Performance Analysis Of Induction Motor For Voltage Mode And Current Mode Control

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Abstract - *At the present time, the vector control technique is widespread used in high performance induction motor drive. The performance of hysteresis controller and SVPWM method in a vector controlled drive is designed. The THD analysis of vector controlled drive is also analysed. With hysteresis current controller, the Fast Fourier transformer profile of the output voltage generated by the VSI is similar to that of a space vector modulated VSI, by maintaining nearly constant switching frequency. Variations in machine parameters can contribute to change in desired switching frequency. The proposed controller assures that the VSI is switched in a pattern similar to SVM. Space vector based and hysteresis current controlled VSI fed IM drive is simulated using MATLAB R2017a.*

Key Words: Space vector, Switching frequency, MATLAB, dSPACE

1. INTRODUCTION

Induction motor is widely used in the industries due to its exclusive features such as high robustness, high reliability and efficiency as well as low cost and maintenance. This results to its increased demand in high performance applications. Using the through vector control method, the induction motor is able to be controlled like a DC motor. The 3-phase stators and 3-phase rotors are considered as two fundamental parts of a 3-phase AC induction motor. When the 3-phase stators are energized by the 3-phase AC power source, current flow is generated in the stators. The magnetic field synthesized by 3-phase stator current is always rotating incessantly with the variation of the current. This rotating magnetic field cuts the rotor and the current generated in it interacts with the rotating magnetic field and thus produces the magnetic torque which makes the rotor rotate. The rotating speed of the rotor n should be less than that of the rotating magnetic field. Reverse rotating of the rotor will be realized by two of the 3-phase power source positions exchanged.

The rotating direction of the rotating magnetic field is consistent with the current phase and its speed is proportional to the power source frequency f and inversely proportional to the magnetic polar pair number.

SVPWM is a modulation algorithm which translates phase voltage (phase to neutral) references, coming from the controller, into modulation times/duty-cycles to be applied to the PWM peripheral. It is a general technique for any three-phase load, although it has been developed for motor control. For induction machines, the most common choices for the direct axis is to align it to the rotor field (rotor FOC) or to the stator field (stator FOC). SVPWM just does a lot of sampling, calculating and wave form manipulation. SV means space vector, as in space vector modulation. SVM basically allows a 3-phase bridge PWM drive to supply about 15 percent higher peak voltage to a motor than the standard sine-triangle modulation scheme by allowing the neutral point of the motor to move away from the nominal 1/2 of the supply rail. The Space Vector Pulse Width Modulation (SVPWM) refers to a special switching sequence of the upper three power devices of a three-phase voltage source inverters (VSI) used in application such as AC induction and permanent magnet synchronous motor drives. It is a more sophisticated technique for generating sine wave that provides a higher voltage to the motor with lower total harmonic distortion. Space Vector PWM (SVPWM) method is an advanced; computation intensive PWM method and possibly the best techniques for variable frequency drive application. SVPWM generates less harmonic distortion in the output voltages and currents in the windings of the motor load and provides a more efficient use of the DC supply voltage in comparison with sinusoidal modulation techniques. Since SVPWM provides a constant switching frequency; the switching frequency can be adjusted easily. The basic principle of SVPWM is based on the eight switch combinations of three phase inverter. The switch combinations can be represented as binary codes that correspond to the top switches S_1, S_3 and S_5 of the inverter. Each switching circuit generates three independent pole voltages V_{ao}, V_{bo} and V_{co}.

2. PERFORMANCE ANALYSIS OF INDUCTION MOTOR FOR VOLTAGE MODE AND CURRENT MODE CONTROL

Principle Of Hysteresis Current Controller

In hysteresis current control the actual current tracks the command current within a hysteresis band. Spacevector modulation (SVM) is an algorithm for the control of pulse-widthmodulation[1]. Space vector based hysteresis controller for VSI fed IM drive is introduced. Hysteresis current controller has a simple implementation, fast transient response and direct limitation of the peak current. Hysteresis current control is relatively a simple method for PWM technique with comparatively good current loop response.

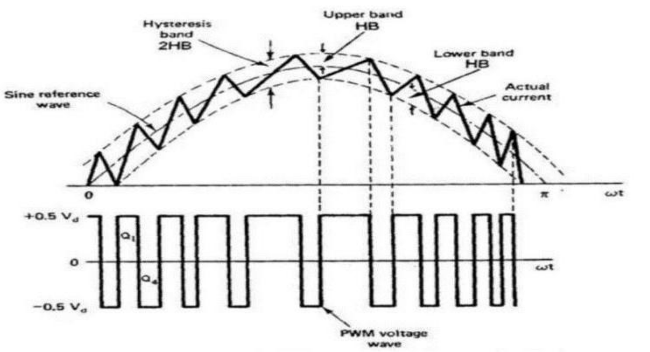

Figure 1 –Hysteresis current control

As shown in Figure 1, current control under hysteresis band principle operation in generating the PWM switching signals. The actual phase current is compared to sinusoidal wave references current which are produced by the control circuit. The upper switch (S_1) is turned off and the lower switch (S_4) is turned on when the actual current exceeds the higher band limit. As a results, the output voltage changes from +0.5V_{dc} to -0.5V_{dc}. The actual current start to decrease and drop until it crosses the lower band limit. At this time, the lower switch is turned off and the upper switch is turned on. Then, the output voltage changes from -0.5 V_{dc} to +0.5 V_{dc} and the current starts to increase. This process is then continuously repeated.

