Performance Analysis of Three Phase Induction Motor Drive Using SPWM & SVPWM Switching Techniques -A Review

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Abstract – We have performed comparative studies of Space Vector Pulse Width Modulation (SVPWM) and Sinusoidal Pulse Width Modulation (SPWM) techniques utilizing MATLAB tools. During these investigations, we carried out intensive simulations, comprehensively analyzed the obtained results and compared the harmonic density, power factor (PF), & switching losses of SVPWM and SPWM. It has been observed during investigations that if the switching frequency is high then losses due to harmonics are negligible, thus based on obtained results we suggested that the SVPWM technique is a more reliable solution. Because SVPWM utilizes DC bus voltage more efficiently, generates less Total Harmonic Distortion (THD) and has higher output quality it provides flexible control of output voltage and output frequency for Variable Speed Drive (VSD).

Index Terms – Space Vector Pulse Width Modulation (SVPWM), Sinusoidal Pulse Width Modulation (SPWM), MATLAB, Total Harmonic Distortion (THD), Power Factor (PF), and Variable Speed Drive (VSD) Voltage Source Inverter (VSI).

1. INTRODUCTION

Indeed, with the advent of advancement in manufacturing & designing, AC drives super-ceded the DC drives due to their higher performance and better efficiency. The most important advantages of AC drives over DC drives are faster predictable dynamic response, constant and better Power Factor (PF) and 100% continuous torque at zero speed (Applicable to flux vector control technology). AC motors have low cost, less complicated, rugged and easy to maintain or replace, therefore this is also a major cause of shifting of technology from DC drives to AC drives.

For optimum performance, we select the best possible switching and control technique for AC drives. The control techniques used in Variable Speed Drives (VSD) are scalar control (Volts per Hertz Control), vector control (Direct torque control and Field-oriented control) where as the switching techniques used in Variable Speed Drive (VSD) are six step switching technique, selected-harmonic-elimination pulse width modulation (SHPWM), delta pulse width modulation (DPWM), delta-sigma pulse width modulation (DSPWM), minimum-ripple current pulse width modulation and sinusoidal pulse width modulation (SPWM) etc.

The Sinusoidal Pulse Width Modulation and Space Vector Pulse Width Modulation are most widely used modulation techniques due to their greater advantages. The SVPWM technique gives higher level of fundamental voltage as compared to SPWM [1].The comparison of these two modulation gives the results that SVPWM is the best and most reliable modulation because it enables efficient use of DC voltages and smartly works with vector control thus, gives less Total Harmonic Distortion (THD), better PF, and less switching losses at high frequencies

2. LITERATURE SURVEY

In this paper the comprehensive analytical analysis and comparison of switching ripple characteristics of two PWM methods for a three-phase Three-level VSI is presented. This paper also presents the evaluation of the flux harmonic distortion factors of the SVPWM techniques. Correlation with corresponding current ripple and total harmonic distortion is established in this paper, where theoretical considerations are verified by simulations and through experimental investigation on a three-phase VSI-fed induction motor drive. In particular, determination of the total harmonic distortion THD has been considered.

In this paper, a switching pattern based on the concept of the conventional space vector Pulse Width Modulated (SVPWM) technique is developed for single-stage, three-phase boost-inverters using the topology of voltage-source inverters. The six main switching states, and two zeros, with three switches conducting at any given instant in conventional SVPWM techniques are modified herein into three-charging states and six discharging states with only two switches conducting at any given instant. The charging states are necessary in order to boost the dc input voltage. The developed switching pattern was experimentally verified through a laboratory-scaled three phase 500-W boost inverter and the results are presented in this paper [2].

Voltage Source Inverters (VSI) have proven to be more efficient, cost effective, less space, faster dynamic response for rapid changes in speed or torque and be capable of running the motor without de-rating.

A typical three phase VSI consist of a diode rectifier (SCR bridge rectifiers in case of variable DC output voltages) which converts AC line to DC, a parallel capacitor DC Link which stores the energy for the system and regulates the DC bus voltages, an inverter is consist of insulated gate bipolar transistors (IGBTs) which provides variable frequency output depending upon the applied reference voltage and switching technique. A typical VSI is shown in figure 1.

