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Random PWM Tecniques to Reduce Total Harmonic Distortion for Cascaded Three-Level Inverter Fed Induction Motor Drive

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Abstract:

The drive utilized for industrial and modern applications should use "spread spectrum" innovation known as Random PWM algorithms where acoustic noise emanating through the duck work is a very critically concerned. This paper illustrates three types of random PWM control algorithms with fixed switching frequency namely 1) Random modulating PWM 2) Random carrier PWM and 3) Random modulating-carrier PWM. The spectrum plots of the motor stator current demonstrate the strength and robustness of the proposed PWM algorithms. To affirm the proposed algorithms, experimental tests have been conducted using dSPACE rt1104 control board on a v/f control three phase induction motor drive fed by DC link cascaded multilevel inverter.

Keywords: *Multilevel inverter, Acoustic noise, CSVPWM, Total Harmonic Distortion, Random PWM algorithm*

1. Introduction

The voltage source inverter fed AC drive produces noise during its operation [1]. This is an unfavorable phenomenon. Noise is harmful to human health and is cumbersome. A noise with more than 80dB is considered as dangerous noise. Noise can be diminishments of up to 20dB, when the magnitude of the stator flux in the motor drive was reduced [2]. However, it can likewise be enhanced noise elimination either by creating an ideal PWM to straightforwardly diminish the harmonic distortion, or by increasing the switching frequency closer to the ultrasonic range where the human ear can't hear, however this is restricted to low power converters (<10kW) due to switching frequency device.

It is accepted that the noise, creating forces is subject to the square of the magnetic induction in the gap. The magnitude of the harmonic voltage is influenced by the noise level. Pulse width modulation algorithm influences the characteristic of the harmonic spectrum of current and voltage. Acoustic Noise can be decreased by randomizing change of the voltage spectrum in the range of higher harmonics.

This can be achieved by randomizing the pulse pattern and such control strategies are known as random PWM algorithms [3-5]. This paper presents three different types of random pulse width modulation algorithms for cascaded multilevel inverter fed induction motor drive.

1) Random modulating PWM algorithm
2) Random carrier PWM algorithm
3) Random modulating-carrier PWM

2. Proposed Random PWM algorithm

The voltage source inverter fed induction motor drives are utilized in most industries and modern applications and they operate at a switching frequency at 1 kHz to 20 kHz. Hence it is audible to human, the noise of high strength and long-lasting results in hearing loss. Because of this switching action, acoustic noise or whistling noise, which is inside human capable of being heard, will be radiated. CPWM, DPWM and level shifted based scalar PWM algorithms developed for multilevel inverter fed induction motor drives operate at 1 kHz

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to 20 kHz switching frequencies result in acoustic noise, vibration and electromagnetic interference. Subsequently, to moderate these impacts the energy concentrated at and around the harmonic spectrum of switching frequency should be minimized [5].

There are fundamentally two types of random PWM algorithms, random pulse position modulation and random carrier frequency modulation algorithms. In CSVPWM, it is noticed that the time periods (T1, T2, Tz) are consistent for all pulses [6-7]. In random pulse position algorithm pulse position is randomized, however switching frequency is kept constant.

In random carrier frequency modulation algorithm carrier frequency is varied over a wide band. With randomly varying switching frequency and randomly varying pulse position algorithms, spread spectra can be accomplished. However, by continuously varying the switching frequency, consequence, complex filter design [8-9]. Hence, for easier filter design and reducing complexity in implementation, fixed switching frequency random PWM (RPWM) techniques are gaining importance. This paper focuses on constant switching frequency random PWM algorithms. In the proposed algorithms with fixed switching frequency algorithms are achieved either, by randomizing the modulating reference signal or by randomizing carrier signal or both.

2.1 Random modulator PWM Algorithms (RMPWM)

In Random modulator PWM Algorithms modulating reference signal is randomized. To generate modulating signals for three-phase cascaded multilevel inverter fed AC drive, three phase reference sinusoidal signals which are phase shifted by 120^{O} are considered as given in (1).

The three phase modulating signals are expressed as

$$V_i = V_p * Sin(w_e t - 2(j-1)\pi/3) \qquad (1)$$

Where i=a,b,c and j=1,2,3 (i = j)

The proposed algorithm uses the concept of injected zero sequence signal, by using the proposed concept modulating signal can be obtained by adding the zero sequence component to the three phase reference sinusoidal signals.

A generalized expression that generates the zero sequence components V_0 as a function of V_M, V_m and Z_0 is given by [10]

$$V_{zs} = -[(1-2*Z_0) + Z_0 * V_M + (1-Z_o)*V_m] \qquad (2)$$

Where $$Z_0 = \frac{T_7}{T_0 + T_7} \qquad (3)$$

By using the zero sequence component various PWM Modulators can be generated, can be expressed in terms of V_0 and reference signal as

$$V_i^* = V_i + V_{zs} \qquad (4)$$

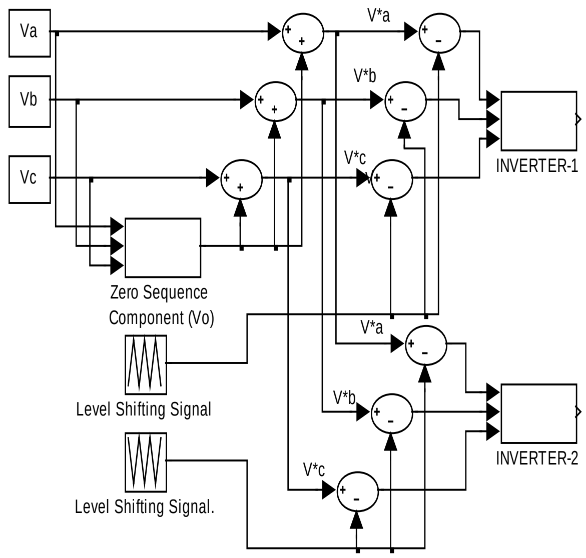

Figure 1. Block diagram of carrier comparison based PWM employing zero sequence injection principle