Principle Of SVPWM Based Induction Motor Drive

A space vector is a sinusoidal voltage vector with constant amplitude and rotating at constant frequency. It is used for the creation of alternating current (AC) waveforms; most commonly to drive 3 phase AC powered motors at varying speeds from DC.

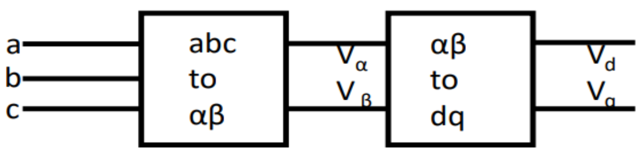

Figure 2 –abc to dq transformation

To implement space vector modulation, a reference signal V_{ref} is sampled with a frequency f_s (T_s = 1/f_s). The reference signal may be generated from three separate phase references using the αβ transform as shown in Figure 2. The reference vector is then synthesized using a combination of the two adjacent active switching vectors and one or both of the zero vectors

3. DESIGN OF COMPONENTS

Clark transformation or αβγ transformation is a mathematical transformation employed to simplify the analysis of three-phase circuits. One very useful application of the αβ transformation is the generation of the reference signal used for space vector modulation control of three-phase inverters.

Rotating Space Vector, $U_{(t)}$ is represented as

$$U_{(t)}=(U_a+ U_b e^\wedge(j(2/3)*pi)+ U_c e^\wedge((j(-2/3)*pi)2/3)$$

The voltage vector V_1 is given by the

$$V_1 = \frac{2V\text{dc}}{3}$$

The general equation for voltage vector,

$$V_n = \frac{2}{3}V_{dc} \quad * \; e^{\,j(n-1)*pi/3}$$

Three-phase VSI generates eight switching states which include six active and two zero states. These vectors form a hexagon which consisting of six sectors spanning 60 each. The reference vector which represents three-phase sinusoidal voltage is generated using SVPWM by switching between two nearest active vectors and zero vector.

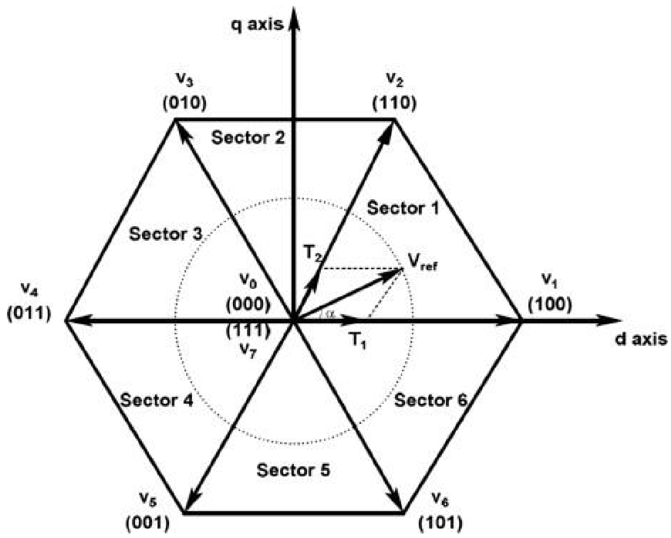

Figure 3- Switching sectors of three phase inverter

To calculate the time of application of different vectors, consider Figure3, depicting the position of differently available space vectors and the reference vector in the first sector. Table 1 shows the switching states correponding to space vector. The sinusoidal reference space vector form a circular trajectory inside the hexagon. The largest output voltage magnitude that can be achieved using SVPWM is the radius of the largest circle that can be inscribed within the hexagon. This circle is tangential to the mid points of the lines joining the ends of the active space vector.

