International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 22 (2018) pp. 15696-15700
© Research India Publications. http://www.ripublication.com

A Comparative Exploration on Random PWM schemes to Spread Harmonics for Multilevel Power Converters using Cascaded H-bridge Configuration

Kiran T S
PhD scholar, Department of EEE,
College of Engineering Trivandrum, Kerala, India

Dr. Bisharathubeevi A
Professor, Department of EEE,
College of Engineering Trivandrum, Kerala, India.

Dr. K N Pavithran
Dean, PRS college of Engineering and Technology,
Professor (Rtd.), Department of EEE,
College of Engineering Trivandrum, Kerala, India.

Abstract
The discrete spectrum of classic PWM generates the problems like acoustic noise in motors, input voltage waveform distortion, and electromagnetic interference. Random pulse width modulation (RPWM) approaches can make the harmonic spectrum of inverter output voltage be continuously distributed and thus the acoustic noise and mechanical vibration of an inverter-fed ac motor drive are greatly reduced. The paper emphasizes mainly on the simulation of voltage-controlled inverters using deterministic PWM and different random PWM schemes such as the scheme in which the switching period is randomized (Randomized Carrier Frequency Modulation: RCFM),the scheme in which the pulse position is randomized (Randomized Pulse Position Modulation: RPPM). In order to get maximum spreading of power spectra the combination of the two schemes (RCFM-RPPM) called Dual RPWM is used. Then proposed Dual RPWM is employed to five level inverter using Cascaded H Bridge configuration. Proposed technique reduces acoustic noise and mechanical vibration.

Keywords: Electromagnetic interference, Random PWM techniques, Cascaded H Bridge configuration

Introduction

Power electronic converters are becoming popular in many applications. A power inverter does the opposite of a rectifier. Variable output voltages are normally controlled by Pulse Width Modulation (PWM). The major purpose of the PWM inverter is to generate a variable-voltage variable-frequency (VVVF) three-phase voltage from a DC voltage. But the problem with classic PWM based converters is that it introduces higher frequency components which are discrete in nature. This is because of the periodicity of the output current and voltage waveform. The entire spectrum energy is localized at discrete frequencies which cause problems like acoustic noise, electromagnetic interference, etc [1].

Random Pulse Width Modulation (RPWM) [2] is one solution to address the problems related to discrete frequency spectrum. Its frequency spectrum will be continuous because of non periodicity of the signal. And this spreading of the spectral energy eliminates the problems associated with classical PWM. Many works regarding RPWM have been published, three RPWM schemes are proposed: the scheme in which the switching period is randomized (Randomized Carrier Frequency Modulation: RCFM) [3]-[5], the scheme in which the period is constant and the pulse position is randomized (Randomized Pulse Position Modulation: RPPM)[7]-[8]. However, to get a maximum spreading, the combination of the two schemes has been proposed (RCFM-RPPM) called Dual RPWM [7].

Multi-level inverters have become an effective and practical solution for increasing power and reducing harmonics of AC waveforms. By synthesizing the AC output voltage from several levels of DC voltages, staircase output waveform can be produced. This allows for higher output voltage and simultaneously lowers the stress on the semiconductor device.

Major purpose of this paper is to simulate the deterministic PWM and RPWM schemes for two level inverters with output frequency of 60Hz. Simulations are done by Simulink. Then spectral and harmonic analyses are analyzed using power guide block. A comparative analysis of conventional PWM and proposed Dual RPWM schemes are employed with five level inverter topology using Cascaded H Bridge configuration.

Conventional triangular pwm scheme

Principle of Classic PWM

The classic triangular PWM scheme [6] using a triangular carrier and modulating sine wave is shown in Fig.1.

