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Analysis and Realization of SPWM and SVPWM Direct Torque Controlled Induction Motor Drive

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Abstract:
This paper addresses with the continuous improvement of technology in power electronics and micro-electronics, variable voltage and variable frequency ac motor drives have come to increased use in various industrial applications. These new approaches need a simple method of control for ac motors. Control of ac motors become very popular because it is possible to obtain the characteristics of dc motors by improving control techniques. It is well-known that the control method of an ac motor is comparatively more difficult to realize because of involvement of various controllable parameters like voltage, current, frequency, torque, flux and so on. Though it is possible to achieve almost the same characteristics of dc motor using induction motor, it is very complicated to realize because of need for on line co-ordinate transformation and continuous need of either speed or position signal. Particularly, field oriented control, which guarantees high dynamic and static performance like dc motor drives, has been very popular and has constantly being developed and improved. But the innovative idea of co-ordinate transformation and the analogy with dc motor control. This substituted non-linear co-ordinate transformation in field oriented control by self control of stator flux and torque. In contrast to the control of the direct and quadrature component stator currents to maintain desired flux and torque respectively, this scheme directly controls those two parameters in stationery frame, while currents and voltages are regulated indirectly. As the concept of instantaneous space vector becomes very popular, ac drives controllers will use this tool as a PWM technique. Moreover, since quick accelerating and decelerating rotation of stator flux vector is achieved, rapid torque response can be obtained. To achieve this, both torque and flux controllers employ hysteresis band with the objective to maintain both the machine variables within their respective tolerance bands. Due to direct application of active voltage vector by the modulator, sometimes stator voltage vector moves very fast tangentially along the circular path of stator flux vector within the flux hysteresis band leading to non-sinusoidal voltage across the stator terminal. This introduces some harmonic voltages leading to increased loss of the machine. So, the concentration should be given on the generation of pulse width modulation waveform such that the inverter output voltage magnitude can be maintained close to sinusoidal wave shape averaged over switching sub-cycle. This paper describes, how space vector pulse width modulation can be realized in direct control method by maintaining the hysteresis band of the stator flux path in a proper way. This band is varied in predefined way which depends on the angle of the reference voltage vector.

Keywords: Direct Torque Control, Sinusoidal Pulse Width Modulation (SPWM), Space Vector Pulse Width Modulation (SVPWM).

I . INTRODUCTION

IMPROVEMENTS in fast switching power devices have led to an increased interest in voltage source inverters (VSI) with pulse width modulation control (PWM). Control methods which generate the necessary PWM patterns have been classified as voltage controlled and current controlled PWM. This paper deals with voltage control PWM methods. Several voltage controlled PWM methods like sinusoidal PWM, sinusoidal PWM with third harmonic injection and space vector modulation. All these methods aim at generating a sinusoidal inverter output voltage without low-order harmonics. This is possible if the sampling frequency is high compared to the fundamental output frequency of the inverter. The performance of each of these control methods is usually judged based on the following parameters: a) Total harmonic distortion (THD) of the voltage and current at the output of the inverter, b) Switching losses within the inverter, c) Peak-to-peak ripple in the load current, and d) Maximum inverter output voltage for a given DC rail voltage. This paper deals with space vector modulation. Space vector modulation is based on representation of the three phase voltages as space vectors. Most space vector modulation schemes generate the same required output voltage but differ in their performance with respect to THD, peak-to-peak ripple and switching losses. The main objective of this paper is to recommend a scheme that is best suitable for a given application. Applications can be distinguished mainly based on their power level and hence the switching frequency or by the type of load. To achieve this goal space vector modulation scheme and SPWM comparison have been considered. The choice of these schemes was governed mainly by the performance criteria. Analysis was first performed for each of these schemes to develop expressions and generate a series of curves under various operating conditions. Then the circuit is simulated in MATLAB to verify the expressions developed and finally the modulation schemes were tested real-time on a prototype inverter to verify the results. The performance of these can be evaluated by rapid prototyping tools – dSPACE.

