DESIGN AND CONTROL OF INDUCTION MOTOR DRIVE WITH PV SYSTEM USING SPACE VECTOR PWM

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ABSTRACT-The speed of induction motor is controlled which is fed from three phase bridge inverter is proposed in this paper. In this paper the speed of an induction motor can be varied by varying input Voltage or frequency or both. To regulate the speed and torque for same induction motor, the motor has to run at variable voltage and frequency. Solar PV has specific advantages as an energy source: its operation generates no pollution and no greenhouse gas emissions once installed, it shows simple scalability in respect of power needs and silicon has large availability in the Earth's crust. A number of PWM techniques are there to obtain variable voltage and variable frequency supply such as PWM, SPWM, SVPWM to name a few, among the various modulation strategies SVPWM is one of the most efficient techniques as it has better performance and output voltage is similar to sinusoidal. The variable voltage and variable frequency can be obtain from (ASD) adjustable speed drives. Variable voltage and variable frequency for Adjustable Speed Drives (ASD) is invariably obtained from a three-phase Voltage Source Inverter (VSI). Voltage and frequency of inverter can be easily controlled by using PWM techniques, which is a very important aspect in the application of ASDs. The SVPWM has several merits such as better dc bus utilization, easier digital realization over the other Pulse width modulation methods. By using the simulation results we can analyze the proposed method.

Keywords— Adjustable Speed Drive (ASD); Voltage source inverter (VSI), Sinusoidal PWM (SPWM), Space Vector PWM (SVPWM).

INTRODUCTION

Photovoltaic (PV) power generation is becoming more promising since the introduction of the thin film PV technology due to its lower cost, excellent high temperature performance, low weight, flexibility, and glass-free easy installation. Induction motor are used in many applications such as HVAC (heating, ventilation and air-conditioning), Industrial drives (motion control, robotics), Automotive control (electric vehicles), etc. The Space Vector Pulse Width Modulation (SVPWM) method is an advanced, computation-intensive PWM method and possibly the best among all the PWM techniques for variable frequency drive application. An adjustable speed drive (ASD) is a device used to provide continuous range process speed control.

An ASD is capable of adjusting both speed and torque from an induction or synchronous motor. An electric ASD is an electrical system used to control motor speed. ASDs may be referred to by a variety of names, such as variable speed drives, adjustable frequency drives or variable frequency inverters. The two terms adjustable frequency drives or variable frequency inverters will only be used to refer to certain AC systems, as is often the practice, although some DC drives are also based on the principle of adjustable frequency (Switching frequency of chopper switch).

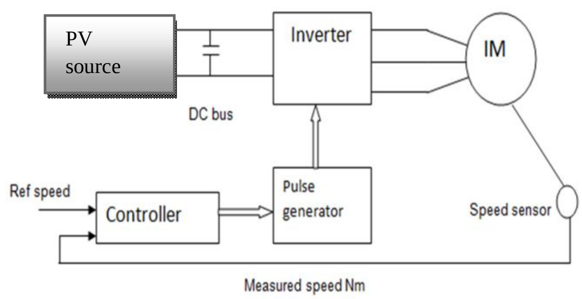


Figure 1: ASD Block Diagram

A photovoltaic system, also PV system or solar power system, is a power system designed to supply usable solar power by means of photovoltaics. It consists of an arrangement of several components, including solar panels to absorb and convert sunlight into electricity, a solar inverter to change the electric current from DC to AC, and mounting cabling and other electrical accessories to set up a working system.

Adjustable speed drives are the most efficient (98% at full load) types of drives. They are used to control the speeds of both AC and DC motors. They include variable frequency/voltage AC motor controllers for squirrel-cage motors, DC motor controllers for DC motors, eddy current clutches for AC motors (less efficient), wound-rotor motor controllers for wound-rotor AC motors (less efficient) and cycloconverters (less efficient). Electricity produced by solar cells is clean and silent. Because they do not use fuel other than sunshine, PV systems do not release any harmful air or water pollution into the environment, deplete natural resources, or endanger animal or human health. Photovoltaic systems are quiet and visually unobtrusive.

