Comparative Study of PV Fed Induction Motor Performance with SPWM and SVPWM

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Abstract— With the advent of power electronic technologies, Induction Motors (IM) has become the major power horse of industries. For the control of inverter fed induction machines, various pulse width modulation techniques were developed. These modulation schemes added to the ease of operating the inverter fed induction machines. Also desired performance could be attained by varying the modulation schemes. The two basic modulation schemes that are popularly used are the Sine triangle pulse width modulation scheme and Space vector pulse width modulation scheme. The paper presents a comparison among the two schemes when they are applied to an inverter fed induction machine. The increasing energy cost has made popular the use of renewable energy systems. The induction machine is supplied from a photovoltaic system and the simulation results in MATLAB/SIMULINK are presented.

Key words: Carrier frequency, Modulation index, Photovoltaic system, Space vector, Switching times, Torque ripple

I. INTRODUCTION

The wide popularity of Induction motor (IM) in industries is due to its various advantages such as simple construction, reliability, ruggedness and low cost. With the wide use of power electronic converters, the use of inverter fed induction machines have gained wide popularity. In conventional inverters, the output voltages change with variations in load applied to the inverter. Pulse width modulation (PWM) is an advanced and useful technique that nullifies this effect. It is used to vary the gain of the inverters by controlling the gate pulses to the devices used. Closed loop control is also possible if the PWM scheme is provided with feedback from the machine to attain desired performance. The use of modulation schemes reduces the presence of lower order harmonics at the inverter output thus minimizing the filtering requirements. The implementation of the scheme does not require any additional components.

Sine triangle pulse width modulation (SPWM) is one of the basic PWM schemes. The controllable switches of the inverter are controlled by comparing a sinusoidal control signal and a triangular switching signal. The inverter output voltage is corrected by changing the pulse width and the switching frequency. The output voltage is thus maintained constant irrespective of the load variations. There is multiple numbers of pulses per half cycle and the pulses are of different width. The scheme is popularly used as it has a very simple implementation.

Space vector modulation (SVM) is an algorithm for the control of PWM. It is commonly used to drive three phase ac powered motors at varying speeds. There are different variations of SVM that differ in computation requirements and results in different quality. It is possibly the best method among all PWM techniques for variable frequency drives. The rapid switching results in reduction in total harmonic distortion (THD). Various switching patterns can be used to realize the Space vector pulse width modulation (SVPWM) scheme.

The paper is organized as follows: Concept of SPWM is explained in section II. The SVPWM algorithm is detailed in section III. Modeling of photovoltaic system is discussed in section IV. The simulation results are presented in section V. Finally the conclusion and future trends are mentioned in section VI.

II. CONCEPT OF SINE TRIANGLE PULSE WIDTH MODULATION

SPWM is based on the comparison between a high frequency triangular carrier wave and a sinusoidal reference wave as shown in fig.1. The carrier and the reference waves are mixed in a comparator. When the sinusoidal wave has higher magnitude, the comparator output is high, else it is low. The comparator output is processed in a trigger pulse generator so that output voltage has a pulse width in agreement with the comparator pulse width. The width of each pulse varies in proportion to the amplitude of the sine wave. If the amplitude of the triangular carrier signal is Ac and that of the modulating signal is Am, then the modulation index in given by m=Am/Ac. Controlling the modulation index controls the amplitude of the output voltage[1].

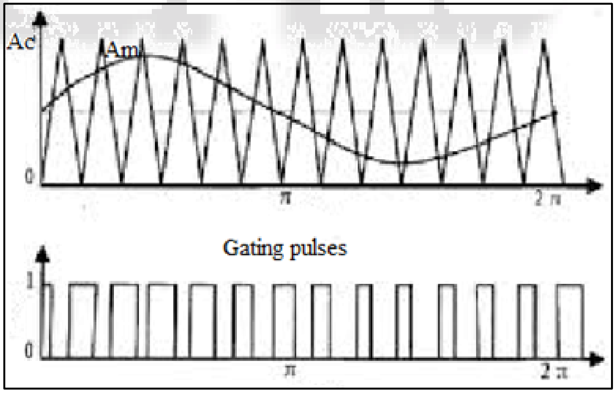


Fig. 1: Principle of sine triangle pulse width modulation

The sinusoidal control waveform determines the fundamental frequency of the inverter output voltage and the triangular waveform decides the switching frequency of the inverter. The ratio of frequency of the triangular carrier wave to the frequency of the sinusoidal modulating wave is referred to as the modulation frequency ratio. For applying SPWM in a three phase inverter, three modulating sinusoidal signals are needed.