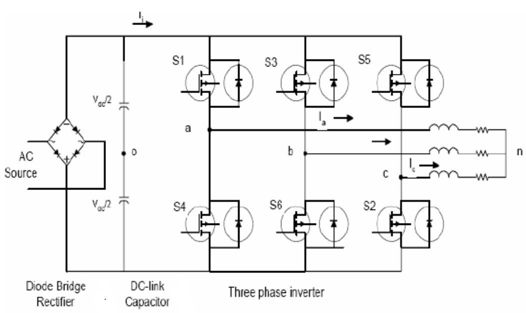


Fig1. Three phase voltage source inverter

For the generation of pure sinusoidal signal, SPWM is the most popular technique. In SPWM a digital waveform is generated and the duty cycle is modulated such that the average voltage of the waveform is corresponds to a pure sine wave. SPWM moves the voltage harmonic components to the higher frequencies. The SPWM technique treats each modulating voltage as a separate signal and compared to the common carrier triangular waveform.

3. PORPOSED MODELLING

Study of space vector pulse width modulation technique for the multilevel inverter fed induction motor drive.

Implementing basic circuit diagram of three level inverter using various switching devices, dc source as input, and clamping diode.

Design of control scheme (SVPWM) for three level inverter Analysis of SVPWM Technique on Performance analysis of three phase induction motor and study of results and possible modifications.

4. RESULTS AND DISCUSSIONS

The working principle of SPWM includes the following points:

- The frequency of triangular wave is the frequency of PWM.
- Frequency of control voltage controls the fundamental frequency.
- The peak value of control voltage controls the amplitude.
- Modulation Index is defined by:

Where *Vao1* = Fundamental component of *Vao.*

For Phase A:

If *Vcontrol* > *Vtriangle* then *Vao = Vd/2.*

If *Vcontrol* < *Vtriangle* then *Vao = -Vd/2.*

For Phase B:

If *Vcontrol* > *Vtriangle* then *Vbo = Vd/2.*

If *Vcontrol* < *Vtriangle* then *Vbo = -Vd/2.*

For Phase C:

If *Vcontrol* > *Vtriangle* then *Vco = Vd/2.*

If *Vcontrol* < *Vtriangle* then *Vco = -Vd/2.*

This paper We analyzed the output line current Ic in MATLAB Simulink and found following readings for THD & Power Factor in table 1:

Table 1. Modulation index and corresponding total harmonic distortion with overall power factor

Modulation index	THD for current %	Overall PF
0.5	26.53	0.829
0.7	0.7	
0.9	5.91	

The ratio of the real power to the apparent power is defined by PF. The lesser the phase shift between the fundamental voltage and current, the greater the PF. It should be noted that PF is not directly related to the THD because in THD calculation, phase shift between current and voltage inputs are not factored. However (PF / CosΦ1) term can be related to the THD which shows if THD increased then the factor (PF / CosΦ1) is decreased. Therefore the readings of power factor in table 1 are measured through scope in MATLAB Simulink instead of calculation by THD and PF formulas. THD is actually the RMS distortion of all AC components excluding fundamental component, THD is expressed as a percentage of the RMS value of the fundamental component. It means THD shows the amount of deviation of the output signal from fundamental signal. Formulas of THD and PF are given in equation (1) and equation (2) respectively.

THD = (Arms-A1)1/2 / A1 (1)

Where *A1* = RMS Value of Fundamental signal.

Arms = Total RMS Value of the complete signal.

PF = Cos*Φ1 / (1+THD2)1/2* (2)

Where *Φ1* = Phase Shift between Fundamental Voltage and Current.

