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Analysis of Various Pulse Width Modulation Techniques Applied To Voltage Source Inverter Fed Induction Motor Drive

V. Bhavyashree
PG student, Department of Electrical and Electronics Engineering, Sastra university, Tamil nadu-613401, bhavya.shree08@gmail.com
K. Vijayarekha
Associate Dean ,Department of Electrical and Electronics Engineering, Sastra university, Tamil nadu-613401
D.UMA
Senior Assistant professor, Department of Electrical and Electronics Engineering, Sastra university, Tamil nadu-613401

Abstract

This paper focuses on design and performance of various pulse width modulation techniques applied to Voltage Source Inverter (VSI) fed Induction Motor (IM) based on the current harmonics present in stator of the Induction motor. Here three phase VSI is considered to convert incoming DC to AC with variable voltage and frequency, which is given to IM. By applying various Pulse Width Modulation (PWM) Techniques, current harmonic present in stator of IM can be reduced. The different PWM techniques applied here are Sinusoidal Pulse Width Modulation (SPWM), Selective Harmonic Elimination (SHEPWM) and Space Vector Pulse Width Modulation (SVPWM). The proposed system is simulated in MATLAB/SIMULINK. The performance of various PWM technique applied in this paper are analyzed based on their Total Harmonic Distortion (THD) and simulation results are provided to validate the proposed model and their results are compared based on stator current harmonics to find the better pulse width modulation that can be applied to IM.

Keywords: Sinusoidal Pulse Width Modulation technique, Space Vector PWM, Selective Harmonic Elimination and harmonic reduction.

Introduction

PWM inverters are very popular in reducing stator current harmonics in the Induction Motor drives. PWM techniques control both frequency and magnitude of the current

or voltage applied to Induction Motor (IM) drive and also mitigates harmonics present in them with lower switching losses. Based on the supply inverters are defined as VSI and Current Source Inverter (CSI). Switching techniques in PWM inverters have been popular in the area of power electronics and `drive systems. PWM is commonly used in application like motor speed control. There is no single PWM method which can be applied for all applications. As per the advanced technology in power electronic devices and microprocessors, various PWM techniques have been applied for different industrial applications. There are different PWM techniques like Single PWM, Multiple PWM, Phase displacement control, SPWM, Harmonic Injection modulation, SVPWM, Hysteresis (Delta) PWM, SHEPWM and Current Controlled pulse width modulation [4]. Among them Hysteresis PWM is used for CSI and all the remaining PWM techniques are used for VSI. In this paper, harmonics are analyzed in stator current of the induction motor drive by using PWM techniques like SPWM [1], SVPWM [2]-[8] and SHEPWM [9].

