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A Comparative Study of Various PWM Techniques

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***Abstract- Pulse-width modulation* is the process of modifying the width of the pulses in a pulse train in direct proportion to a small control signal; the greater the control voltage, the wider the resulting pulses become. By using a sinusoid of the desired frequency as the control voltage for a PWM circuit, it is possible to produce a high-power waveform whose *average* voltage varies sinusoidally in a manner suitable for driving ac motors. This paper presents the MATLAB/Simulink based models of various PWM techniques usually employed.**

Keywords: Sinusoidal PWM, Sine Triangle PWM, SVPWM

I. INTRODUCTION

Present day drive types are the Induction motor drives with voltage source inverters. Also the voltage waveforms of traditional two level inverter fed Induction motor shows that the voltage across the motor contains not only the required "fundamental" sinusoidal components, but also pulses of voltage i.e. "ripple" voltage. In a variable speed application of the three phase induction motor, a voltage source inverter is normally used to supply a variable frequency variable voltage supply. A suitable Pulse Width Modulation (PWM) technique is employed to obtain the required output voltage in the line side of the inverter. The various methods for PWM generation can be generally classified into Triangle Comparison based PWM (TCPWM) and Space Vector based PWM (SVPWM).
In one of the most utilized TCPWM methods i.e. the sine triangle PWM, three phase reference modulating signals are compared against a common triangular carrier to generate the PWM signals for the three phases. The frequency of the carrier signal is very high compared to the modulating signal.

The magnitude and frequency of the fundamental component in the line side are controlled by the magnitude and frequency, respectively, of the modulating signal. With sine-triangle PWM, the highest possible peak phase fundamental voltage is $0.5V_{dc}$, where V_{dc} is the DC bus voltage, in the linear modulation zone. In TCPWM based methods, increasing the reference magnitude beyond a certain level leads to pulse dropping.

II. SPACE VECTOR PULSE WIDTH MODULATION

In Space Vector pulse width modulation (SVPWM) methods, a revolving reference voltage vector is provided as voltage reference instead of three phase modulating waves (figure 4.3). The magnitude and frequency of the fundamental component in the line side are controlled respectively, by the magnitude and frequency, of the reference vector.
The fundamental line side voltage is proportional to the reference magnitude during linear modulation.

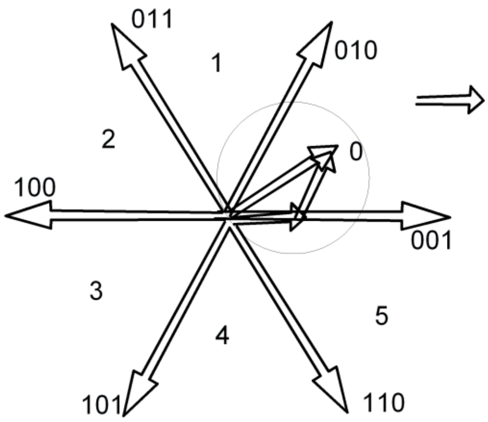

Figure 1: Switching states of inverter in SVPWM

From figure (1) it is observed that in the SVPWM, there are six non-zero or active states (001,010,011,100,101,110) and two zero states (000,111). Also, the voltage vectors for active states can be located as shown in figure (1), zero vectors being at the origin. Thus we can divide the space into six sectors i.e. from zero to five. Every sector is made up of two active vectors and two zero vectors. In order to obtain a voltage vector like u_S that lies in a sector and is not among the active or zero vectors we make use of the volt-second equality principle. Thus we find that the locus of the complete range of voltages available in the linear SVPWM method is a hexagon. In the space vector based PWM, the peak phase fundamental voltage can be as high as 0.577 V_{dc} during linear modulation.
To increase the line side voltage further, the operation of the voltage source inverter (VSI) must be extended into the overmodulation region. The overmodulation region extends up to the six-step mode, which gives the highest possible ac voltage for a given V_{dc} i.e. $\frac{2V_{dc}}{\pi}$ or $0.637V_{dc}$.

However, in SVPWM methods, an overmodulation algorithm is required for controlling the line-side voltage during overmodulation and to achieve a smooth transition from PWM to six-step mode.

