International Journal of Electrical, Electronics and Computer Engineering **4**(1): 136-142(2015)
ISSN No. (Online): 2277-2626

A Review of PWM Techniques for Inverters in Induction Motor Drives

Aparna Sharma*, Abhijeet Singh** and Prof. P. Yadav***
**Research Scholar, Department of Electrical Engineering, Oriental College of Technology, Bhopal, (MP) India*
***Asst. Prof., Department of Electrical Engineering, Oriental College of Technology, Bhopal, (MP) India*
****Professor, Department of Electrical Engineering, Oriental College of Technology, Bhopal, (MP) India*

(Corresponding author: Aparna Sharma)
(Received 03 February, 2015 Accepted 23 March, 2015)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: Recent advances in semiconductor devices lead to development in microprocessors and solid state power devices which enhanced the application of switching power converters in the domain of industries where conversion of power and its delivery to the load or machine is required. Many industrial applications which require superior performance are now relaying on pulse width modulation (PWM) variable speed drives. The PWM based power converters are easy to implement as compared with linear power amplifier. In this article a survey of different PWM techniques for Inverter in Induction motor drives, such as single pulse modulation, carrier based modulation (sinusoidal pulse modulation), multiple pulse modulation and state vector pulse width modulation (SVPWM). In this paper SVPWM technique is explained in detail.

Keywords: Induction motor, PWM technique, SVPWM technique etc.

I. INTRODUCTION

An induction motor is a kind of asynchronous AC motor in which electric power is supplied to the rotating device utilizing the principles of electromagnetic induction (EMI) [1], [2]. Because of the advantages of induction motors (IM) over the other electric motors, these induction motors are the most broadly utilized electrical motors, particularly polyphase induction motors, which are to a great extent utilized as a part of Industrial drives. In the greater part of many modern motor application AC induction motors are utilized due to the high strength, reliability, high efficiency and low cost [3,4,5]
Due to all the advantages mentioned above, induction motor is treated as the ideal machine to convert electrical energy into mechanical energy. However, more often mechanical energy required at variable speed, where controlling speed is not a very easy matter. Now a days Industries have many areas, where variable operating speed is the principal requirement. Prior to the times of power electronics, very limited speed control of Induction Motor (IM) was achieved using switching the three-stator winding's from delta connection to star connection, which allows the voltage at the motor winding's to be reduced [1, 3, 4, 5, 6, 7]. At that time methods mentioned above were the only only methods to control the speed of AC asynchronous motor, whereas a DC drive was already invented which can infinity vary the speed of DC motor. However, the main drawback of these drives was a compulsory requirement of brushes.
In 1985 with the development of Power Electronics-based drives, especially IGBT based PWM Inverters for efficient frequency-changing favorable conditions for developing variable speed drives for AC motors are present Pulse-width modulation (PWM) inverters reduce harmonics in the output current and/or voltage by increasing the switching frequency and control the inverter output voltage as well as frequency by changing modulating wave. PWM inverters are more appropriate for speed control of induction motor (IM) instead of other techniques. The most popular technique is Sinusoidal PWM (SPWM), which is appropriate for, linear modulation index up to 0.7855 only. Above this modulation index, SPWM produce more harmonics in output voltage and current of the inverter. For enhancing the linear modulation range up to 0.907, third harmonic injected PWM (THIPWM) and space vector PWM (SVPWM) techniques are used to improve the total harmonic distortion THD as well as increase the basic value of inverter output voltage. [8,9,10 ,11] Space Vector Pulse width Modulation (SVPWM) generates the appropriate gate drive waveform for each pulse width modulation (PWM) cycle. The inverter is treated as one single unit and can combine different switching states (number of switching states depends on levels of the inverter). The SVPWM provides unique switching time calculations for each of these states.

II. PULSE WIDTH MODULATION

Recently semiconductors size and price have reduced due to the development in their fabrication technology. Hence, in place of mechanical motor drive which are not energy efficient, switching power converter Variable Frequency Drive (VFD) can be used. These Variable Frequency Drives (VFD) control the motor speed as well as enhance the steady state and dynamic characteristics of motors. Switching power converter based VFDs are also energy efficient. That is why switching power converters are extensively used in Industries.

