

Chaotic Triangular Carrier Based Non-Deterministic SPWM Strategy for Voltage Source Inverter Drives

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Abstract

Even the prime advantage of Sinusoidal Pulse Width Modulation (SPWM) technique is having an assortment of performances such as high output quality, less Total Harmonic Distortion (THD), low rating filtering requirements and linear control on fundamental component etc., the harmonic components of the output voltage are concerted around switching frequency and its integer multiples. These distinct dominant harmonics result mainly in torque ripples and acoustic noise in drives. These problems are mitigated by spreading the harmonic power in the output voltage through non-deterministic pulse width modulations. A chaos function based Random Pulse Width Modulation (RPWM) is proposed in this paper. A random frequency through chaotic number is generated first and then compared with the conventional sinusoidal reference function. The meticulous comparison of SPWM and the proposed Chaotic Carrier Sinusoidal Pulse Width Modulation (CCSPWM) is presented. The distribution of harmonic power in the output voltage of Voltage Source Inverter (VSI) with induction motor load is studied using MATLAB software. The discussion includes Total Harmonic Distortion (THD) in output line voltage, DC bus utilization and the Harmonic Spread Factor (HSF).

Keywords: Chaotic Carrier Sinusoidal Pulse Width Modulation (CCSPWM), Harmonic Spread Factor (HSF), Random Pulse Width Modulation (RPWM), Total Harmonic Distortion (THD)

1. Introduction

Adjustable-Speed Drives (ASDs) based on Voltage Source Inverter (VSI) have become mandatory choice in almost all applications. The other important applications of VSI are power supplies, heating, air conditioners, refrigerators, washers, dryers, static VAR compensators, active filters etc. Pulse Width Modulation (PWM) is a unanimously accepted technique for controlling power electronic converters¹. The conventional deterministic PWM in the inverter drive systems, however, results in the concentration of the output power harmonics at discrete frequencies at the PWM switching frequency and multiples of it. This results in objectionable acoustic noise, electro-magnetic interference, vibration and harmonic heating. If the randomness is introduced (either in pulse position or in the switching frequency) in the pulse generation, the

harmonics content will spread over wide range and the specific harmonic parts can be significantly reduced. This is the principle of Random Pulse Width Modulation (RPWM) techniques which have received much attention very recently^{2,3}.

A new hybrid random Pulse Width Modulation (PWM) scheme has been proposed in order to disperse the acoustic switching noise spectra of an induction motor drive⁴. The proposed random PWM pulses are produced through the logical comparison of a Pseudo Random Binary Sequence (PRBS) bits with the PWM pulses corresponding to two random triangular carriers. A constant frequency approach, which has gained popularity by introducing the randomness in the position of switching pulses within switching cycles, has been studied⁵. Yash Shrivastava et al. have suggested a statistical approach to the analysis of random Pulse Width Modulation (RPWM)

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methods which generate PWM signals by comparing a reference modulating function with random numbers or signals⁶. Chaotic sequences have also been the randomization tool in modulators. Chaotic frequency-spreading technique has been accepted as a prospective technology for EMI suppressing⁷. It has been proved that chaos system poses a continuous spectrum⁸ and energy can be distributed around an acceptable range.

The chaotic sequence can always be employed for incorporating randomness in PWM strategies. This paper proposes a novel Chaotic Carrier Sinusoidal Pulse Width Modulation (CCSPWM) method for three-phase VSI drives. The required randomness for carrier signal is achieved through a chaotic function. The conventional sinusoidal reference helps in retaining habitual merits of Sinusoidal PWM (SPWM) strategies. The meticulous comparison of SPWM and the proposed Chaotic Carrier Sinusoidal Pulse Width Modulation (CCSPWM) is presented. The distribution of harmonic power in the output voltage of Voltage Source Inverter (VSI) with induction motor load is studied using MATLAB software. The discussion includes Total Harmonic Distortion (THD) in output line voltage, DC bus utilization and the Harmonic Spread Factor (HSF).