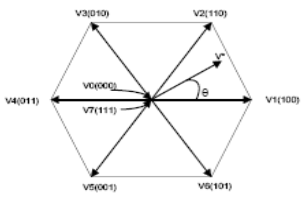
II. SWITCHING TECHNIQUE

When Sinusoidal Pulse Width Modulation (SPWM) In many industrial applications, Sinusoidal Pulse Width

Modulation (SPWM), also called Sine coded Pulse Width Modulation, is used to control the inverter output voltage. SPWM maintains good performance of the drive in the entire range of operation between zero and 78 percent of the value that would be reached by square-wave operation. If the modulation index exceeds this value, linear relationship between modulation index and output voltage is not maintained and the over-modulation methods are required.

Space Vector Pulse Width Modulation (SVPWM)

A different approach to SPWM is based on the space vector representation of voltages in the d, q plane. The d, q components are found by Park transform, where the total power, as well as the impedance, remains unchanged. Fig. 1 shows 8 space vectors in according to 8 switching positions of inverter, V* is the phase-to-center voltage which is obtained by proper selection of adjacent vectors V1 and V2.



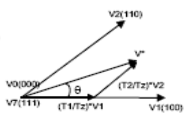


Fig. 1 Inverter output voltage space vector

Fig. 2 Determination of Switching times

The reference space vector V* is given by Equation (1), where T1, T2 are the intervals of application of vector V1 and V2 respectively, and zero vectors V0 and V7 are selected for T0.

V* Tz = V1 *T1 + V2 *T2 + V0 *(T0/2) + V7 *(T0/2) (1)

Fig. 3(a) shows that the inverter switching state for the period T1 for vector V1 and Fig. 3(b) is for vector V2, resulting switching patterns of each phase of inverter are shown in Fig. 4.

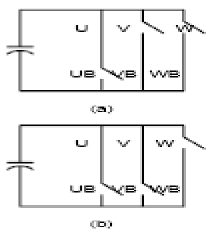


Fig. 3 Inverter switching state for (a)V1, (b) V2

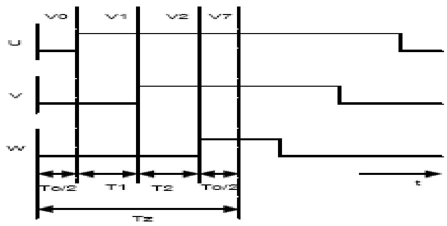
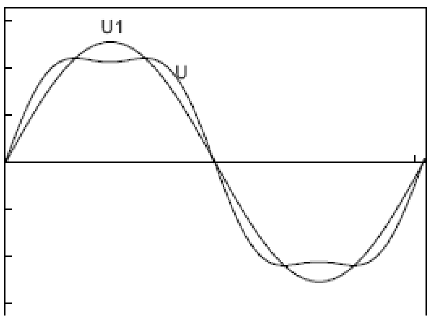


Fig. 4 Pulse pattern of Space vector PWM



In Fig. 5, U is the phase to-center voltage containing the triple order harmonics that are generated by space vector PWM, and U1 is the sinusoidal reference voltage. But the triple order harmonics are not appeared in the phase-to-phase voltage as well. This leads to the higher modulation index compared to the SPWM.

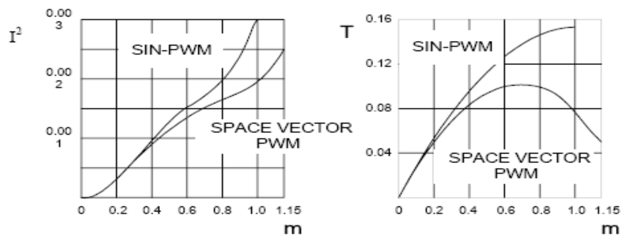
III. COMPARISON OF SPWM AND SPACE VECTOR PWM

As mentioned above, SPWM only reaches to 78 percent of square wave operation, but the amplitude of maximum possible voltage is 90 percent of square-wave in the case of space vector PWM.The maximum phase-to-center voltage by sinusoidal and space vector PWM are respectively;

Vmax = Vdc/2 : Sinusoidal PWM

Vmax = Vdc/√3 : Space Vector PWM

Where, Vdc is DC-Link voltage.This means that Space Vector PWM can produce about 15 percent higher than Sinusoidal PWM in output voltage.