For the simulation, we selected the following parameters parameters to observe the comparison between SPWM and SVPWM techniques:

Vdc = 600V

Carrier Signal Frequency = 3K Hz

Fundamental Frequency = 50 Hz

Modulation Index = 0.1 to 1

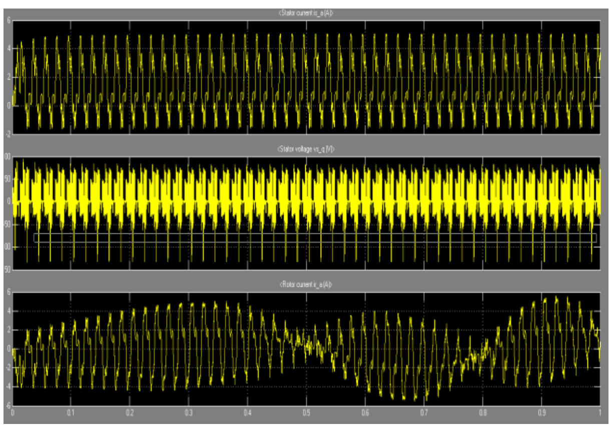


Fig.2 Simulation results of the SPWM

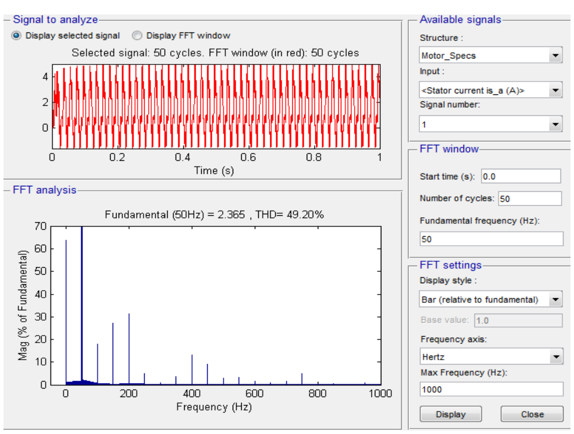


Fig. 3 FFT Analysis of stator current

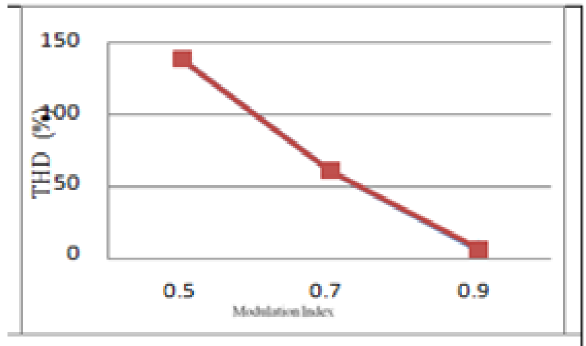


Fig.4 Modulation index Vs THD in spwm

Graphical representation of modulation index and THD in SPWM is shown in figure 4 which represents that THD decreases as modulation index increases.

In this paper we analysis SVPWM is the best computational PWM technique for a three phase voltage source inverter because of it provides less THD & better PF. SVPWM works on the principle that when upper transistor is switched ON; corresponding lower transistor is switched OFF. The ON and OFF state of the upper switches (S1, S3, S5) evaluates the output voltages. Switching states and corresponding phase and line voltages are shown in table 2.

Table 2. Switching states and corresponding phase and line voltages

Switching States			Phase Voltages			Line Voltages		
a	b	c	V_a	V_b	V_c	V_{ab}	V_{bc}	V_{ca}
0	0	0	0	0	0	0	0	0
1	0	0	2/3	-1/3	-1/3	1	0	-1
1	1	0	1/3	1/3	-2/3	0	1	-1
0	1	0	-1/3	2/3	-1/3	-1	1	0
0	1	1	-2/3	1/3	1/3	-1	0	1
0	0	1	-1/3	-1/3	2/3	0	-1	1
1	0	1	1/3	-2/3	1/3	1	-1	0
1	1	1	0	0	0	0	0	0

For the sector determination, we developed a flow chart showing the different conditions for different sectors. Six sectors and their conditions are shown in figure 5. SVPWM provides approximately 10-20% increment in maximum voltage. The SVPWM can be implemented with the following steps [3] [4]:

□Determination of Vd, Vq, Vref, and angle (α).