2. Study of Harmonic Distribution in SPWM VSI Drive

A typical IGBT based VSI fed Induction Motor (IM) drive is shown in Figure 1. The drive consists of front end rectifier, dc link filtering components, VSI and the motor. As the PWM techniques are having fabulous merits, PWM had become a most important part of power electronic systems, and there has been considerable research effort over the years to determine optimum PWM strategies and operating criteria for various applications. Much of this work has investigated the benefits of alternative theoretical approaches, but there has been somewhat less emphasis on the more practical issues of implementation. The practical issues are output filter design, device thermal behavior, EMI issues, occurrence of non-dominant even harmonics, spectral errors etc. The basic SPWM considers triangular signal as carrier and the sinusoidal signal as reference. The conventional deterministic PWM in the VSI drive systems, however, results in the concentration of the output power harmonics at discrete frequencies related to the fixed switching frequency⁹⁻¹¹.

These harmonic powers may cause the undesired electromagnetic noise and psychoacoustic noise for human beings.

The harmonic spreading effects of conventional SPWM is evaluated in this section. The simulation study is performed in MATLAB/Simulink software. A three-phase VSI inverter with induction motor load is considered. The input dc voltage (V_{dc}) is 415V and the output frequency is taken as 50 Hz. The carrier frequency (f_c) is taken as 3kHz. The load is a three-phase squirrel cage induction motor load (0.75KW and 2.5A) and ODE Solver ode23_{tb} is used. The line voltage waveform resulted from SPWM is illustrated in Figure 2, for $Ma = 0.8$ and its corresponding harmonic spectrum is shown in Figure 3. The THD, HSF and fundamental component (V_1) of the output voltage are listed for the complete working range in Table 1. The variation HSF with respect to modulation index is shown in Figure 4. The linear relation between V_1 and Ma , and indirect proportionality of THD with Ma are studied. The variation of HSF with Ma is an interesting result and worth to note.

Table 1. Performance of SPWM

Ma	V_1 (V)	THD %	HSF
0.2	49.059	257.97	8.312
0.4	75.86	164.31	6.142
0.6	114.00	121.10	5.880
0.8	153.30	90.60	5.566
1.0	190.90	68.42	4.952
1.2	280.22	58.30	4.733

From the results it is understood that the harmonic spectrum resulted in SPWM has clustered harmonics at its switching frequency and multiples. Both THD and HSF are decreased at higher Ma values. The HSF at $Ma = 0.8$ is 5.566.

3. Chaotic Carrier Sinusoidal Pulse Width Modulation

The basic principle of the CCSPWM is described in Figure 5. The chaotic algorithm generates a random number, which decides the carrier frequency of next cycle. After having decided on the carrier cycle, the pulses are generated for all the three-phases through the comparison with the conventional sinusoidal reference.

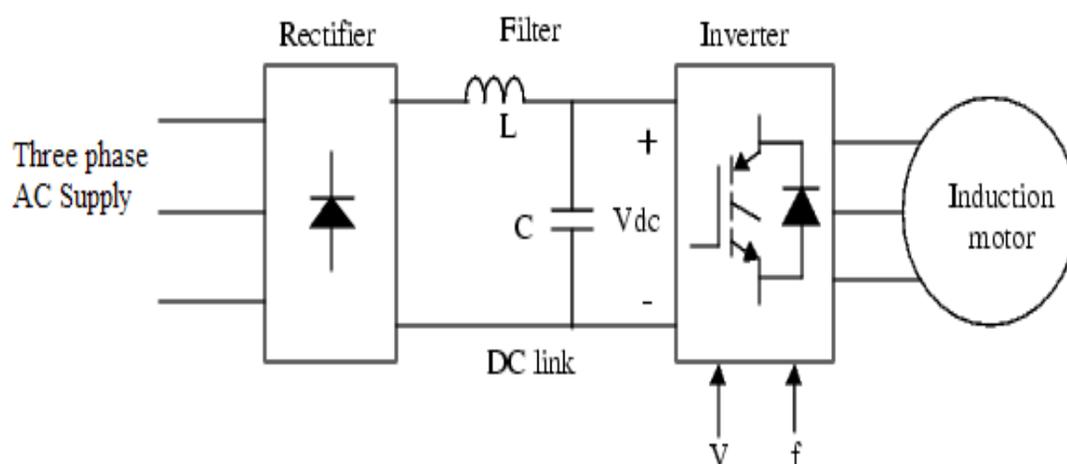


Figure 1. IGBT based VSI fed IM Drive.

