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Simulation Of A 4-Switch,3-Phase Inverter Fed Induction Motor (IM) Drive System

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ABSTRACT

This paper investigates the performance of a 4-switch, 3-phase inverter (4S3P) fed cost effective induction motor (IM)drive system for high performance industrial drive systems. In the proposed approach, instead of a conventional 6-switch, 3-phase inverter (6S3P) a 4-switch, 3-phase inverter is utilized. This reduces the cost of the inverter, the switching losses, and the complexity of the control algorithms and interface circuits to generate 6PWM logic signals. The Simulation results of the proposed 4S3P inverter fed drive is also made in terms of speed response &total harmonic distortion (THD) in terms of stator current and inverter current. The proposed inverter fed IM drive is found acceptable considering its cost reduction and other advantageous features. A general space vector pulse width modulation (SVPWM) method for control of four-switch three-phase inverters is presented.

Keywords: FSTPI- Four Switch Three Phase Inverter, IM-Induction Motor, SVPWM-Space Vector Pulse Width Modulation, PWM- Pulse Width Modulation, THD-Total Harmonic Distortion. 3-pahse inverter, speed control

Introduction

Over the years induction motor (IM) has been utilized as a workhorse in the industry due to its easy build, high robustness, and generally satisfactory efficiency. With the invent of high speed power semiconductor devices three-phase inverters play the key role for variable speed ac motor drives. Traditionally 6-switch, 3-phase (6S3P) inverters have been widely utilized for variable speed IM drives. This involves the losses of the six switches as well as the complexity of the control algorithms and interface circuits to generate six PWM logic signals.In the past, researchers mainly concentrated on the development of the efficient control algorithms for high performance variable speed IM drives. However, the cost, simplicity and flexibility of the overall drive system which become some of the most important factors did not get that much attention to the researchers. That is why, despite tremendous research in this area most of the developed control system failed to attract the industry. Thus, the main issue of this paper is to develop a cost effective, simple and efficient high performance IM drive.

A. THE DRIVE SYSTEM AND CONTROL APPROACH

The block diagram of the proposed system is shown in Fig.1. The block diagram of the proposed system is shown in Fig.1.The drive system consists of a 3 phase AC supply, 3 phase Diode bridge Rectifier, 3 phase four switch Inverter, 3-phase Induction Motor and controlled circuits. The standard AC power supply is converted to a DC by using a 3-phase diode bridge rectifier. A voltage source FSTPI is used to convert the DC voltage to the controlled AC voltage. The output of FSTPI is fed to 3-phase induction motor. VHDL program is used in Xilinx software to generate the controlled PWM pulses at different duty ratio for FSTPI to drive the Induction Motor at different speeds.

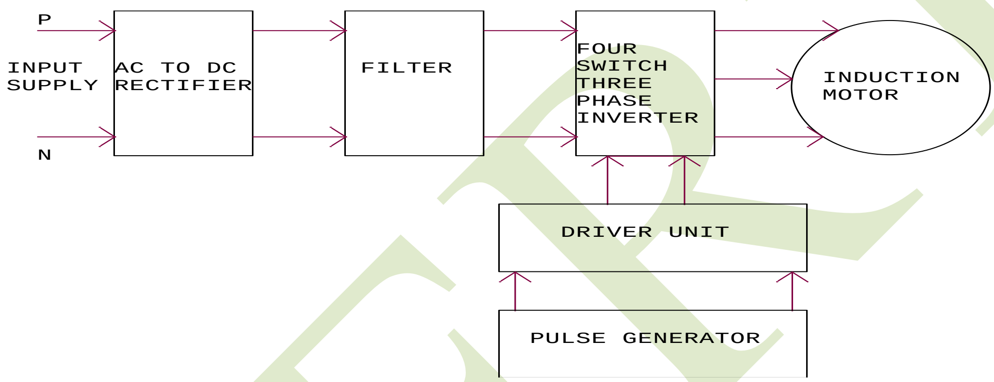

Figure.1. Block diagram of computational scheme

The complete drive system involves IM, inverter and the controller, which are discussed in the following subsections [1]:

1. Inverter model:

The power circuit of the IM fed from 4S3P voltage-source inverter is shown in Fig.1. The circuit consists of two parts; first part is a front-end rectifier powered from single-phase supply [2]. The output dc voltage is smoothed through a two series connected capacitors. The second part of the power circuit is the three-phase four-switch inverter. The maximum obtainable peak value of the line voltages equals Vdc, in the analysis, the inverter switches are considered as ideal switches. The output voltages are defined by the gating signals of the two leg switches and by the two dc link voltages, Vdc. The phase voltages equations of the motor can be written as a function of the switching logic of the switches. [3]

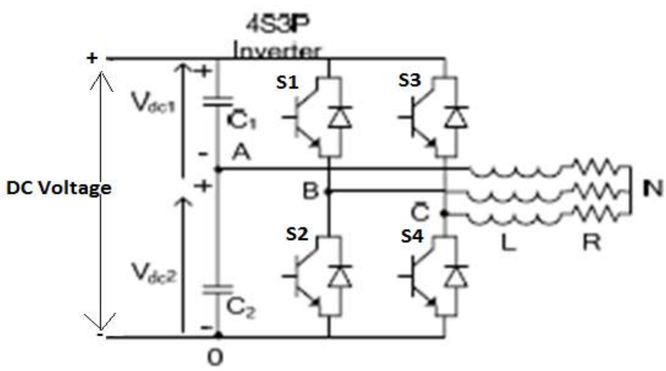

Figure.2.FSTPI

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Fig. 2. presents the circuit diagram of a 4S3P inverter fed by a three-phase diode rectifier. The 4S3P inverter topology consists of four switches that provide two inverter output phases: B and C. The third output phase, phase A, is connected to the midpoint of the two split capacitors. The zero potential point is defined as point 0 in Fig.2.

The phase-to-zero voltages VA0, VB0 and VC0 depend on the switching states of S1, S2, S3 and S4, and two dc-link voltages (Vdc1, Vdc2). The phase-to-zero voltages are determined as follows:

$$V_{A0}=V_{dc2} \qquad (1)$$

$$V_{B0}=S_1(V_{dc1}+V_{dc2}) \qquad (2)$$

$$V_{C0}=S_2(V_{dc1}+V_{dc2}) \qquad (3)$$

Where Vdc is the total dc-link voltage. Vdc1, Vdc2 are voltages across two capacitors C1 and C2, respectively.[3]

Switching state Sx = 0 when the switch Sx is off and Sx = 1 when the switch Sx is on (x=1,2). The following equations are obtained under balanced load conditions:

$$V_{AN}+V_{BN}+V_{CN}=0 \qquad (4)$$

$$V_{A0}+V_{B0}+V_{C0}-3V_{N0}=0 \qquad (5)$$

$$V_{N0}=\frac{V_{A0}+V_{B0}+V_{C0}}{3} \qquad (6)$$

From (4)-(6), the phase-to-neutral voltages VAN, VBN and VCN are derived:

$$V_{AN}=\frac{2}{3}V_{A0}-\frac{1}{3}(V_{B0}+V_{C0}) \qquad (7)$$

$$V_{BN}=\frac{2}{3}V_{B0}-\frac{1}{3}(V_{A0}+V_{C0}) \qquad (8)$$

$$V_{CN}=\frac{2}{3}V_{C0}-\frac{1}{3}(V_{A0}+V_{B0}) \qquad (9)$$

By solving the above equations of 7,8,9 using the values from 1,2,3 we can derive the equations:

$$Van=2/3Vdc[1-S1-S2]$$

$$Vbn=Vdc/3[4S1-2S2-1]$$

$$Vcn=Vdc/3[4S2-2S1-1]$$

Table:1 Switching function ,Switching thyristors and Phase & Line voltages

Switching Functions		**Switching Thyristors**		**Van**	**Vbn**	**Vcn**	**Vab**	**Vbc**	**Vca**
S1	**S2**								
0	0	T2	T4	2/3Vdc	-Vdc/3	-Vdc/3	Vdc	0	-Vdc
0	1	T2	T3	0	-Vdc	Vdc	Vdc	-2Vdc	Vdc
1	0	T1	T4	0	Vdc	-Vdc	-Vdc	2Vdc	-Vdc
1	1	T1	T3	-2/3Vdc	Vdc/3	Vdc/3	-Vdc	0	Vdc