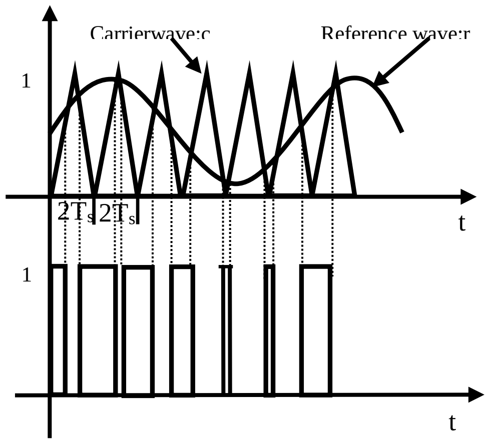


Figure1. Modulating principle of classic triangular PWM

In Sine triangle PWM, a modulating sine wave corresponding to the fundamental frequency (60 Hz) of the output voltage is compared with a triangular carrier of high frequency. Each leg of the Voltage source inverter is controlled by 120^0 phase shifted PWM signals.

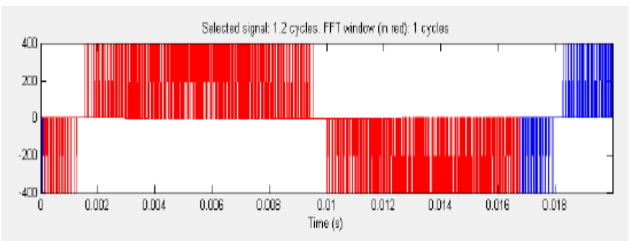
Switching frequency of a classic triangular PWM is expressed as follows:

$$f = \frac{1}{2T_s}$$

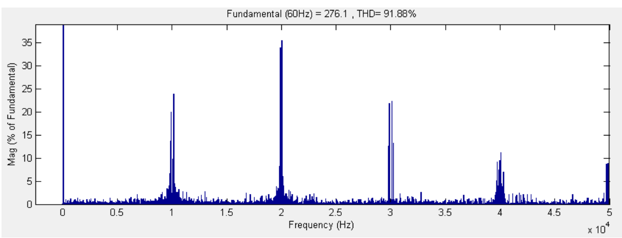
Where f is the switching frequency and T_s is the constant period.

Voltage spectrum analysis

Using the classic PWM technique, the line voltages and the corresponding spectrums of a PWM inverter with two different switching frequencies (10 kHz & 20 kHz) are shown in Fig.2 and Fig.3, respectively.

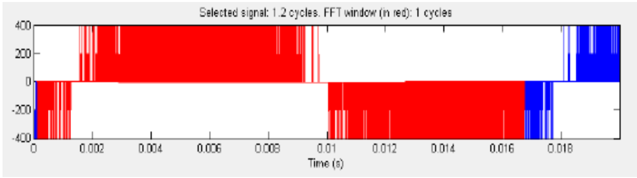


(a)

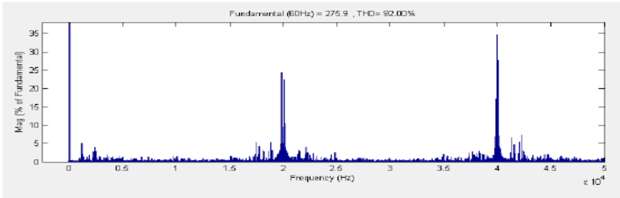


(b)

Figure 2 Output line voltage with switching frequency 10 kHz (a) PWM line output voltage, (b) line voltage spectrum



(a)



(b)

Figure 3: Output line voltage with switching frequency 20 kHz (a) PWM line output voltage, (b) line voltage spectrum

The FFT analysis of line voltage is obtained by using the Power Guide block during the Matlab simulation. Total Harmonic Distortion (THD) is a standard measure used to characterize the distortion in the output. The simulation result shows that their output harmonic spectrums are located at discrete frequencies for fixed switching frequency. Fig.2 shows that voltage THD is 0.9188 when the switching frequency is 10 kHz and the modulation index is 0.8. The THD becomes 0.92 when the switching frequency becomes 20 kHz. This modulation technique results in several voltages harmonic magnitudes shoot up and the worst case occurs at the fundamental switching frequency.