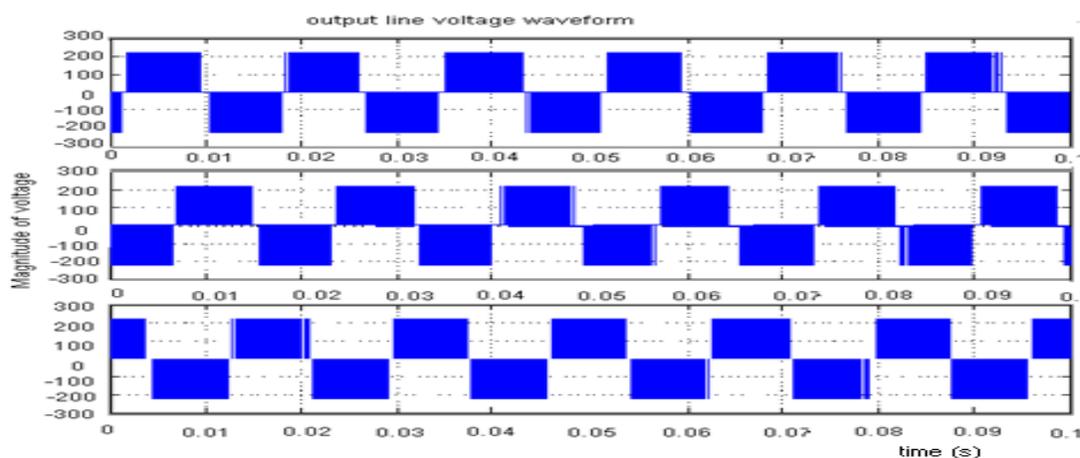


Figure 2. Line voltage waveform-SPWM.

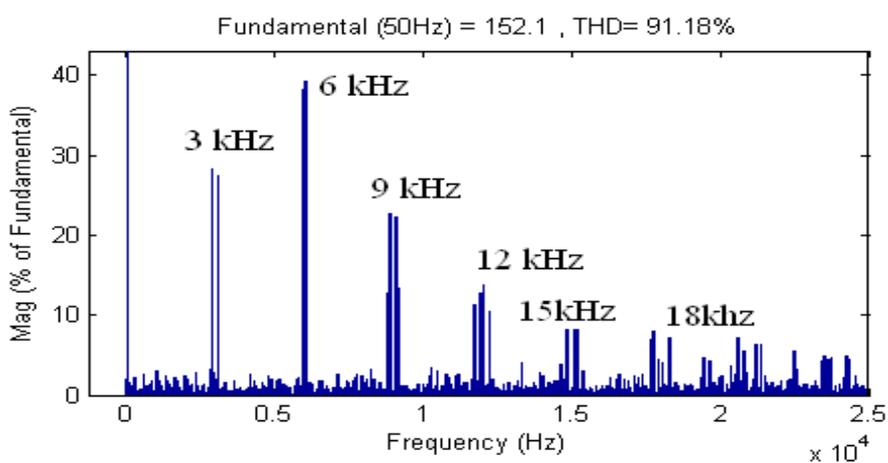


Figure 3. Harmonic spectrum of line-line voltage - SPWM.

