SPACE VECTOR PULSE WIDTH MODULATION TECHNIQUE FOR FIVE LEVEL CASCADED H-BRIDGE INVERTER INCLUDING OVER MODULATION REGION

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ABSTRACT

This paper presents optimal control strategy of Space Vector Pulse Width Modulation method including over modulation region with linear transfer characteristic for cascaded H-bridge inverters. the over modulation operation is very complex which also requires incorporation complex calculations involving both under modulation and over modulation algorithms. The proposed control strategy is effective in terms of selecting the optimal switching states with reduced computational complexity using simplified linear calculations. The performance of the proposed method is simulated for five level cascaded H-Bridge Inverter.

Keywords: *Space Vector Modulation, Cascaded H-Bridge Inverter, Over Modulation, Induction Motor.*

I INTRODUCTION

All Multilevel inverters are used as an alternate choice for high power medium voltage applications, The unique feature of these topologies that they can reach high voltage levels with minimum harmonics without the need of transformers which makes them a alternative choice for high power applications and FACTS [1]. Due to their ability of synthesizing the waveforms with good harmonic spectrum with fast response with autonomous control by which the power quality problems are reduced and dynamic behavior is improved they are extensively used in industrial drive applications. The various multilevel inverter topologies such as Cascaded H-Bridge Inverter with separate dc sources, Neutral point clamped Inverter, Flying Capacitor are being used in various applications [2]. Among various Pulse Width Modulation techniques for controlling the inverter output voltage , proposed is theliterature[3-10], SVM method has greater flexibility of selecting switching states and their pattern design makes them suitable for digital implementation. Many of the SVPWM algorithms presented in the literature requires the extensive computation of switching patterns, with many algebraic equations inevery sector which makes the SVPWM method complex. The main objective of this paper is to design asimplified SVPWM method with optimal switching states for linear and over-modulation regions. Operation in over modulation region is very much required in medium-voltage applications. Since it gives the effective utilization of dc bus thus minimizing the cost of the overall system [11]. This paper presents simplified SVPWM method including over modulation operation implemented experimentally for five level cascaded H-Bridge inverter with FPGA processor. The performance of the method for both linear and over modulation regions are simulated and analyzed.

II CASCADED H-BRIDGE INVERTER

The five level Cascade H-bridge multilevel inverter is shown in Fig.1. The total output voltage is sum of each individual inverter module output voltage. Each H-Bridge inverter uses dc link voltage to generate a modulated voltage at output terminals. And produces three output voltage levels. $+V_{dc}$, 0, $-V_{dc}$. For higher level several units of H bridge inverter modules are connected in series.The number of H Bridges required for „L" level is $N = \frac{L-1}{2}$. The number of voltage levels in a phase voltage V_{ph} with „N" number of H-Bridges is 2N+1.

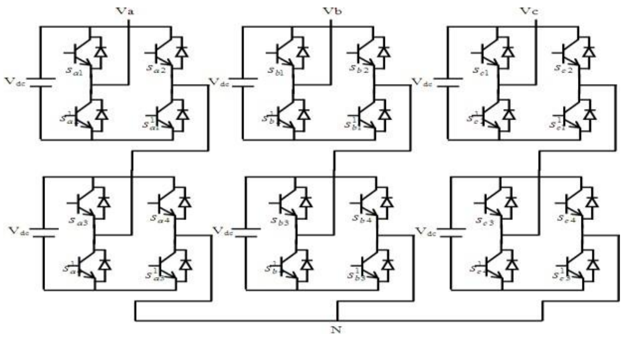

Figure 1: Three Phase five level Cascaded H-Bridge Inverter.

single phase five level cascaded multilevel inverter will produce the output voltages of +2Vdc,+Vdc,0,-Vdc,-2Vdc.

III SPACE VECTOR PULSE WIDTH MODULATION

Space Vector PWM relies on the representation of the inverter output voltage as space vectors. The space vector diagram of three phase inverter is a Hexagon with six sectors. Considering the geometrical characteristic that the angle between basic space vectors of 3-level inverter is all 60^0, using a non orthogonal 60^0 reference frame, the synthesis of reference vector and dwell time calculation becomes less computational. Therefore the orthogonal system is transformed into 60^0 co-ordinate system. Components of reference vector along 60^0 axes

$$V_{RM} = V_{ref}\left(n-1\right) * \cos\left(\frac{\pi}{3}-\alpha\right) - \sin\left(\frac{\pi}{3}-\alpha\right) / \sqrt{3} \quad (1)$$

$$V_{RN} = V_{ref}\left(n-1\right) * \cos\alpha - \sin\alpha / \sqrt{3} \quad (2)$$

$$m = \text{floor}\left(V_{RM}\right) \quad (3)$$

$$n = \text{floor}\left(V_{RN}\right) \quad (4)$$

Where m and n are defined by vector (m, n) in m^1-n^1 axis

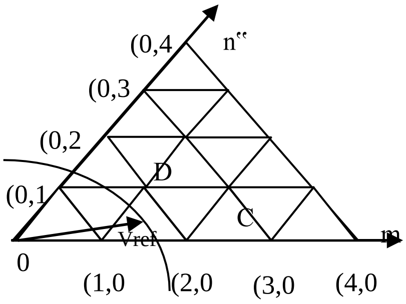

Figure 2: Location of reference vector and identification of triangle in 60° axis