(a)rms harmonic current (b) torque harmonics

Fig. 6 Current and torque harmonics

Simulation results in Fig. 6 show that the higher modulation index is, the less the harmonics of current and torque by space vector PWM are than those of sinusoidal PWM.

IV. MATLAB / SIMULINK DIAGRAM FOR SPWM AND SVPWM

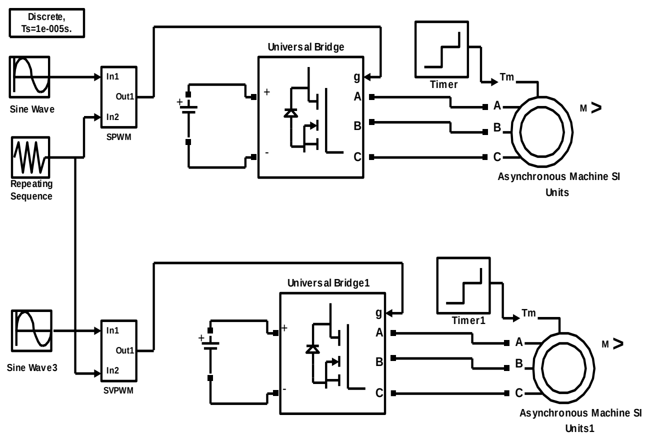


Figure.7. Simulation diagram for SPWM and SVPWM

V . HARMONIC ANALYSIS

Table 1 shows that THD variation with varying modulation index ma at constant carrier frequency fc = 2000Hz and maximum harmonic frequency considered for Fast Fourier Transform (FFT) is 8000Hz. We can notice that if ma is increased from 0 to 1 as THD is decreases. Table 2 shows that THD variation with varying carrier frequency fc and maintain constant ma=0.8 if fc increases the THD will decreases. Table 3 shows that total harmonic analysis of both SPWM and SVPWM.

Table.1. Comparative THD variation with modulation index vary at constant fc=2000hz

Carrier frequency (f_C)	THD (%) SPWM	THD (%) SVPWM
500	88.54	74.91
1000	86.57	72.91
1500	83.53	69.78
2000	80.08	66.25
2500	79.04	62.55
3000	68.92	56.88
3500	69.01	56.61

Table .2. THD variation with vary carrier frequency fc at constant ma=0.8

M_a	THD (%) SPWM	THD (%) SVPWM
0.2	161.92	157.26
0.4	136.66	127.34
0.6	105.07	127.34
0.8	80.08	66.25
1.0	59.25	44.9
1.2	51.47	40.17
1.4	48.25	37.47

VI .RESULTS AND DISCUSSION

The results of SVPWM technique has compared with SPWM technique. The fig.8 and fig.9 shows reference waveforms are compared with the carrier waveform, and make ensure the difference of reference waveforms improve harmonic optimization, as well as utilization of dc link voltage. The fig. 14 shows the graph of per unit value of fundamental component of line-line EMS voltage with base value of dc link voltage Vdc as function of modulation index ma, from this slope of SVPWM is steeper as compared to SPWM and hence dynamic performance improve in case of SVPWM. Fig. 17 shows the stator flux for inverter fed motor, here we notice that flux can stable before in case of SVPWM as compared to the SPWM, and hence give the good dynamic performance in case of SVPWM. The fig. 10 and fig. 11 shows the fundamental line-line RMS voltage 343 volts ,and THD is 80.08% for SPWM, in case of SVPWM fundamental line-line RMS voltage 392.7 volts and THD 66.25%, this shows the harmonic optimization and utilization of dc link voltage improved in case of SVPWM (switching frequency is 2000Hz and maximum harmonic frequency consider as 8000Hz for FFT analysis). Fig. 15 and 16 shows flux trajectory of inverter fed induction motor, where inverter is controlled by both SPWM and SVPWM techniques. Fig. 12 and fig.13 shows the developed torque of inverter fed induction motor, where inverter is controlled through SPWM and SVPWM techniques, ripple in the torque is less with SVPWM technique when compared to SPWM technique.