2. Control Approach:

With the 4S3P inverter, the unbalance between the halves of the split capacitors is the main cause directly affecting its ability to generate balanced output currents. The dc-link voltage ripples occur for several reasons. The first is caused by rectification of the power supply. The second occurs as a result of phase current circulating through the dc-link capacitors. The solution for output distortions can be carried out by increasing the capacitances of two dc-link capacitors, but this increases the cost and size of the 4S3P inverter. Hence, some compensating methods were suggested to generate a balanced output without increasing the capacitance of the dc-link capacitors and that method is SVPWM .[3]

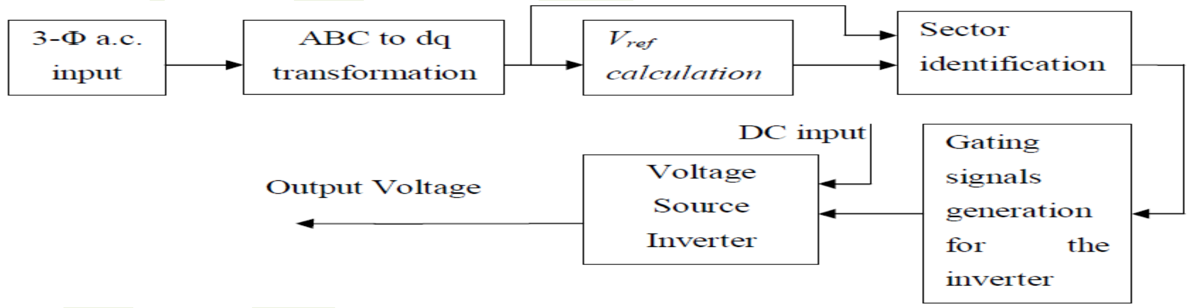

Figure.3.Block Diagram of SVPWM

Realization of Space Vector PWM :

Step 1. Determine Vd, Vq, Vref, and angle (α) Step
2. Determine time duration T1, T2, T0
Step 3. Determine the switching time of each transistor (S1 to S4)

Two phase voltage representation:

We can represent the two phase by referring the following equations:[6]

Vqn=Vcn and

Vdn =1/√3(Van-Vbn)=1/√3Vab

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Table 2: Two phase voltage representation

Vectors	**S1**	**S2**	**Vd**	**Vq**	**V=Vd+jVq**
V1	0	0	Vdc/√3	-Vdc/3	(2Vdc/3)e^-j2π/3
V2	1	0	Vdc/√3	-Vdc	(2Vdc/√3)e^-j π/6
V3	1	1	- Vdc/√3	Vdc/3	(2Vdc/3)e^j π/3
V4	0	1	- Vdc/√3	Vdc	(2Vdc/√3)e^ 5π/6

Table 3: Magnitude, angle& sector representation

Sector	Range of angles
1	$-120^0 < \alpha < -30^0$
2	$-30^0 < \alpha < 60^0$
3	$60^0 < \alpha < 150^0$
4	$150^0 < \alpha < 180^0$
4	$-180 < \alpha < -120^0$

Vectors	Magnitude	Angle (α)
V_1	2/3 V_{dc}	-120^0
V_2	2/√3 V_{dc}	-30^0
V_3	2/3 V_{dc}	60^0
V_4	2/√3 V_{dc}	150^0

By using the combination of sector time we are calculating the switching time for 4 switches Vref signal lies between 3 vectors such as zero vector (corresponding time T0)and two adjacent vectors T1 and T2 so by using T0=Ts-(T1+T2) we are calculating total time for rotating reference vector. And by using that total time we are calculating switching time for each switch ,finally by using total time angle and dc source we are calculating switching time to trigger switch .[3] [2]