Pulse width modulation (PWM) signals are pulse string with unchanging magnitude and frequency & variable pulse width. In every PWM period there is 1 pulse of fixed magnitude. Though, the pulse width varies from pulse to pulse as per the modulating signal. At the point when a PWM signal is applied to the gate of a power transistor, it causes the turn on and turns off interims of the transistor to change starting with one PWM period then onto the next PWM period as indicated by the same modulating signal. PWM signal's frequency has to be much higher than the frequency modulating signal.

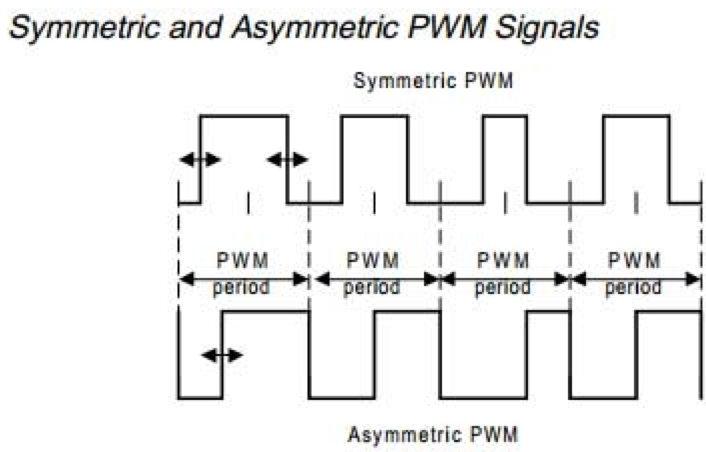

Fig. 1. Symmetric and Asymmetric PWM Signals.

PWM signals are of two types symmetric and asymmetric PWM signals as shown in Fig. 1. From the center of each PWM period, the pulse of symmetric PWM is always symmetric. In asymmetric PWM the pulse one fixed side of the pulse is always aligned along one end of PWM period. Symmetric PWM normally generates very few harmonics in output waveforms (voltages and currents). In this article we have focused on three very popular pulse width modulation (PWM) techniques which are extensively used in 3 phase voltage source inverter (VSI) applications.

PWM technique is used very extensively because it consumes very less power, its ease of implementation, no degrading in linearity, no ageing caused drifting and no variation due to temperature and most importantly this technique is compatible with today's digital microprocessor and semiconductor technology. One of the big advantages of PWM technique is that output voltage can be controlled without using any additional components and algorithms, through this technique lower order harmonics is minimized to its output voltage control and due to the fact that harmonics can be filtered through this technique so requirement of filter is minimized.

III. FUNDAMENTAL PWM TECHNIQUES

A. Single Pulse Width Modulation.

In this control technique, in order to control the inverter output waveform (voltage or current) the width or duration of the pulse is varied and there is just one pulse half per cycle. Here gating signals are generated by comparing the triangular carrier wave with the rectangular reference signal as depicted in in Fig 2. The frequency of the reference signal determines fundamental frequency of the output voltage. The main advantages of this PWM technique are that the even harmonics in this approach are not present as if the pulse width is made the equal to $2\pi/n$. However the disadvantages are the output voltage introduces an immense amount of harmonic content and the distortion factors increase significantly at low output voltage.