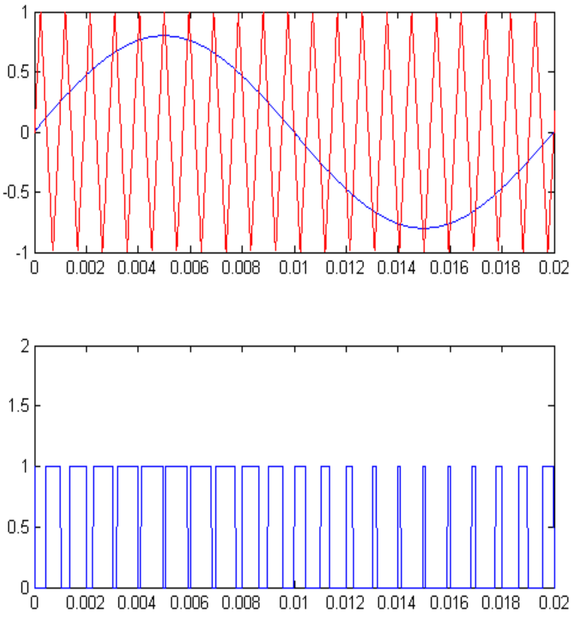


Figure.8. Generation of SPWM

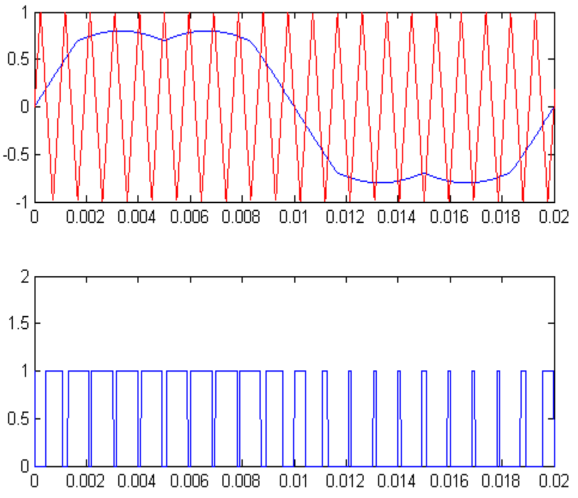


Figure.9. Generation of SVPWM

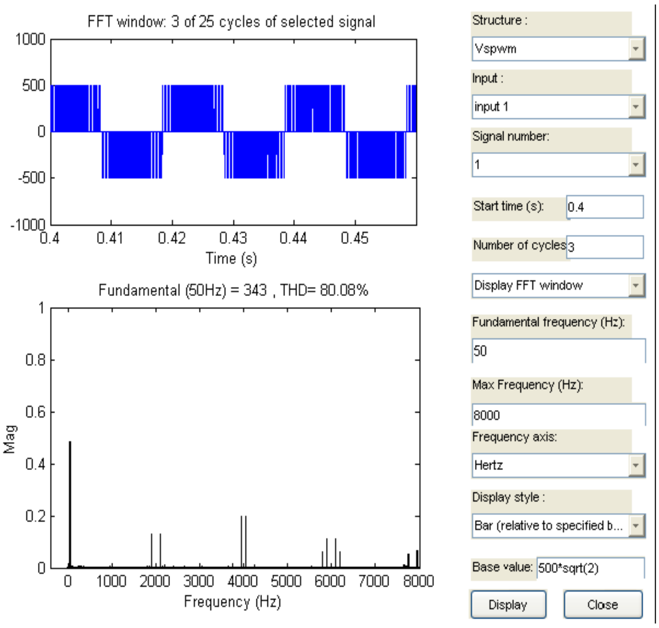


Figure.10. L-L voltage of SPWM

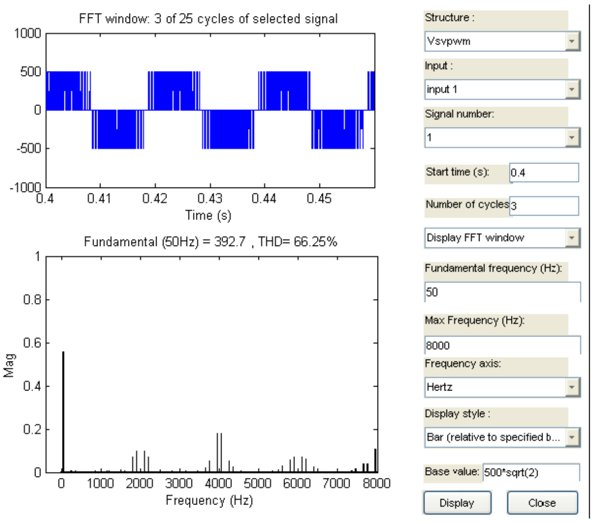


Figure.11. L-L voltage of SVPWM

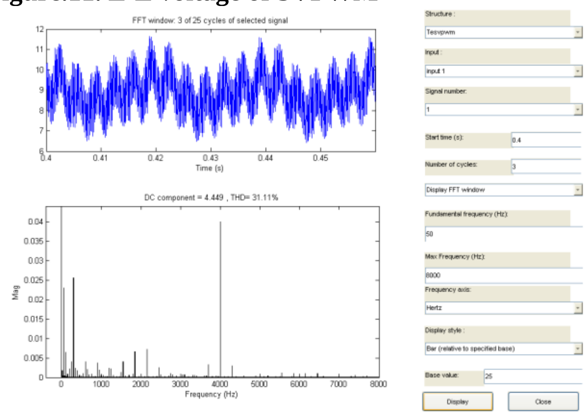


Figure.12. Torque for SPWM

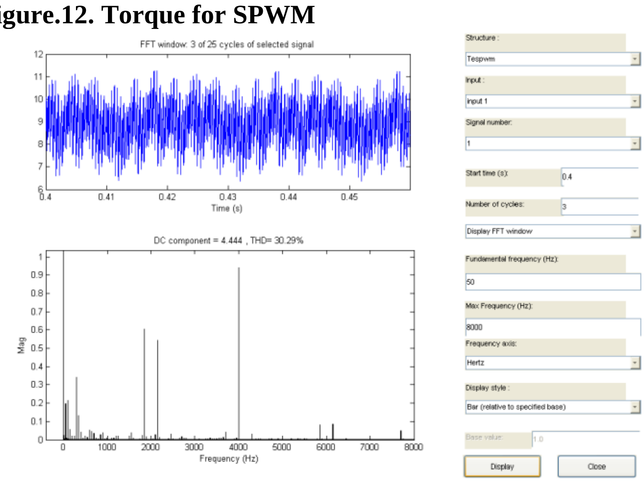


Figure.13. Torque for SVPWM

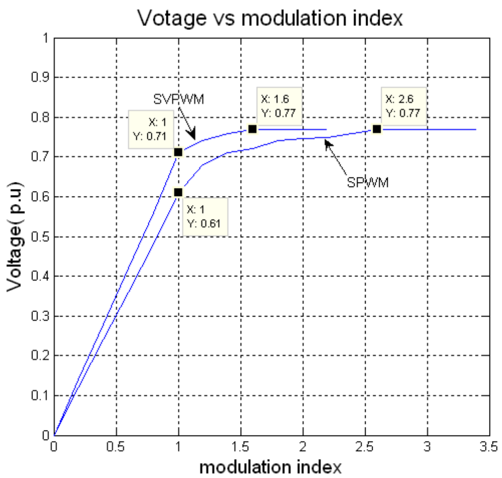


