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Digital Simulation of Space Vector Modulation Based Induction Motor Drive

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Abstract: This study deals with simulation of Space vector modulated inverter fed induction motor drive. The drive system is modeled using matlab simulink and the results are presented. This drive has advantages like reduced harmonics and heating. Fixed AC is converted into DC and this DC is converted into variable voltage and variable frequency AC using SVM inverter. The output of SVM is applied to the stator of induction motor. The simulation results are compared with the analytical results. The FFT analysis shows that the current spectrum has reduced harmonics compared to the conventional system.

Key words: Induction motor, MATLAB, SVM, VSI

INTRODUCTION

Like most motors, an AC induction motor has a fixed outer portion, called the stator and a rotor that spins inside with a carefully engineered air gap between the two. Virtually all electrical motors use magnetic field rotation to spin their rotors. A three-phase AC induction motor is the only type where the rotating magnetic field is created naturally in the stator because of the nature of the supply. DC motors depend either on mechanical or electronic commutation to create rotating magnetic fields.

There is no direct approach to have the controlled outputs from the commanded inputs. So it is necessary to generate equivalents of the inputs for the output control. This is achieved by three-phase to two-phase transformation where the output equivalent currents for flux and torque respectively are obtained. The per phase equivalent circuit of the machine, is valid only in steady state condition. In adjustable speed drives, the machine normally constituted as element within a feedback loop, and therefore its transient behavior has to be taken into consideration. Besides, high performance over control, such as space vector control is based on the dynamic d-q model of the machine. Therefore, we go for d-q model to understand space vector control principle. The machine model can be described by differential equations with time-requires mutual inductance, but such a model tends to be very complex.

Ciro *et al*. (2002) developed space vector modulation Algorithm for Torque control of Inverter fed Induction Motor Drive. The Advent of vectorial control strategies in conjunction with space vector modulation techniques for voltage source inverters have made possible to achieve high quality current and torque responses in induction motor drives. Ebenezer *et al*. (1998) developed sensorless Vector Control Scheme for Induction Motors using a Space Phasor based Current Hysteresis Controller. This scheme measures the stator current hysteresis error direction to determine the rotor flux position, during inverter zero vector states. This measurement of the rotor flux position is done indirectly by sensing the motor back emf. Williamson and Healey (1996) developed space Vector representation of advanced motor models for vector controlled induction motors. This method presents a transient induction motor model that accounts for skin effect and saturation in both the main and rotor leakage flux paths is described and also shown that magnetizing flux oriented control is a more suitable form of vector control. Joao *et al*. (2001) discussed Stator-flux-oriented Vector-Controlled Induction Motor Drive with Space-Vector PWM and Flux-Vector Synthesis by Neural Networks. This method used the ANN's, when implemented by dedicated hardware application-specific integrated circuit chips, provide extreme simplification and fast execution for control and feedback signal processing functions in high performance ac drives. Kuo-Kai and Hsin-Jang (1995) discribed Variable Structure Current Control for Induction Motor Drives by Space Voltage Vector PWM. This method proposed current controller, which is based on space voltage vector PWM

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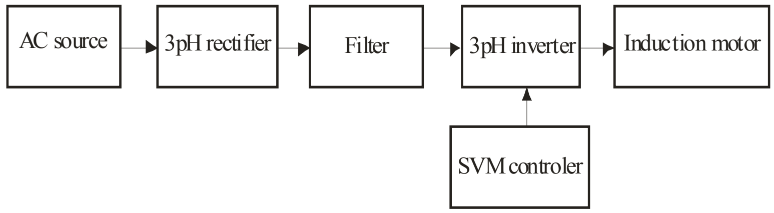