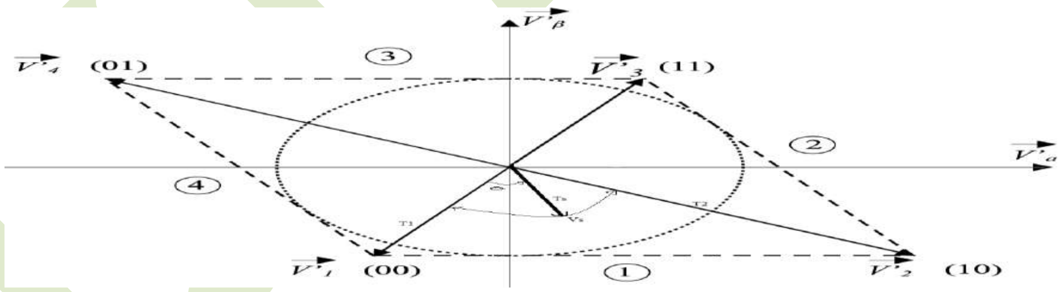

Fig 4: Time durationTs,T1 & T0

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Table 4: Determine time duration T1, T2, T0

SECTOR 1	SECTOR 2
$T_1 = \frac{3\, V_{ref} Ts \cos(\alpha)}{2V_{dc}}$ $T_2 = \frac{\sqrt{3}\, V_{ref} Ts \sin \alpha}{2V_{dc}}$ $T_0 = Ts - (T_1 + T_2)$	$T_2 = -\frac{\sqrt{3}\, V_{ref} Ts \sin(\alpha)}{2V_{dc}}$ $T_3 = -\frac{3\, V_{ref} Ts \cos(\alpha)}{2V_{dc}}$ $T_0 = Ts - (T_2 + T_3)$
SECTOR 3	**SECTOR 4**
$T_3 = -\frac{3\, V_{ref} Ts \cos(\alpha)}{2V_{dc}}$ $T_4 = -\frac{\sqrt{3}\, V_{ref} Ts \sin(\alpha)}{2V_{dc}}$ $T_0 = Ts - (T_3 + T_4)$	$T_4 = \frac{\sqrt{3}\, V_{ref} Ts \sin(\alpha)}{2V_{dc}}$ $T_5 = \frac{3\, V_{ref} Ts \cos(\alpha)}{2V_{dc}}$ $T_0 = Ts - (T_4 + T_5)$

Table. 5: Determine the switching time of each transistor (S1 to S4)

sector	Upper switches	Lower switches
1	S1=T2+To/2 S3=To/2	S2=T1+To/2 S4=T1+T2+To/2
2	S1=T1+T2+To/2 S3=T2+To/2	S2= To/2 S4=T1+To/2
3	S1=T1+T2+To/2 S3=T1+To/2	S2=T2+To/2 S4= To/2
4	S1= To/2 S3=T1+To/2	S2=T1+T2+To/2 S4=T2+To/2

We know max possible phase voltage without over modulation is $1/\sqrt{3}$ Vdc

$\therefore$ amplitude of line-line = Vdc

Line-line voltage increased by: $$\frac{V_{dc} - \frac{\sqrt{3}}{2} V_{dc}}{\frac{\sqrt{3}}{2} V_{dc}} x100 \approx 15\%$$

B. SIMULATION WORK AND RESULTS

This FSTPI fed drive system consists of a three-phase diode bridge rectifier, a split capacitor, four switch three phase inverter and 3- phase squirrel cage Induction Motor. Input supply voltage: 3-phase, 415 V (rms), 50 Hz;□ Induction Motor: 0.25 HP 415 V, 50 Hz, 1430 rpm. Vabc and Iabc block is used to display the 3-phase voltage and current waveforms. The Simulation circuit diagram of the drive system is shown in Fig A. This circuit contains 3-phase input AC power supply, diode bridge rectifier, split capacitor, 4-IGBT switches and 3-phase 3hp IM. The 3-phase output currents of FSTPI ia, ib and ic with IM are shown in Fig.B. The speed and torque characteristics of induction motor with load are shown in Fig C and Fig D respectively It is observed that the speed increases linearly and reaches the rated speed (1430 rpm) at steady state in 0.75 sec. At starting the torque increases and reduces to a minimum value when the speed reaches the rated value.