$T_0+T_7 = T_z$ gives the total freewheeling time (Zero state time) of the inverter, V_M and V_m are the maximum and minimum values of the three phase reference signal (V_i). When Z_0=0.5, and Z_0=random(1) from equation (2) results in the conventional space vector PWM algorithm and Random modulator PWM algorithm respectively. Random is a function which generates a random number between o and 1. The modulating signal shown in figure 2 and figure 3 compare with high frequency level shifting triangular signals to generate the control signals for inverter-I and inverter-II.

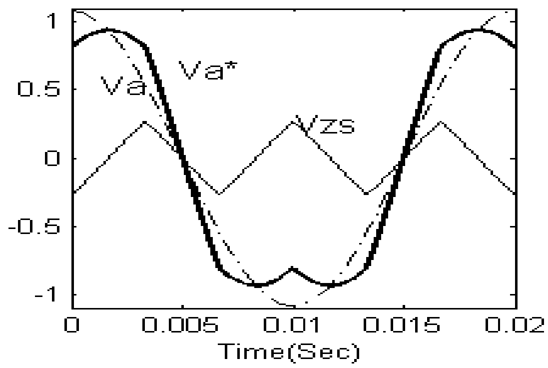

Figure 2. Sin signal (V_a), zero sequence signal (V_{zs}) and Modulating signal (V_a*) : CSVPWM algorithm

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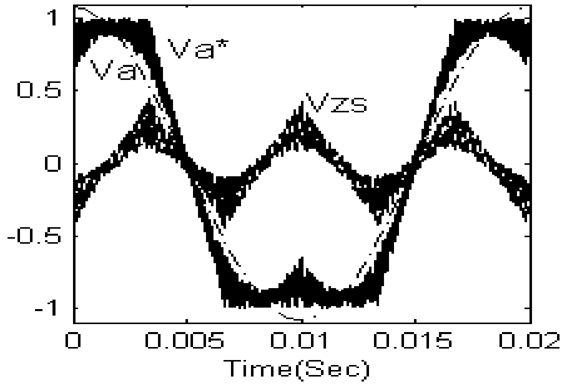

Figure 3. Sin signal (V_a), zero sequence signal (V_{zs}) and Modulating signal (V_a*) : RMPWM algorithm

2.2 Random Carrier PWM Algorithms (RCPWM)

In the proposed random carrier PWM algorithm, modulating reference signals (UN randomized) will be compared with randomly varying level shifted carrier signals. As shown in Figure 4, positive and negative level shifting carrier signals with fixed frequency are considered. The decision among positive and negative carrier signals relies up on random generator.The random generator generates a high or low (0 or 1) with a frequency equivalent to that of switching frequency which is kept fixed.

If the random generator generates 1 then carrier selector choose positive or else it generates 0 then the carrier selector chooses a negative level shifting carrier signals. Thus, relying upon random generator, the yield of carrier selector is a mix of both positive and negative level shifting carrier signals.

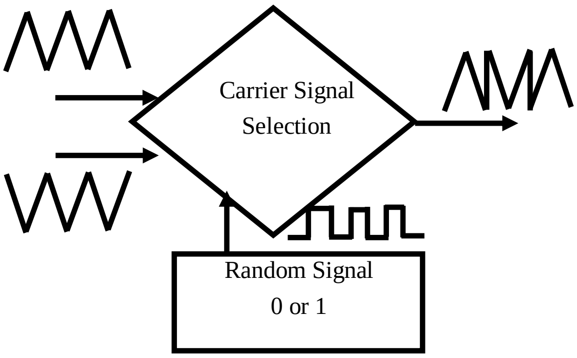

Figure 4. Block diagram describing the basic principle of carrier selection.

2.3 Random Modulator-Carrier PWM Algorithms (RMCPWM)

In the preceding two randomized control algorithms, either modulating signal or level shifting carrier signals are randomized. Presently in this algorithm with the idea of diminishing the magnitudes of harmonics at and around the side bands of switching frequencies, both modulating signal and carrier signals are randomized as discussed in previous sections. Fig. 5 illustrates the random modulating-carrier PWM algorithm for cascaded 3-level inverter configuration.

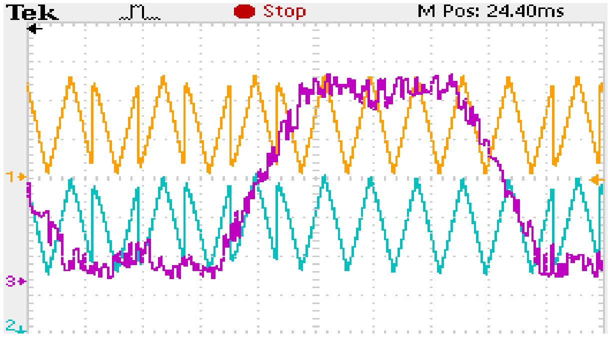

Figure 5. Illustrating Random M-C PWM algorithm

3. Cascaded three level inverter fed induction motor drive description

In this paper, a 3-level inverter has been proposed with a novel configuration. In this circuit configuration, 3-level pole voltage is obtained by cascading two 2-level inverters as shown in figure 6. . From Figure 6, it might be noticed that the phases of inverter-1 are connected with the DC-input terminals of the corresponding phases in inverter-2.