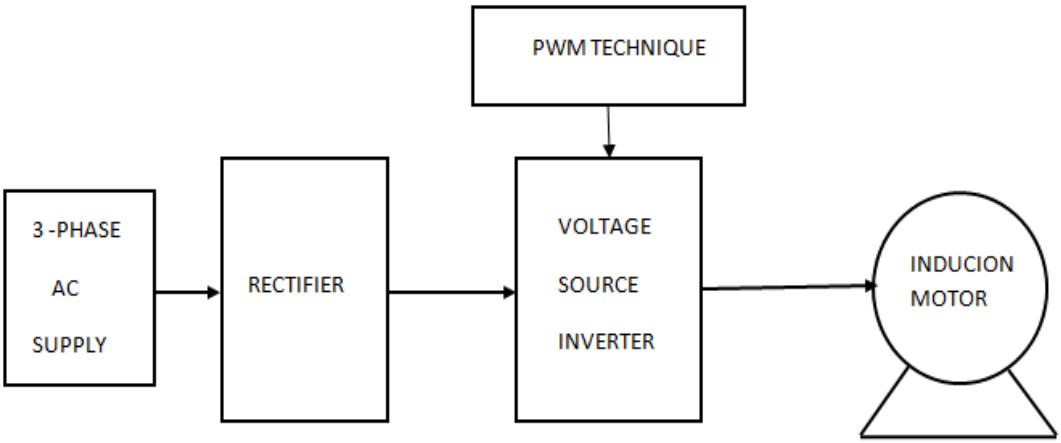

Figure 1: Proposed Model

The Fig.1 describes the proposed model. In which the input three phase AC supply is converted in to suitable form for VSI by using diode bridge rectifier. The performance of the VSI is analyzed by using different PWM techniques as mentioned above. The obtained corresponding output AC current from VSI is fed to the induction motor. The PWM techniques used in this paper are explained below.

A. Sinusoidal Pulse Width Modulation Technique

It is the switching schemes applied here to control the magnitude as well the frequency of the output current. In this paper generation of gating signals is done by comparing a sinusoidal wave with a triangular wave as shown in Fig.2. The ratio of the amplitude of sinusoidal wave to the amplitude of triangular carrier wave is defined as modulation index. This technique is defined by pulses with various duty cycles for each period. The width of the pulses is modulated to ger desired output current of inverter which reduces its harmonic content.

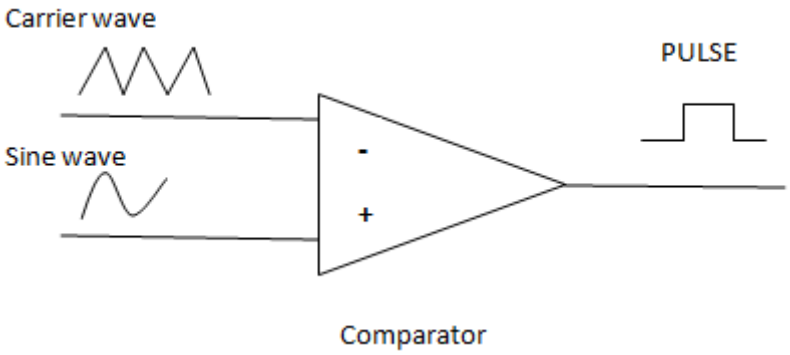

Figure 2: Generation of pulses

B. Space Vector Pulse Width Modulation

It is described by vector approach to PWM for inverters. It describes of space vectors to be applied accordingly to where vector of the output voltage is located. The switches in VSI is shown in fig.3 must be controlled in space vector So that, both switches of same leg is not turned on together else DC source will be shorted. This requirement is done by complementary action of the switches in same leg. This results in eight switching vectors for the inverter, and is represented from V_0 to V_7, in which six are active vectors and remaining two are zero vectors. In this the obtained three phase voltages at the output of the inverter is shown by an equivalent vector rotating in the counter clock wise direction as shown in Fig4 and their switching states are shown in below table 1. In this paper carrier based space vector modulation is used where by comparing the duty ratio with a higher frequency triangular carrier the pulses can be produced and based upon vector selection as in [4] the harmonic content and the switching losses are mitigated. The equation in carrier based space vector modulation is given below