Fig. 1: Block diagram of SVM1 fed induction motor drive

drive, exhibits several advantages in terms of reduced switching frequency, robustness to parameter variations, elimination of current/torque ripple, and improved performance in induction motor drive. Chakrabarti *et al*. (1997) used Space Vector Modulation Based Pulse Width Modulation for reduction of Torque Ripple in Direct Torque Control of Induction Motor Drives. This method approaches the switching instants of different space vectors are determined to reduce torque ripple compared to commonly used space vector concept based on sinusoidal PWM technique. A Variable Structure Controller Approach is given by Brahmananda *et al*. (2006) for Sensor less Direct Torque Control of Induction Motor based on Hybrid Space Vector Pulse width Modulation to Reduce Ripples and Switching Losses. This scheme for direct torque control of induction machines using hybrid space vector PWM to reduce switching losses and the study state ripple in torque and flux. Zelechowski *et al*. (2005) designed Controller for Direct Torque Controlled Space Vector Modulated (DTC-SVM) Induction Motor Drives. In a DTC-SVM scheme the switching harmonics are neglected in the control algorithm. Pedro and Ramirez (2004) developed Fuzzy Logic Controller Based on Space Vector Modulation for Induction Motor Control. This method adopts a new direct torque control scheme which reduces the stator flux ripple and keeps the switching frequency constant using space vector modulation based on fuzzy logic controller. Hadiouche *et al*. (2000) conducted simulation studies of Space Vector PWM Control of Double-Star Induction Motors. The modeling of DSIM is made using an arbitrary shift angle between the two-three phase windings.

SPACE VECTOR MODULATION

The block diagram of SVM inverter fed induction motor drive is shown in Fig. 1. SVM compares a high frequency triangular waveform with modified waveform to generate pulses. Mathematical modeling can be implemented by the following steps.

Step 1: Determine V_d,V_q, V_{ref} and angle (á) (Fig. 2):

$$\begin{aligned} V_d &= V_{an} - v_{bn}\cos 60 - V_{cn}\cos 60 \\ &= V_{an} - ½\, V_{bn} - ½\, V_{cn} \\ V_q &= 0 + V_{bn}\cos 30 - V_{cn}\cos 30 \\ &= 0 + \sqrt{3}/2.\, V_{bn} - \sqrt{3}/2\,.\, V_{cn} \end{aligned}$$

$$\therefore \begin{bmatrix} V_d \\ V_q \end{bmatrix} = \tfrac{2}{3}\begin{bmatrix} 1 & -\tfrac{1}{2} & -\tfrac{1}{2} \\ 0 & \tfrac{\sqrt{3}}{2} & -\tfrac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix}$$

$$\therefore \left|\overline{V}_{ref}\right| = \sqrt{V_d^2 + V_q^2}$$

$$\therefore \alpha = \tan^{-1}\left[\frac{V_q}{V_d}\right] = \omega t = 2\pi f t$$

where, f = fundamental frequency.

Step 2: Determine time duration T_1, T_2, T_0 (Fig. 3).
The switching time duration can be calculated as follows:
Switching time duration at Sector 1:

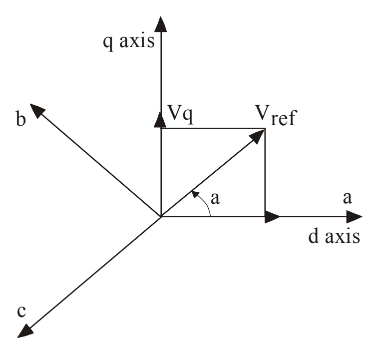

Fig. 2: Voltages V_d and V_q

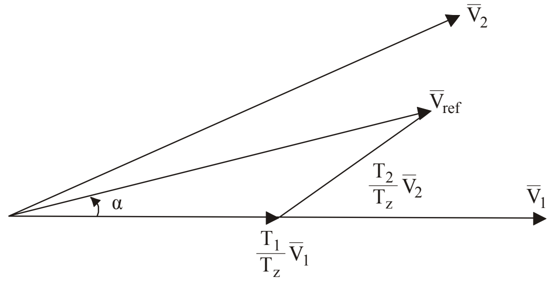

Fig. 3: Reference vector realization at sector 1

$$\int_0^{Tz} \overline{V}_{ref}\, dt = \int_0^{Tz} \overline{V}_1 dt + \int_{T_1}^{T_1+T_2} \overline{V}_2 dt + \int_{T_1+T_2}^{Tz} \overline{V}_0 dt$$

$$T_z.V_{ref} = T_1.V_1 + T_2.V_2$$

$$T_z.\left|V_{ref}\right|.\begin{bmatrix} Cos(\alpha) \\ Sin(\alpha) \end{bmatrix} = T_1.\tfrac{2}{3}.V_{dc}.\begin{bmatrix} 1 \\ 0 \end{bmatrix} + T_2.\tfrac{2}{3}.V_{dc}.\begin{bmatrix} Cos(\pi/3) \\ Sin(\pi/3) \end{bmatrix}$$