Numerous overmodulation algorithms have been proposed in the literature for space vector modulated inverter. A well known algorithm among these divides the overmodulation zone into two zones, namely zone-I and zone-II [30]. During overmodulation, the fundamental line side voltage and the reference magnitude are not proportional, which is undesirable from the control point of view. The present work explores the possibilities of betterment of the overmodulation region performance by ensuring a linear relationship between the two.

Reference [54] gives detailed analysis of the different PWM methods and compares them on the basis of higher fundamental voltage content and minimum distortion. In [55] and [56] the authors describe the space vector modulation technique of PWM and discuss different variations of the method.

In SVPWM, one cycle of switching sequence is divided into two sub-cycles each of period T_s, a set sub-cycle and a reset sub-cycle.

Dynamic control of torque and flux require the ability of the PWM scheme to apply the maximum possible voltage vector on the machine. Figure (2) shows that SVM is superior to the conventional sine-triangle method in this regard. Thus the comparison of the two methods is,

• Carrier based or Sine-triangle method requires separate modulators for every phase and also it does not fully utilize the available DC-link voltage.

• In the Space vector modulation method (SVM) the reference vector is processed as a whole. It fully utilizes the installed inverter capacity. Also the switching sequence is such that there is minimum number of commutations.

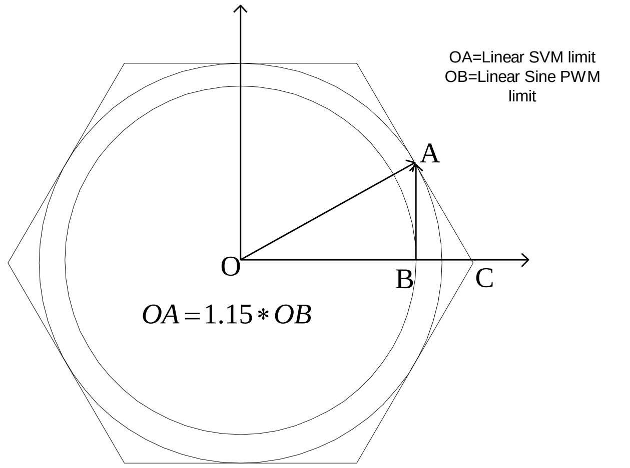

Fig2: Comparison between Sine-Triangle PWM and SVPWM methods

As the scheme of flux control explained in this proposal is based upon the principle of SVM, let us try to review the basics of SVM and develop equations for switching times. We will use normalized time τ_s in the entire analysis. It is therefore necessary to define τ_s.

If the rated angular velocity of the motor is ω_{sr} then,

$$\tau_s = (2\pi\omega_{sr})T_s$$

where T_s is the actual sampling interval in seconds. In the SVM technique, voltage vector u_s^* (which is called reference voltage vector) can be obtained as a time average of the adjacent active voltage vectors. This can be explained using figure (4) for the location of u_s^* in sector 1.

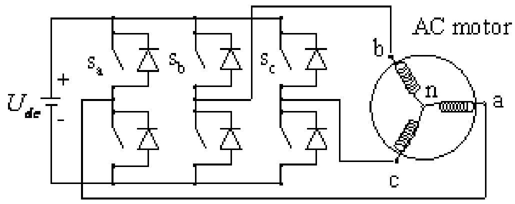

Figure 3: Three-phase induction motor drive

Here we have vectors u_a = (1 1 0) and u_b = (0 1 0) as the active vectors which can be switched for times τ_a and τ_b in one sub-

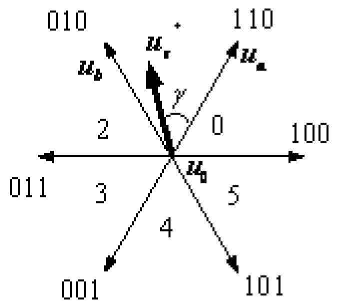

Figure 4: Space vector modulation for different switching combinations of S_a, S_b and S_c

cycle period τ_s. γ is the angle of the voltage vector within a sector. One sub-cycle of period τ_s consists of active voltage vectors switched for times τ_a and τ_b and zero vectors switched for τ_0 such that,

$\tau_s = \tau_a + \tau_b + \tau_0$ The maximum voltage vector magnitude $|u_s^*|$ that can be applied in a phase is given as,

$$|u_s^*|(\max) = \frac{2V_{dc}}{3}$$

For normalizing voltages, the maximum value of the fundamental component during six-step operation is taken as base value. This value is $\frac{2}{\pi}V_{dc}$.