Table 1-Switching states corresponding to Space Vector

Voltage vectors	Switching vectors			Line to neutral voltage			Line to line voltage		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_0
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

Table 2 – Switching time in all sectors

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

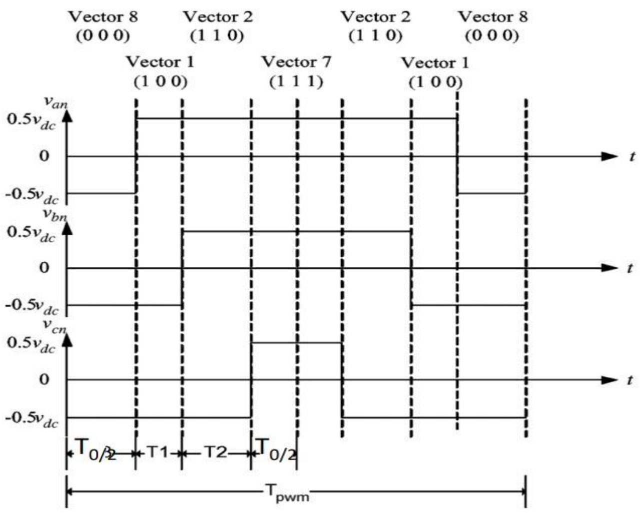

Figure 4– Space vector sequences

Figure 4 shows the leg voltages and space vector disposition for one switching period in sector I.

3. SIMULATION AND RESULTS

❖ SVPWM based controller

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MATLAB is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy way to use environment where problems and solutions are expressed in familiar mathematical notation. SIMULINK is a software package for modelling, simulating, and analysing dynamical systems.

Simulation parameters for 1HP Induction Motor is given in Table 3. Simulink model for vector controlled IM drive and hysteresis controller is designed. Simulation is carried out using 1HP induction motor with following parameters.

Table -3: Simulation parameters

Parameters	Specification
Stator Resistance	0.087Ω
Stator Inductance	0.8mH
Rotor Resistance	1.157 Ω
Rotor Inductance	0.8mH
Mutual Inductance	34.7mH
Inertia	0.03Kg.m^2
Friction Factor	0.1Nms
Pole Pair	2

The Space Vector PWM for VSI Fed IM Drive is simulated in MATLAB/SIMULINK by choosing the parameters listed in Table 3 and the Simulink model is shown in Figure 5. The gate pulse generation circuit is shown in figure 6. The gate pulse is generated by converting the three phase quantity into two phase quantity and then obtained V_{ref} and angle. From there time period for each leg is calculated and compared to generate the pulses for each switches.

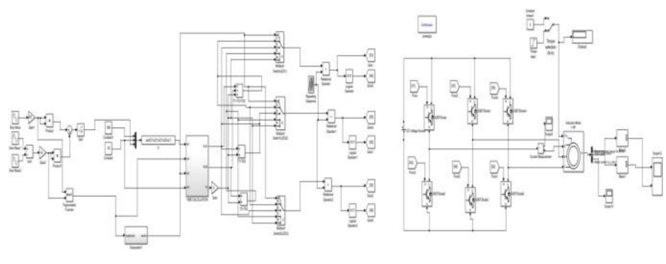

Fig 5 – Simulink mode lof SVPWM based IM Drive

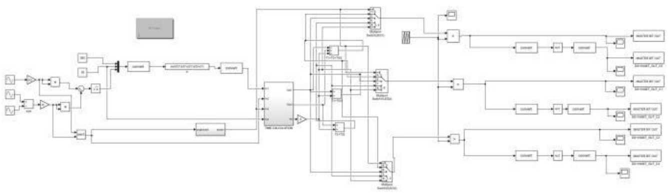

Figure 6 – Gate pulse generation circuit

The simulation results of the Space Vector Based Hysteresis Controller for VSI Fed IM Drive are shown in the following figures. Three phase Input voltage is shown in figure 7 to obtain SVPWM. Simulation is carried out by using 1HP motor and parameters are calculated by using No-load and blocked rotor test.

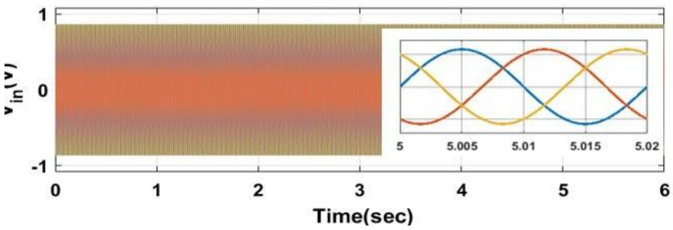

Figure 7- Input voltage

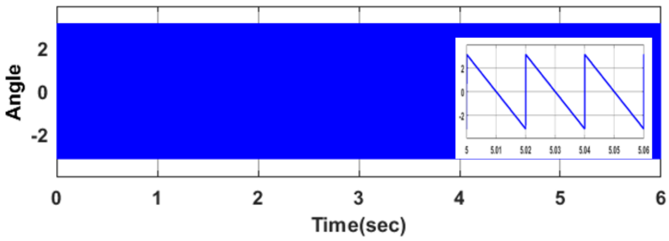

Figure 8 - Angle

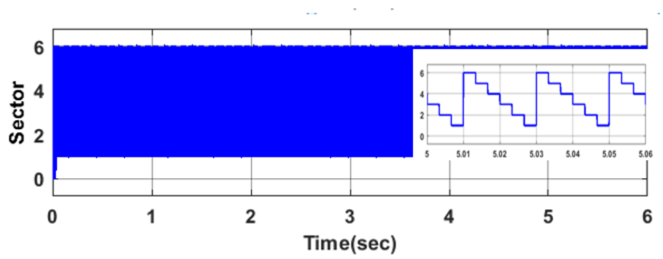

Figure 9 - Angle to sector

The three phase quantity is converted into two phase quantity by clarks transformation. And from the two phase quantity, V_{ref} and angle is obtained . The angle obtained is shown in Figure 8. Figure 8 shows the conversion of angle to sector where angle is converted to 6 sectors. Figure 10 shows the space vector PWM.