III. SPACE VECTOR PULSE WIDTH MODULATION

Space vector pulse width modulation (SVPWM) is a modulation scheme popularly used in three phase inverters. The sinusoidal phase voltage reference is converted into modulation times or duty cycles to be applied to the controllable switches of the inverter. The sinusoidal voltage is treated as a constant amplitude vector rotating at constant frequency. SVPWM maximizes the dc bus utilization. The reference voltage is generated through the switching combinations of eight voltage vectors. The six active voltage vectors V1 to V6 divide the plane into six sectors each of 60 degree. The concept of space vector is shown in fig.2. For the generation of the reference vector as in fig.2, the adjacent vectors V1 and V2 of sector 1 can be used along with the zero vectors (V0 or V7). The time for which the various voltages are to be applied (T1, T2 and T0) can be calculated using equations as detailed in [2].

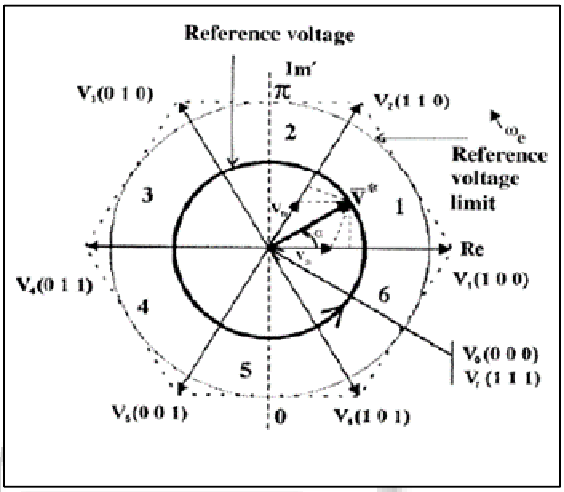


Fig. 2: Space vector of two level inverter with reference voltage vector in sector 1

The three phase voltages need to be transformed to two phase quantities which make the technique computationally complex. But because of its superior performance such as reduction in harmonics and the efficient use of the DC bus voltage makes it popular for use in various industrial applications.

IV. MODELING OF PHOTOVOLTAIC SYSTEM

The increasing demand for energy led to the revolutionary development in renewable energy systems in the last decade. Photovoltaic (PV) systems and wind energy systems are the most popular ones among them. PV systems convert the sun's radiation into usable electricity. Large number of solar cells, made of semiconductor material, are connected together in series and parallel combinations to form a solar array of required power.

The system may be a stand-alone one or a grid connected one. The output from the PV array may vary depending on the irradiation. To extract maximum power from an array, Maximum Power Point Tracking (MPPT) techniques could be employed. A PV system can be modeled by using the equations described in [5] and [6].

V. SIMULATIONS AND RESULTS

A 2 HP, 4 pole, inverter fed induction machine has been modeled in MATLAB/Simulink and the modulation schemes were implemented to evaluate the performance. The inverter is fed from a PV array of 1kW.The specifications of the machine are detailed in Table I.

The block diagram of an inverter-fed induction motor supplied from a PV system is shown in fig.3. Fig.4 shows the P-V and I-V curve of the photovoltaic array (1kW) used.