(where, $0 \le \alpha \le 60$)

Table 1: Switching sequence

Sector	Upper Switches (S_1, S_3, S_5)	Lower Switches (S_4, S_6, S_2)
1	$S_1=T_1+T_2+T_0/2$	$S_4= T_0/2$
	$S_3=T_2+T_0/2$	$S_6=T_1+T_0/2$
	$S_5= T_0/2$	$S_2=T_1+T_2+T_0/2$
2	$S_1=T_1 +T_0/2$	$S_4=T_2+T_0/2$
	$S_3= T_1+T_2+T_0/2$	$S_6= T_0/2$
	$S_5= T_0/2$	$S_2=T_1+T_2+T_0/2$
3	$S_1= T_0/2$	$S_4=T_1+T_2+T_0/2$
	$S_3= T_1+T_2+T_0/2$	$S_6= T_0/2$
	$S_5=T_2+T_0/2$	$S_2=T_1+T_0/2$
4	$S_1= T_0/2$	$S_4=T_1+T_2+T_0/2$
	$S_3=T_1+T_0/2$	$S_6=T_2+T_0/2$
	$S_5=T_1+T_2+T_0/2$	$S_2= T_0/2$
5	$S_1=T_2+T_0/2$	$S_4=T_1+T_0/2$
	$S_3= T_0/2$	$S_6=T_1+T_2+T_0/2$
	$S_5=T_1+T_2+T_0/2$	$S_2= T_0/2$
6	$S_1=T_1+T_2+T_0/2$	$S_4= T_0/2$
	$S_3= T_0/2$	$S_6=T_1+T_2+T_0/2$
	$S_5=T_1+T_0/2$	$S_2=T_2+T_0/2$

$$\therefore T_1 = T_z.a.\frac{Sin(\pi/3-\alpha)}{Sin(\pi/3)} \quad \therefore T_2 = T_z.a.\frac{Sin(\alpha)}{Sin(\pi/3)}$$

$$\therefore T_0 = T_z - (T_1 + T_2)$$

where, $T_z = \frac{1}{f_z}$ and $a = \frac{\left|\overline{V}_{ref}\right|}{\frac{2}{3}V_{dc}}$

Step 3: Determine the switching time of each transistor (S_1 to S_6). The switching sequence is listed in Table 1.

The switching sequence tables for the lower and upper thyristors are shown above. The above construction of the symmetrical pulse pattern for two consecutive T_z