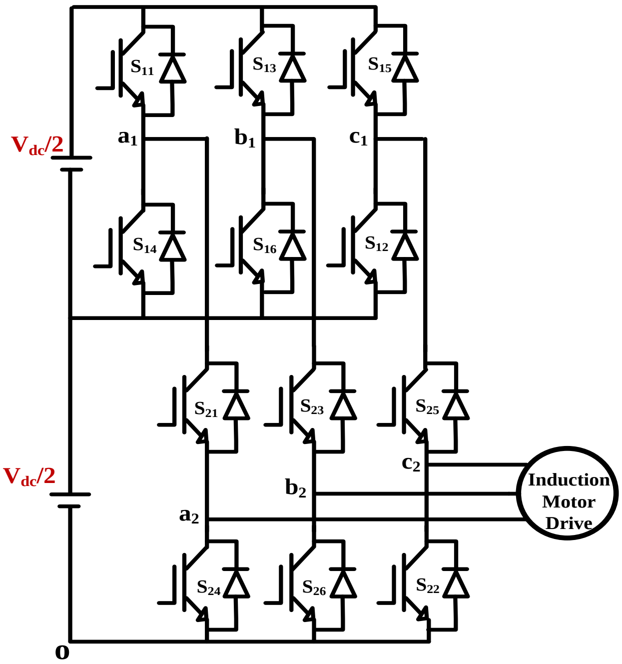

Figure 6. Proposed three-level cascaded inverter configuration

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Table 1 Pole Voltage of Inverter-2

Switches turn on Inverter-I	Switches turn on Inverter-2	Pole voltage of nverter-2
S14 or S16 or S12	S21 or S23 or S25	V_{dc}
S14 or S16 or S12	S21 or S23 or S25	$V_{dc}/2$
S11 or S13 or S15	S22 or S24 or S26	0
S11 or S13 or S15	S22 or S24 or S26	0

An isolated DC-power supply voltage of Vdc/2 is fed to each inverter. The notations V_{a1o}, V_{b1o}, Vc_{1o} individually denote the output voltages of inverter-1 with respect to the point 'O'. Similarly, the notations V_{a2o}, V_{b2o}, V_{c2o} individually denote the pole voltages of inverter-2 with respect to the point 'O'.

In inverter-2 of any phase, the pole voltage of V_{dc} is obtained when top switching device of that phase in inverter-2 is turned on or the top switching device of the corresponding phase in inverter-1 is turned on. Similarly the pole voltage of $V_{dc}/2$ of inverter-2 of any phase is obtained when the top switching device of that phase in inverter-2 is turned on or the bottom switching device of the corresponding phase in inverter-1 is turned on. Furthermore, the pole voltage of zero in inverter-2 of given phase is obtained, if the bottom switching device of the corresponding phase in inverter-2 is turned on.

Therefore, the pole voltage of 0, $V_{dc}/2$ and V_{dc} which is the feature of a three level inverter is obtained.

The main advantage of the proposed cascaded inverter is that if any of the top switching device of inverter-1 fails, it can be operated as a conventional 2-level inverter. This is accomplished by turning on the bottom switching devices of Inverter-1, i.e. the devices S14, S16 and S12 (Figure 6) and only the devices of Inverter-2 (S21 through S26) are utilized. Another advantage is to obtain three level output, it requires only two DC power supplies of $V_{dc}/2$ each while the H-bridge topology requires three isolated DC power supplies (of $V_{dc}/2$ each).

4. Experimental Results

To validate the performance of proposed Scalar random PWM algorithms, experimental tests have been conducted on v/f controlled AC drive. Fig. 7 shows the hardware measurements of positive and negative level shifting carrier signals at constant frequency of 500 Hz. Random generator generates either positive or negative logic signal based on which level shifting carrier signal is selected as shown form Fig.8. to figure 9. For the analysis and comparison of results, the harmonic spectra of effective phase voltage and line current for cascaded 3 level inverter are shown. The zoomed portions of harmonics at and around switching frequency are shown from figure 27 to figure42.