$$d_1V_1 + d_2V_2 = V = mV_g e^{je}$$

Where d is duty cycle

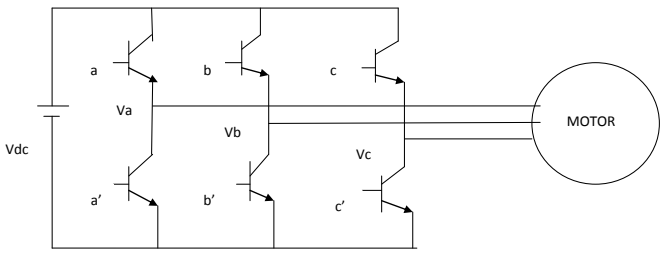

Figure 3: Block diagram of three phase VSI

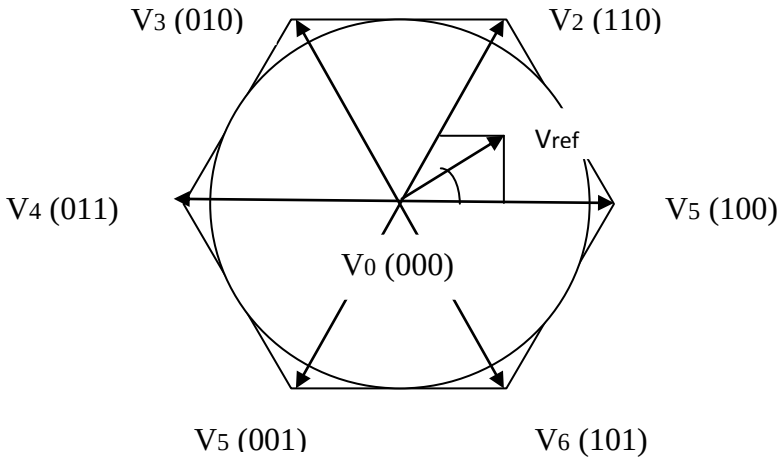

Figure 4: Schematic diagram of space vector

Table 1: Switching States of Space Vector

Vector	**a**	**b**	**c**	**a'**	b'	**c'**	$\mathbf{V_{ab}}$	$\mathbf{V_{bc}}$	$\mathbf{V_{ca}}$	
V_0 = {000}	OFF	OFF	OFF	ON	ON	ON	0	0	0	zero vector
V_1 = {100}	ON	OFF	OFF	OFF	ON	ON	$+V_{dc}$	0	$-V_{dc}$	active vector
V_2 = {110}	ON	ON	OFF	OFF	OFF	ON	0	$+V_{dc}$	$-V_{dc}$	active vector
V_3 = {010}	OFF	ON	OFF	ON	OFF	ON	$-V_{dc}$	$+V_{dc}$	0	active vector
V_4 = {011}	OFF	ON	ON	ON	OFF	OFF	$-V_{dc}$	0	$+V_{dc}$	active vector
V_5 = {001}	OFF	OFF	ON	ON	ON	OFF	0	$-V_{dc}$	$+V_{dc}$	active vector
V_6 = {101}	ON	OFF	ON	OFF	ON	OFF	$+V_{dc}$	$-V_{dc}$	0	active vector
V_7 = {111}	ON	ON	ON	OFF	OFF	OFF	0	0	0	zero vector

C. Selective Harmonic Elimination

SHE technique has been a widely researched technique to many pulse-width modulation techniques. The elimination of specific lower order harmonics from a given current waveform is achieved by SHE technique. This technique can be used with both the VSI and current source inverter (CSI). In SHE switching angles are calculated by the help of optimization technique. The harmonics equation obtained is nonlinear in nature and thus optimization methods are available to solve the

harmonics equation to eliminate the particular harmonics. The available methods to solve these nonlinear equations include Newton Raphson method and many other. Here Newton Raphson method is used to eliminate the dominant 3rd harmonics with 5th, 7th and 9th harmonics as in [10]. The nonlinear equations used here are

$$\cos(\alpha_1)-\cos(\alpha_2)+.....+\cos(\alpha_N)=\frac{\pi}{4}M$$

$$\cos(3\alpha_1)-\cos(3\alpha_2)+.....+\cos(3\alpha_N)=\frac{3\pi}{4E}h_3$$

$$\cos(5\alpha_1)-\cos(5\alpha_2)+.....+\cos(5\alpha_N)=\frac{5\pi}{4E}h_5$$

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$$\cos(N\alpha_1)-\cos(N\alpha_2)+.....+\cos(N\alpha_N)=\frac{N\pi}{4E}h_N$$

In general it can be written as $F(\alpha)=B(M)$

Where m is the modulation index M=$\frac{h_1}{E}$, α_N is the switching angle which must satisfy condition $\alpha_1 \prec \alpha_2 \prec ...\alpha_N \prec \frac{\pi}{2}$.