Thus the normalized value of DC-link voltage becomes $\frac{\pi}{2}$ while the normalized magnitude of every switching state voltage vector is,

$$|u_a| = |u_b| = \frac{\frac{2}{3}V_{dc}}{\frac{2}{\pi}V_{dc}} = \frac{\pi}{3}$$

The reference voltage can be expressed on the basis of the volt-second (i.e. change of flux) equality as follows,

$$u_s^* \ \tau_s = u_a\tau_a + u_b\tau_b + u_0\tau_0$$

Therefore, the maximum possible volt-second or the maximum possible magnitude of vector displacement $\Delta\Psi_s(\max)$ in the stator flux vector error that can be obtained in a sampling time period is given as

$$\Delta\Psi_s(\max) = \frac{\pi}{3}\tau_s$$

This vector displacement will be along one of the voltage vectors selected for switching in that sampling period.

An important feature of the space vector modulation method is the sequence of switching. This is done in such a manner that there is minimum number of commutations in a sub-cycle. Considering the switching in sector 1 again, figure (5) shows the switching sequence for minimum number of commutations. Here S_a, S_b and S_c represent the top switches of the inverter legs. A ‘1’ means that this switch is on, while ‘0’ indicates that this switch is off.

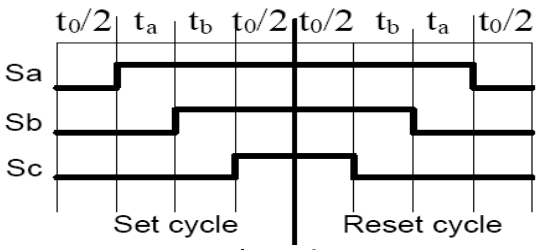

Figure 5: On times for switching in sector zero

III. SIMULATED MODEL AND RESULT

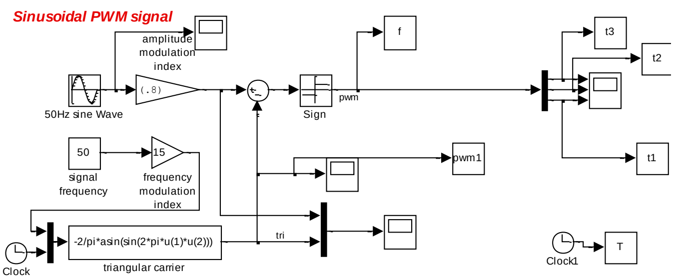

Figure 6

IV. LINEAR RANGE

In sine-triangle PWM, a common triangular carrier signal is compared with the three phase modulating sinusoidal signals of required magnitude and frequency to generate PWM signals. The three phase modulating reference signals are given in equation (4.1).

$$m_r = m\cos(wt)$$

$$m_y = m\cos(wt - 2\pi/3)$$

$$m_b = m\cos(wt - 4\pi/3)$$

Figure 7 shows the three phase modulating waveforms with amplitude m = 0.75 and time period *T*. The triangular carrier signal is also shown along with modulating signal. In this work a half carrier cycle is called as a subcycle T_s. The triangle carrier signal is shown with low frequency for clarity. In practice the frequency of the triangular carrier is so high that the reference modulating signal can be assumed to be constant over the given subcycle T_s. The positive peak of the triangular carrier is +1 and the negative peak is -1.

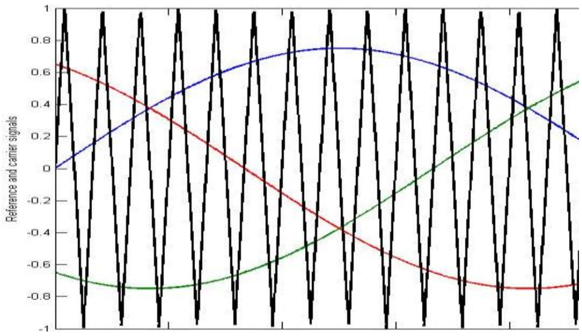

Fig. 7Three phase reference signals for SPWM with $m = 0.8$.