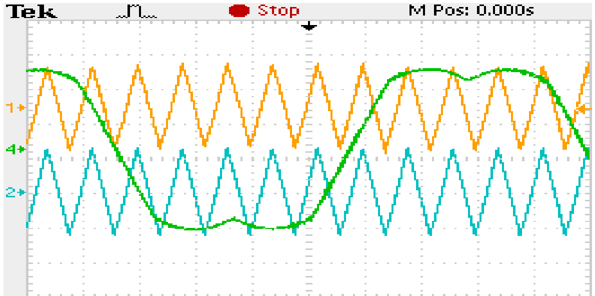

Figure 7. Modulating reference and level shifting carrier signals: CSVPWM

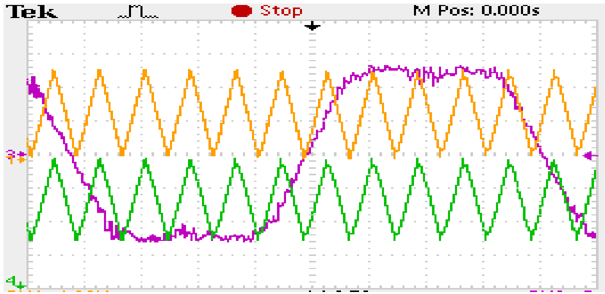

Figure 8. Modulating reference and level shifting carrier signals: RMPWM

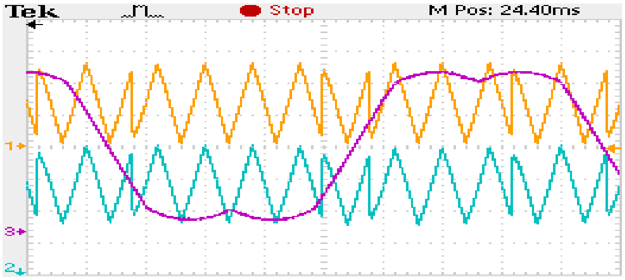

Figure 9. Modulating reference and level shifting carrier signals: RCPWM

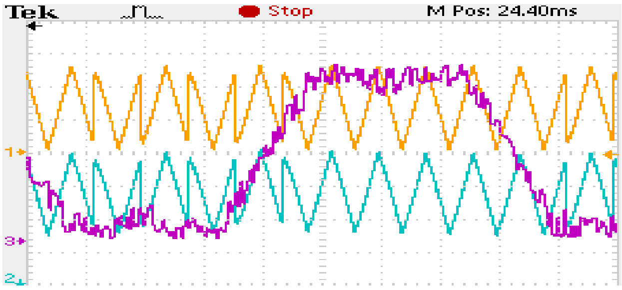

Figure 10. Modulating reference and level shifting carrier signals: RMCPWM

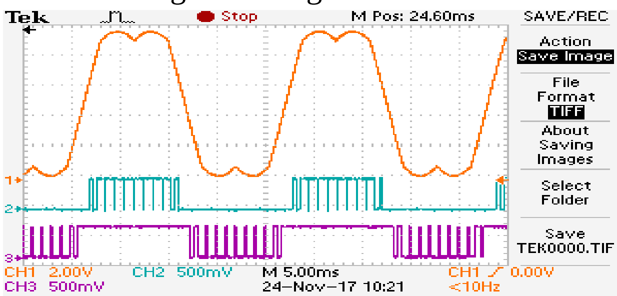

Figure 11. SVPWM: Modulating Signal, Pulses for Inverter-I & II

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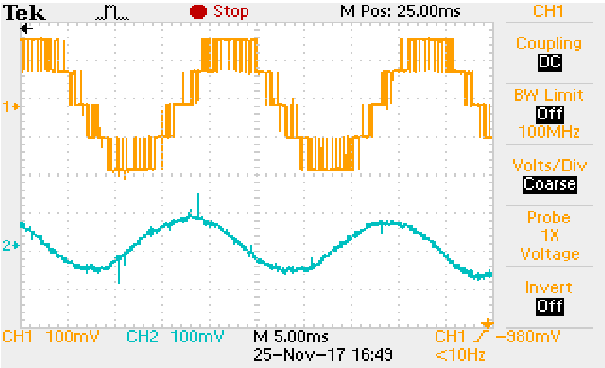