The algorithm for the Newton-Raphson method is as shown below

1. Take initial value say α_0 satisfying above condition.
2. Set m=0.
3. Find $F(\alpha_0)$, $B(m)$, *and* Jacobian $J(\alpha_0)$.
4. Calculate the correction using $\Delta\alpha = j^{-1}(\alpha_0)(B(m_1)-F(\alpha_0))$.
5. Update switching angle $\alpha(N+1)=\alpha(N)+\Delta\alpha(N)$.
6. Perform $\alpha(N+1)=\cos^{-1}(abs(\cos(\alpha(N+1))))$ to bring angles in optimal range.
7. Repeat step 3 to 6 to attain zero error.

Using this method switching angles are calculated and then applied to the pulse generators to get lesser stator current harmonics. This method is simple and easily implemented.

Simulation Results

The simulation schematic shows the various pulse width modulation techniques applied to VSI fed IM.

A) Sinusoidal Pulse Width Modulation

The simulation SPWM for VSI fed IM is shown in Fig.5 to analyze the stator current harmonics for system with AC Voltage=400V, Current=10Amp, Speed=1500rpm and Capacitor=1F.

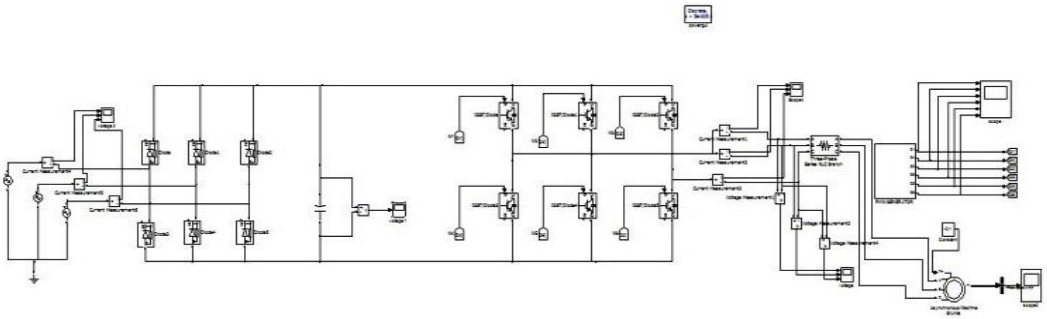


Figure 5: Simulink Model of SPWM VSI fed IM

The waveform of Stator current of VSI fed IM based on SPWM is shown in Fig.6.

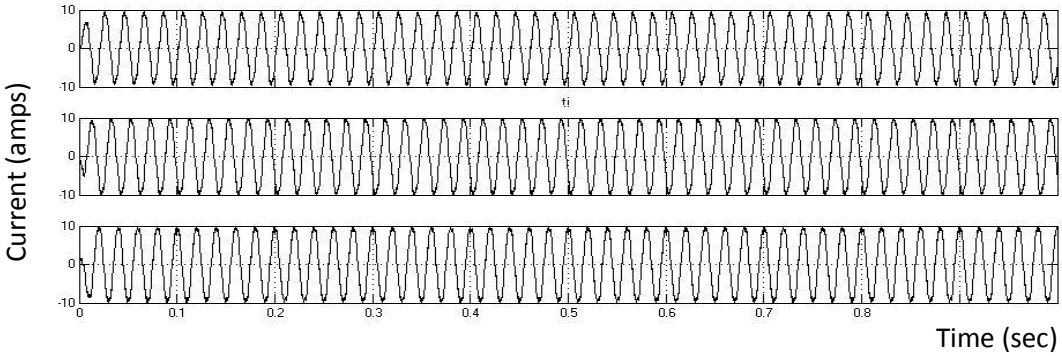
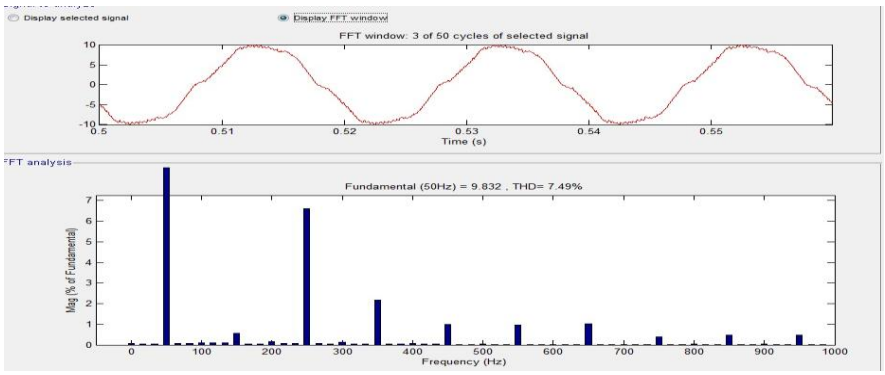