Photovoltaics (PV) is a term which covers the conversion of light into electricity that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry. A squirrel cage induction motor with constant frequency, constant magnitude voltage supply is supplied, the motor provides constant torque and speed characteristic. AC to DC converter is the first step by which we get DC voltage from AC utility grid. This step is called rectification it occur by diodes connected in bridge form. The second step is DC to AC by operating in inversion operation mode is called inverter device. The converter in ASD is operated in such a way that to obtained variable voltage and frequency at output of the ASD by which motor speed, torque can be controlled with high performance. Solar PV has specific advantages as an energy source: its operation generates no pollution[1] and no greenhouse gas emissions once installed, it shows simple scalability in respect of power needs and silicon has large availability in the Earth's crust.

PULSE WIDTH MODULATION (PWM)

Variable voltage and frequency supply for Adjustable Speed Drives (ASD) is invariably obtained from a three-phase VSI. In power electronics, converters and motors, the PWM technique is mostly used to supply AC current to the load by converting the DC current and it appears as a AC signal at load or can control the speed of motors that run at high speed or low.

Advantages of PWM technique:

• Output voltage can be controlled without other components.

• Output voltage can be controlled, lower order harmonics can be eliminated and filtering out higher order harmonics by this filter requirements is minimized.

Disadvantages of PWM technique:

• The inverter switches are costly as they must have low turn off and turn on times.

Types of PWM techniques:

A number of PWM techniques are there to obtain variable voltage and frequency supply such as,

(i) Single-pulse modulation
(ii) Multiple-pulse modulation
(iii) Selected harmonic elimination PWM
(iv) Minimum ripple current PWM
(v) Sinusoidal-pulse PWM (SPWM)
(vi) Space vector-pulse PWM (SVPWM)

Single Pulse Modulation:

The output voltage waveform of single pulse full-bridge inverter is modulated, it contains pulse of width located symmetrically about ʌ/2 and another pulse located symmetrically about 3ʌ/2. The range of pulse width 2d varies from 0 to ʌ; i.e.0<2d<ʌ. The output voltage is controlled by varying the pulse width 2d. This shape of the output voltage wave is called quasi-square wave.

Multiple-pulse modulation:

This method of pulse modulation is an extension of single-pulse modulation. In this method, several equidistant pulses per half cycle are used.

Selected harmonic elimination PWM:

The undesirable lower order harmonics of a square wave can be eliminated and the fundamental voltage can be controlled as well by what is known as selected harmonic elimination (SHE) PWM.

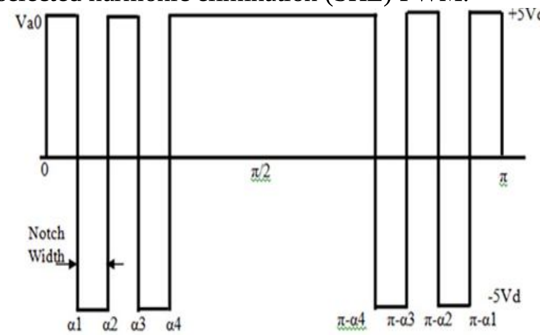


Figure 3: Phase Voltage Wave for SHEPWM

A large no. of harmonics can be eliminated if the waveform can accommodate additional notch angles.

The general Fourier series of the wave can be given as

$$v(t) = \sum_{n=1}^{\infty}(a_n \cos n\omega t + b_n \sin n\omega t) \quad (1)$$

Where;

$$a_n = \frac{1}{\pi}\int_0^{2\pi} v(t)\cos n\omega t d\omega t;$$

$$b_n = \frac{1}{\pi}\int_0^{2\pi} v(t)\sin n\omega t d\omega t;$$

For a waveform with quarter-cycle symmetry only the odd harmonics with sine components will be present.