Random Pwm Schemes

Randomized Carrier Frequency Modulation (RCFM)

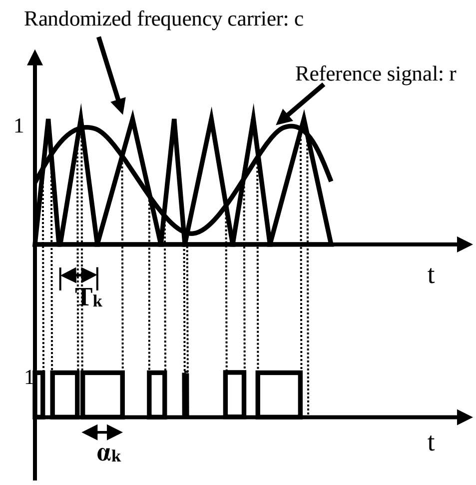


Figure 4. Modulating principle of RCFM

The most common means of RPWM is the Randomization of the switching frequency. It can be performed in natural sampling mode. It uses the classic triangulation method. In triangulation, instead of keeping the width of all switching intervals, *T*, identical, the length of each interval is selected at random still keeping the pulses centre-aligned. The triangular carrier signal, with which the reference voltage signal is compared, can be generated with a randomly varying T within a specified range [8].

The randomized frequency PWM is achieved by varying the switching interval of triangular wave, T_k as shown in the figure. α_k is the duration of the gate pulse in the k^{th} cycle.

Randomized Pulse Position Modulation (RPPM)

RPPM [7] is similar to the classical PWM scheme with constant switching frequency. However, the position of the gate pulse is randomized within each switching period, instead of commencing at the start of each cycle. In this method, the pulses of switching signals are randomly placed in individual switching intervals. In Randomized Pulse Position the triangular carrier signal generated with a randomly varying slope is compared with the reference voltage signal.

Fig. 5 shows the modulating principle of RPPM. The randomized pulse position PWM is achieved by varying the slope of triangular wave shown in the figure. α_k is the duration of the gate pulse in the k^{th} cycle. β_k is the fall time of the gate pulse.

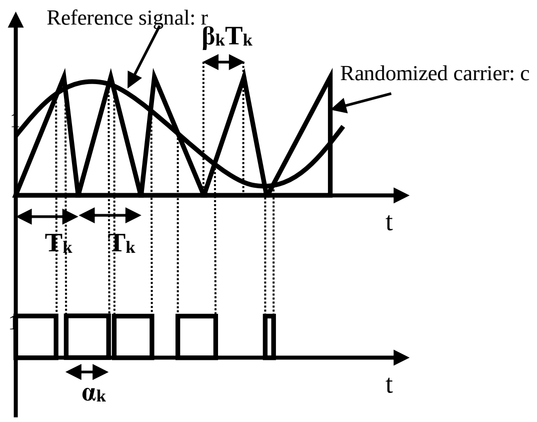


Figure.5. Modulating principle of RPPM

Dual RPWM

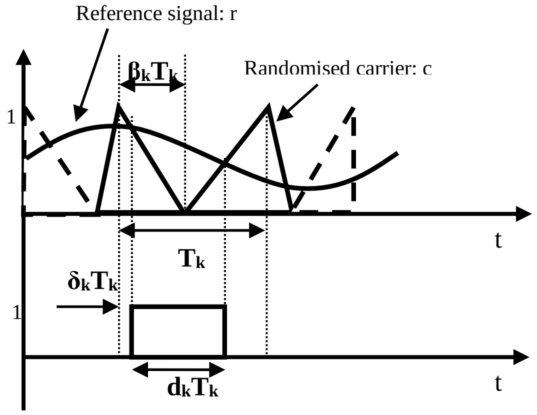


Figure 6. Modulating principle of Dual RPWM

To obtain a maximum spectral spreading, the combination of the two schemes can be used (RCFM-RPPM) that is called Dual RPWM [7].

Fig. 6 shows the modulating principle of Dual RPWM. From the Figure, r is assumed to be constant during a period T_k (generally, r is updated once a period); the duty cycle d_k is then equal to the value of the reference. In practice, r is deterministic; it allows the control of the output voltage and only the parameters (T and β) of the carrier are randomized: Randomized T provides (random carrier frequency: RCF) and randomized β provides (random pulse position: RPP), δ_k (δ is the delay) can be expressed as follows:

$$\delta_k = \beta_k (1 - d_k)$$

For randomized β_k between 0 and 1, δ_k varies randomly between 0 and $(1 - d_k)$.