Figure 12. SVPWM: Line Voltage, Stator Current

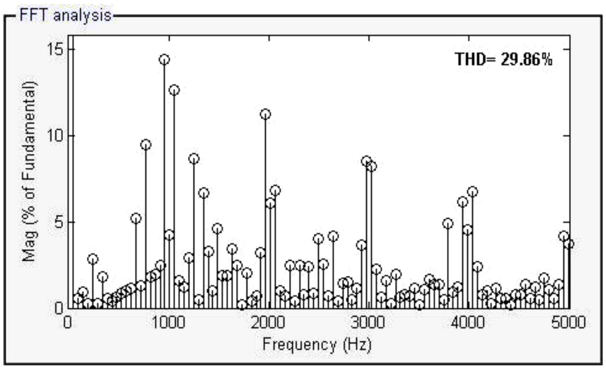

Figure 13. SVPWM:: Harmonic distortion of line Voltage

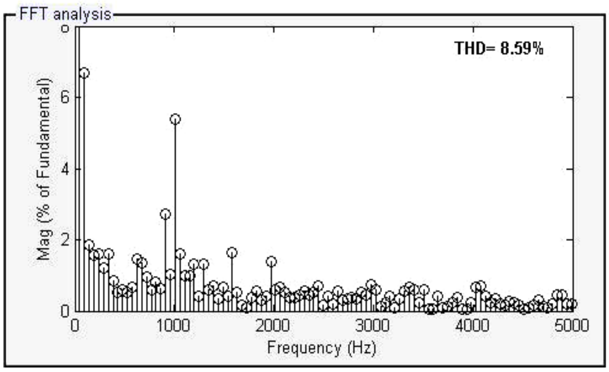

Figure 14. SVPWM: Harmonic distortion of stator current

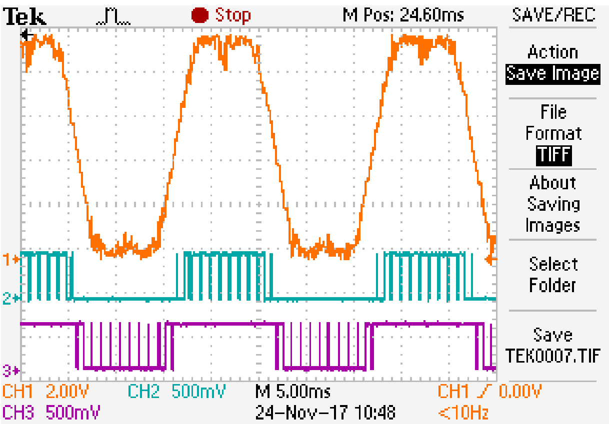

Figure 15. RMPWM: Modulating Signal, Pulses for Inverter-I & II

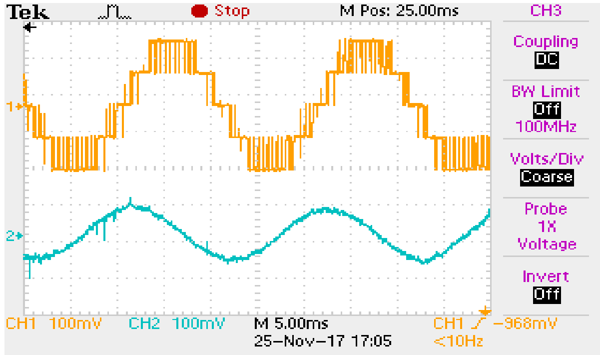

Figure 16. RMPWM: Line Voltage, Stator Current

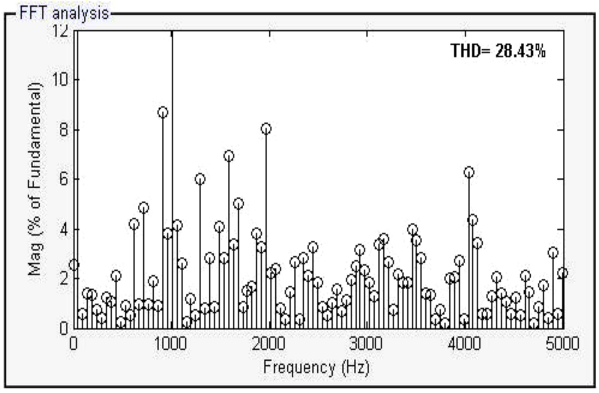

Figure 17. RMPWM: Harmonic distortion of line Voltage

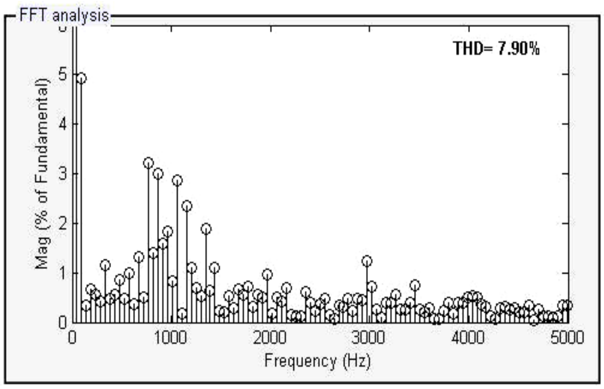

Figure 18. RMPWM: Harmonic distortion of stator current

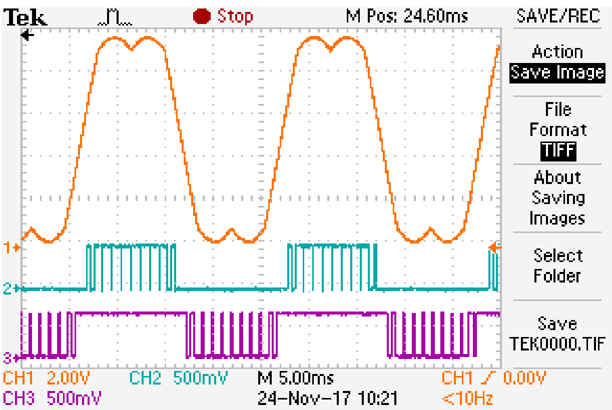

Figure 19. RCPWM: Modulating Signal, Pulses for Inverter-I & II

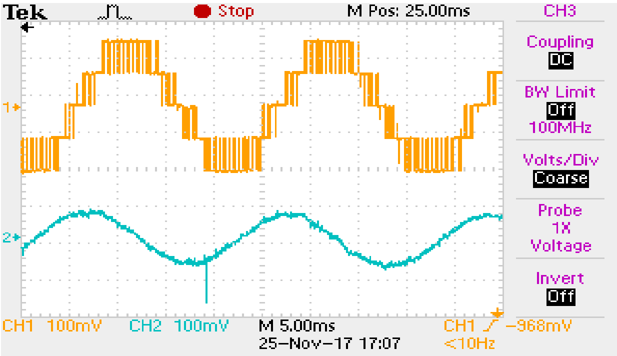

Figure 20. RCPWM: Line Voltage and Stator Current

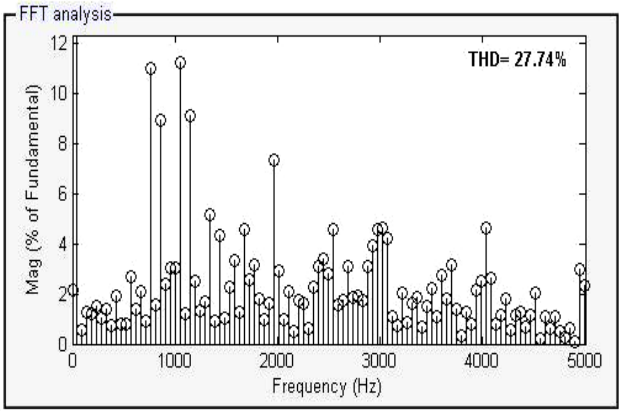