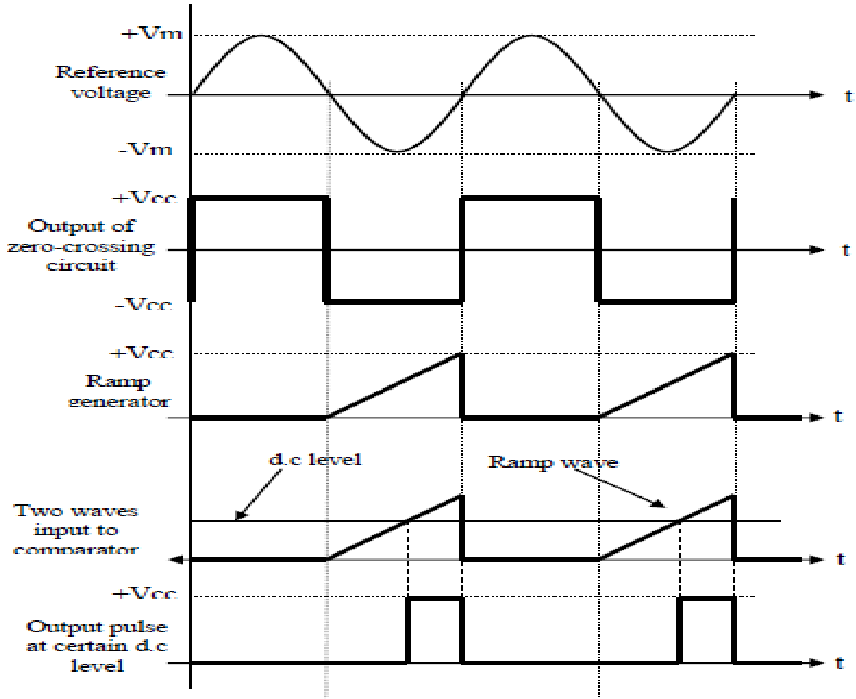

Fig. 2. Single Pulse Width Modulation.

B. Multiple Pulse Width Modulation.

In this Pulse Width Modulation (PWM) several pulses with same distance per half cycle are generated as presented in Fig 3. Here the harmonic content can be reduced by using many pulses in each half cycle of output voltage. Amplitudes of lower order harmonics and derating factor are reduced by applying this technique. However the primary component of output voltage is very less and the amplitudes of higher order harmonics increase considerably.

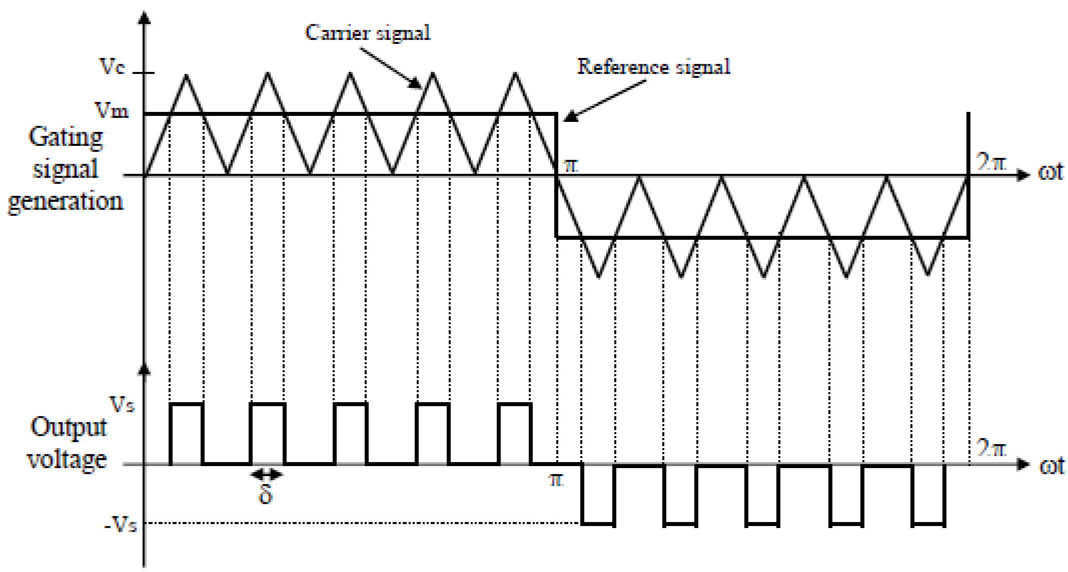

Fig. 3. Multiple Pulse Width Modulation.