Figure.14. Voltage Vs Modulation Index

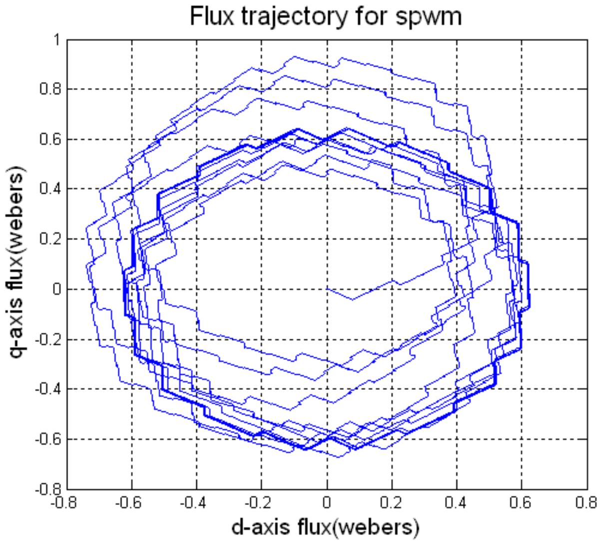


Figure.15. Flux trajectory for SPWM

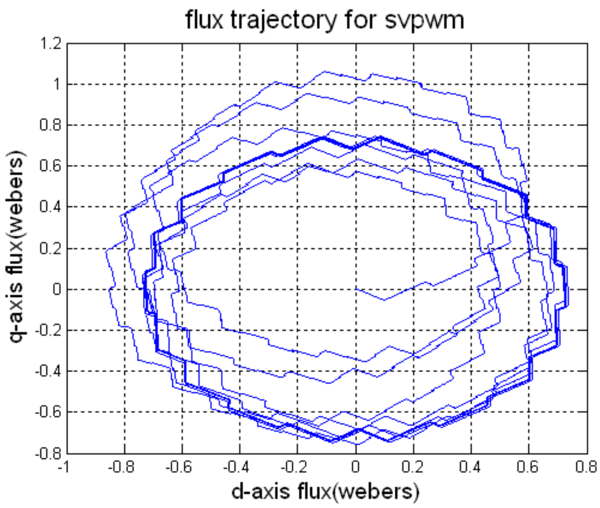


Figure.16. Flux trajectory for SVPWM

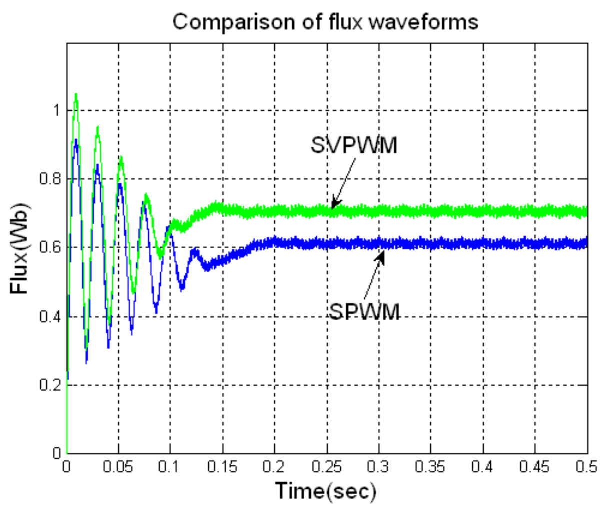


Figure.17. Comparison of flux waveforms

VII. CONCLUSIONS

From the obtained results it is concluded that SVPWM technique has less harmonic distortion than SPWM technique. Losses caused by switching frequency harmonics are reduced and hence the efficiency of motor is improved with SVPWM technique. Due to the effective utilization of DC link voltage in SVPWM technique, the inverter line-line output voltage is 15% more than that of SPWM technique. Hence it improves the efficiency of power processing unit. Because of steeper gradient characteristics of output voltage Vs modulation index the dynamic performance of the motor is improved.

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