [15-16, 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 different ways. One such method based on carrier comparison approach is discussed in [11-13].

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Alone with the existing method two new different methods were discussed in this paper. In these methods higher commutations are introduced in order to get best performance.

With constant switching frequency random PWM techniques magnitudes of reduction in harmonics at multiples of switching frequencies are small. With variable switching frequency PWM techniques [14-17] harmonic magnitudes can be reduced but filter design becomes complex. In literature [16] it is proved that 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 also discussed. In these PWM techniques switching frequency is varied in a band of ±500 Hz of base frequency. The realization of both constant switching frequency and variable switching frequency PWM techniques are discussed and the results are presented and evaluated using MATLAB/Simulink.

2. CONVENTIONAL CARRIER BASED PWM TECHNIQUE

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).

$$\begin{aligned} Va\ \text{ref} &= Vm * \cos(\omega t) \\ Vb\ \text{ref} &= Vm * \cos(wt - 120) \\ Vc\ \text{ref} &= Vm * \cos(wt - 240) \end{aligned} \tag{1}$$

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 (Vb, mod and Vc,mod) is compared with a common carrier signal.

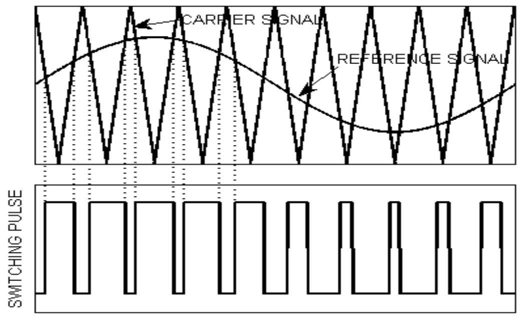

Fig. 3 Realization of carrier comparison scheme

The carrier comparison scheme discussed in Fig. 3 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 (Vi mod) is obtained by adding a zero sequence signal to the old reference signal as in (2). The expression for zero sequence signal is considered as in (3). Here Vdc is the normalized DC bus voltage, ko is the constant value between 0 and 1, Vmax and Vmin 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.

$$\begin{aligned} V^*_{i\ \text{ref}} &= V_{i\ \text{ref}} + V_{zs} \\ where \quad & i = a,b,c \end{aligned} \tag{2}$$

$$V_{zs} = \frac{V_{dc}}{2}(2k_o - 1) - k_o V_{\max} + (k_o - 1)V_{\min} \tag{3}$$

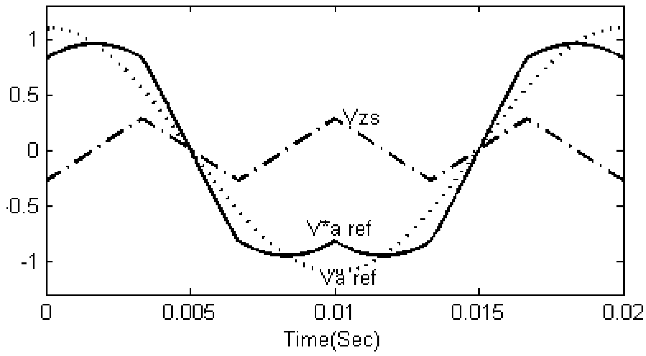

Fig. 4 Old reference signal, zero sequence signal and Continuous new reference signal

The continuous new reference signal as shown in Fig. 4 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

3. CONSTANT SWITCHING FREQUENCY RANDOM PWM TECHNIQUE

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.

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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 ko as 0.5 (0.5 to generate continuous new reference signal) ko is chosen randomly between 0 and 1. The resulting random modulating signal is shown in Fig. 5. It is observed from the modulating signals shown in Fig. 4 and Fig.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.

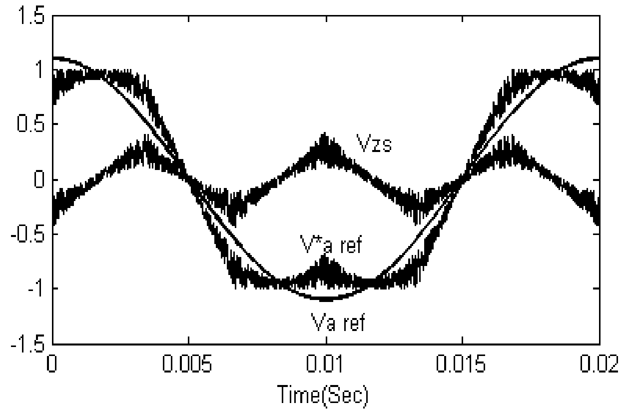

Fig. 5 Old reference signal, zero sequence signal Random Modulating signal

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 Fig. 6. From Fig. 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 Fig. 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 Fig. 7.