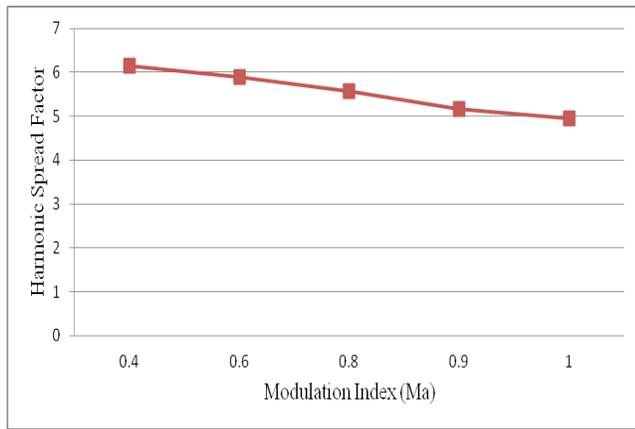


Figure 4. Harmonic spread factor versus modulation index- SPWM.

The basic principle of CCSPWM is to use a chaotic signal to vary the switching (or carrier) frequency. The following chaotic function is involved in generating the variable frequency carrier signal.

$$f_n = f_{low} + (f_{high} - f_{low} + 1) \frac{x_n}{0.5(5^c - 1)} \tag{1}$$

Where, f_n is the n^{th} switching frequency of chaotic PWM, chaotic sequences x_n may be generated simply by iteration. Thus the switching frequency may be varied from f_{low} to f_{high} . The constant c is assumed as 6.

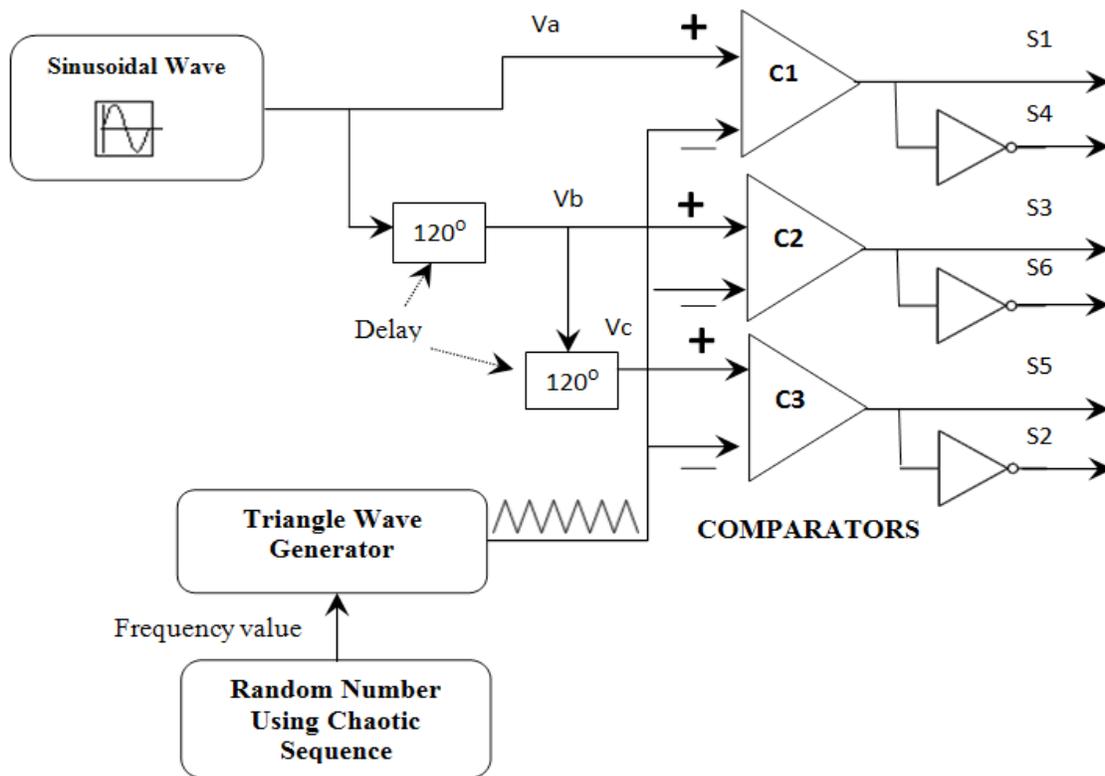


Figure 5. Chaotic carrier sinusoidal pulse width modulation.

