https://doi.org/10.1051/e3sconf/20198701002

Speed Control of an Induction Motor Fed by an Inverter Using dSPACE Controller

Srinivasrao Janiga[1], *Syed* Sarfaraz Nawaz[2], *Suresh Kumar* Tummala[3] and *Srinivasa Varma* Pinni[4]

[1]Research Scholar, EEE Department, KLEF & Assistant Professor, EEE Dept., Anurag Engineering College
[2]Associate Professor, EEE Department, GRIET, Hyderabad, India
[3]Professor, EEE Department, GRIET, Hyderabad, India
[4]Associate Professor, EEE Department, KLEF, India

Abstract. This paper presents the design and implementation of Inverter system for driving three phase Induction motor using DSPACE DS1104 controller with the controlling objective space vector pulse width modulation (SVPWM) technique. AC motor drives are commonly used over DC motor drives because of their more advantages. Induction motor is the most commonly used AC motor drive for various industrial and domestic applications. The project will be commenced by a basic understanding of SVPWM inverter, components used in the design and study the mathematical equations of the Induction motor. The performance of SVPWM based Induction motor (IM) in open loop is presented with simulation. Here the hardware implementation of the three phase inverter which is fed to a three phase induction motor driven by DSPACE CP1104 is been implemented.

1 Introduction

AC motor drives are commonly used over DC motor drives because of their more advantages. Induction motor is the most commonly used AC motor drive for various industrial and domestic applications. Generally Pulse Width Modulation (PWM) technique is used for driving a motor drive. In this paper design of variable speed induction motor drive using Space Vector Pulse Width Modulation (SVPWM) inverter is explained. PWM signals are generated using a DSPACE Controller.

1.1 Open loop Block diagram

Block diagram of single phase or three phase induction motor drive fed by an inverter driving in open loop is given below.

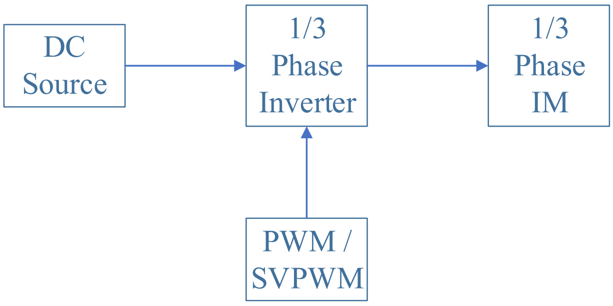

Fig. 1. Open Loop Block Diagram

2 Inverter

Depending on the supply inverters are classified in to two types. They are

- Single-phase Inverter
- Three-phase Inverter

2.1 Space vector pulse width modulation

Space vector pulse width modulation (SVPWM) is a pulse width modulation (PWM) technique which is used to apply to a three phase induction motor. The main objective of this technique is to use a dc voltage source and by means of six IGBT switches produce a three phase sine waveform in which frequency and amplitude is adjustable.

To implement space vector pulse width modulation, the voltages equations in abc reference frame can be transformed in to the stationary d-q reference frame that consists of horizontal and vertical axis

---

* Corresponding author: janigasrinivasrao@gmail.com

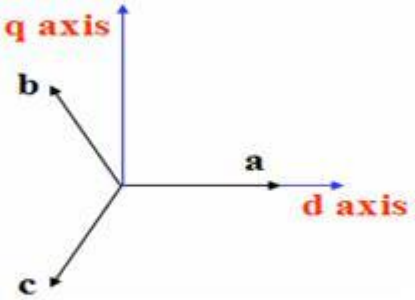

Fig. 2. Transformation of three axis to two axis reference frame

In space vector pulse width modulation six non-zero vectors (V1, V2, V3, V4, V5, V6) and two zero vectors (V0, V7) are formed. These are called the space vectors. The objective of space vector pulse width modulation technique is to approximate the reference voltage vector Vref using the eight switching patterns.