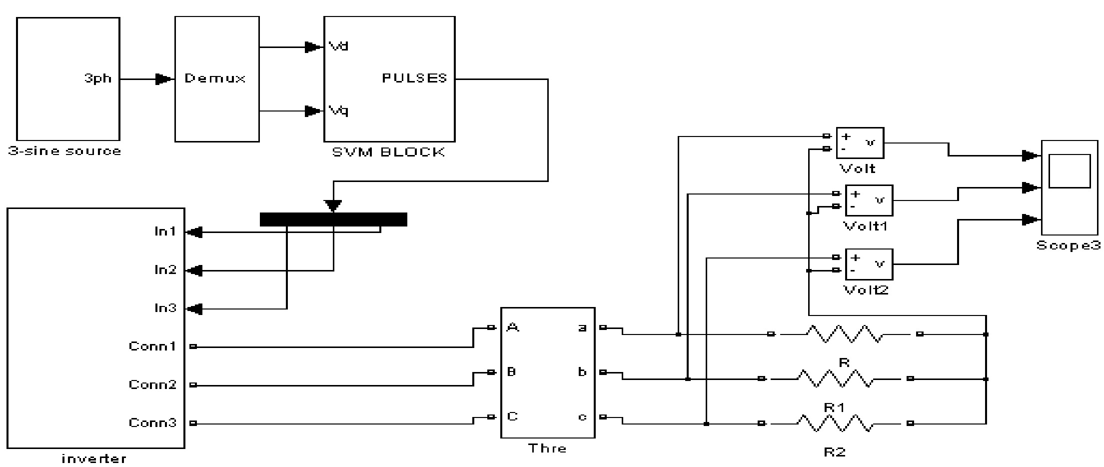

Fig. 4a: SVM based VSI inverter fed resistive load

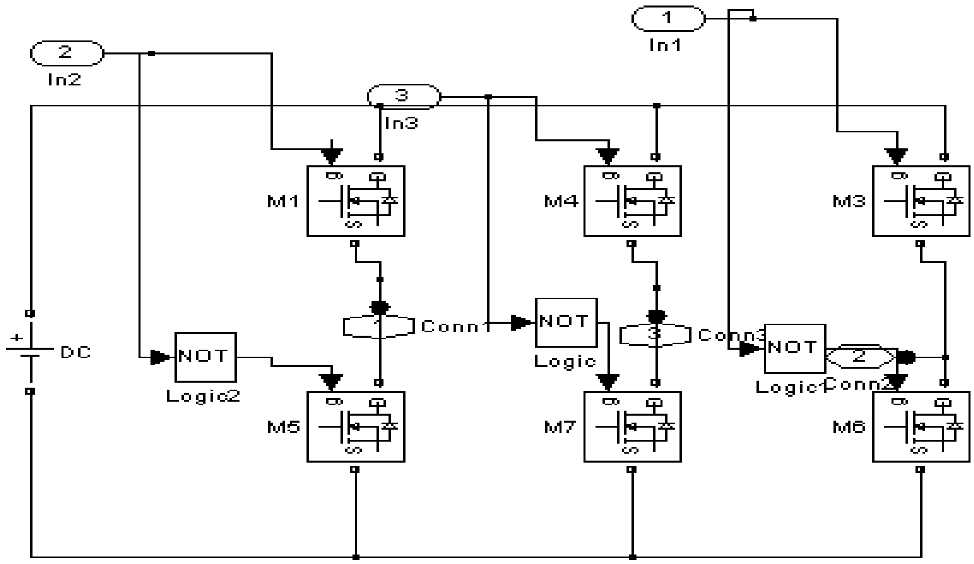

Fig. 4b: Inverter model

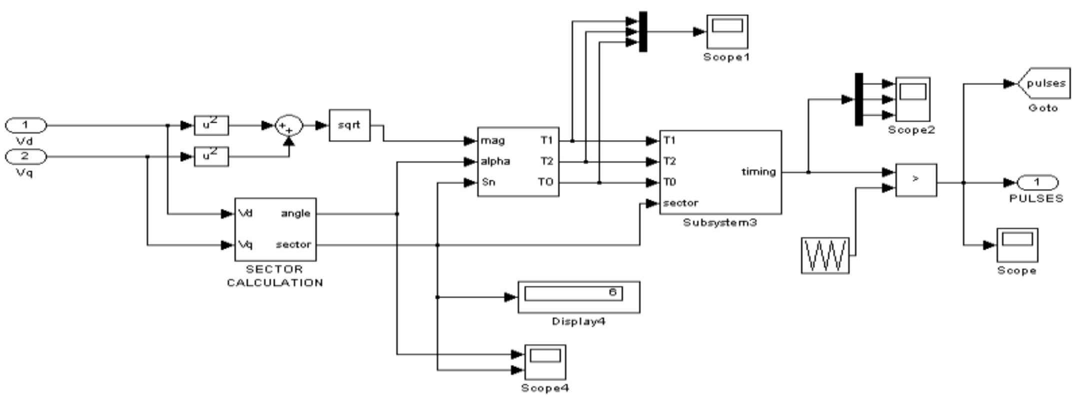

Fig. 4c: SVM model

intervals are shown and $T_s = 2T_z = 1/f_s$ (f_s = switching frequency) is the sampling time. Note that the null time has been conveniently distributed between V_0 and V_7 vectors to describe the symmetrical pulse width.

SIMULATION RESULTS

The induction motor drive system is simulated using matlab and the results are presented. From Fig. 2 the angle V_d, V_q, V_{ref} and (á) can be calculated. From Fig. 3 the switching time duration can be calculated. The simulink circuit diagram of SVM inverter is shown in Fig. 4a. Inverter circuit alone is shown in Fig. 4b. The details of SVM system is shown in Fig. 4c. The driving pulses for the mosfets 1, 3 and 5 are shown in Fig. 4d. The phase voltages of the inverter are shown in Fig. 4e. They are displaced by 120º and line voltages are shown in Fig. 4f. They are also displaced by 120º. The line currents are shown in Fig. 4g.