Figure 6: Stator current of SPWM VSI fed IM

The FFT analysis of stator current for SPWM VSI fed IM is shown in Fig.7.



The THD of SPWM VSI fed IM is found to be 7.49%

Figure 7: FFT analysis of stator current

B) Space Vector Pulse Width Modulation

The simulation SVPWM VSI fed IM is shown in Fig.8 to analyze the current harmonics for system with AC Voltage=400 V, Current=10Amp, Speed=1500rpm and Capacitor=1F

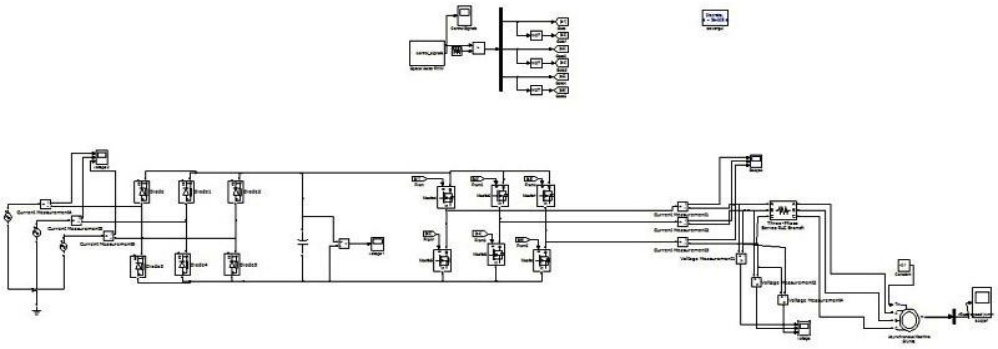


Figure 8: Simulink Model of SVPWM VSI Fed IM

The waveform of Stator current of SVPWM VSI fed IM is shown in Fig.9.