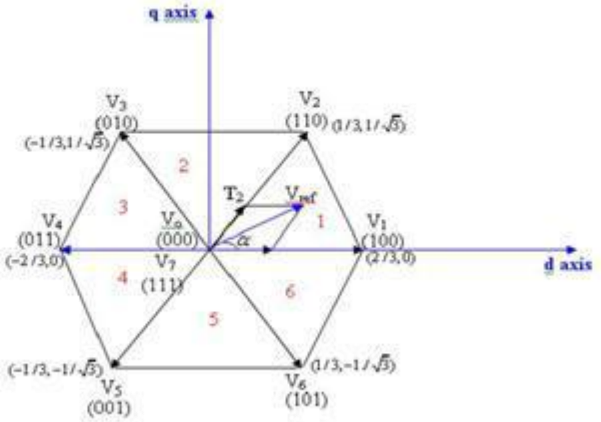

Fig.3. Basic switching vectors and sectors

Therefore, space vector pulse width modulation can be implemented by the following steps:

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 S6)

Step 1: Determine the Vd, Vq, Vref, and an angle (α)

From figure 4, the Vd, Vq, Vref, and angle (α) can be determined as follows:

$$V_d = V_{an} - V_{bn}.\cos(60) - V_{cn}.\cos(60)$$

$$= V_{an} - \frac{1}{2}V_{bn} - \frac{1}{2}V_{cn}$$

$$V_q = 0 + V_{bn}.\cos(30) - V_{cn}.\cos(30)$$

$$= 0 - \frac{\sqrt{3}}{2}V_{bn} - \frac{\sqrt{3}}{2}V_{cn}$$

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

$$\left|V_{ref}\right| = \sqrt{{V_d}^2 + {V_q}^2}$$

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

Where f= fundamental frequency

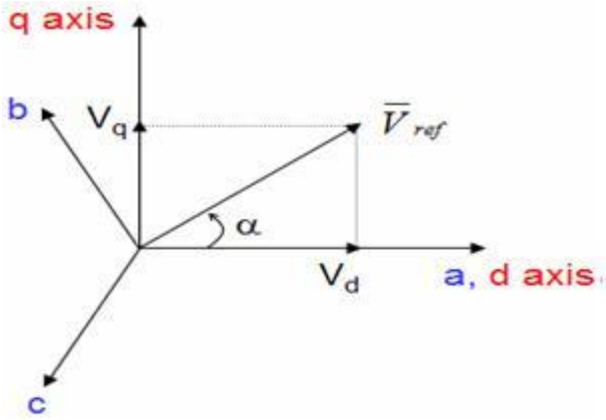

Fig. 4. Voltage Space Vectors and its components in d-q axis

Step 2: Determine time duration of T1, T2, T0
From figure5, the switching time duration can be calculated as follows:

Switching time duration at Sector 1

$$\int_0^{T_Z} V_{ref} = \int_0^{T_1} V_1 dt + \int_{T_1}^{T_1+T_2} V_2 dt + \int_{T_1+T_2}^{T_Z} V_0 dt$$

$$T_Z V_{ref} = T_1 V_1 + T_2 V_2$$

$$T_Z \cdot \left|V_{ref}\right| \begin{bmatrix} \cos\alpha \\ \sin\alpha \end{bmatrix} = T_1 \cdot \frac{2}{3} . V_{dc} \begin{bmatrix} 1 \\ 0 \end{bmatrix} + T_2 \cdot \frac{2}{3} . V_{dc} \begin{bmatrix} \cos(\frac{\pi}{3}) \\ \sin(\frac{\pi}{3}) \end{bmatrix}$$

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

$$T_1 = T_z . a . \frac{\sin(\frac{\pi}{3} - \alpha)}{\sin(\frac{\pi}{3})}$$

$$T_2 = T_z . a . \frac{\sin(\alpha)}{\sin(\frac{\pi}{3})}$$

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

$$(\text{where } T_z = \frac{1}{f_z} \text{ and } a = \frac{|V_{ref}|}{\frac{2}{3} V_{dc}})$$