The simulink diagram of SVM inverter fed induction motor is shown in Fig. 5a. The speed is indicated by using a display block. A scope is connected to display the driving pulses. The phase voltages are shown in Fig. 5b. The line currents are shown in Fig. 5c. The line currents

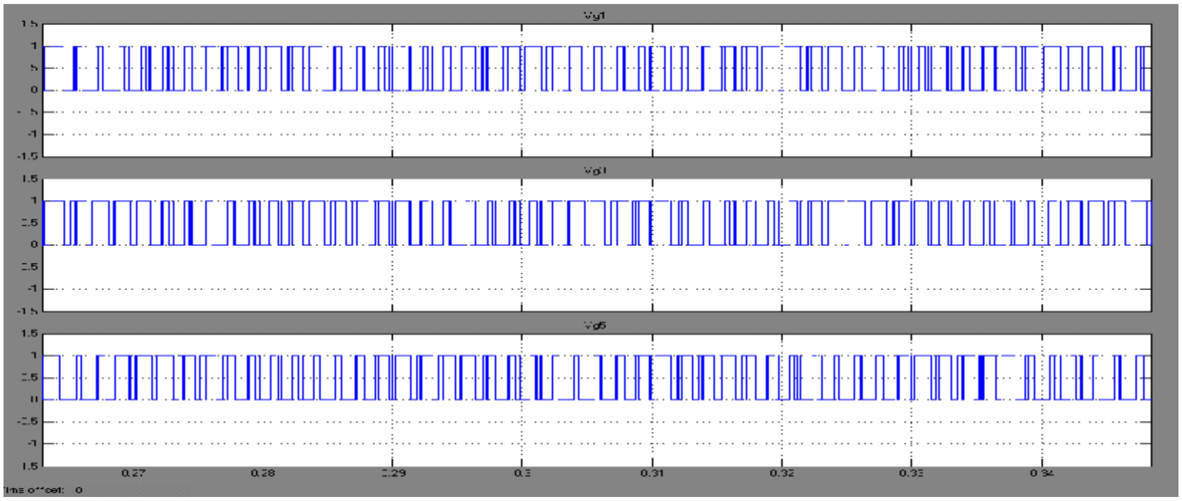

Fig. 4d: Driving Pulses (1,3,5 mosfets)