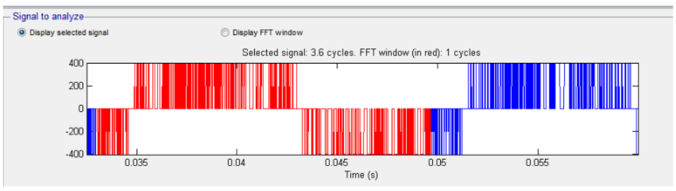
Table 1: Characteristics and results Of Different Switching Schemes

Switching schemes	T_k(period)	α_k(duration)	β_k(fall time)
Standard PWM	Fixed	Fixed	Fixed
RCFM	Randomized	Randomized	Fixed
RPPM	Fixed	Fixed	Randomized
Dual RPWM	Randomized	Randomized	Randomized

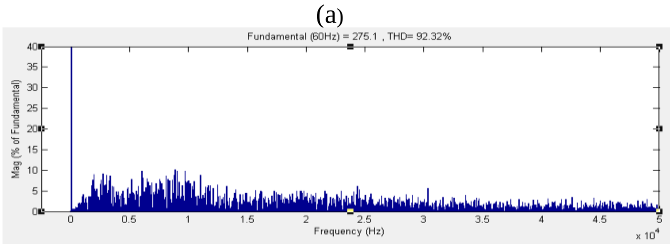
Computer Simulations

RCFM and RPPM

For RCFM, the triangular carrier signal generated with a randomly varying period having an average frequency of 10 kHz and modulation index of 0.8 within a specified range. The simulated results are shown in the Fig.7.



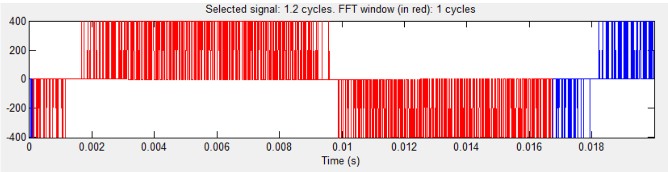
(a)



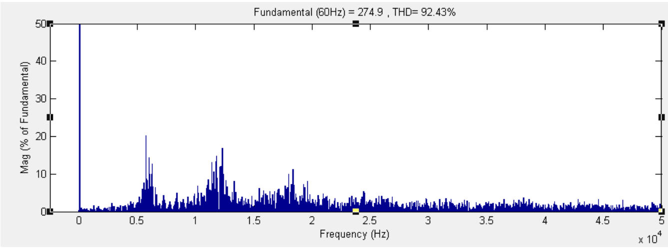
(b)

Figure 7 Output line voltages with random frequency (a) PWM line output voltage, (b) line voltage spectrum

For RPPM, the triangular carrier signal generated with a randomly varying slope having a frequency of 10 kHz and modulation index of 0.8 within a specified range. The simulated results are shown in the Fig.8.



(a)



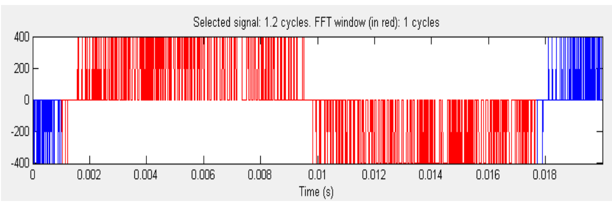
(b)

Figure 8 Output line voltage with switching frequency 10 kHz and varying slope (a) PWM line output voltage, (b) line voltage spectrum

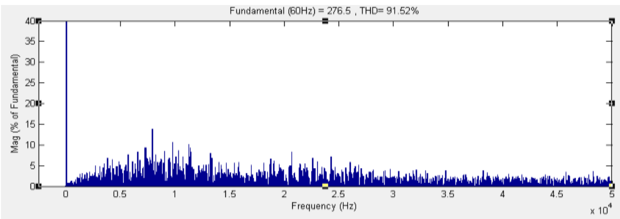
Figure shows that the spectrum become continuous and harmonics reduced. Using RCFM, the THD is 0.9232 and by RPPM, the THD is 0.9243. Both the means of randomization result in shifting part of the harmonic power to a continuous spectrum, but they differ in their effects on the discrete spectrum. But the problem with RPPM is that the spectrum is not that much flat because of fixed switching frequency. Hence RCFM is better compared to RPPM.