Switching time duration at any Sector

$$T_1 = \frac{\sqrt{3}.T_z.|V_{ref}|}{V_{dc}} (\sin(\frac{\pi}{3} - \alpha + \frac{n-1}{3}\pi))$$

$$= \frac{\sqrt{3}.T_z.|V_{ref}|}{V_{dc}} (\sin \frac{n\pi}{3} \cos\alpha - \cos\frac{n\pi}{3} \sin\alpha))$$

$$T_2 = \frac{\sqrt{3}.T_z.|V_{ref}|}{V_{dc}} (\sin(\alpha - \frac{n-1}{3}\pi))$$

$$= \frac{\sqrt{3}.T_z.|V_{ref}|}{V_{dc}} (-\cos\alpha \sin\frac{n-1}{3}\pi + \sin\alpha \cos\frac{n-1}{3}\pi)$$

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

[where, n=1 to 6 (i.e, sector 1 to 6)]
$(0 \le \alpha \le 60)$

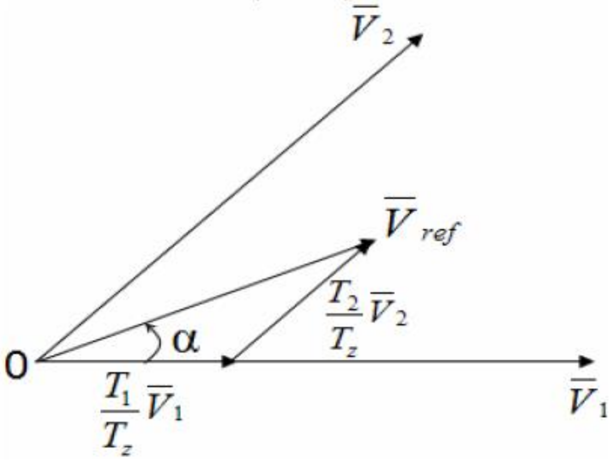

Fig.5. Reference vector from combination of adjacent vectors

Step 3: Determine the switching time of each transistor (S1 to S6)

Table 1. Switching time at each sector

Sector	Upper Switches (S1, S3, S5)	Lower Switches (S4, S6, S2)
1	S1=T1+T2+T0/2 S3=T2+T0/2 S5=T0/2	S4=T0/2 S6=T1+T0/2 S2=T1+T2+T0/2
2	S1=T1+T0/2 S3=T1+T2+T0/2 S5=T0/2	S4=T2+T0/2 S6=T0/2 S2=T1+T0/2
3	S1=T0/2 S3=T1+T2+T0/2 S5=T2+T0/2	S4=T1+T2+T0/2 S6=T0/2 S2=T1+T0/2
4	S1=T0/2 S3=T1+T0/2 S5=T1+T2+T0/2	S4=T1+T2+T0/2 S6=T2+T0/2 S2=T0/2
5	S1=T2+T0/2	S4=T1+T0/2
	S3=T0/2	S6=T1+T2+T0/2
	S5=T1+T2+T0/2	S2=T0/2
6	S1=T1+T2+T0/2	S4=T0/2
	S3=T0/2	S6=T1+T2+T0/2
	S5=T1+T0/2	S2=T2+T0/2

3 Induction motor

An Induction motor works on the principle of Electro Magnetic Induction (EMI). Stator and rotor are the two parts of induction motor which are separated by an air gap. When a three phase supply is given to an induction motor, it produces a constant amplitude and rotating magnetic field (RMF). This field cuts the rotor conductor and induces an Electro Magnetic Force (emf) which drives current in short circuited rotor conductor.

3.1 Dynamic Modelling of Induction Motor

Dynamic model of an induction motor can be obtained from two-axis theory of electrical machines. The following assumptions are made for dynamic model of induction motor.

1. Space harmonics are negligible.
2. The slotting in stator and rotor produces negligible variations in respective inductances.
3. Mutual Inductances are equal.
4. Voltage and Current harmonics are neglected.
5. Saturation, hysteresis and eddy current losses are negligible.