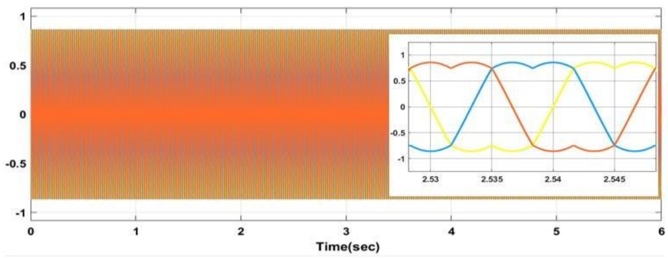

Figure 10 - SVPWM

Figure 11 and Figure 12 shows gate pulse applied for switches S1, S4, S3, S6 and S5 , S2.

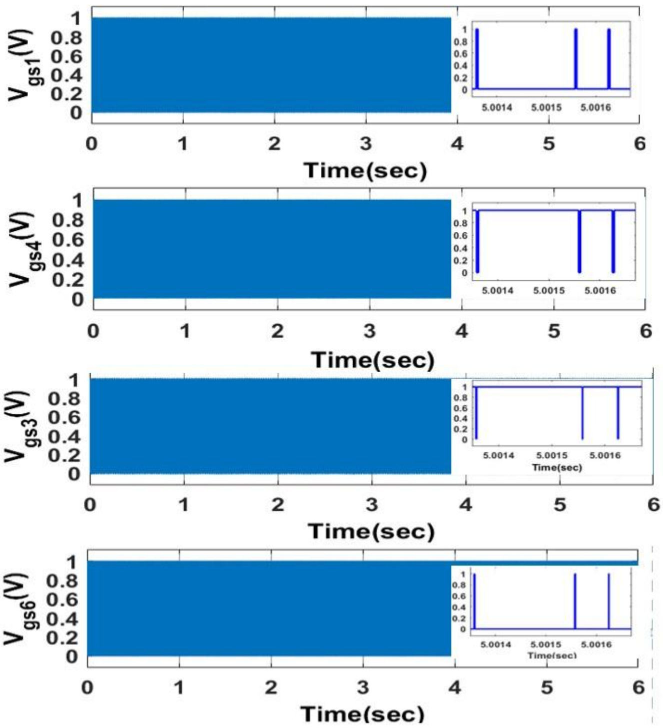

Figure 11-Gate pulse for switch S_1, S_4, S_3 and S_6

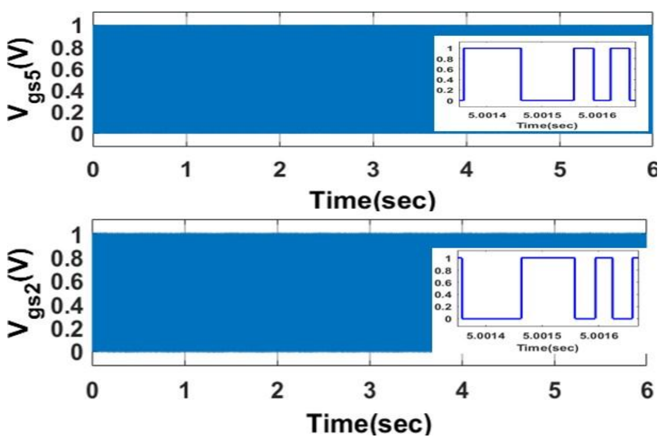

Figure 12- Gate pulses for switch S_5 and S_2

Figure 13 shows the operation of motor at no load condition. Intially motor is started at no load and a load torque of 5 Nm is applied at t = 3 seconds by means of a step input as shown in Figure 14. The speed is reduced when load torque is applied. The torque is increased from 15 Nm to 18 Nm when the torque is applied.