Rated Power	2 HP
Rated Speed	1450 rpm
Frequency	50 Hz
Rotor Type	Squirrel Cage
Reference Frame	Stationary
Poles	4
R_s	0.435 Ω
R_r	0.816 Ω
$L_{ls} = L_{lr}$	2e-3 H
L_m	8e-3 H
J, Moment of inertia	0.089

Table 1: 3 Phase Induction Motor Specifications

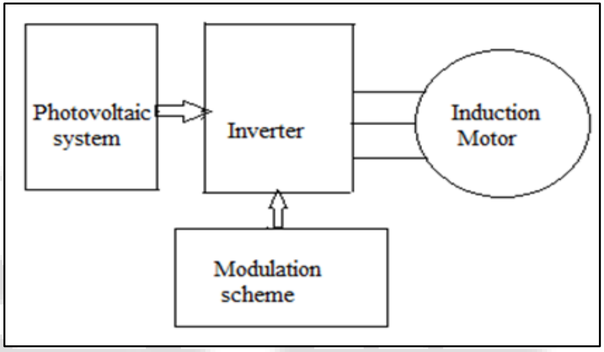


Fig. 3: Block diagram of the system implementation

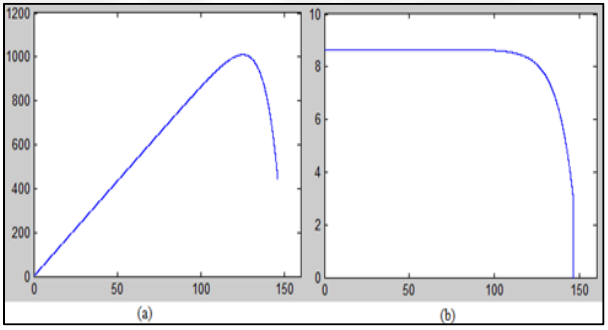
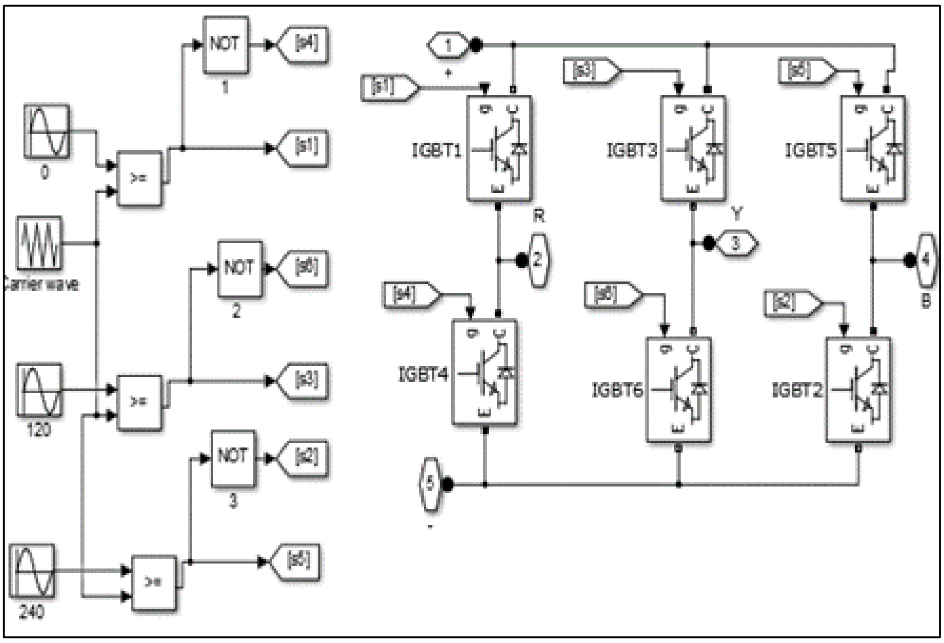


Fig. 4: (A) P-V Curve And (B) I-V Curve Of The PV Array (X Axis:50V/Div, Y Axis: (A)200W/Div (B) 2A/Div)

The operation of a three phase SPWM is shown in fig.5 (a) where a triangular wave of frequency 1 kHz is compared with three sinusoidal modulating signals that have a phase shift of 120 degree. The waveforms of comparison are shown in fig.5 (b).The pulses obtained from the comparison of each signal are given to the corresponding switches in the upper leg of the inverter.