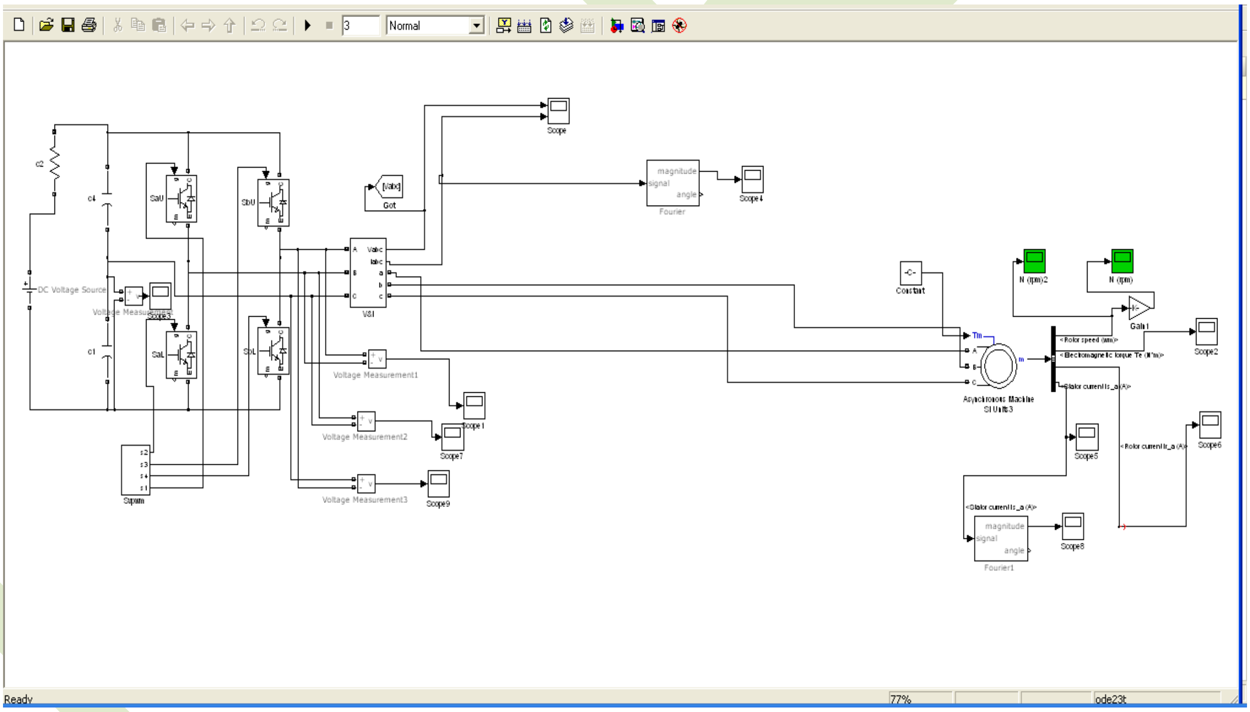

Fig. .A. Simulink diagram FSTPIM

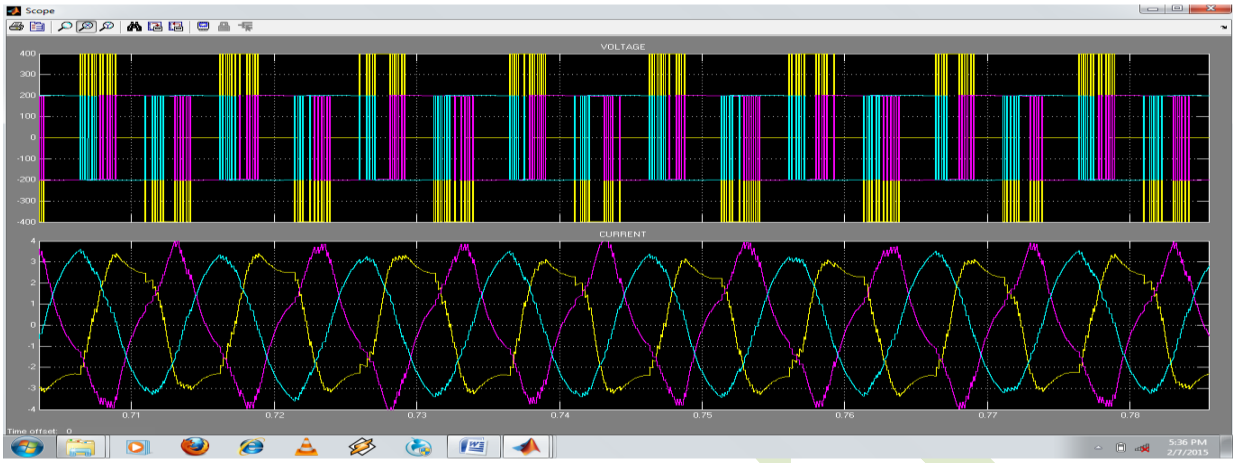

Fig B. 3 phase voltage and current

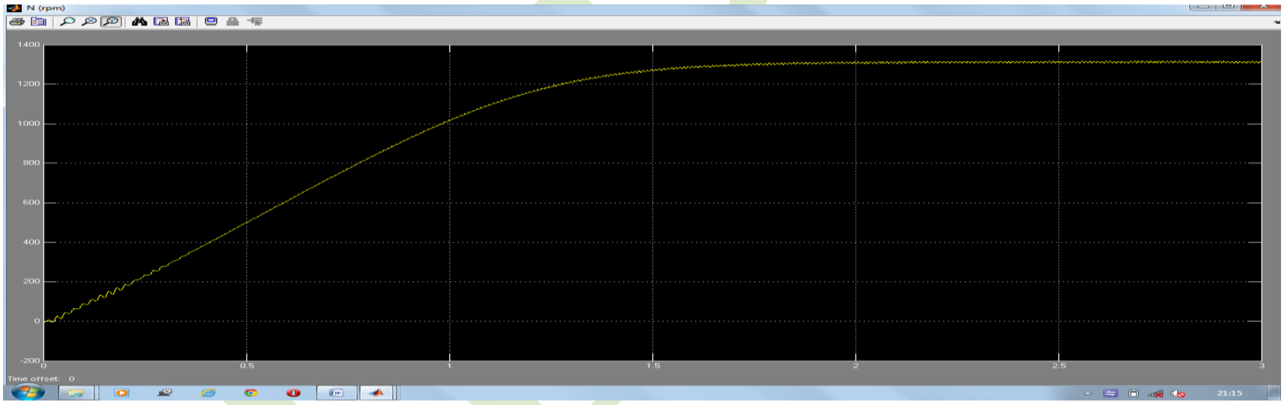

Fig .C. Speed characteristics

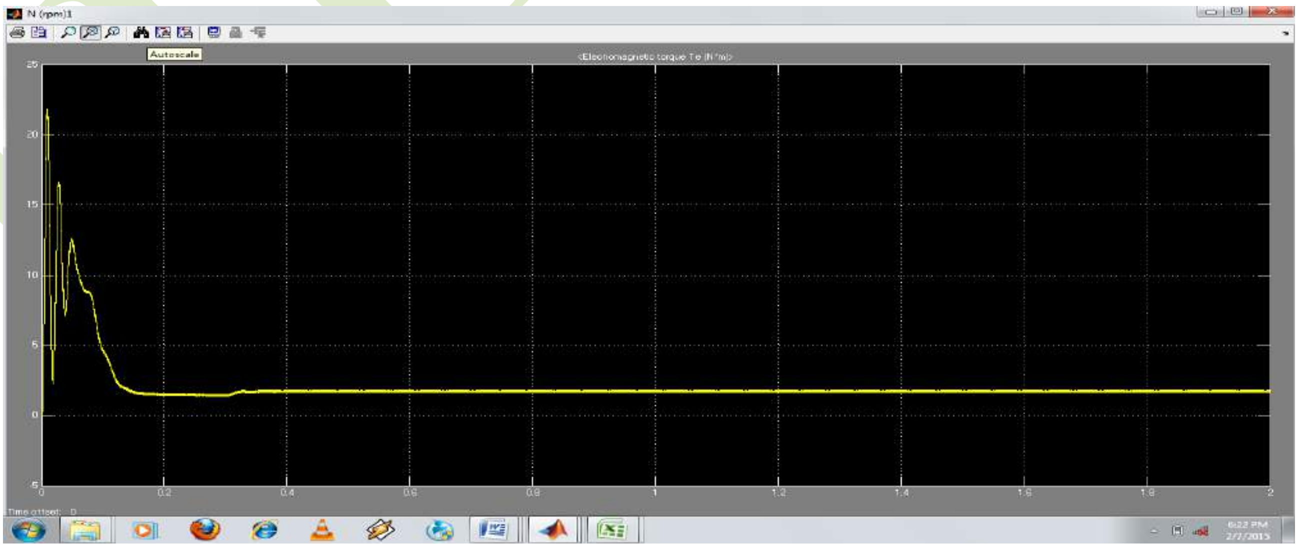

Fig .D.Torque Characteristics

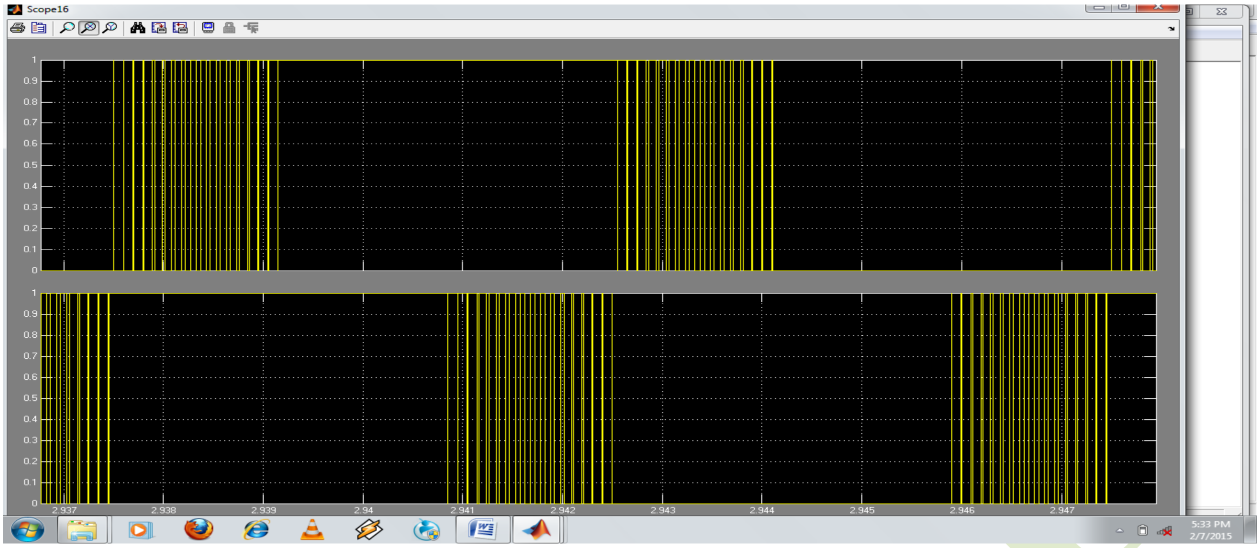

Fig .E.Switching Characteristics

V. CONCLUSION

A cost effective FSTP inverter fed IM drive has been simulated successfully. This paper presents a complete simulink model development and analysis for four switch three phase inverter fed synchronous reluctance motor drive. The results obtained and presented in this work indicate that the proposed control scheme produces very fast response of the Synchronous IM drive. The drive also shows good performance in speed operation under the effect of load disturbances, parameter variation, and reversal of speed. The proposed control scheme with low cost implementation is suitable for commercial applications. A SVPWM based implementation of FSTPI fed IM drive using PWM control is successfully carried out in simulation. MATLAB SIMULINK is used for simulation and the hardware implementation can be carried out using SPARTAN-3 processor. The proposed FSTP inverter fed PMSM drive is found acceptable considering its cost reduction and other advantageous features.

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