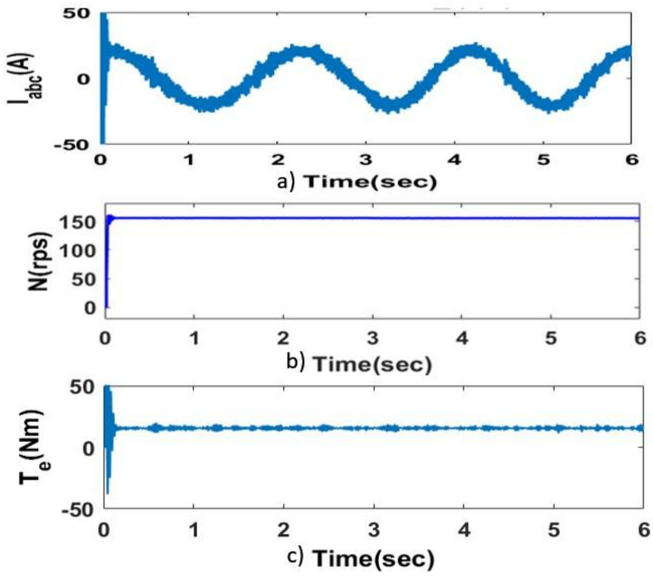

Figure 13 – Operation with load

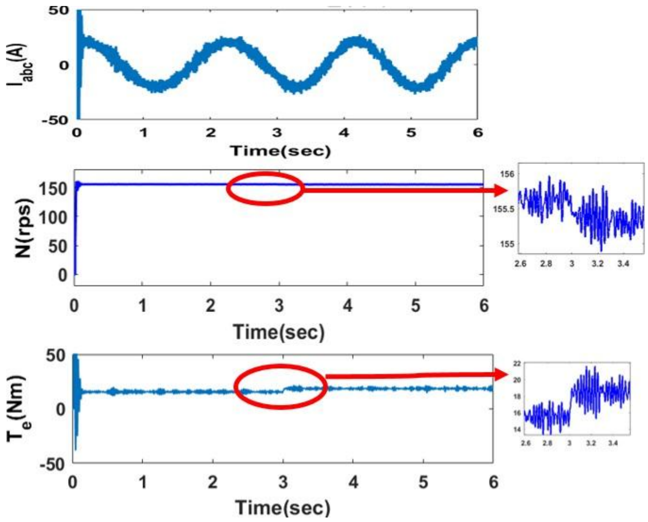

Figure 14 – Operation with load

❖ HYSTERESIS CONTROLLER

The Hysteresis controller based VSI Fed IM Drive is simulated in MATLAB/SIMULINK by choosing the parameters listed in Table 3 and the Simulink model is shown in Figure 15.

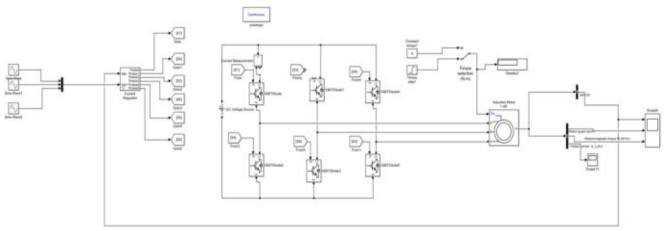

Figure 15 – Simulink model with Hysteresis Controller

The simulation results of the Hysteresis controller Based VSI Fed IM Drive are shown in the following figures. Simulation is carried out by using 1HP motor and parameters are calculated by using No-load and blocked rotor test. Figure 16 shows the stator current and three phase reference current . The stator current and three phase reference current are given to a hysteresis controller with a band of 0.1. The output of hysteresis controller is given as the pulses for each switches. The voltage across the switch and gate pulse to S_1 , S_4 and S_5 are shown in the Figure 17. The voltage across the switch and gate pulse to S_3 , S_6 and S_2 are shown in the Figure 18.

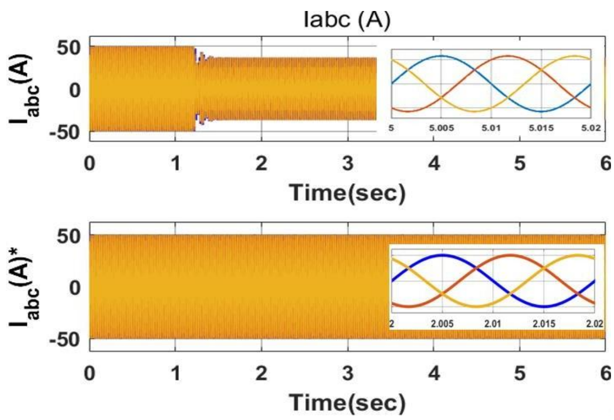

Figure 16–Stator current and Reference Current

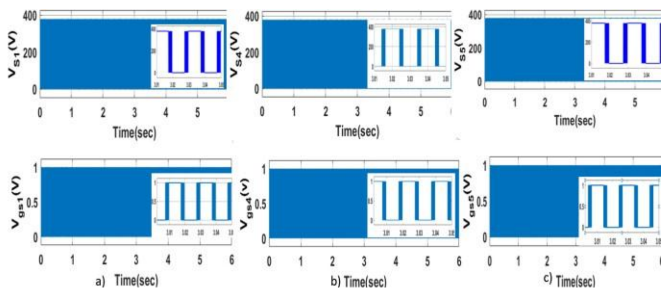

Figure 17:

a)Voltage across switch S_1 and Gate pulse to S_1
b)Voltage across switch S_4 and Gate pulse to S_4
c)Voltage across switch S_5 and Gate pulse to S_5