4. Discussion on Results

The simulated waveforms of three-phase motor line voltages and currents are reopresented in Figure 6, and Figure 7, respectively. The harmonic spectrum and Power Spectral Density (PSD) for two representative modulation indices viz. 0.8 and 1.2 are diagrammed as from Figure 8 to Figure 11.

From the Table 2, it is understood that THD and HSF of the proposed CCSPWM are reduced for the entire range of Ma. At the modulation depth of 0.2, the reduction HSF is about 50% in the CCSPWM. The percentage reduction in HSF is more at lower modulation depths in linear modulation and also at higher depths in over modulation region.

Table 2. Performance comparison of SPWM and CCSPWM

Ma	THD (%)		HSF		Reduction HSF (%)
	SPWM	CCSPWM	SPWM	CCSPWM	
0.2	257.97	255.41	8.312	4.1416	50.17
0.4	164.31	162.44	6.142	3.9262	36.08
0.6	121.10	120.74	5.880	3.8430	34.64
0.8	90.60	92.06	5.566	3.7899	31.91
1.0	68.42	67.50	4.952	3.5380	28.55
1.2	58.30	57.72	4.733	3.3225	29.80

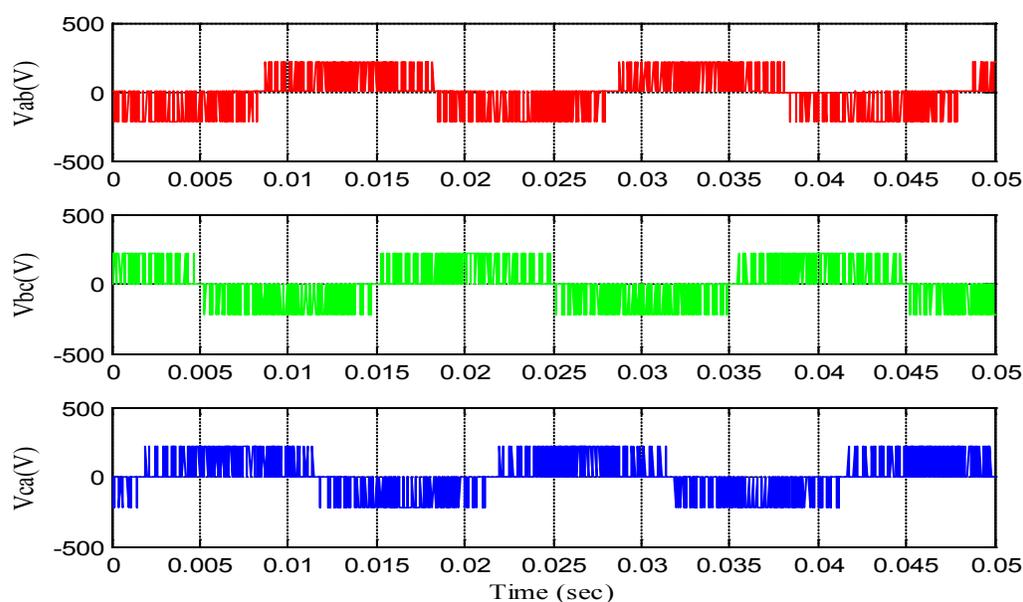


Figure 6. Simulated line-line voltage waveform for Ma=0.8.