(a)

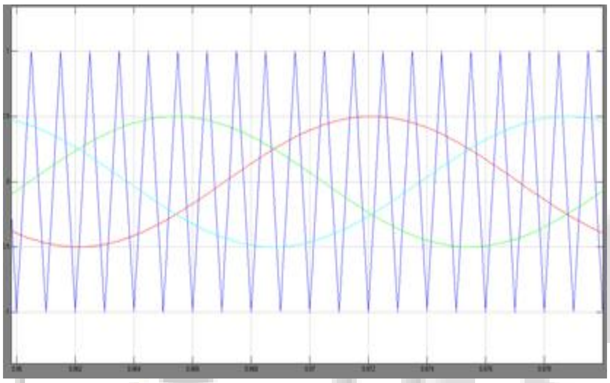


Fig. 5: (A) SPWM Of A Three Phase Inverter In MATLAB (Ac=1V,Am=0.5V) (B) Waveforms Of SPWM
(X Axis:0.002s/Div, Yaxis:0.5V/Div)

The space vector algorithm is implemented in the inverter with a sinusoidal reference voltage. The operation of the scheme in the six sectors can be obtained by using angle and sector identification algorithms. The locus of the space vector forms a hexagon as shown in fig.6. The SVPWM controlled three phase inverter is shown in fig.7 (a) and the angle and sector of operation are shown in fig.7 (b).

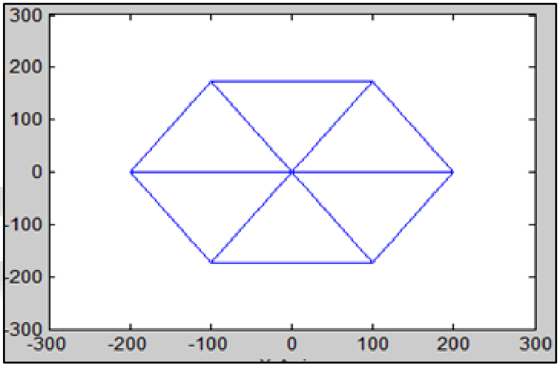
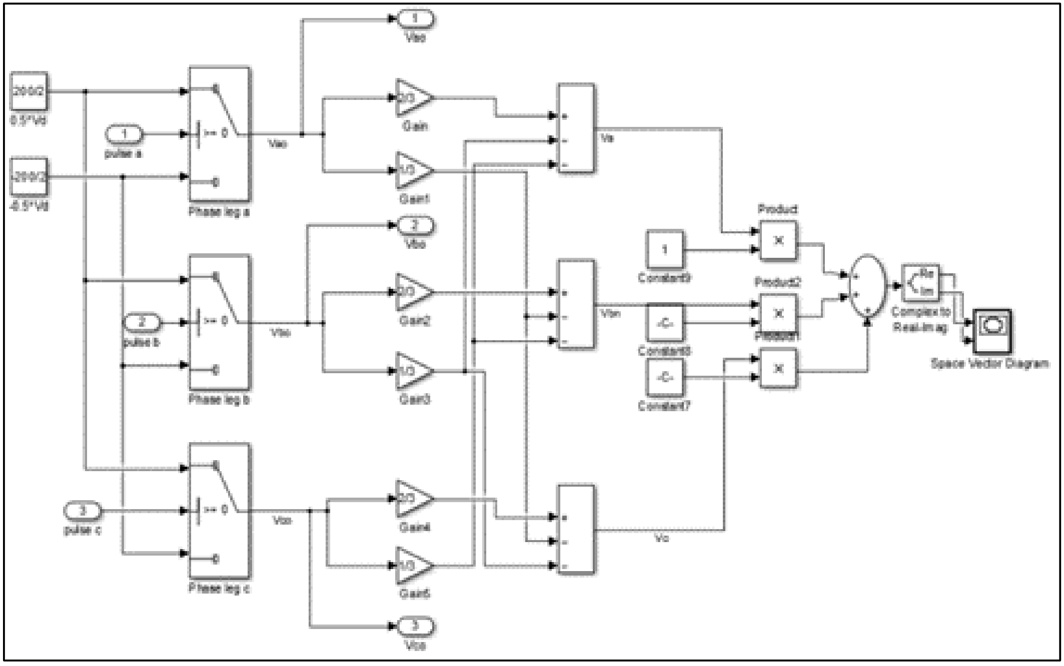
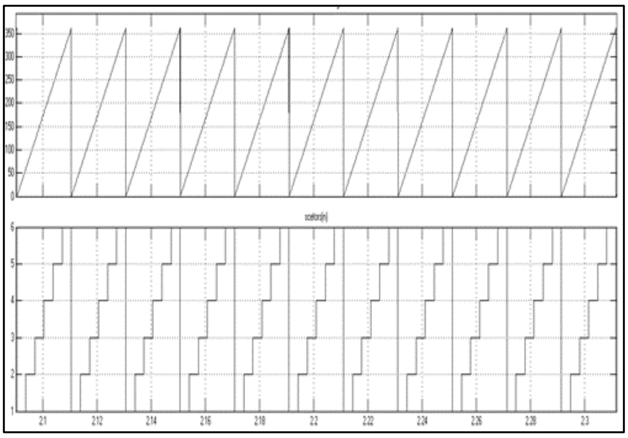