Therefore, an=0

$$v(t) = \sum_{n=1}^{\infty}(b_n \sin n\omega t) \quad (2)$$

Where,

$$b_n = \frac{4}{\pi}\int_0^{\pi/2} v(t)\sin n\omega t d\omega t;$$

Assuming that the wave has unit amplitude that is v(t)=+1, bn can be expanded and after solving we can get,

$$v(t) = \frac{4}{n\pi}\left[1 + 2\sum_{k=1}^{k}(-1)^k(sinn\alpha_k)\right] \quad (3)$$

Minimum ripple current PWM:

One disadvantage of the SHE PWM method is that the elimination of lower order harmonics considerably boosts the next higher level of harmonics. Since the harmonic loss in a machine is dictated by the RMS ripple current, it is the parameter that should be minimized instead of emphasizing the individual harmonics.

Sinusoidal-pulse PWM (SPWM):

Sinusoidal PWM is a modulation technique in which a sinusoidal signal is compared with the triangular signal, in which the frequency of triangular signal (ftri) is equals to the desired sinusoidal output and the frequency of triangular signal gives the switching frequency of the switches.

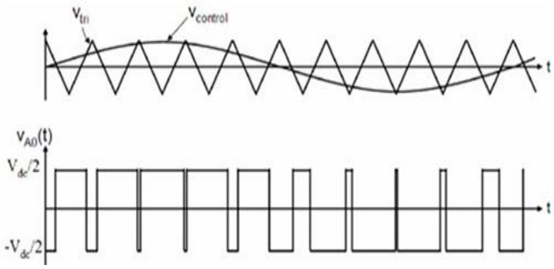


Figure 4: Output Voltage Waveform with Sinusoidal Pulse Modulation

The magnitude of o/p voltage depends on modulation index which is defined as, "the ratio Vtri/VC is called Modulation Index (Ma)" and it controls the harmonic content of the output voltage waveform.

Advantages

- Controlled inverter output voltage
- Reduction of harmonics

Disadvantages

- Increase of switching losses due to high PWM frequency
- Reduction of available voltage
- EMI problems due to high-order harmonics

Space vector-pulse PWM (SVPWM):

The advance method in PWM techniques is space vector PWM method. It computation intensive PWM method and is excellent method among all the PWM techniques for variable frequency drive application. Its characteristic's is superior to other methods so it is wide spread application in recent years.

SPACE VECTOR-PULSE PWM (SVPWM)

Space vector pulse width modulation (SVPWM) is an algorithm which is applied to the inverter to control the pulses generated from the inverter. It is used for the creation of AC waveforms which is mostly used to drive three-phase motors at different speeds from Dc using multiple class-D amplifiers. Various variations of SVPWM that result in different quality and computational requirements. The development is in the reduction of total harmonic distortion (THD) created by the rapid switching inherent to these algorithms.

Space vector pulse width modulation can be classified into four types as a) Sector selection based SVPWM b) Reduced switching SVPWM c) Carrier based SVPWM d) Reduced switching carrier based SVPWM.

Space vector modulation is a PWM regulator algorithm for multi-phase AC generation. The reference signal is sampled frequently, after each sample, non-zero active switching vectors adjacent to the reference vector and one or more of the zero switching vectors are preferred for the suitable fraction of the sampling period in order to integrate the reference signal as the average of the used vectors.

Principle of Space Vector PWM:

The circuit model of a typical three-phase voltage source PWM inverter is shown in Fig. 5, S1 to S6 are the six power switches that shape the output, which are controlled by the switching variables a, a' , b, b' , c and c' . When an upper IGBT is switched on, i.e., when a, b or c is 1, the corresponding lower IGBT is switched off, i.e., the corresponding a' , b' or c' is 0.

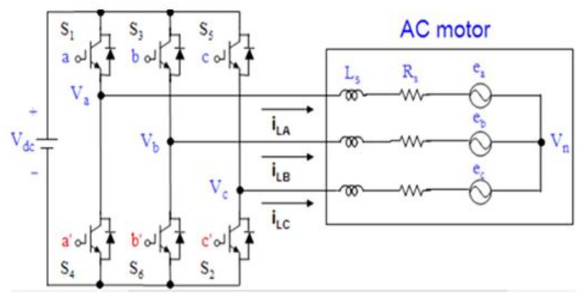


Figure 5: Three-phase voltage source PWM Inverter

Therefore, the ON and OFF states of the upper IGBTs S1, S3 and S5 can be used to determine the output voltage. The relationship between the switching variable vector and the line-to-line voltage vector is given by in the following:

$$\begin{bmatrix} V_{ab} \\ V_{bc} \\ V_{ca} \end{bmatrix} = V_{dc} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (5)$$