The average pole voltage (V_{ro}, V_{yo}, V_{bo}) over a given sub-cycle will be $0.5V_{dc}$ times of the reference modulating signal as given in equation below.

$$V_{ro} = 0.5V_{dc}m\cos(wt)$$

$$V_{yo} = 0.5V_{dc}m\cos(wt - 2\pi/3)$$

$$V_{bo} = 0.5V_{dc}m\cos(wt - 4\pi/3)$$

From the average pole voltages the average line to neutral voltages (V_{rn}, V_{yn}, V_{bn}) can be derived. Figure 8 shows modulating signals with m = 0.75 and their corresponding average pole voltages and line to neutral voltages are shown in Figure 9 and 10. With m = 0.75 the average line to neutral voltages are same as the average pole voltages. Figure 10shows the transformed average two phase voltages V_{sa} and V_{sb}, and magnitude and the position of the average voltage vector over a fundamental cycle. Certain average voltage vector is applied in every half-carrier cycle or subcycle. The average voltage vectors applied over different subcycles in a fundamental cycle. The angle between the average voltage vectors in two consecutive cycles is wT_s. In this range, the line-side voltage is proportional to *m*.

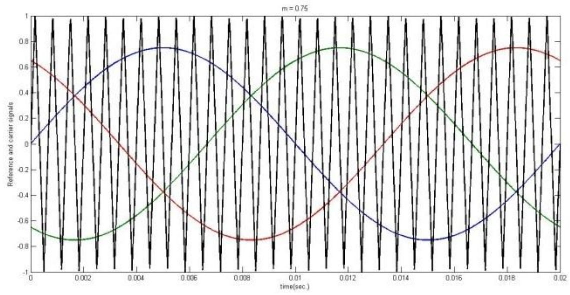

Fig.8Reference modulating signals

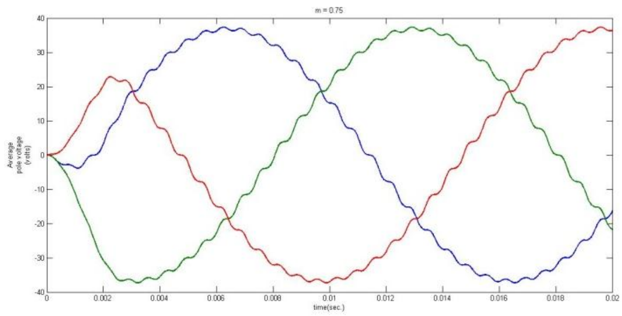

Fig. 9 Average pole voltages

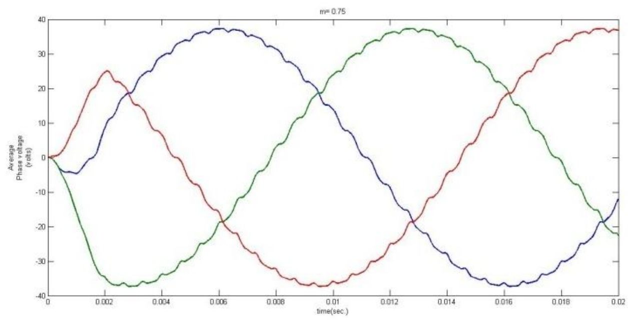

Fig. 10 Average phase voltages

CONCLUSION

In Sine PWM, for $m \leq 1$ (linear zone), the average voltage vector produced is of uniform magnitude and of uniform angular frequency. In this zone modulation index (*MI*) varies from 0 to 0.785. For $1 \leq m \leq \frac{2}{\sqrt{3}}$ and $\frac{2}{\sqrt{3}} \leq m \leq 2$, the average voltage vector produced is of non-uniform magnitude and angular frequency is constant or almost constant. The SVPWM method is far better than the sine PWM method in terms of the linearity.

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