Fig. 6: Space vector locus diagram of the inverter
(x axis:100V/div, y axis:100V/div)



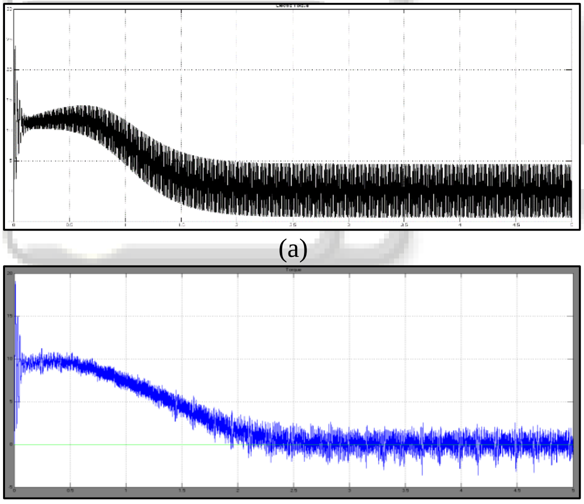
(a)



(b)

Fig. 7: Angle and sector of operation of SVPWM controlled inverter (x axis: 1 unit=0.01s/div; y axis=600/div,1 sector/div)

The inverter is operated from both SPWM and SVPWM and the output in both cases is given to drive the induction motor. The performance of the machine in both cases is analyzed. The motor electro-mechanical torque under no load condition is shown in fig.8. It can be seen that the ripples are more when the inverter is operated with SPWM. This is owing to the fact that when SVPWM is used the active and zero vectors are switched in the sampling period several times lowering the harmonics in the inverter outputs and the dc bus utilization is improved.



(a)

(b)

Fig. 8: No load torque response of the machine with (a) SPWM and (b) SVPWM (x axis:0.5s/div, y axis:5Nm/div)