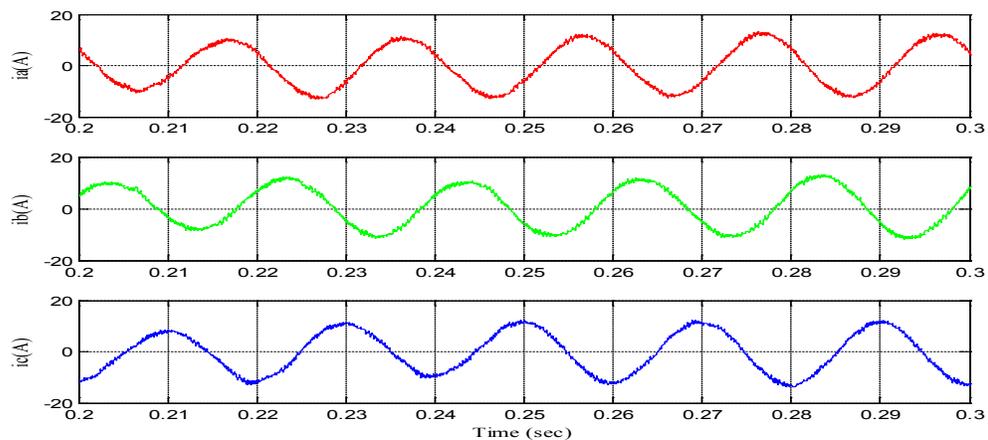


Figure 7. Simulated line current waveform for Ma = 0.8.

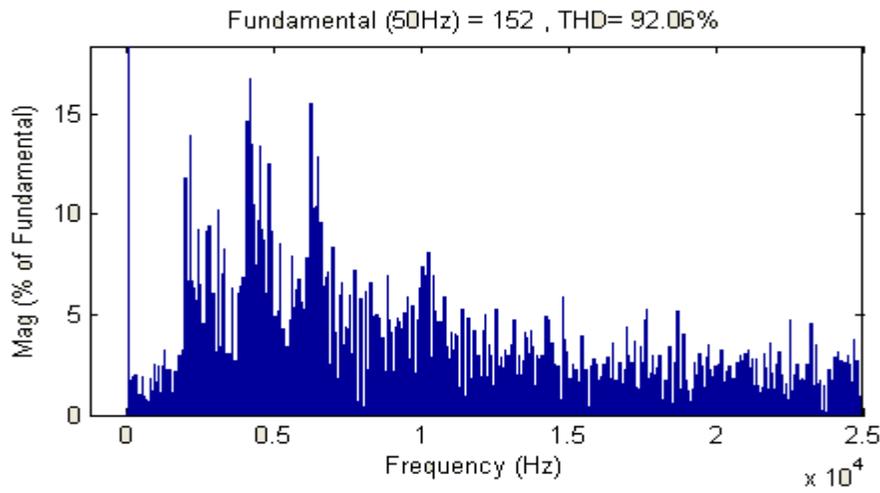


Figure 8. Line voltage harmonic spectrum for Ma= 0.8.

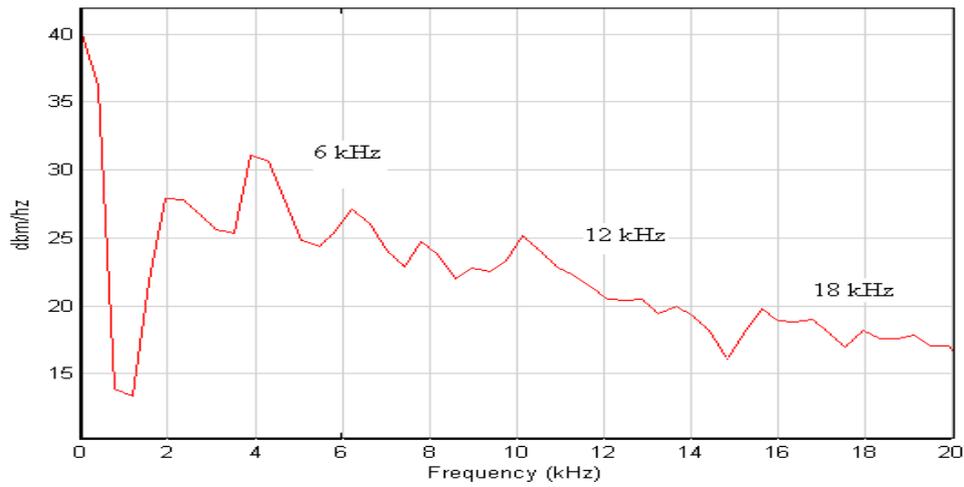


Figure 9. Power spectral density for Ma= 0.8.