Figure 21. RCPWM: Harmonic distortion of line Voltage

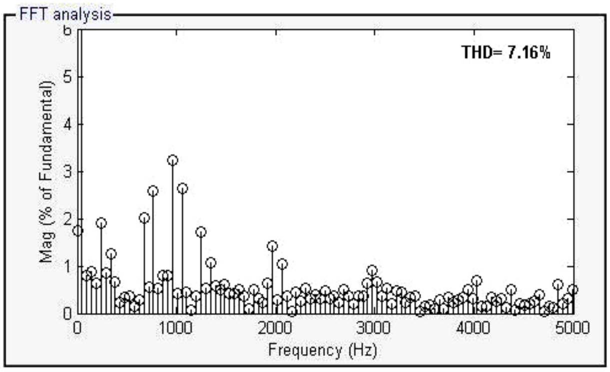

Figure 22. RCPWM: Harmonic distortion of stator current

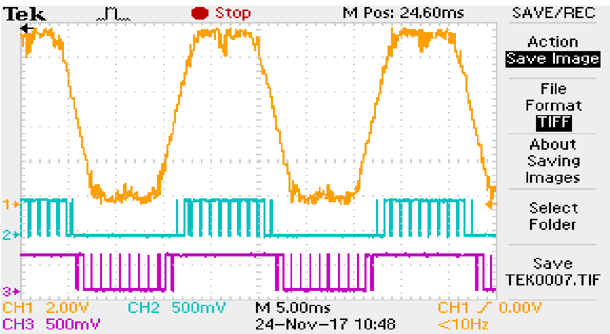

Figure 23. RMCPWM: Modulating Signal, Pulses for Inverter-I & II

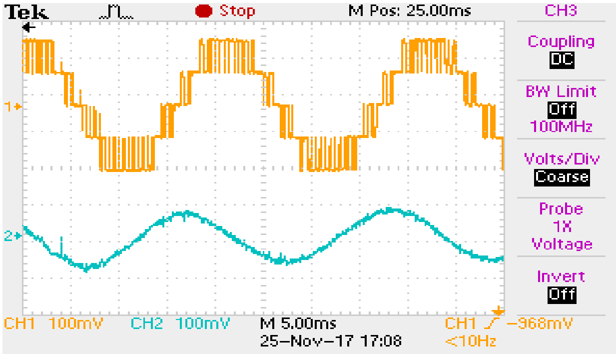

Figure 24. RCMPWM: Line Voltage and Stator Current

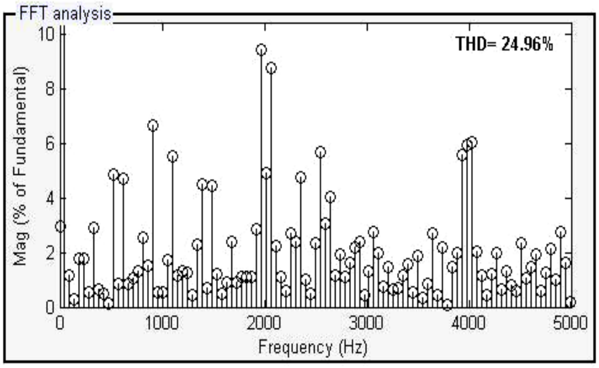

Figure 25. RCPWM: Harmonic distortion of line Voltage

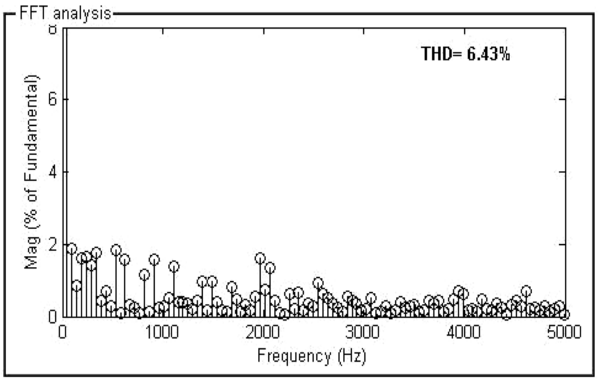

Figure 26. RCPWM: Harmonic distortion of stator current

Table 2: Comparison of Line Current THD & harmonic spectrum

S.No.	Control Algorithm	THD	
		Voltage	Current
1	CSVPWM	29.46%	8.59%
2	RMPWM	28.43%	7.90%
3	RCPWM	27.64%	7.16%
4	RMCPWM	24.96%	6.43%

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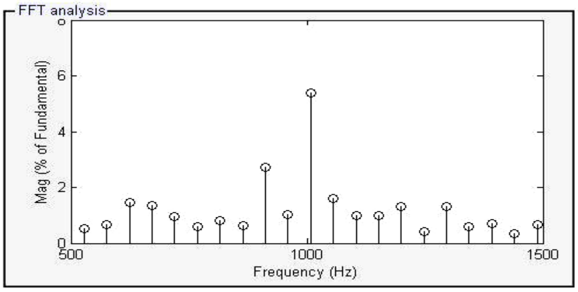