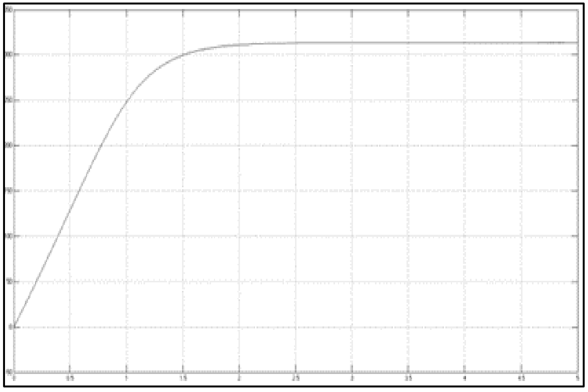
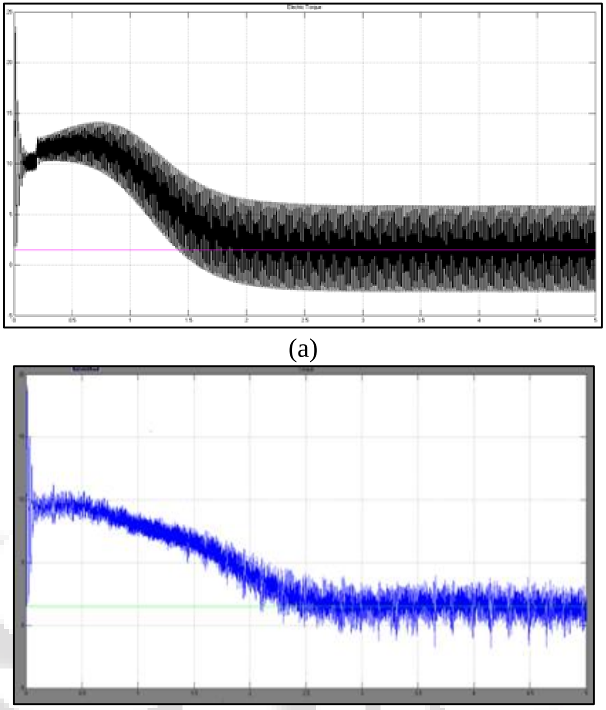


Fig. 9: Sped Response Of The Machine Under No Load (X Axis:0.5s/Div, Y Axis:50 Rad/S/Div)

Under no load conditions the speed of the machine under the two schemes remains the same as shown in fig.9. This speed corresponds to the fundamental frequency of operation of the machine.

When the machine is loaded with a load torque of 1.5 Nm, the machine output torque is shown in fig.10 for the two schemes. The ripple with SVPWM operated inverter-fed machine is lower. While considering the speed as in fig.11 the machine operated with SPWM gives a slightly lower speed due to the high ripples in developed torque.



(a)

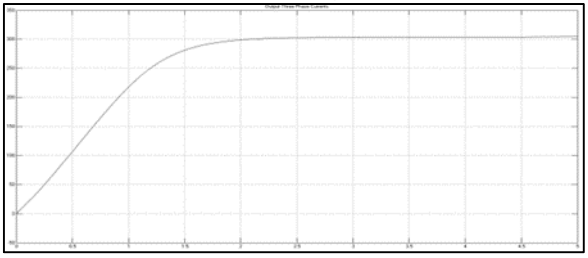
(b)

Fig. 10: Torque response of the machine for a load torque of 1.5Nm with (a) SPWM and (b) SVPWM (x axis:0.5s/div, y axis:5Nm/div)

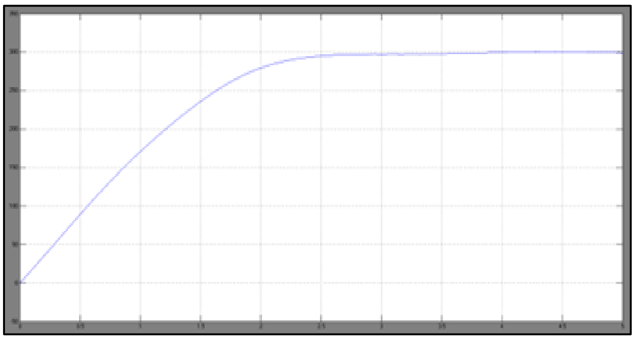
VI. CONCLUSIONS AND FUTURE SCOPE

The paper provided a comparison between the two popular modulation schemes: SPWM and SVPWM when applied to an induction machine fed from a photovoltaic system. It is seen that the use of SVPWM scheme is superior as it considerably reduces that amount of ripples in the machine output torque. Changes are effected in the speed also as it depends on the torque.

There are different schemes in SVPWM that could be incorporated in the system to evaluate the performance. The system operation can be made closed loop by comparing the motor output to a reference value. The comparator output can then be used as the modulating input for PWM.



(a)



(b)

Fig. 11: Speed response of the machine for a load torque of 1.5Nm with (a) SPWM and (b) SVPWM (x axis:0.5s/div, y axis:50rad/s/div)

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