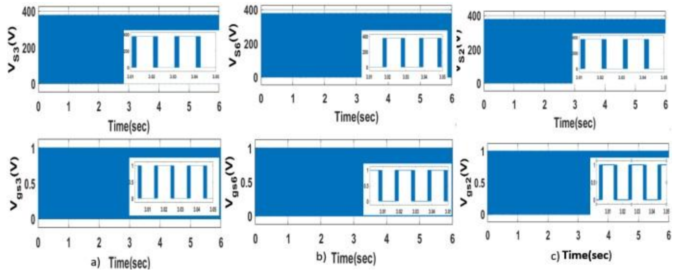

Figure 18: a)Voltage across switch S_3 and Gate pulse to S_3 b)Voltage across switch S_6 and Gate pulse to S_6 c)Voltage across switch S_2 and Gate pulse to S_2

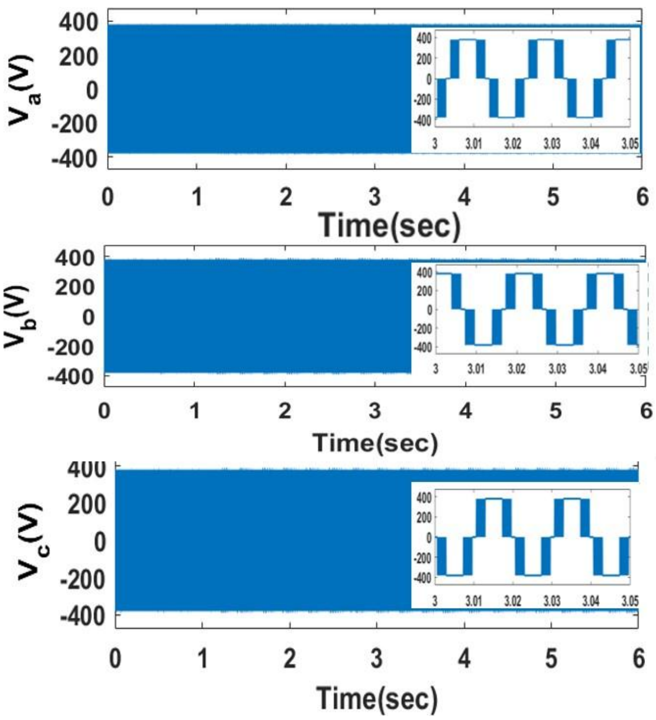

Figure 18- Phase Voltages

The phase voltages of inverter is shown in Figure 18 which has maximum value of 400V. The motor current, the speed of motor and motor torque at no load are given in Figure 19. It can be seen that we are getting a constant speed of 157 rps and motor torque is 15 Nm as shown in Figure 19 . Under load condition, a load torque of 3Nm is applied.

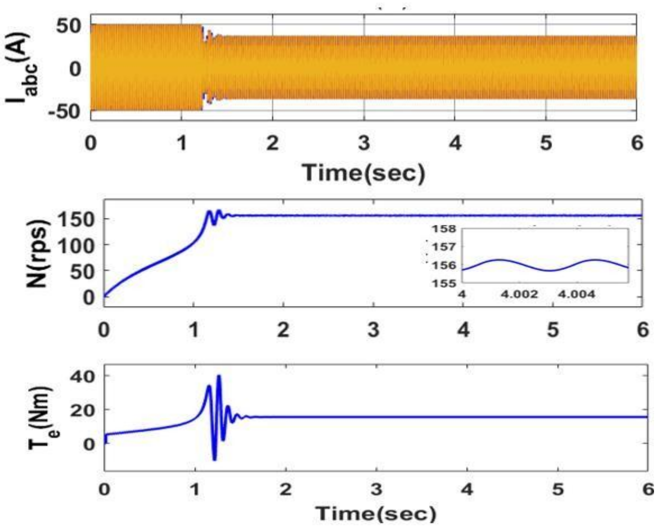

Figure 19- Operation at no load

Under load condition, a load torque of 5 Nm is applied at t = 3 second by means of a step input as shown in following Figure 20. When load is applied the current is decreased and there is a dip in speed at t = 3 sec . The tracking time to attain constant speed is less than 0.2 sec with a speed error of 0.1rps . Starting torque of motor is high and decreased when speed is attained. The torque is of 15 Nm. It is then increased to 18 Nm when load is applied.