Dual RPWM

The triangular carrier can be generated with varying slope and frequency within a specified range. Then it is compared with the modulating sine wave of fundamental frequency 60Hz. The RPWM signal is given as the gate signal for the inverter.



(a)



(b)

Figure 9 Output line voltage with switching frequency 10 kHz and varying slope (a) PWM line output voltage, (b) line voltage spectrum

Dual RPWM results a better spectral quality with higher fundamental component and reduced THD 0.9152 compared to other Random PWM techniques. It has a continuous spectrum of the output voltage, while the discrete (harmonic) part is significantly reduced.

Cascaded H Bridge Configuration

A single phase 5-level cascade H-bridge inverter is shown in fig10. An N level Cascaded H bridge inverter [9] consists of series connected (N-1)/2 number of cells in each phase. Each cell consists of single phase H bridge inverter with separate dc source. The converter consists of two series connected H-bridge cells which are fed by independent voltage sources. The outputs of the H-bridge cells are connected in series such that the synthesized voltage waveform is the sum of all of the individual cell outputs.

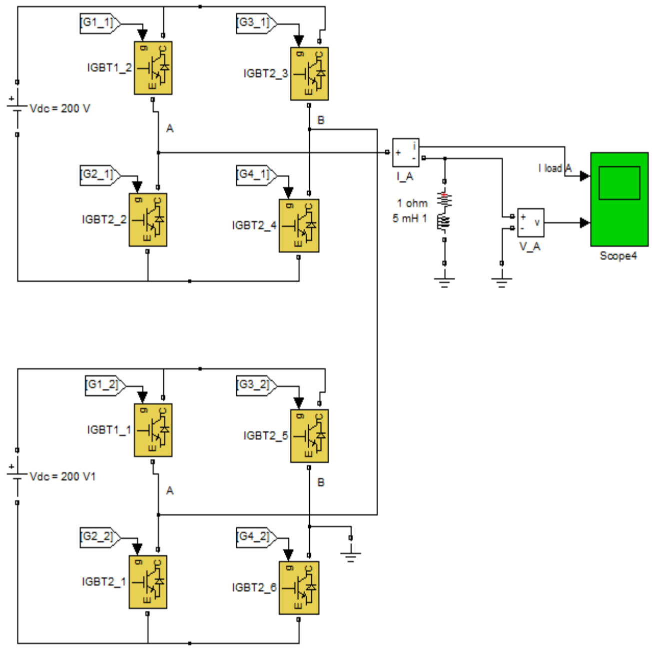
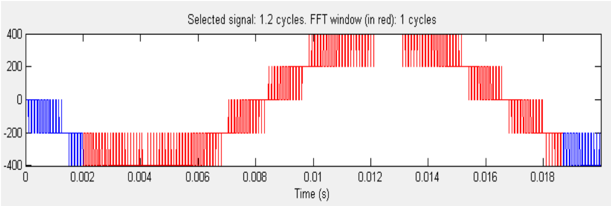


Figure 10. Five level inverter with Cascaded H Bridge configuration

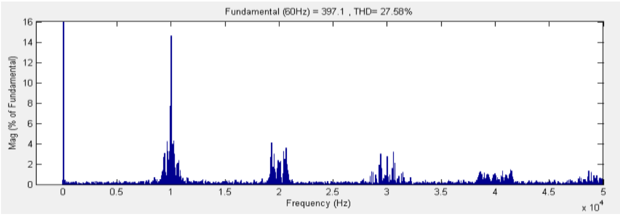
Both the conventional Sine triangle PWM and Dual RPWM are used for the comparison purpose. The Figure shows the 5 level output pole voltage and its corresponding FFT spectrum.

The spectrum is discrete with a fundamental voltage of 397 and has a THD of 0.2758.