The relationship between the switching variable vector [a,b,c]^t and the phase voltage vector [Vab Vbc Vca]^t is given by in the following:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = V_{dc} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad (6)$$

The major advantage of SVPWM method is from the fact that there is a degree of freedom of space vector placement in a switching cycle. This improves the harmonic performance of this method. As shown in Fig.5, there are eight possible combinations of ON and OFF patterns for the three upper power switches. The on and off states of the lower power devices are opposite to the upper one and so are easily determined once the states of the upper power IGBTs are determined. According to equations (5) and (6), the eight switching vectors, output line to neutral voltage (phase voltage), and output line-to-line voltages in terms of DC link Vdc, are given in Table 1, and Fig. 5 shows the eight inverter voltage vectors (V0 to V7).

Table 1
Switching vectors, phase voltages and output line to line voltages

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

To implement the space vector PWM, the voltage equations in the abc reference frame can be transformed into the stationary dq reference frame that consists of the horizontal (d) and vertical (q) axes.

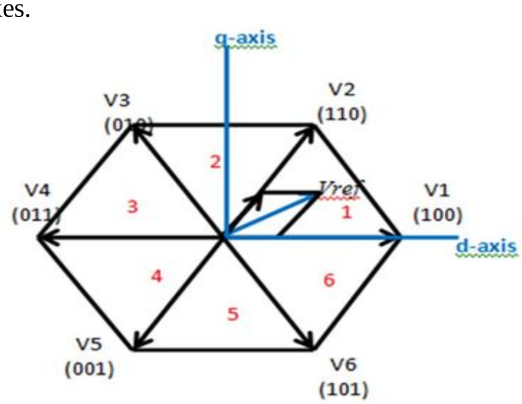


Figure 6: Basic Sector and Vector diagram.

The relation between these two reference frames is below,

$$f_{dq0} = K_s f_{abc} \quad (7)$$

$$Ks = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \quad (8)$$

$$f_{dq0} = [f_d f_q f_0]^T$$

$$f_{abc} = [f_a f_b f_c]^T \quad (9)$$

And f denotes either a voltage or a current variable. As described in Fig. 7, this transformation is equivalent to an orthogonal projection of [a,b,c]t onto the two-dimensional perpendicular to the vector [1,1,1] t (the equivalent d-q plane) in a three-dimensional coordinate system. As a result, six nonzero vectors and two zero vectors are possible. Six nonzero vectors (V1 - V6) shape the axes of a hexagonal as depicted in Fig. 7, and feed electric power to the load. The angle between any adjacent two nonzero vectors is 60 degrees. Meanwhile, two zero vectors (V0 and V7) are at the origin and apply zero voltage to the load. The eight vectors are called the basic space vectors and are denoted by V0, V1, V2, V3, V4, V5, V6, and V7.

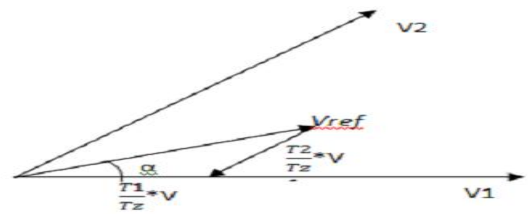


Figure 7: Reference vector as a combination of adjacent vectors at sector 1.

Steps for implementation 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 IGBT (S1 to S6)

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

From Fig. 5.5, the Vd, Vq, Vref,and angle (Ị) can be determined as follows:

$$V_d = V_{an} - \frac{1}{2}V_{bn} - \frac{1}{2}V_{cn} \quad (10)$$

$$V_q = V_{an} - \frac{\sqrt{3}}{2}V_{bn} - \frac{\sqrt{3}}{2}V_{cn} \quad (11)$$

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & 1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} v_{an} \\ v_{an} \\ v_{an} \end{bmatrix} \quad (12)$$

$$|\bar{v}_{ref}| = \sqrt{v_d^2 + v_q^2}; \quad \alpha = \tan^{-1}(v_d / v_q) \quad (13)$$