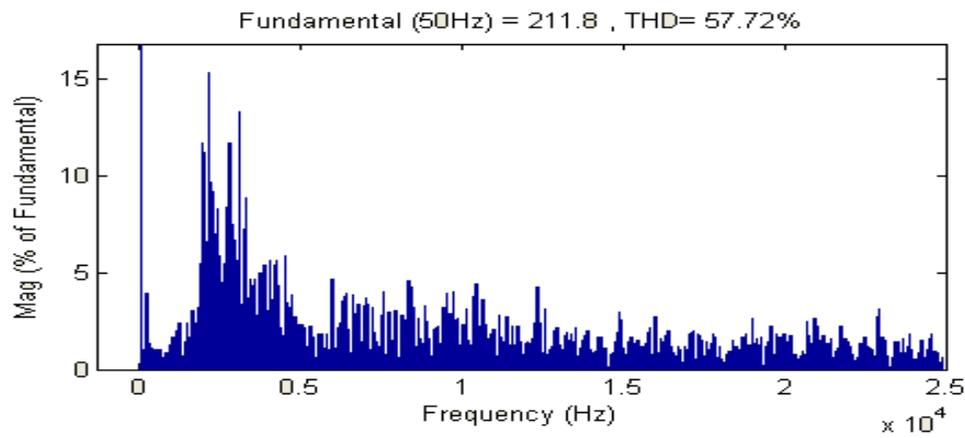


Figure 10. Line voltage harmonic spectrum.

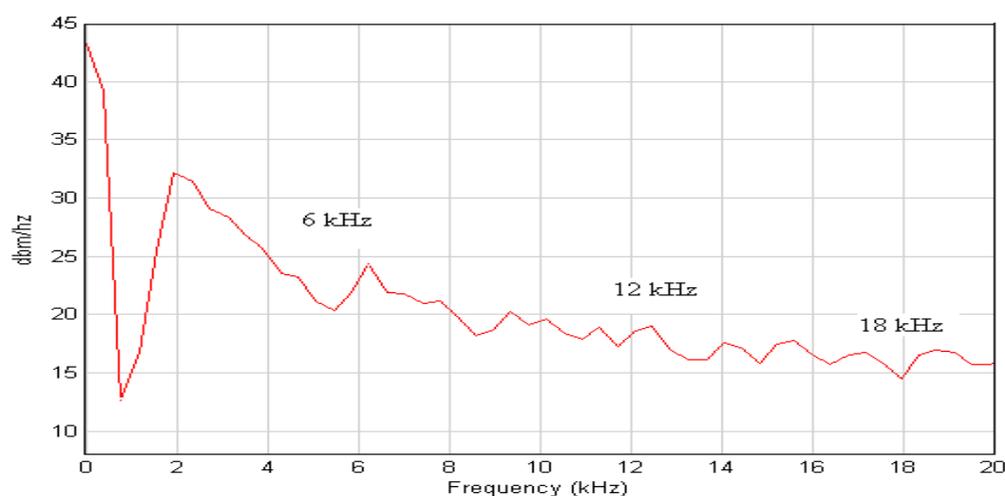


Figure 11. Power spectral density for $M_a=0.8$.

5. Conclusion

A novel random pulse width modulator, which employs a chaotic triangular signal of continuously varying switching frequency and conventional sinusoidal reference, is developed for three-phase voltage source inverters fed induction motor drives. The proposed method is the modified version of conventional sinusoidal pulse width modulation and hence it retains all the merits of it, while the harmonic spreading effect is enhanced. Harmonic Spread Factor is computed for quality evaluation of voltage spectra of inverters with the proposed chaotic carrier sinusoidal pulse width modulation and SPWM. The simulation study reveals that the proposed scheme helps in reducing the HSF about 50%. This offers the reduction in acoustic noise and vibration in ASDs.

6. References

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