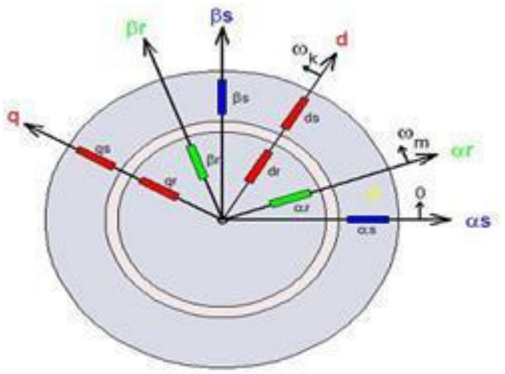

Fig.6. Two axis representation of IM

Equations corresponding to the two axis representation of Induction Machine are reduced through KVL as follows

$$V_{qs} = R_q i_{qs} + P(L_{qq} i_{qs}) + P(L_{qd} i_{ds}) + P(L_{q\alpha} i_d) + P(L_{q\beta} i_\beta) \text{----}(1)$$

$$V_{ds} = P(L_{dq} i_{qs}) + R_d i_{ds} + P(L_{dd} i_{ds}) + P(L_{dd} i_d) + P(L_{d\beta} i_\beta) ----(2)$$

$$V_\alpha = P(L_{\alpha q} i_{qs}) + P(L_{\alpha d} i_{ds}) + R_\alpha i_\alpha \; P(L_{\alpha\alpha} i_\alpha) + P(L_{\alpha\beta} i_\beta) ----(3)$$

$$V_\beta = P(L_{pq} i_{qs}) + P(L_{pq} i_{ds}) + P(L_{\beta\alpha} i_\alpha) + R_\beta i_\beta + P(L_{\beta\beta} i_\beta) ----(4)$$

$$\begin{aligned} L_{\alpha\alpha} &= L_{\beta\beta} = L_{rr} \\ L_{dd} &= L_{qq} = L_{ss} \\ L_{\alpha\beta} &= L_{\beta\alpha} = 0 \\ L_{dq} &= L_{qd} = 0 \end{aligned}$$

$$\begin{aligned} L_{\alpha d} &= L_{d\alpha} = L_{sr}\cos\theta_r \\ L_{\beta d} &= L_{d\beta} = L_{sr}\sin\theta_r \\ L_{\alpha q} &= L_{q\alpha} = L_{sr}\sin\theta_r \\ L_{\beta q} &= L_{q\beta} = -L_{sr}\cos\theta_r \end{aligned}$$

With respect to the fictitious rotor

$$\begin{aligned} i_\alpha &= i_{drr}\cos\theta_r + i_{qrr}\sin\theta_r \\ i_\beta &= i_{drr}\sin\theta_r + i_{qrr}\cos\theta_r \end{aligned}$$

with respect to the arbitrary reference frame

$$\begin{aligned} i_{ds} &= i^c_{ds}\cos\theta_c - i^c_{qs}\sin\theta_c \\ i_{qs} &= i^c_{ds}\cos\theta_c + i^c_{qs}\sin\theta_c \end{aligned}$$

$$\begin{bmatrix} V^c_{qs} \\ V^c_{qr} \\ V^c_{ds} \\ V^c_{dr} \end{bmatrix} = \begin{bmatrix} R_s + L_s P & -w_c L_S & L_m.P & w_c L_S \\ w_c L_S & R_s + L_s P & w_c L_S & L_m.P \\ L_m.P & -(w_c - w_r)L_m & R_s + L_s P & -(w_c - w_r)L_m \\ -(w_c - w_r)L_m & L_m.P & -(w_c - w_r)L_m & R_s + L_s P \end{bmatrix} \begin{bmatrix} V^c_{qs} \\ V^c_{qr} \\ V^c_{ds} \\ V^c_{dr} \end{bmatrix}$$