The proposed PWM control strategy has a better spectral quality with continuous spectrum and a higher fundamental output voltage without any pulse dropping. It has a THD of 0.2737

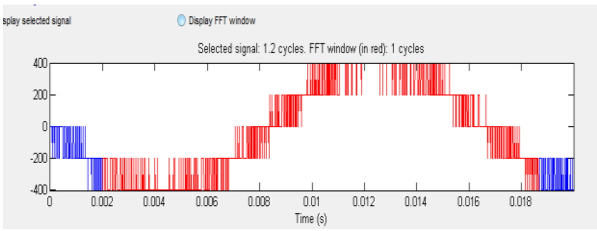


(a)

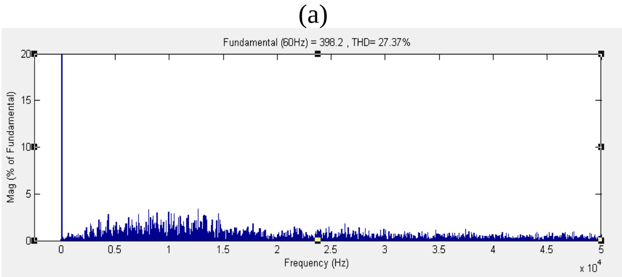


(b)

Figure 11 Output pole voltage with switching frequency 10kHz (a) PWM output pole voltage, (b) voltage spectrum



(a)



(b)

Figure 12 Output pole voltage using DRPWM method (a) PWM output pole voltage, (b) voltage spectrum

Conclusion

To reduce the acoustic noise and mechanical vibration due to the conventional PWM, Random PWM schemes have been developed. The simulation shows that by using RPWM schemes spectrum become continuous. A novel method of Dual RPWM has been proposed for multi level inverters. Simulation shows the effectiveness of the proposed method with reduced acoustic noise.

References

[1] Tse K. K., Henry Shu - hung, Hui S. Y. R. and So H. C., “A comparative investigation on the use of random modulation schemes for DC/DC converters”, IEEE Trans. On Ind. Electron. vol. 47, N0. 2, pp 253-263, April 2000.

[2] A.M. Trzynadlowski, S. Legowski, and R. L. Kirlin, "Random pulse width modulation technique for voltage-controlled power inverters," International Journal of Electronics. vol. 68, no. 6, 1990, pp. 1027-1037.

[3] Lynn Kirlin R., Michael M. Bech and Andrzej M. Trzynadlowski, “Analysis of power and power spectral density in PWM inverters with randomized switching frequency”, IEEE Trans. On Ind Electron. vol. 49, N0. 2, pp 486-499, April 2002.

[4] Liaw C. M., Lin Y. M., Wu C. H. and Hwu K. I., “Analysis, design, and implementation of a random frequency PWM inverter”, IEEE Trans. On power Electron. vol. 15, N0. 5, pp 843-854, Sept. 2000.

[5] K. El KhamlichiDrissi, P.C.K. Luk*, B. Wang and J. Fontaine “A Novel Dual-Randomization PWM Scheme for Power Converters” IEEE Trans. On power Electronics Sept. 2003.

[6] K.L. Shi, Hui Li, “Optimized Random PWM strategy Based on Genetic Algorithms” IEEE Transactions On Industrial Electronics, June 2003

[7] N. Boudjerda, A. Boudouda, M. Melit and B. Nekhoul, K. El KhamlichiDrissi and K. Kerroum “Optimized Dual Randomized PWM Technique for Reducing Conducted EMI in DC-AC Converters” Proc. of the 10th Int. Symposium on Electromagnetic Compatibility (EMC Europe 2011), York, UK, September 26-30, 2011

[8] Andrzej M. Trzynadlowski, FredeBlaabjerg, John K. Pedersen, R. Lynn Kirlin, and Stanislaw Legowski, “Random Pulse Width Modulation Techniques for Converter-Fed Drive Systems-A Review” IEEE Transactions on Industry Applications, Vol. 30, No. 5, September / October 1994

[9] D.Zhong, L.M.Tolbert, J.N.Chiasson, B.Ozpineci, Li Hui, and A.Q.Huang,“Hybrid cascaded Hbridges multilevel motor drive control for electric vehicles”, in Proc.37th IEEE Power Electronics Specialists Conference,PESC’06,June 2006,pp.1- 6