Figure 27. SVPWM: Zoomed Portions at and around 1kHz

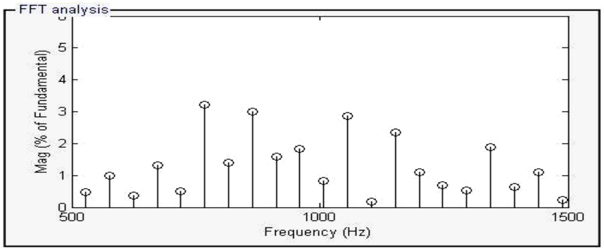

Figure 28. RMPWM: Zoomed Portions at and around 1kHz

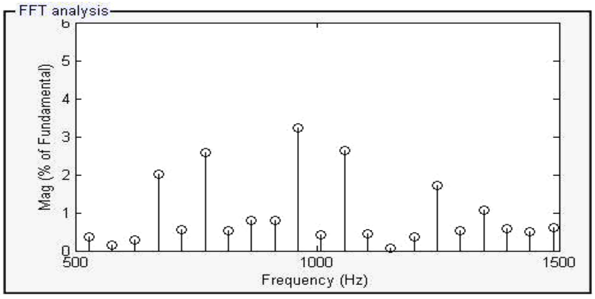

Figure 29. RCPWM: Zoomed Portions at and around 1kHz

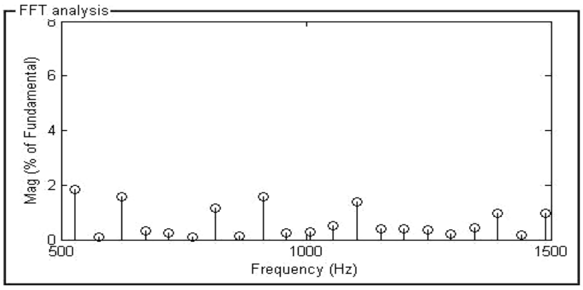

Figure 30.RMCPWM: Zoomed Portions at and around 1kHz

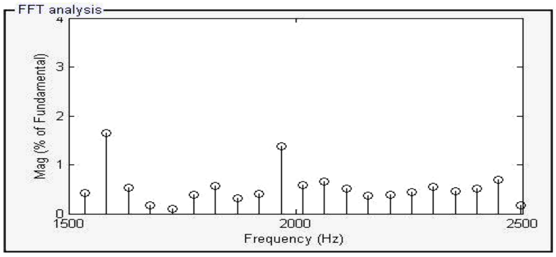

Figure 31. SVPWM: Zoomed Portions at and around 2kHz

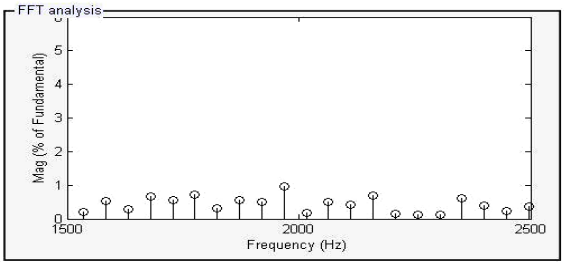

Figure 32. RMPWM: Zoomed Portions at and around 2kHz

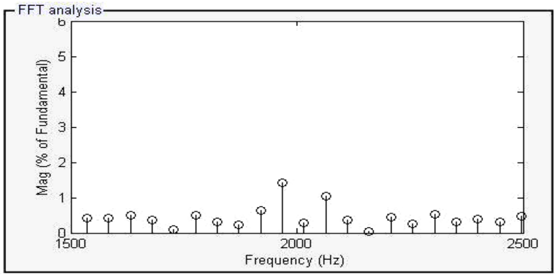

Figure 33. RCPWM: Zoomed Portions at and around 2kHz

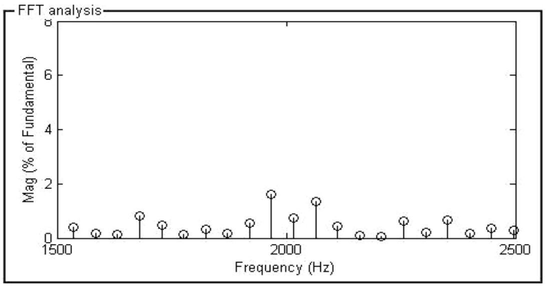

Figure 34.RMCPWM: Zoomed Portions at and around 2kHz

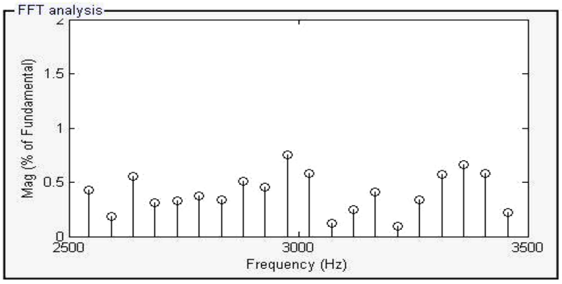

Figure 35. SVPWM: Zoomed Portions at and around 3kHz

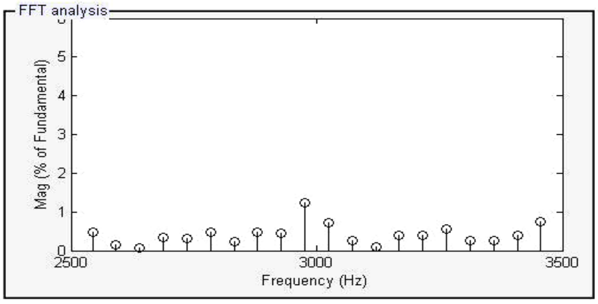

Figure 36. RMPWM: Zoomed Portions at and around 3kHz

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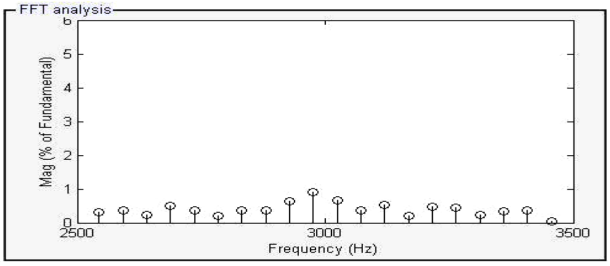