Torque: $V = [R]i + [L]Pi + [G]w_r i + [F]w_c i$

$$I^t.V = i^t[R] = i^t[L]Pi + i^t[G]w_r i + i^t[F]w_c i$$

$i^t[L]Pi$ Rate of change of stored magnet energy

$i^t[G]w_r i$ Air gap power = Mech Rot speed x Air gap

$$\begin{aligned} w_n T_e &= P_a = i^t[G]iw_r \\ T_e &= \frac{P}{2} i^t[G]i \end{aligned}$$

$$[G]i = i^t \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & -l_m & 0 & -l_m \\ l_m & 0 & l_m & 0 \end{bmatrix} \begin{bmatrix} i^c_{qs} \\ i^c_{qr} \\ i^c_{ds} \\ i^c_{dr} \end{bmatrix}$$

$$I^t[G]i = L_m\left[i^c_{qs} i^c_{dr} - i^c_{ds} i_{qr}\right]$$

$$T_e = \frac{3}{2}\cdot\frac{P}{2} L_m (i^c_{qs} i^c_{dr} - i^c_{ds} i^c_{qr})$$

$$T_e = \frac{3}{2}\cdot\frac{P}{2}\cdot\frac{1}{w_b}\left[\psi^c_{ds} i^c_{qs} - \psi^c_{qs} i^c_{ds}\right]$$

Through the above analysis speed, torque of an Induction Motor can be controlled by voltage current parameters.

4 Simulation

Matlab is an interactive software program for numerical computations and graphics. In this paper three phase SVPWM inverter is explained in open loop.

Open loop three phase inverter:

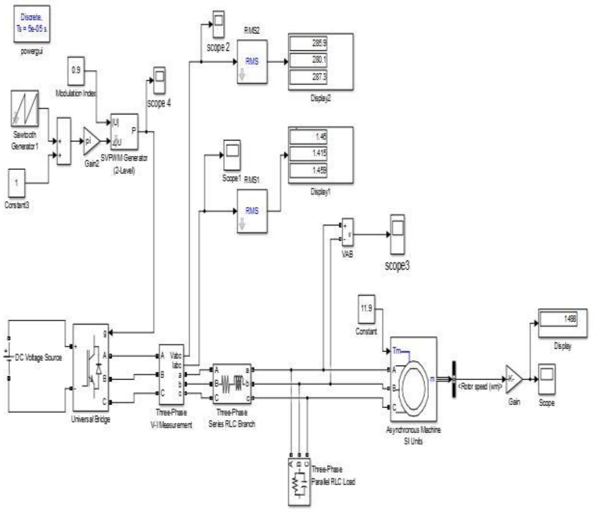

Fig.7. Simulink of three phase inverter driving IM in open loop

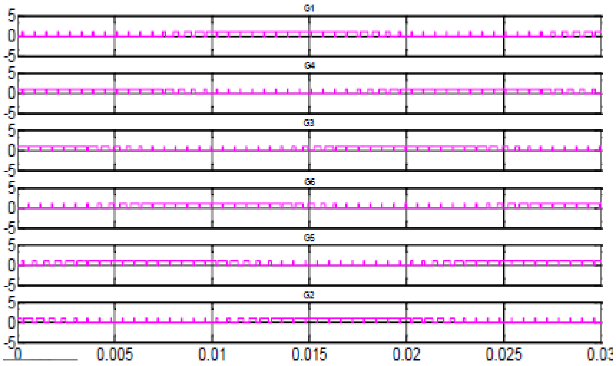

Fig.8. Gate pulses

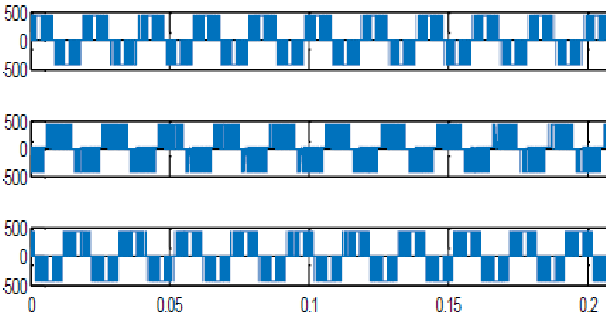

Fig.9. Output phase Voltages

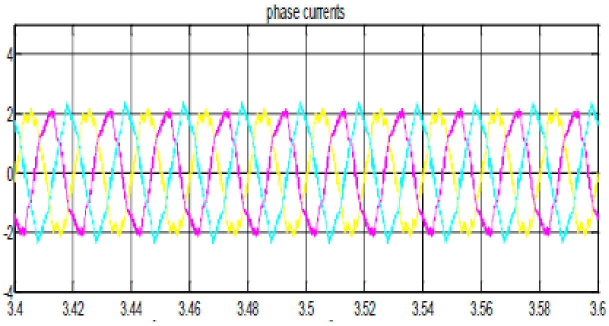

Fig.10. Output phase Currents

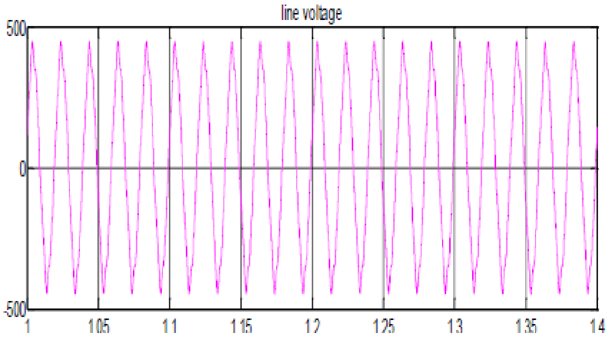

Fig.11. Output Line Voltage

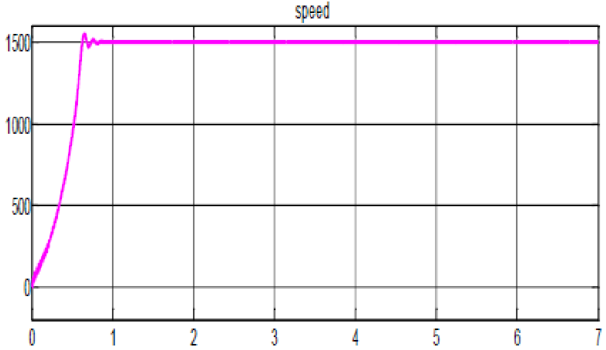

Fig.12. Response of Speed

5 DSPACE DS1104 Controller

The hardware unit comprises of the DSPACE unit installed to a desktop where in the MATLAB files can be interfaced through the DSPACE package software. Three phase Inverter is been designed with an isolation circuit to protect the controller board from the sudden voltage fluctuations feeding back to the controller board. Pulses from the controller board reaches the switches through the isolation circuit through opto-couplers EL817, pulses passes through the EL817 by light manner.

Inverter feeds the induction motor. And it is well suited for drive control. DSPACE unit operates for 250MHz and the pulse width generated is of 2k frequency. DSPACE unit comprises of 8 analog and 8 digital pins. 20 input and output signals can be interchanged randomly. Input to the Inverter unit is 440volts where the output of the Inverter received is 400 Volts 2 A