IV. CARRIER BASED PWM TECHNIQUES

The most common PWM method is called the Sinusoidal PWM which is appropriate for, linear modulation index up to 0.7855. As specified previously, it is fancied that the AC output voltage Vo=VaN follow a given waveform for e.g., sinusoidal on a constant basis by appropriately switching the power valves. This technique fulfills such type of requirement as it defines the on state and off states of the switches of one leg of a voltage source inverter (VSI) by comparing Vc (modulating signal, desired AC output voltage) and a triangular waveform VΔ (the carrier signal). In practice, while Vc > VΔ the switch S+ is on along with the switch S- is off; in the same way, while Vc < VΔ the switch S+ is off along with the switch S- is on. For the resulting plot of SPWM using Matlab, see Fig. 4

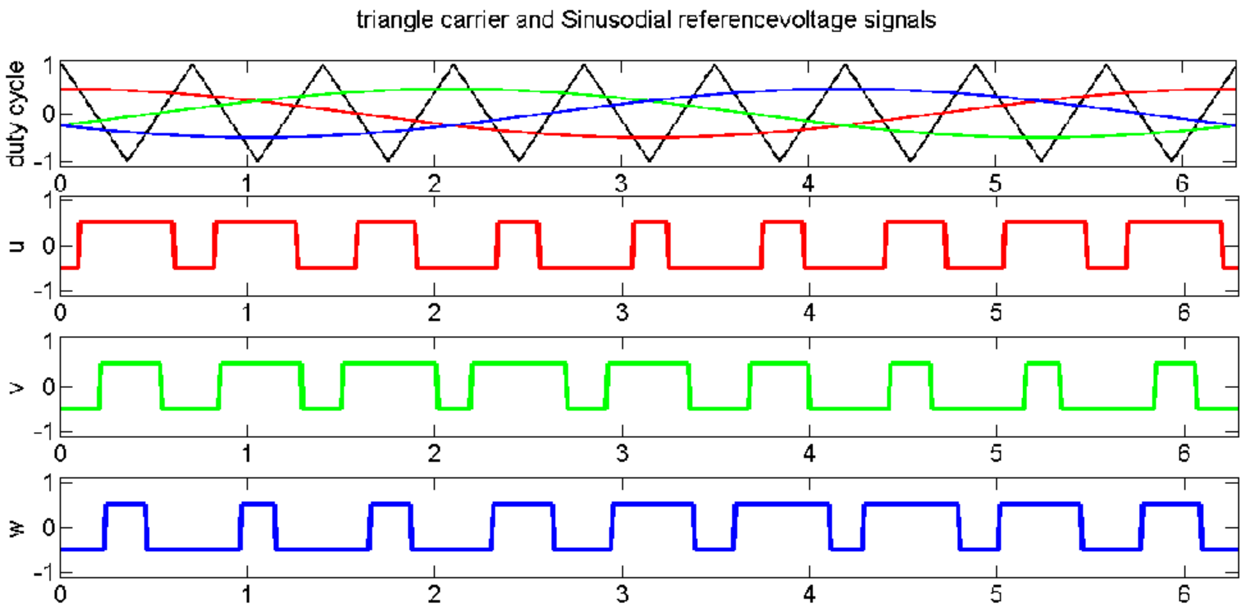

Fig. 4. Carrier based (Sinusoidal) Pulse width Modulation.

V. SVPWM BASED PWM TECHNIQUES

This pulse width modulation is comparatively latest and trendy technique applied to control motor devices. This technique was at first developed as a vector approach to PWM for 3-phase inverters. SVPWM technique is used to generate a reference voltage when current control is applied. This method is advanced, sophisticated and computationally very rigorous technique. In this technique the output voltage is approximated via the closest 3 output vectors that the nodes of the triangle containing the reference vector in the space vector diagram of the inverter. It may induce an abrupt change in an output vector when the reference vector changes from one region to another, this can induce abrupt change in an output vector. As well as, at every change of the reference voltage location one required to compute the switching sequences & switching time of the states. The primary advantage of this technique is that it generates less harmonic distortion in the output.