Figure 37. RCPWM: Zoomed Portions at and around 3kHz

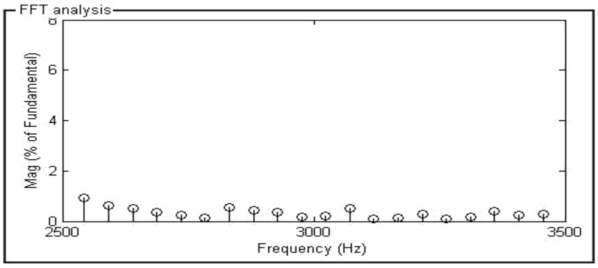


Figure 38.RMCPWM: Zoomed Portions at and around 3kHz

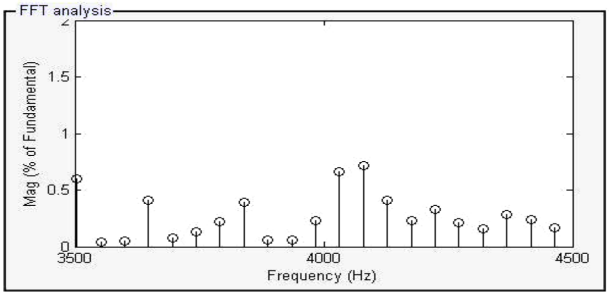


Figure 39. SVPWM: Zoomed Portions at and around 4kHz

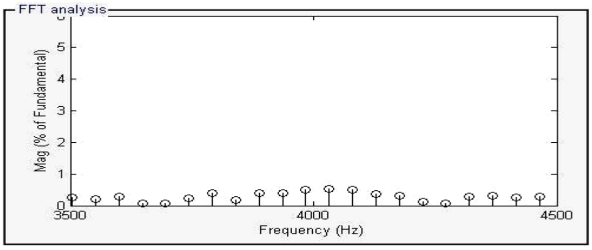


Figure 40. RMPWM: Zoomed Portions at and around 4kHz

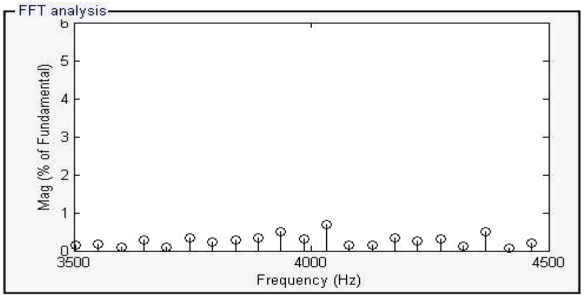


Figure 41. RCPWM: Zoomed Portions at and around 4kHz

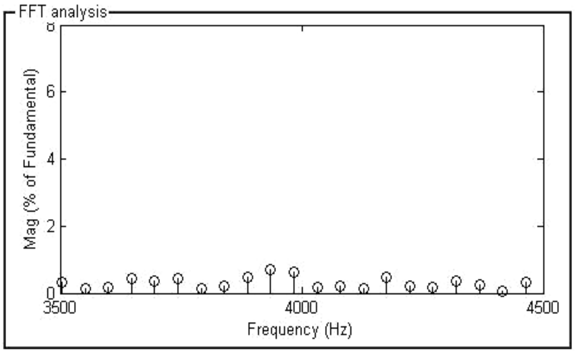


Figure 42.RMCPWM: Zoomed Portions at and around 4kHz

It is to be noted that the switching frequency is maintained constant at 1 kHz for all PWM algorithms, it is observed from the zoomed portion of the harmonic spectrum shown in Figure27 to Figure42 that lot of energy is concentrated at harmonics (multiples) of switching frequency (around 1kHz, 2Khz, 3kHz and 4kHz), but with the proposed Random PWM algorithm the harmonic around the switching frequency are reduced. Voltage levels created in phase voltage plots with all the random PWM techniques (SVPWM, RMPWM, RCPWM and RMCPWM) are same but, because of the randomization pulse position may be changed. Hence, harmonic magnitude may increase or decrease. So, THD values of voltage and current plots with random PWM techniques may deviate (increment or decrement) from that of CPWM technique. Moreover, it is observed that there is a reduction in THD with random PWM.This reduction is because of a reduction in magnitude of the harmonics at and around harmonics of switching consequence in decreasing noise.

5. Conclusions

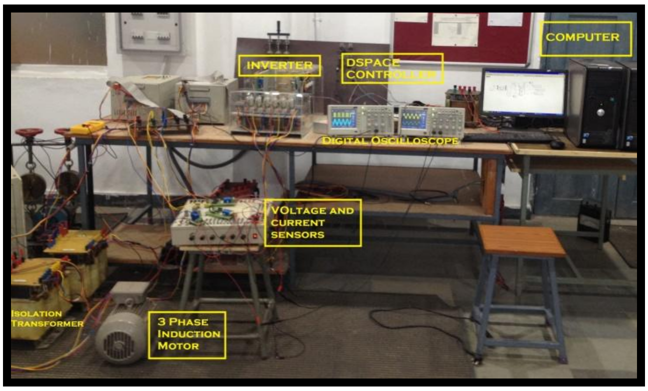
In this paper level shifted carrier signal based three scalar random PWM algorithms, namely RMPWM, RCPWM and RMCPWM for cascaded three level inverter fed v/f controlled induction motor drive is presented. The modulating signal can be achieved by adding a zero sequence signal to the sinusoidal reference signals. From the consequences it is concluded that the Random PWM algorithms employed for AC drive resulted in reduced harmonic distortion and also confirms the superiority when compared to SVPWM algorithm in the form of distributed spectra that resulted in reduced acoustic noise.

Appendix

Induction Motor: 1Hp, 415V, 1.8A and 50Hz
DC-link converter: 3-phase, 9.3 kVA and 415V, 13 A.
Control board: dSPACE 1104 control board.

Switching frequency: 1 kHz
Applied effective input DC-voltage: 510 V
Voltage sensor: LV-20P: 500 V - 6.3 V
Current sensor: LA-55P: 50A - 6.3 V (used with six turns)

Hardware setup of the drive



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