Fig.13. DSPACE Controller Board

6 Experimentation Results

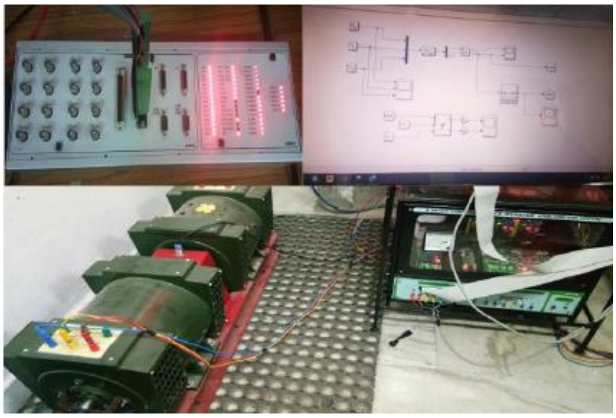

Fig.14. Hardware unit of Three phase Inverter driving IM using DSPACE

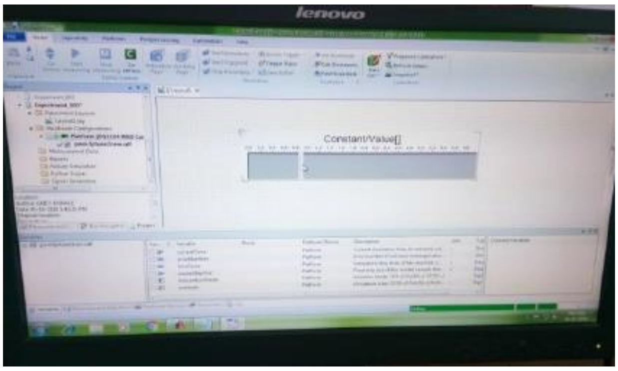

Fig.15. Varying Modulation index in DSPACE

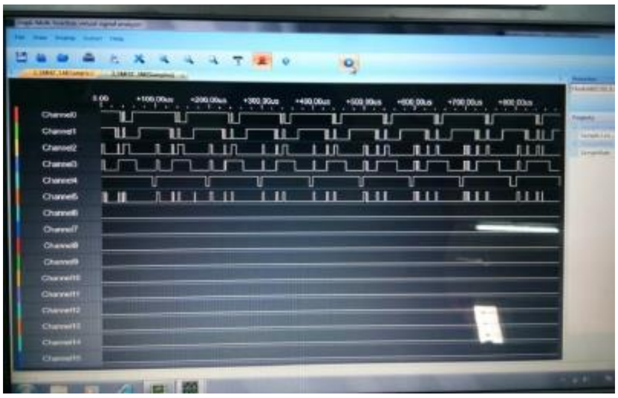

Fig.16. Pulses generated through DSPACE

Fig.17. Output Voltage of Inverter

Fig.18. Speed of Induction motor

Practical Results:

Table 2. Output Voltage and Speed

S.NO	DC InputVoltage (V)	Modulation Index (M)	AC Output Voltage (V)	Speed (rpm)
1	330	0.8	164.6	1128
2	330	0.85	164.0	1189
3	330	0.9	163.5	1250
4	330	0.95	162.1	1309
5	330	1.0	162.0	1410
6	330	1.1	161.9	1427

By varying the width of the PWM pulse in slider control display of the DSPACE desk speed o induction motor is varying accordingly.

7 Conclusion

In this paper Induction motor speed drive is designed using DSPACE DS1104 Controller. Speed, output voltage and current of induction motor at different duty cycles are obtained. The pulse width modulation(PWM) technique used here is space vector pulse width modulation (SVPWM). Simulation of three phase inverter fed induction motor in open loop operation is explained and its respective output waveforms are shown

References

1. L. Vinod Kumar and Syed Sarfaraz Nawaz, “Design and Implementation of Inverter System to Drive Induction Motor using DSPACE” International Journal for Research in Applied Science & Engineering Technology (IJRASET) Volume **4** Issue XI, November (2016), ISSN: 2321-9653.
2. “DSPACE direct torque control Implementation for induction motor” by A.Abbou , Y Sayouti, H Mahmoudi M. Akherraz in 18th Mediterranean Conference on Control &Automation
3. M. Depenbrock, “Pulse width modulation control of a three phase inverter with non-sinusoidal phase voltages,” in Proc. IEEE-IAS Int. Semiconductor Power Conversion Conference., Orlaando, FL, (1975), pp.389-398.
4. “Modern Power Electronics and AC Drives, by Bimal K. Bose. Prentice Hall Publishers”.
5. “Power Electronics by Dr. P.S. Bimbhra. Khanna Publishers, New Delhi”.
6. “DSPACE CP1104 installer guide and model executions”.
7. DS1104 R&D Controller Board, "Hardware Installation and Configuration", CRC Press, Release 4.1 - March (2004).