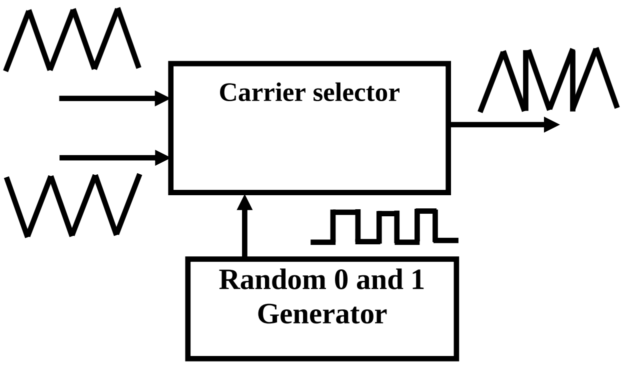

Fig. 6 Illustration of random carrier selection scheme

From Fig.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.

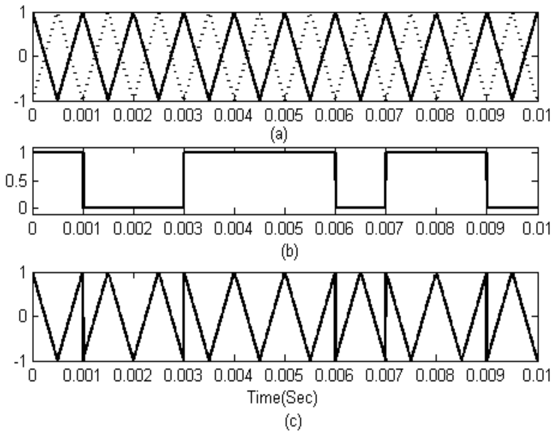

Fig. 7 Simulation results (a) input positive and negative carrier signals (b) Random generator output (c) out of carrier selector

4. VARIABLE SWITCHING FREQUENCY RANDOM PWM TECHNIQUE

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. 8. In the Fig. 8 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.

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In this VSF-RPWM1 the output, variable switching frequency carrier signal is compared with continuous modulating signal to generate control signals.

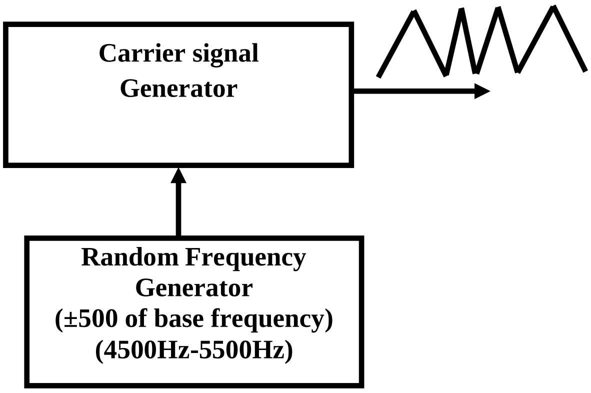


Fig. 8 Block diagram illustrating variable switching frequency carrier signal generation scheme

B. Random carrier selection and random variable switching frequency PWM (RCVSF-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. 9. In the Fig.9 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.

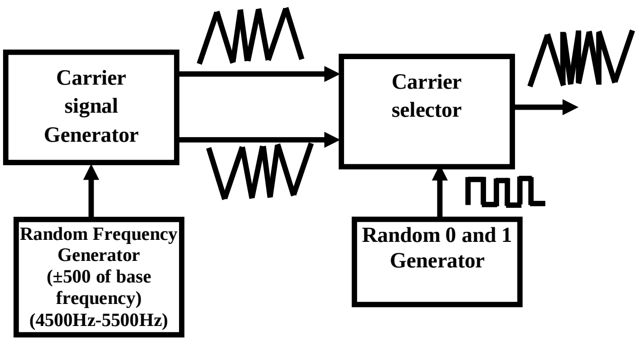
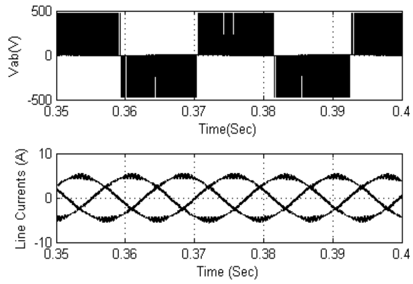


Fig. 9 Block diagram illustrating random carrier selection and random variable switching frequency PWM technique

5. RESULTS AND DISCUSSION

To validate the performance of proposed constant and variable switching frequency 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 for constant switching frequency random PWM techniques. 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 CPWM, RRPWM, RCPWM, RRRCPWM, VSF-RPWM and RCVSF-PWM are shown in Fig. 10 (a) to Fig. 15(a).