Space Vector Pulse width Modulation (SVPWM) generates the appropriate gate drive waveform for each pulse width modulation (PWM) cycle. The inverter is treated as one single unit and can combine different switching states (number of switching states depends on levels of the inverter). The SVPWM provides unique switching time calculations for each of these states [12]. This technique can easily be changed to higher levels and works with all kinds of multilevel inverters (capacitor clamped, cascaded, diode clamped). The three vectors that form one triangle will provide duty cycle time for each state, giving the desired voltage vector (Vref). This can be described with the formula given below:

$V = (T_1V_1 + T_2V_2 + T_3V_3)/ T_c$

With a 3-phase VSI as shown in fig. there are eight possible switching states. For instance, if the upper switch of the inverter's pole a is on, whereas the other legs both have the lower switch turned on. Then the pole voltages are (+0.5V DC; -0.5V DC; -0.5V DC) for poles a, b, c respectively. This switching state can be nominated as + - - or 100. To designate the all possible switching state code numbers 0 to 7 are used. In case of the switching states - - - (V 0) and + + + (V 7), all The three poles are connected to the same DC bus, which effectively shorts the induction motor and resulting in no transfer of power between the source and induction motor. These two states are called zero voltage vectors or zero states. The zero vectors are placed in the axis origin. In other switching states, power gets transferred between the source and induction motor. These states (1; 2…..6) are called active voltage vectors or active states [15,16,17]. The space vector locations form the vertices of a regular hexagon, forming six symmetrical sectors as shown in Fig. 5.

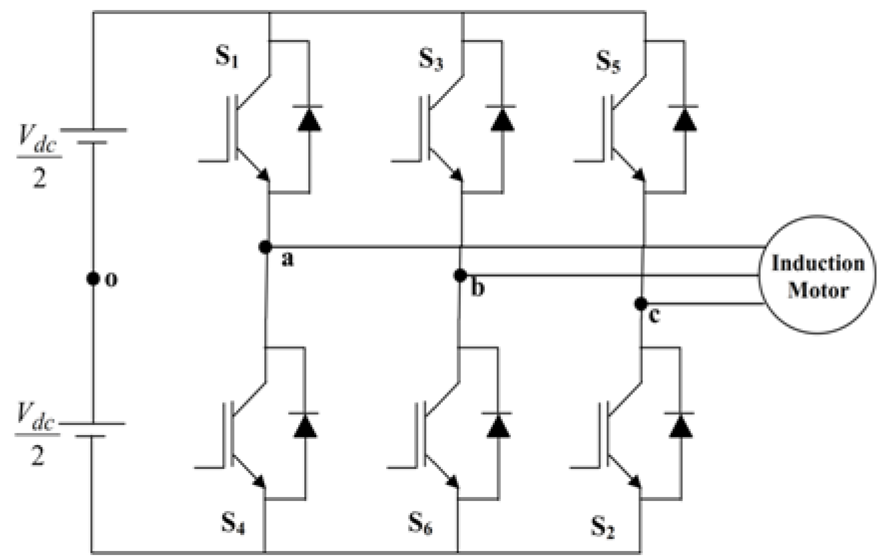

Fig. 5. Three-phase voltage source inverter (VSI).