Step 2: Determine time duration T1, T2, T0:

From Fig. 5.6, the switching time duration can be calculated as follows:

Switching time duration at Sector 1:

$$\int_0^{Tz} \bar{V}_{ref} = \int_0^{T_1} \bar{V}_1 dt + \int_{T_1}^{T_1+T_2} \bar{V}_2 dt + \int_{T_1-T_2}^{T_1} \bar{V}_0 dt \quad (14)$$

$$T_z \bar{V}_{ref} = T_1 . \bar{V}_1 + T_2 . \bar{V}_2$$

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

Following figure gives the switching times of each IGBT switches.

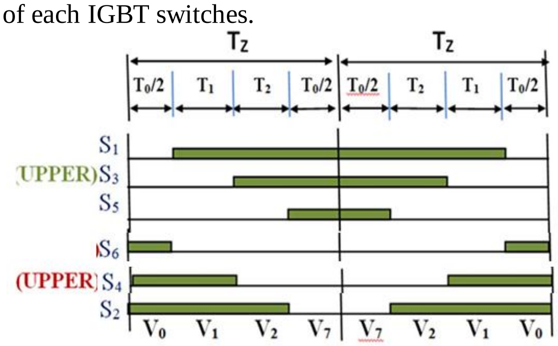


Figure 8: Switching pulse pattern for the three phases in Sector 1.

Here Fig. 8 gives the brief idea about the switching timing pattern of inverter IGBT switches under different sectors to generate three phase voltage waveform.

Based on above figure, the switching time at each sector is summarized in Table (2), and it will be built in Simulink model to implement SVPWM.

Table 2

Switching time calculation 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	S1=T0/2; S3=T1+T0/2; S5=T1+T2+T0/2
2	S1=T1+T0/2; S3=T1+T2+T0/2; S5=T0/2	S1=T2+T0/2; S3=T0/2; S5=T1+T2+T0/2
3	S1=T0/2; S3=T1+T2+T0/2; S5=T2+T0/2	S1=T1+T2+T0/2; S3=T0/2; S5=T1+T0/2
4	S1=T0/2; S3=T1+T0/2; S5=T1+T2+T0/2	S1=T1+T2+T0/2; S3=T2+T0/2; S5=T0/2
5	S1=T2+T0/2; S3= T0/2; S5=T1+T2+T0/2	S1=T1+T0/2; S3=T1+T2+T0/2; S5=T0/2
6	S1=T1+T2+T0/2; S3= T0/2; S5= T1+T0/2	S1=T0/2; S3=T1+T2+T0/2; S5=T2+T0/2

PV SOURCE

Photovoltaics (PV) covers the conversion of light into electricity using semiconducting materials that exhibit the photovoltaic effect, a phenomenon studied in physics, photochemistry, and electrochemistry. The dynamic model of PV cell is shown in below Fig.6.

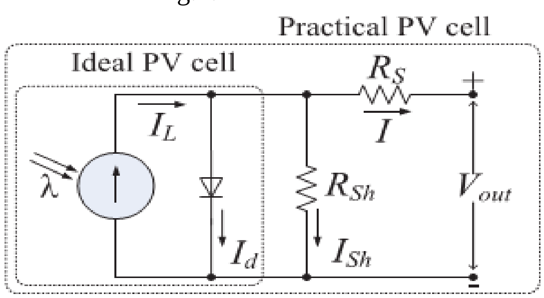


Fig 6.Equivalent electrical circuit of the PV cell.

The basic equation describing the I -V characteristic of a practical PV cell is

$$I = I_L - I_d - I_{sh} = I_L - I_D\left[e^{\frac{QV_{OC}}{AKT}-1}\right] - \frac{V_{out}+IR_S}{R_{Sh}} \quad (27)$$

where I D is the saturation current of the diode, Q is the electron charge, A is the curve fitting constant (or diode emission factor), K is the Boltzmann constant and T is the temperature on absolute scale. PV systems convert light directly into electricity and shouldn't be confused with other technologies, such as concentrated solar power or solar thermal, used for heating and cooling.