□Time duration T1, T2, T0 Determination.

□Determination of the switching time of each transistor (S1 to S6).

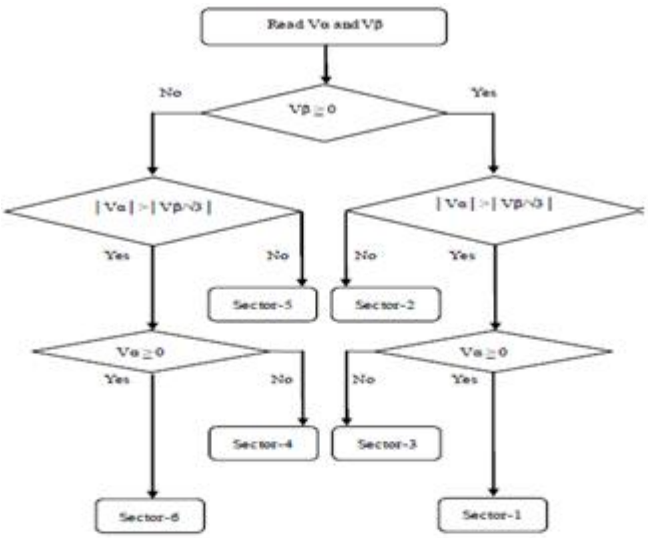


Fig 5. Flowchart of sector

In this paper we analysis SVPWM method in which the overall power factor & THD has improved as compared to SPWM. Analysis of the output line current Ic in MATLAB Simulink for THD & Power Factor is shown in table 3. It should be noted that power factor reading is overall power factor of the system analyzed by power factor analyzer.

Table 3. Modulation index and corresponding total harmonic distortion with overall power factor.

Modulation index	THD for current (%)	Overall PF
0.5	129.61	0.871
0.7	40.71	
0.9	3.42	

In the simulation of SVPWM, we selected the following parameters to observe the comparison between SPWM and SVPWM techniques:

Vdc = 600V

Carrier Signal Frequency = 3K Hz

Fundamental Frequency = 50 Hz

Modulation Index = 0.1 to 1

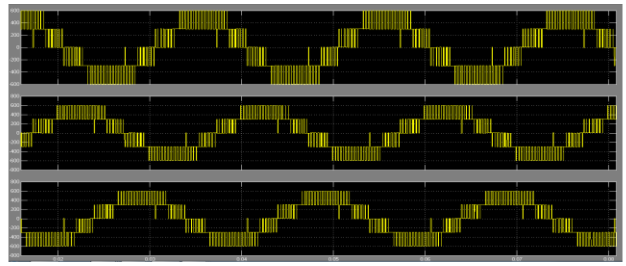


Fig. 6(a) output voltage of inverter

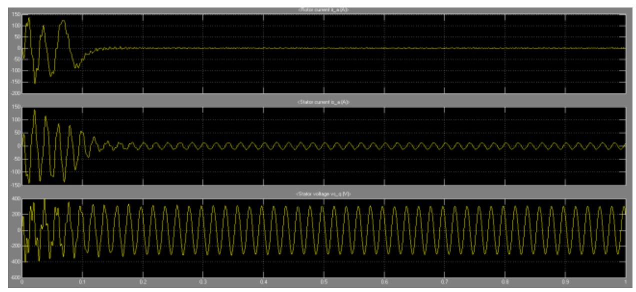


Fig.6(b) Rotar current, stator current, stator voltage

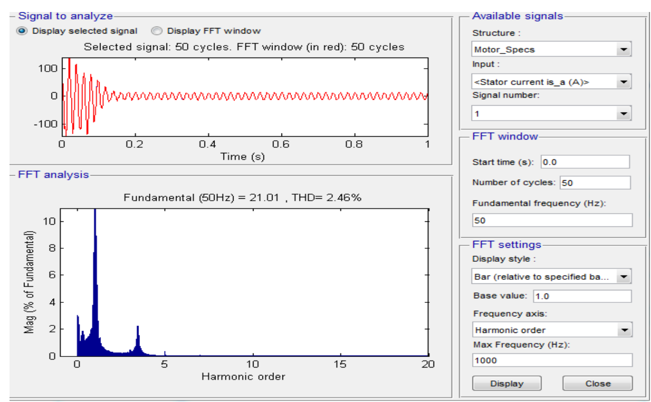


Fig.6 (c) THD analysis of stator current

Figure 6 (a), 6 (b), 6 (c) is showing the graphical results of three phase output line voltages Vab, Vbc, Vac, transformed two phase voltages, control signals of SVPWM, THD of output line voltage Vac, magnitude (Fourier analysis of output line voltage Vac), angle (Fourier analysis of output line voltage Vac), THD of output line current Ic, magnitude (Fourier analysis of output line current Ic), and angle (Fourier analysis of output In the simulation of SVPWM, we selected the following parameters to observe the comparison between SPWM and SVPWM techniques:

Vdc = 600V

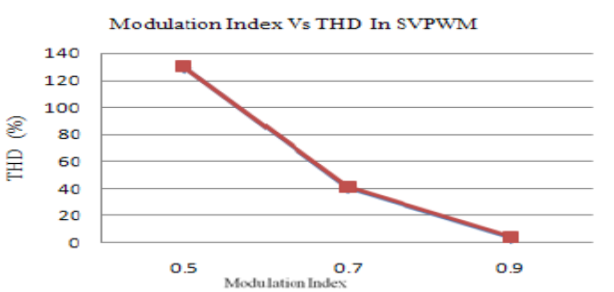
Carrier Signal Frequency = 3K Hz

Fundamental Frequency = 50 Hz

Modulation Index = 0.1 to 1

Figure 6 is showing the graphical results of three phase output line voltages Vab, Vbc, Vac, transformed two phase voltages, control signals of SVPWM, THD of output line voltage Vac, magnitude (Fourier analysis of output line voltage Vac), angle (Fourier analysis of output line voltage Vac), THD of output line current Ic, magnitude (Fourier analysis of output line current Ic), and angle (Fourier analysis of output line current Ic) simultaneously. SVPWM has good drive response if we have variable speed reference or load torque [2].

Graphical representation of modulation index & THD in SVPWM are also shown in figure 7.



For low power applications, switching losses are acceptable for specific range but for high power applications, switching losses become more significant. Because of switching losses, high frequencies (greater than 20 kHz) are less efficient than lower frequencies (as low as 100 Hz) due to efficiency of system reduces as switching losses increased, since for reducing filtering requirements we have to increase switching frequency which results in greater switching losses. Although switching losses can be reduced by modifying carrier signal in SPWM or using zero switching technique or shifting to multilevel inverters [5] but on the other hand it results in greater harmonic distortion or poor power factor.

SVPMW has greater flexibility to reduce switching losses. In SVPWM reduced switching losses are because of the changing of any one switching state which results in one single phase voltage change every time. If system needs further reduction in switching losses than another technique could be used for switching loss reduction based on stopping the control pulses of SVPWM for some duration and this duration depends upon angle of the load power factor. For different modulation indexes, extra switching can be eliminated in SVPWM

5. CONCLUSION

In this paper, SPWM and SVPWM techniques have been investigated and compared. During the investigations, we realized harmonic density, power factor & switching losses in both techniques. For this purpose we also performed extensive simulations of these techniques using MATLAB tools. It has been observed that SVPWM has showed superior performances due to less THD, greater PF and less switching losses because SVPWM utilizes advance computational switching technique to reduce THD. It also reduces switching losses because of the changing of any one switching state which results in one single phase voltage change every time. Furthermore, at high switching frequencies SVPWM gives better results as compared to SPWM. Thus, based on all obtained results, we concluded that SVPWM technique provides greater overall performance and efficiency as compared to SPWM technique.

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