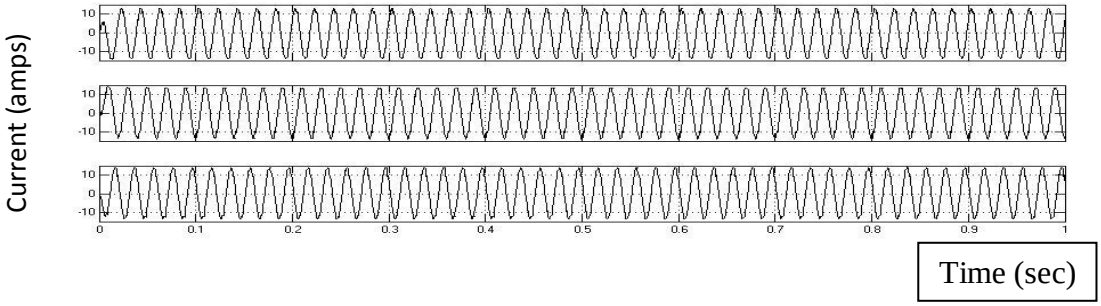
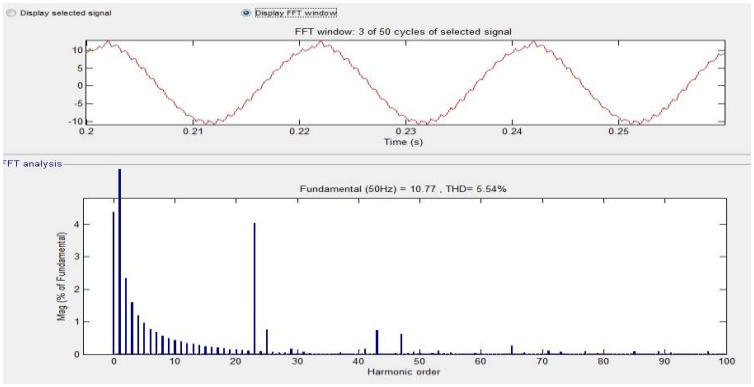


Figure 9; Stator current of SVPWM VSI fed IM

The FFT analysis of stator current of SVPWM VSI fed IM is shown in fig.10.



The THD of SVPWM VSI fed IM is found to be 5.54%

Figure 10: FFT analysis of stator current

C) Selective Harmonic Elimination

The simulation of SHEPWM VSI fed IM is shown in Fig.11 to analyze the current harmonics for system with AC Voltage=400V, Current=10Amp, Speed=1500 rpm and Capacitor=1F

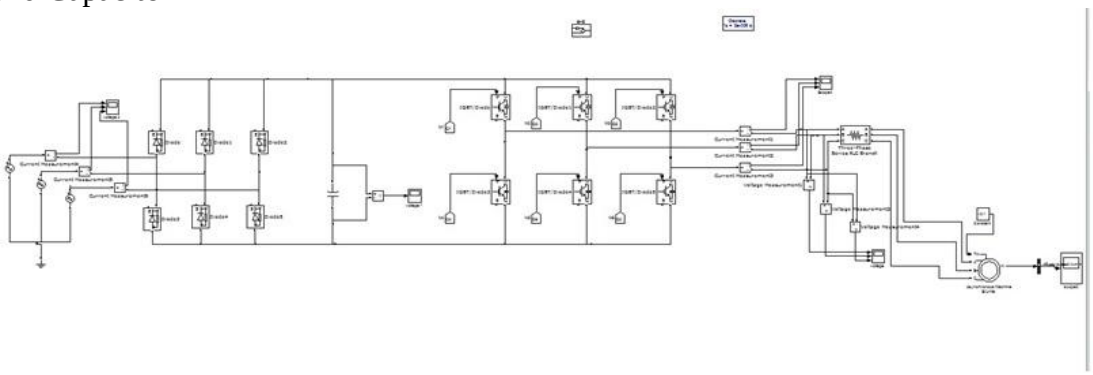


Figure 11: Simulink Model of SHEPWM VSI Fed IM

The waveform of Stator current of motor of SHEPWM VSI fed IM is shown in Fig.12.