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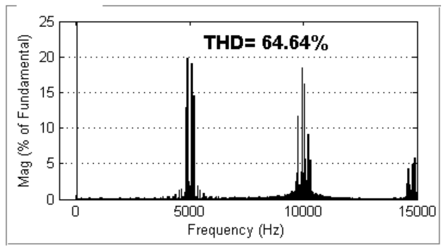

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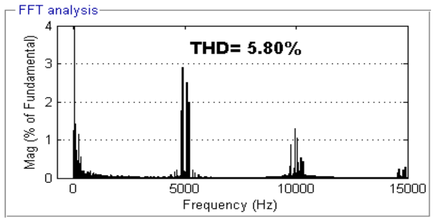
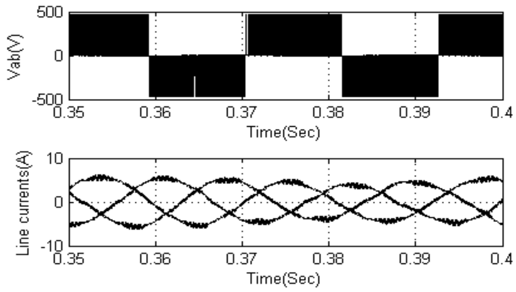


(c)

Fig. 10 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)

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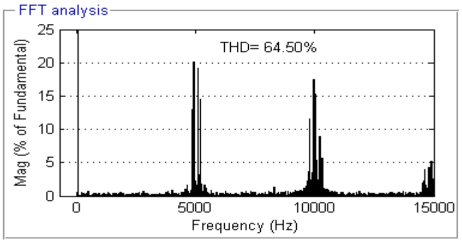

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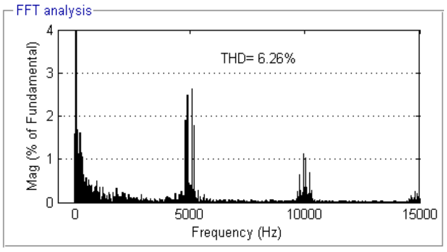
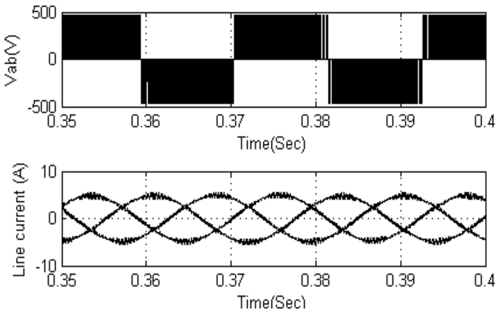
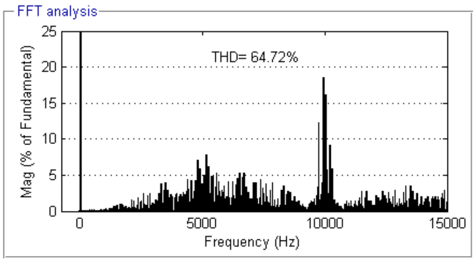


(c)

Fig. 11 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)



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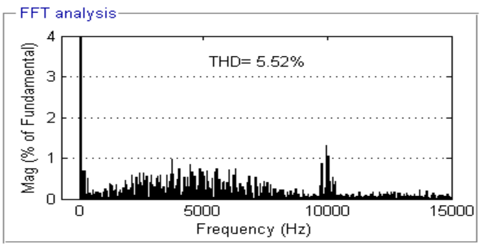
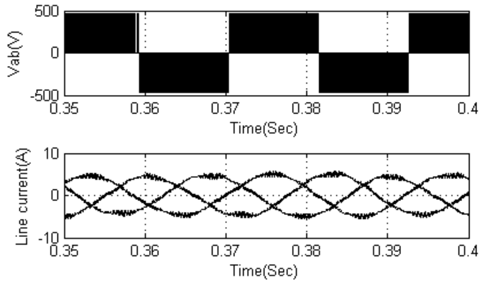
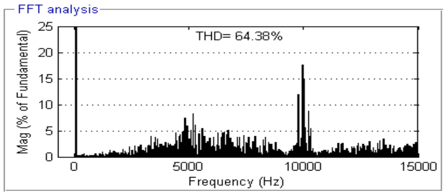