SIMULATIONS AND RESULTS

Simulation of sinusoidal PWM based model:

In Sinusoidal PWM three phase reference modulating signals are compared against a common triangular carrier to generate the PWM signals for the three phases.

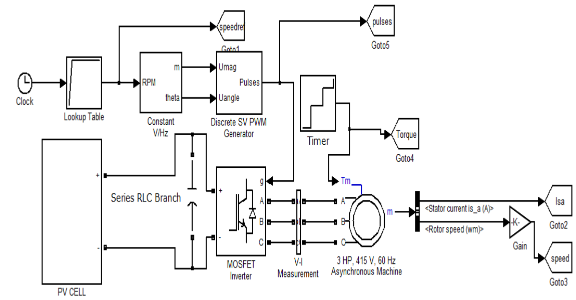


Fig.9.Block diagram of simulation

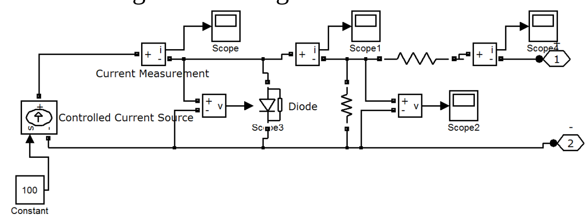


Fig.10. Equivalent circuit of pv system

It is simple and linear between 0% and 78.5% of six step voltage values, which results in poor voltage utilization. Frequency in conventional SPWM output waves owing to their fixed switching frequencies.

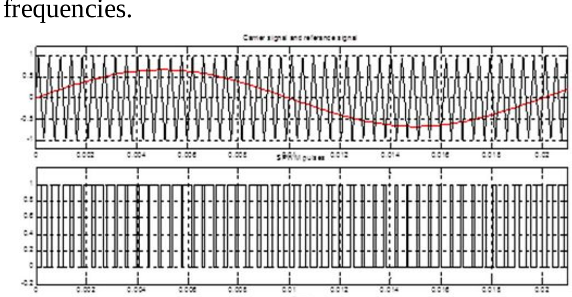


Fig.11: SPWM Pulses

The simulation circuit connection of a three phase inverter based induction motor drive with Sinusoidal PWM (SPWM) is as shown in above figure. Here the three-phase 415V, 50Hz ac supply is converted into dc and then this DC voltage is converted into 3-phase variable frequency ac. Here the controlling of inverter is done by PWM method i.e. sinusoidal PWM.

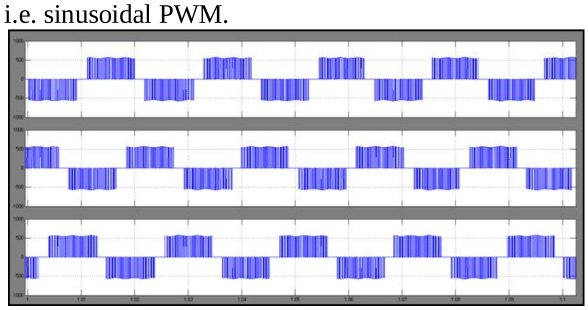


Figure 12: Inverter o/p line voltages

The speed and electromagnetic responses of induction motor with the different load torques at different instants are as shown in Fig. 13. From this figure it is observed that when load is applied on the motor the speed of motor gets reduced.

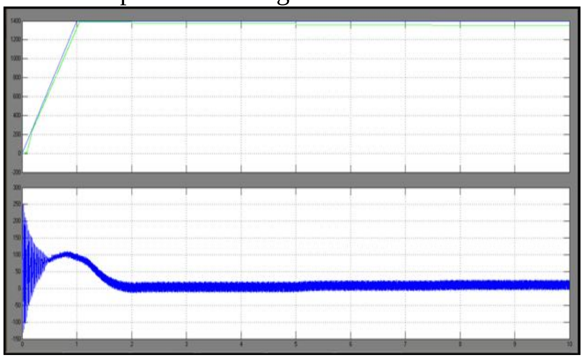


Fig.13. Motor Speed and Electromagnetic torque.

