Investigation of SPWM and SVPWM VSI for Induction Motor Drive

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Abstract—This paper investigates the different modulation techniques of voltage source inverter (VSI) for induction motor drive concerning the harmonic distortion. Two types of PWM strategies are analyzed under various operating conditions regarding total harmonic distortion. Both sinusoidal PWM and space vector PWM strategies have been analyzed. THD has a suitable value that reduces the torque ripple, since the high switching frequency provides high ripple. The system is simulated by using Matlab.

Index Terms: induction motor drive, space vector PWM, sinusoidal PWM, voltage source inverter.

1. Introduction

Torque ripple and THD with low switching frequency (fs) may develop an important problem in motor drive systems and it will be a source of mechanical oscillations. Since the switching frequency has typically a high value, it is related to the torque ripple. Mathematical modeling and analytical analysis of the three-phase VSI with SVPWM energizing an induction machine drives under DC link voltage ripple components [1-2]. It has been shown that DC link voltage ripple components with angular frequency may be a source of huge torque pulsation. In addition, torque ripple created in pulse width modulation inverter fed induction motor drives decreases both dynamic and static characteristics of drives. A current and torque ripple are produced due to an additional switching sequence that is embedded in the control. To solve these problems, a new algorithm of flux estimation is utilized [3].
Due to the high torque ripple, the inherent PWM voltage signal has been used in [4]. Thus, the temperature is calculated according to the change in the input impedance. In contrast, a synchronized PWM strategies are applied to minimize the switching frequency of the VSI in order to reduce the losses [5-6]. It is shown that THD of the stator current of the induction motor drives due to low fs can be reduced by using a synchronized PWM techniques. On the other hand, a low order harmonic pulsating torque is concerned [7] for high speed drives, high power drives, and machine drives operating in an over modulation area. It attempts to reduce the low order current harmonic and torque ripple in induction motor drives. A hybrid PWM technique is proposed [8]. It is significantly less than that according to conventional SVPWM at high speed induction motor drives.

An adjustable frequency modulation for machine drives that include deterministic, probabilistic (randomized or random), and chaotic PWM are directed at acoustic noise frequency spectrum spreading [9-10]. A multilevel VSI have been investigated by many authors [11-13]. A stepped voltage is obtained by using multiple input dc voltage that lowers the THD and improves the power quality. However, these systems are used for high power applications as well as, the multilevel inverter has effects on voltage levels that will be lost when the reference voltage is decreased according to the modulation index (MI) value. in addition, the individual harmonic content will be increased.

In this paper, both SPWM and SVPWM have been investigated for induction motor drives considering the total harmonic distortion. In addition, an experimental three phase induction motor drive SPWM VSI model has been applied practically to prove the results of the simulation.

2. Induction Motor Drive Modeling

The dynamic model of the induction motor assumes the following: uniform air gap, the inductance versus rotor position is sinusoidal and the saturation and parameter changes are neglected [8]. The model is simulated with Matlab / Simulinkis shown in Figure 1.
3. Induction Motor with SPWM on VSI Inverter

The Matlab/Simulink for an induction motor based on SPWM inverter is shown in Figure 2. The induction motor and its drive specifications are: Modulation Frequency = (FM) = 50 Hz. Rotor type (squirrel-cage), TM = 30 NM. Nominal power = 18450 VA, voltage (line-line) = 400 V, RS = 20 Ω, RR = 37 Ω, LS = 0.4 H, LR = 0.4 H, LM = 0.0354 H. Inertia = 0.001 (J(KG·M²)), friction factor = 0.00014 (N·M·S), pole pairs = 4. The value of carrier frequency (Fc) will be changed to illustrate its effects on the THD. The THD is calculated according to equation 1:

$$THD = \frac{1}{Vo1} \left( \sum_{n=2,3,\ldots}^{\infty} Vo1^2 \right)^{1/2} \quad (1)$$
4. Simulation Results

The Matlab/Simulink for an induction motor based on PWM inverter is shown in Figure 3. A PI controller have been used for speed, and currents regulators. The proportional and integral gains of the speed controller are 15 and 9000, respectively. Both current controllers are $K_p = 15$ and $K_i = 0.4$. The speed response takes a time of 0.025 to reach its reference.

The block diagram of the SVPWM generating pulses are shown in Figure 4 [8], where the inverter circuit is illustrated in Figure 5.

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Figure 4: SVPWM block diagrams

Figure 5: inverter circuit

The speed response for a reference of 1500rpm, three phase motor current, and electromagnetic torque response are shown in Figure 6.
Figure 6 Induction motor responses

Case 1: SPWM

Figures 7 and 8 show the simulation results of SPWM for induction motor when \( F_c = 5 \text{kHz} \) and \( F_c = 15 \text{kHz} \), respectively. THD equals 0.673 when \( F_c = 5 \text{kHz} \) which is less than its value for \( F_c = 15 \text{kHz} \).
Figure 7: SPWM simulation results when $F_c = 5 \text{ kHz}$, $THD = 0.673$

Figure 8: SPWM simulation results when $F_c = 15 \text{ kHz}$, $THD = 0.6938$
Case 2: SVPWM

Figures 9 and 10 show the simulation results of SVPWM for induction motor when $F_c = 5\, \text{kHz}$ and $F_c = 15\, \text{kHz}$ respectively. THD is 1.744 when $F_c = 15\, \text{kHz}$ which is less than that when $F_c$ becomes 5kHz. It can be observed that the control of the voltage phasor both in its magnitude and phase that will be sampled at every switching period leads to minimize the switching losses but higher voltage and current ripples.

![SVPWM simulation results](image)

**Figure 9**: SVPWM simulation results when $F_c = 5\, \text{kHz}$, $THD = 1.911$
5. Experimental Setup

The experimental system is implemented with a sinusoidal PWM as shown in Figure 11. The system includes 3 phase induction motor drive of 0.3kW, 400V, SPWM inverter with dc voltage of 300V, and oscilloscope. The experperimental results are shown in Figure 12 illustrating (a) the DC voltage of the inverter (300V), (b) the induction motor voltage , (c) the inverter signal at f=130Hz and (d) the inverter signal at f < 10Hz, respectively. It can be observed that the output voltage of the inverter is distorted when increasing the frequency of SPWM. Two transducers have been used for dc link voltage and the gate drive signals in order to make the system reliable and robust as well as the cost effective than that with using position sensor.
Figure 11: experimental setup

Figure 12: Experimental Results

(a) DC voltage  
(b) output voltage

(c) inverter waveform at f=130Hz  
(d) inverter waveform at f < 10Hz
6. Conclusion

From the contrasting on the current ripple caused by using various PWM strategies, it can be concluded that a good quality current signal is obtained with a low total harmonic distortion of 1.744 for a SVPWM at $F_c = 15\text{kHz}$ while with SPWM produces a low THDi of 0.673 at $F_c = 5\text{kHz}$.

The experimental results observed that the output voltage of the inverter is distorted when increasing the frequency of SPWM.

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