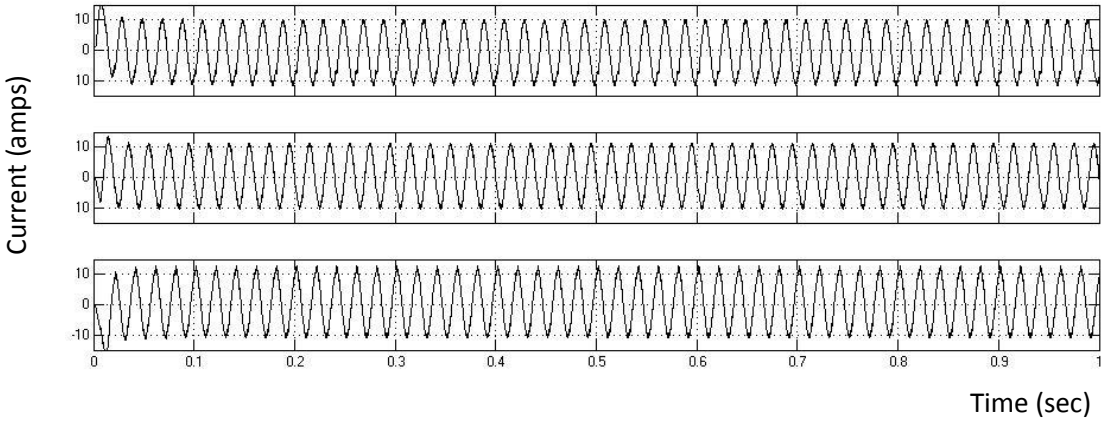
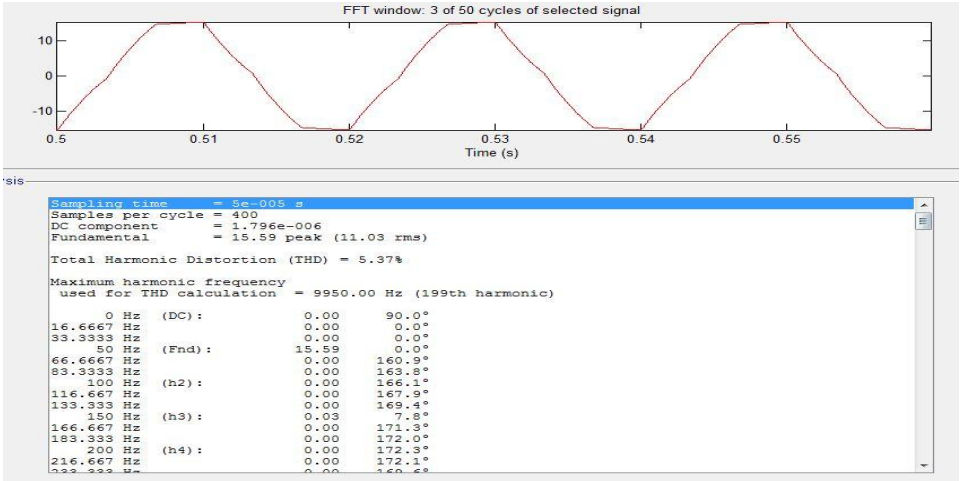


Figure 12: Stator current of SHEPWM VSI fed IM

The FFT analysis of stator current for SHEPWM VSI fed IM is shown in Fig.13



The THD of SVPWM VSI fed IM is found to be 4.30%

Figure 13: FFT analysis of stator current

Comparison Table

Table 2: Comparison Table

PWM Techniques	**THD of Stator Current**
SPWM	7.49%
SVPWM	5.54%
SHEPWM	4.30%

The results shows that by applying SVPWM we can reduce 1.95% harmonic content compared to SPWM technique and by applying SHEPWM, harmonics further decreased by 1.24%.

Conclusion

In this paper three different PWM techniques has been designed and applied to Voltage Source Inverter (VSI) fed Induction Motor (IM) and their performances are compared based on the current harmonics present in stator of the Induction motor. During comparison, it is found that the stator current harmonics of induction motor is reduced considerably in all above PWM techniques. The results from table 2 show that by applying SHEPWM, harmonic content is decreased by 3.39% compared to SPWM. Finally it has been observed that the SHEPWM technique improves the quality of the stator current by reducing the harmonics and increasing the system efficiency.

Motor parameters

The motor is rated at 3.7kW, 400V, 50 Hz

The motor parameters are-

Stator resistance=7.35 ohms
Stator inductance=0.028 Henry
Rotor resistance=2.25 ohms
Rotor inductance=0.028 Henry
Mutual inductance=0.05 Henry

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