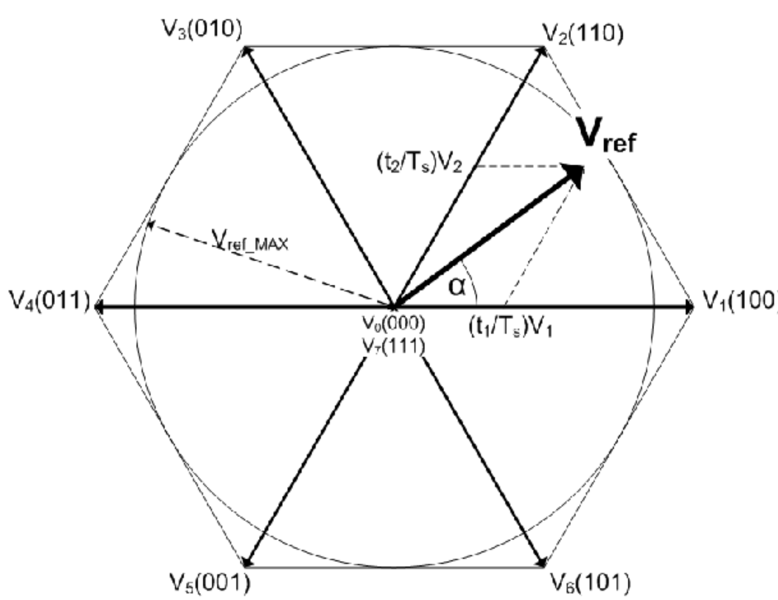

Fig. 6. Space Vector diagram of Two level SVPWM Inverter.

SVPWM also have good utilization of the DC link voltage, low current ripple and comparatively straightforward hardware execution. The SVPWM has a 15% higher utilization ratio of the voltage then the SPWM [10]. These features make SVPWM suitable for high voltage, high power applications, such as renewable power generation. As the amount of level increase the redundant switching states increases as well as the complexity of the selection of the switching states [11]. So, deciding which level is right for a certain application, it is important to find a balance between losses and the specification of the positioning of the reference vector. Figure 6 presents the space vector voltage and space voltage trajectory of the phase current.

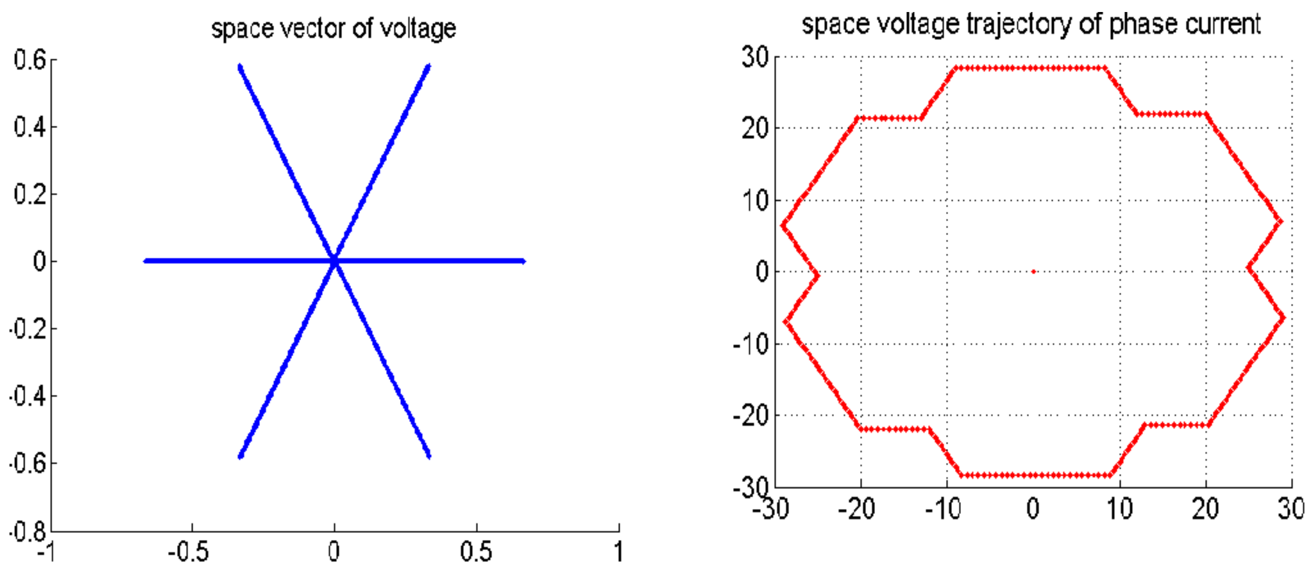

Fig. 7. Space vector voltage and space voltage trajectory of the phase current.

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