Simulation of Space Vector PWM based model:

SVPWM based pulse generator simulation diagram is as shown in Fig. 16. T1 to T6 pulse signals are as shown in Fig. 14. These pulsed are given to the six IGBT switches of bridge inverter.

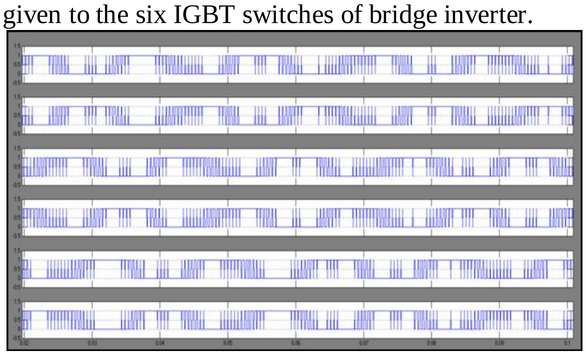
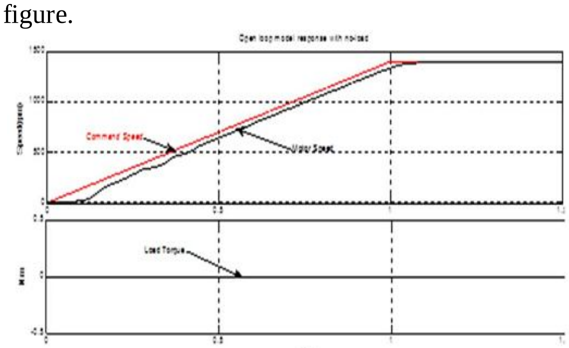


Figure 14: SVPWM output gate pulses

When SVPWM pulse generator is connected to 3-phase bridge inverter with the induction motor load form a open loop drive. The motor will run at a reference speed. The SVPWM block generates gate pulses with respect to speed command so as to run motor at reference speed.

The reference speed and motor speed graph with time and load torque=0 are as shown in below figure.



Speed response of Induction motor with different load torque is as shown in below Fig.

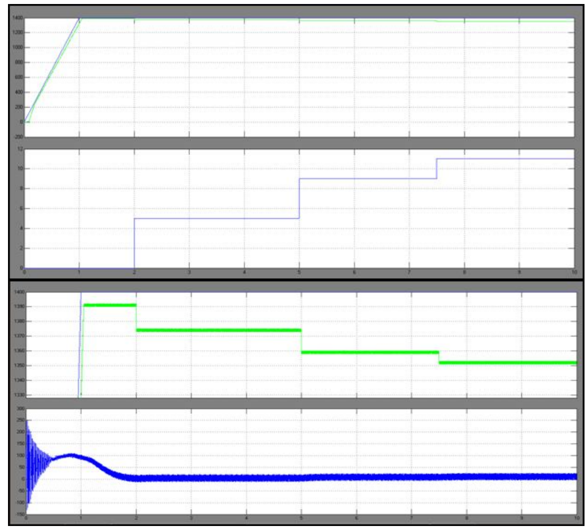


Figure 16: Speed response with different TL

CONCLUSION

The speed of an induction motor can be varied by varying input Voltage or frequency or both. The speed of induction motor is controlled which is fed from three phase bridge inverter is proposed in this paper. Variable voltage and variable frequency for Adjustable Speed Drives (ASD) is invariably obtained from a three-phase Voltage Source Inverter (VSI). Solar PV has specific advantages as an energy source: its operation generates no pollution and no greenhouse gas emissions once installed, it shows simple scalability in respect of power needs and silicon has large availability in the Earth's crust. A number of PWM techniques are there to obtain variable voltage and variable frequency supply such as PWM, SPWM, SVPWM to name a few, among the various modulation strategies SVPWM is one of the most efficient techniques as it has better performance and output voltage is similar to sinusoidal. Also observed that for the change in input speed commands the motor speed is settled down to its final value within 0.1sec in closed loop model. The simulation of "Control of Induction Motor Drive Using Space Vector PWM" is carried out in MATLAB/Simulink. The simulation has been done for open loop as well as closed control. The appropriate output results are obtained.

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