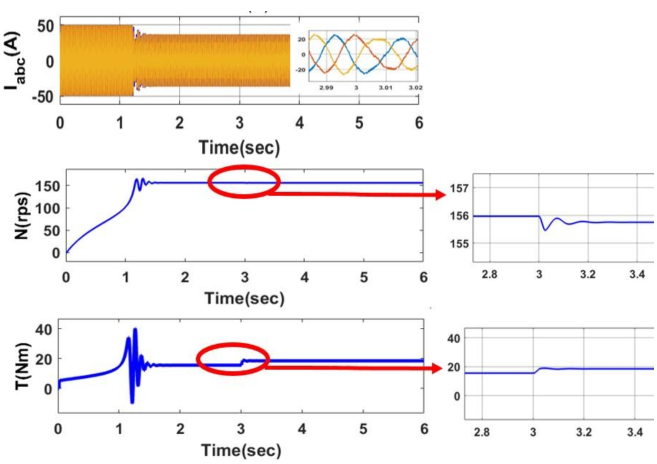

Figure 20-Operation with load

ANALYSIS

The FFT analysis is carried out with a switching frequency of 50Hz. The THD of output current is observed as 7.17 for SVPWM and 19.39 percent for the hysteresis controlled. THD of output voltage is also analyzed. THD of output voltage for SVPWM and Hysteresis are 2.09 and 25.69 percent. So, it is observed that the THD of hysteresis controlled is higher than the SVPWM controlled for both

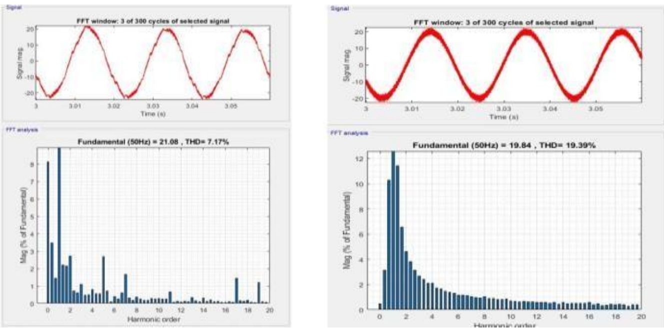

Figure 21-THD of the output Current a) SVPWM [THD = 7.17 percent] b) Hysteresis controller [THD=19.3percent]

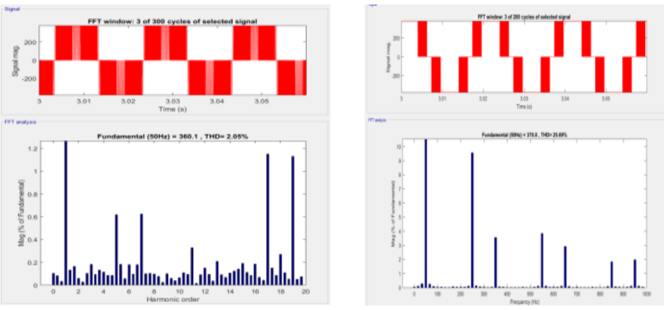

Figure 22: THD of the output Voltage a) SVPWM [[THD = 2.05 percent]] b) Hysteresis controller [THD = 25.6 percent]

❖ **Switching Pulse**

Also observed the switching pulse of SVPWM and hysteresis controlled for 0.0003 sec and analyzed that switching pulse of hysteresis is more than that of SVPWM controlled IM drive. There are 14 switching for a time period of 0.001 sec in SVPWM method and for the same time period there are 44 switching for Hysteresis controlled.

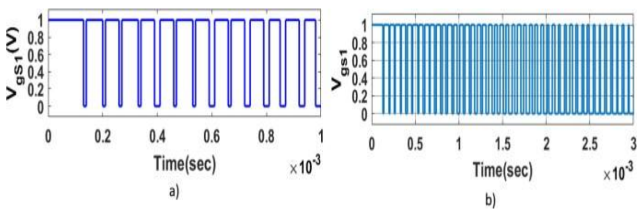

Figure 23: Switching Pulses a)SVPWM b) Hysteresis controller

Table 4 shows the comparison between SVPWM and Hysteresis controlled modulation technique. It is observed that THD of output current and switching pulses of SVPWM is less compared to Hysteresis controlled.

Table4 -Comparison between SVPWM and Hysteresis

	SVPWM	Hysteresis
THD of output current	7.17%	19.3%
THD of output voltage	2.05%	25.69%
Switching Pulses	Less	More compared to SVPWM
Switching Losses	Less	High

4. EXPERIMENTAL SETUP WITH RESULT

❖ **REAL TIME PULSE GENERATION SIMULINK MODEL**

With Real-Time Interface (RTI), you can easily run your function models on the DS1104 R and D Controller Board. You can configure all I/O graphically, insert the blocks into a Simulink block diagram, and generate the model code via Simulink Coder. The real-time model is compiled, downloaded, and started automatically. This reduces the implementation time to a minimum. The experimental setup is shown below.