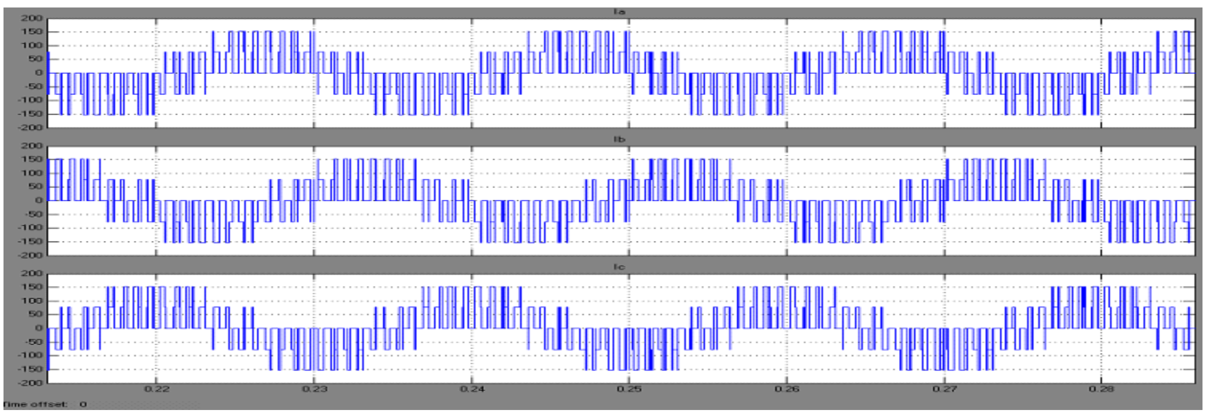

Fig. 4e: Phase voltages

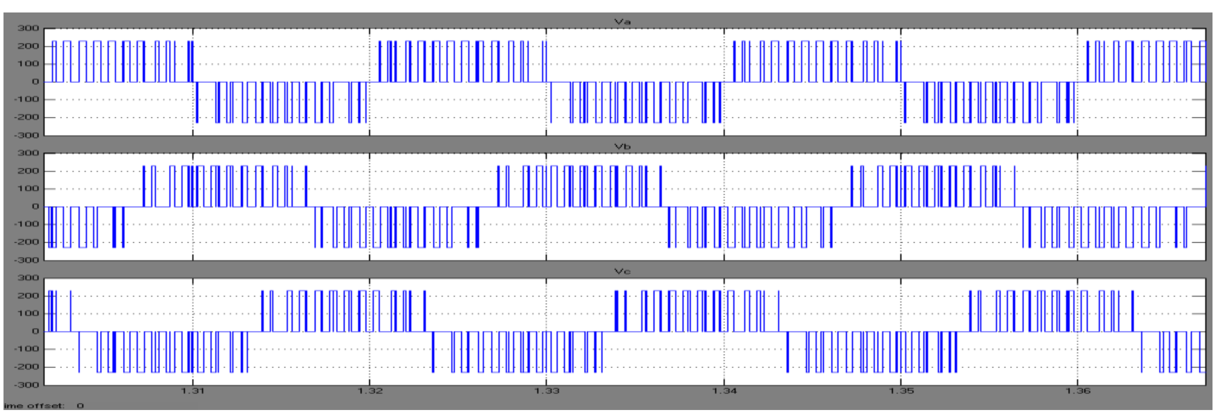

Fig. 4f: Line voltages

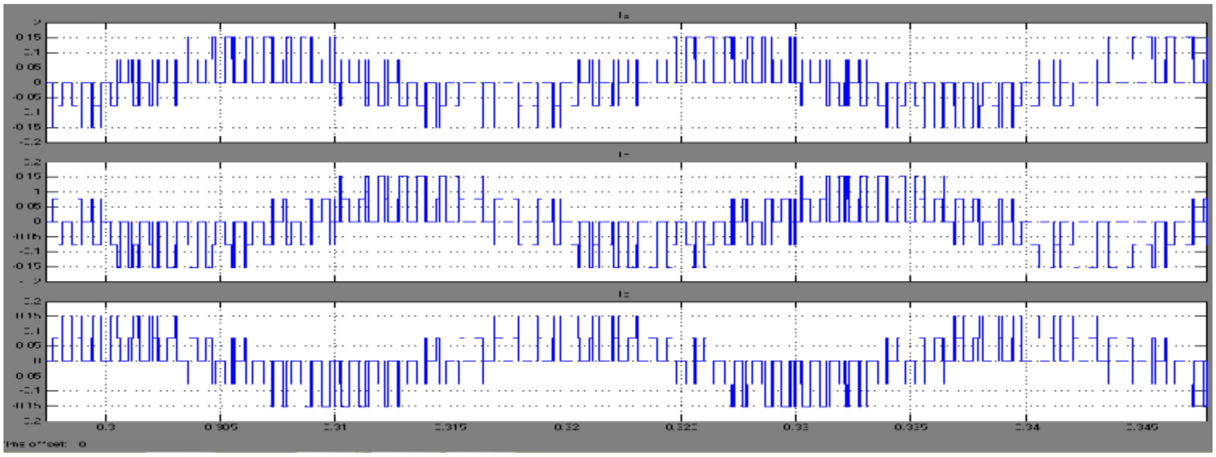

Fig. 4g: Line currents

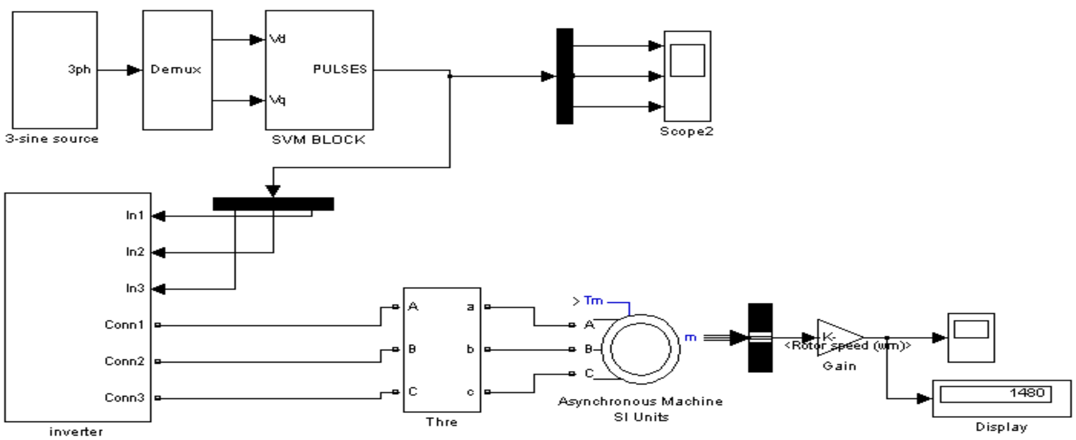

Fig. 5a: SVM Inverter fed induction motor drive

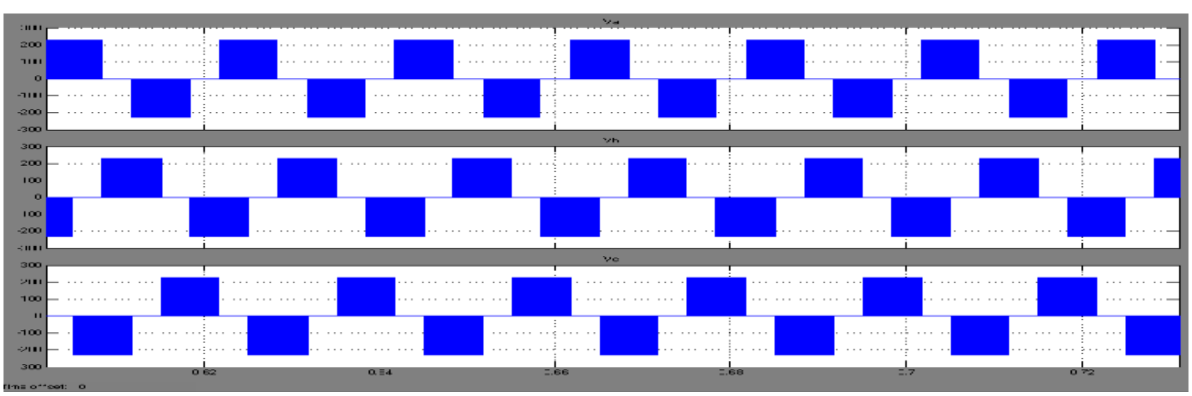

Fig. 5b: Phase voltages

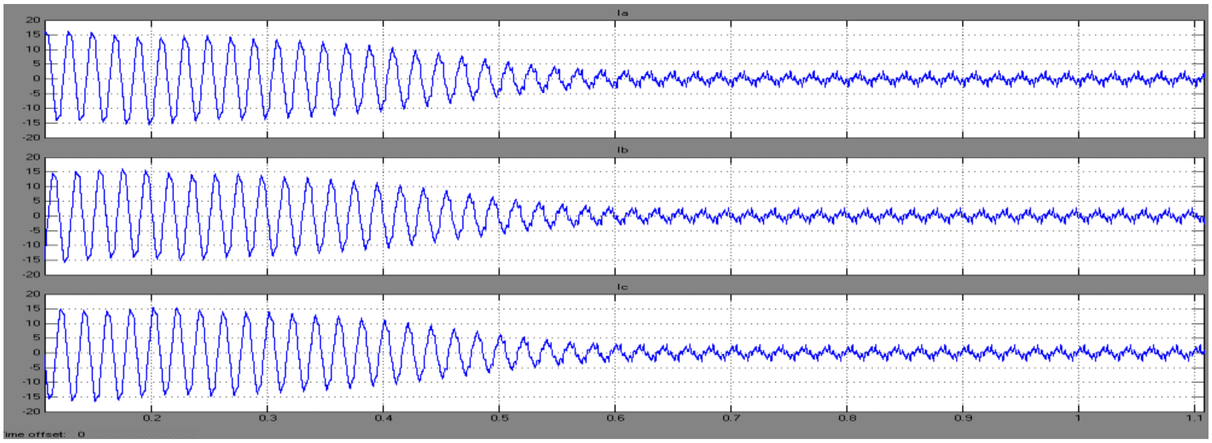

Fig. 5c: Line currents

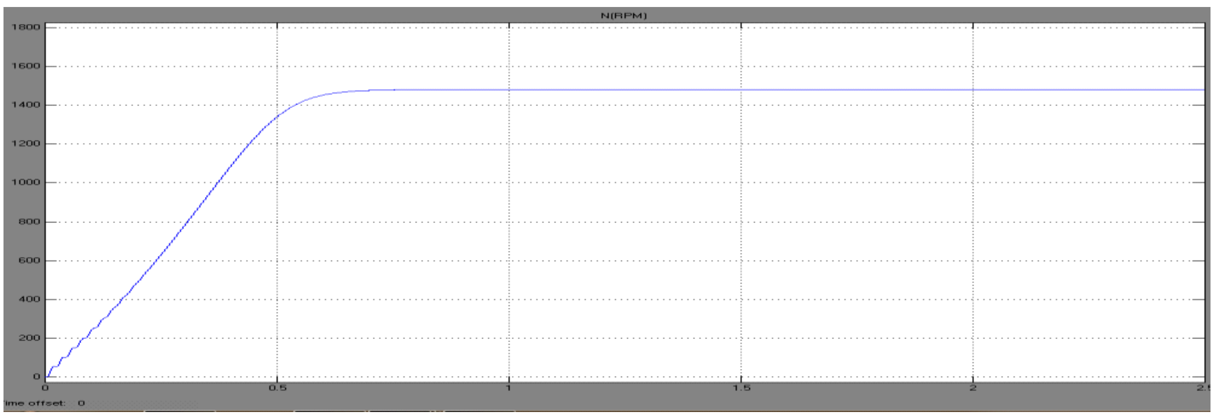