(c)

Fig. 12 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)



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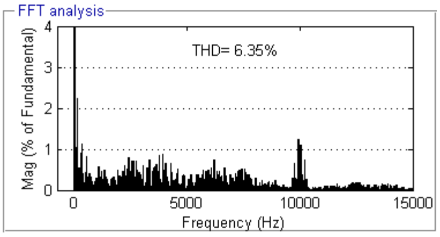

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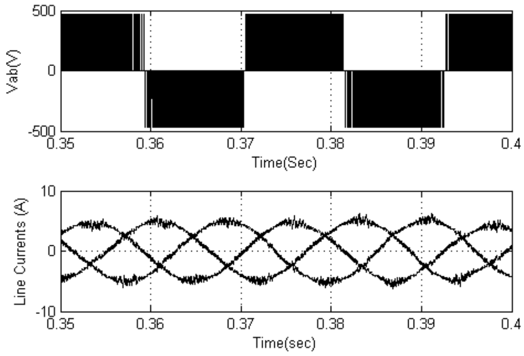
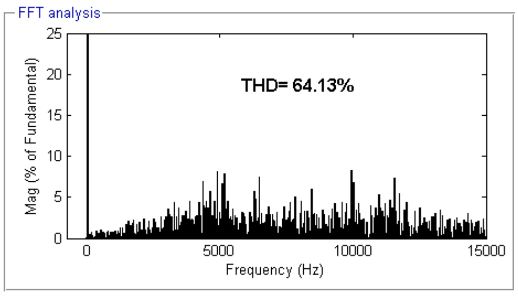
Fig. 13 Simulation results of RRRCPWM based inverter fed induction motor drive
(a) line voltage and three phase line current
(b) Harmonic spectrum of line voltage
(c) Harmonic spectrum of line current



(a)



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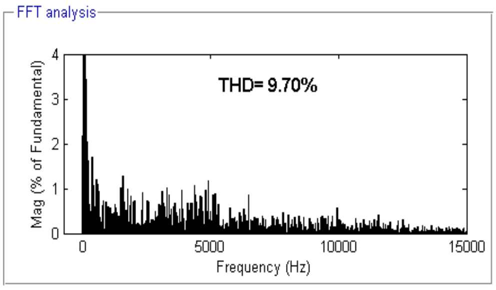
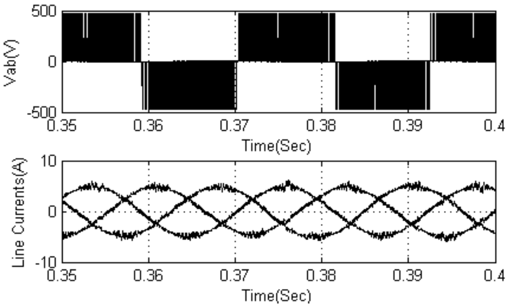
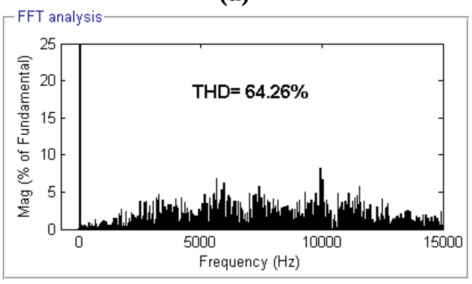


(c)

Fig. 14 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



(a)



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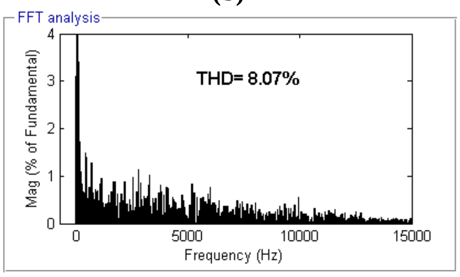

(c)

Fig. 15 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.

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. Along with line voltage and line currents, their harmonic spectrums are also shown in Fig. 10 (b, c) to Fig. 11 (b, c).

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 Fig. 10 to Fig. 15 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 Fig. 12 and Fig.13, 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…….). 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.

6. CONCLUSION

In this paper five different types of constant switching frequency and variable switching frequency 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 constant switching frequency 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.

With constant switching frequency PWM techniques it is observed that much amount of harmonics are still present at multiples of switching frequencies. With the 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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