Figure 24 –Hardware Setup

For making simulink model, a svpwm is compared with repeating sequence and the output is given to master bit out block. For 6 switches the output pins are given as C_0 to C_5 and the output of pulse is taken from digital I/O connector from dspace connector panel. Figure 24 shows the simulink Master bit out blocks. The switching pulse of S1 and S4 (first leg), S3 and S6(of second leg) , S5 and S2 (of third leg)is shown in Figure. Switch S1, S4 , S3, S6 , S5 and S2 has a frequency of 3kHz.

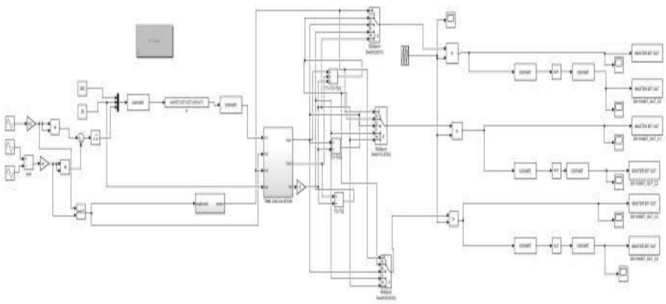

Figure 25 – Generation of switching Pulse

shows the simulink model of Pulse Generation of Switches using Master bit out blocks. The switching pulse of S_1 and S_4 (first leg), S_3 and S_6(of second leg) , S_5 and S_2 (of third leg)is shown in Figure 26:(a),(b),(c) respectively. Switch S_1, S_4 , S_3, S_6 , S_5 and S_2 has a frequency of 3kHz.

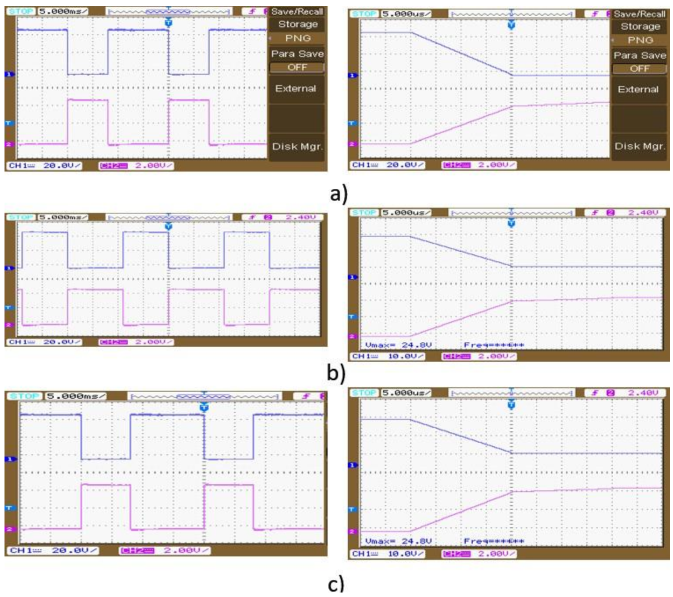

Figure 26- Switching Pulses and dead time for switches a)S_1, S_4 ,b) S_3, S_6 and c)S_5 ,S_2

The pulses for first leg that is for the switch 1 and 4 anddead time of 20 msec are shown in figure 26. The pulses are 180 degree out of phase. The pulses to the switch 3 and 6 and dead time of 20 msec are shown in figure 26 (b) and The pulses to the switch 5 and 2 and dead time of 20 msec are shown in figure 26 (c) . Figure 5.6 shows the current waveform. of motor for the three phases.

Motor current of phase A in open loop is shown in Figure 27. The other two are 120 degree phase shifted as shown in Figure 27 .

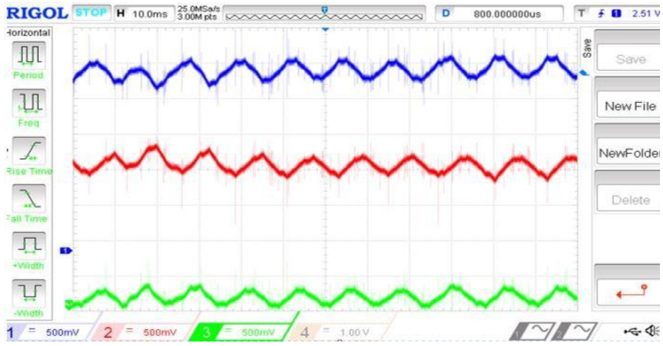

Figure 27 - Current waveform I_a, I_b and I_c

CONCLUSION

A Matlab/Simulink model is done to implement SVPWM for three-phase VSI. The VSI model is based on space vector representation. Current control is done by hysteresis current controller. Vector control and hysteresis control of induction motor drive is simulated. Speed of motor was maintained constant at varying load using SVPWM control. Studied the switching frequency variation, losses for SVPWM and hysteresis based IM drive. Analysed the total harmonic distortion of output current, voltage and switching pulses for both SVPWM and hysteresis controlled IM drive. Hardware implementation is done with dSPACE ds1104 controller.

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