Fig. 5d: Rotor speed in rpm

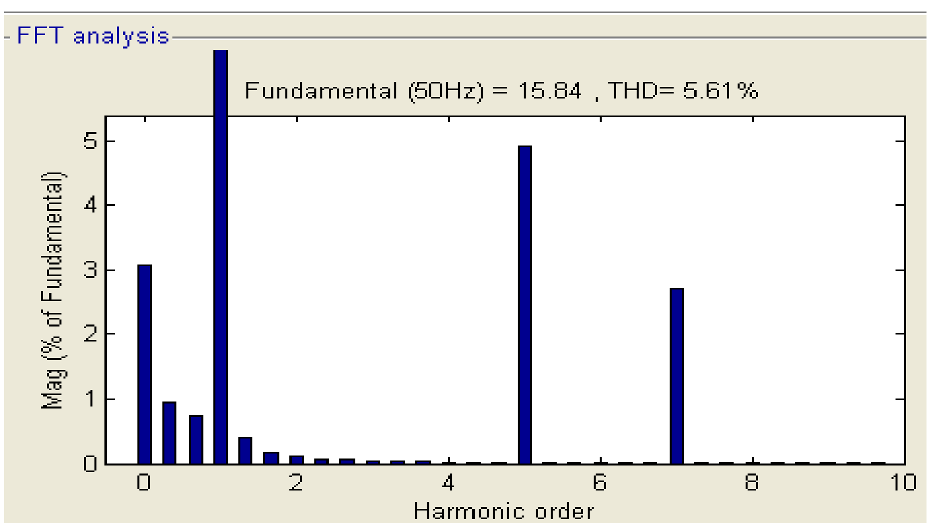

Fig. 5e: FFT analysis for curren

are high at starting and they reduce to the steady state value. The response of the speed is shown in Fig. 5d. The speed settles at 1450 r.p.m. FFT analysis is done and the spectrum for the current is shown in Fig. 5e. The THD value is 5.6%.

CONCLUSION

SVM inverter fed induction motor drive is modeled and simulated successfully using mat lab simulink & the results are presented. The FFT analysis shows that the current spectrum has reduced harmonics compared to the conventional system. The present work indicates that SVM inverter fed induction motor drive is an economical drive with reduced harmonics. The simulation results are in line with the predictions. This study deals with the simulation of the induction motor drive system. The hardware implementation is beyond the scope of this study.

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