The reference voltage in a sector is synthesized by using V_1, V_2, V_0 applied for the time T_1, T_2, T_0.In the proposed technique the reference vector is synthesized in non orthogonal 60^0 reference frame. If V_{ref} <= (m+n+1) then V_{ref} is located in ΔABD else ΔCBD. After identifying the triangle where the reference vector is located, the dwelling times are calculated using the equations 5,6and 7 where (m_1, n_1) (m_2, n_2) and (m_3,n_3) are the vertices of triangle where the reference vector lies then

$$m_1T_B + m_2T_D + m_3T_A = T_S \quad (5)$$

$$n_1T_B + n_2T_D + n_3T_A = T_S \quad (6)$$

$$T_B + T_D + T_A = T_S \quad (7)$$

Where T_B, T_D, T_A are dwell times of vector V_B, V_D, V_A

IV OVER MODULATION-OPERATION

For the value of m higher than 0.866 the operating region is considered as over modulation region. In the linear modulation region (m_i <= 0.866) the trajectory of the reference vector is a circle inscribed inside the hexagon with maximum sinusoidal output voltage. In the over modulation region (0.866<=m_i<=0.953) the trajectory of the reference vector crosses the hexagonal track which is shown identified by the cross over angle. In the over modulation region its magnitude of the reference vector is modified through multiplication of decomposition vectors with the voltage reduction factor given as.

$$q = (n-1)/V_{RM} + V_{RN} \quad (8)$$

The modified reference vector is calculated by the equations (9) and (10) this modified vector in called distorted continuous reference voltage space vector, in which the angle remains the same.

$$\mathbf{V}_{RM}{}' = q(V_{RM}) \quad (9)$$

$$V_{RN}{}' = q(V_{RN}) \quad (10)$$

In circular track region ON-times are modified and given by equation (11)

$$[T_1', T_2', T_3'] = q \quad [T_1, T_2, T_3] \quad (11)$$

The loss in volts-seconds during hexagonal region is compensated by gain in volts-seconds during circular track region. For the over modulation zone- II (0.953 < m < 1), the magnitude of the reference vector is modified to compensate for the loss in fundamental voltage in the hexagonal track region.

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Else the reference is held at two large vectors sequentially for the time period till $\theta < \theta_c$ *and* $\theta > \left(\frac{\pi}{3} - \theta_c\right)$ to compensate for the loss in volt seconds.

This method brings the characteristics of linear range without increasing computationalcomplexity. In this method the redundancy of the switching states is utilized to minimize voltage THD.The triangles of the space vector diagram are classified based on their switching states and given in the Table

Table 2: Classification of Triangles

If (m+n) is even then Type-I	If m is odd and n is even then Type-II	Otherwise If m is even and n is odd then Type-III
Sa=(m+n)/2 **Sb=(n-m)/2** **Sc=-(m+n)/2**	Sa=(m+n+1)/2 Sb=(n-m+1)/2 Sc=-(m+n-1)/2	Sa=(m+n-1)/2 Sb=(n-m-1)/2 Sc=-m+n+1)/2

The switching sequence design is selected so that there will be minimum number of switches per switching period. There will be only one level change per commutation of switching devices and lower output THD. The sequence is designed based on co-ordinates of the vertices of the triangle where the reference vector lies.The sequence followed corresponding to Type-I switching states of the inverter triangle where the reference vector lies is (m_3,n_3)→(m_1,n_1) → (m_2,n_2) → (m_1,n_1) → (m_3,n_3). For Type-II the switching sequence is (m_1,n_1) → (m_3,n_3) (m_2,n_2) → (m_3,n_3) → (m_1,n_1). Otherwise for Type-III (m_1,n_1) → (m_2,n_2) → (m_3,n_3) → (m_2,n_2) → (m_1,n_1). By selecting the switching states in the above manner the average inverter phase voltage will have lowered substantial total harmonic content. The proposed technique is simulated with induction motor load.

The induction motor model is developed in stator reference frame; the electromagnetic torque is given by

$$T_e = \frac{3}{2}\frac{p}{2}\frac{L_m}{\sigma L_s L_r}|\lambda_r||\lambda_s|\sin\eta \qquad (13)$$

Where η = angle between the stator and rotor flux linkage

σ = Leakage coefficient = $1-\left(\frac{L_m^2}{L_s.L_r}\right)$

V RESULTS AND DISCUSSIONS

The simulation is carried out with DC voltage of 100V .The parameters of Induction motor for simulations are,

The parameters of the Induction motor for simulation are V=240V, 0.5Hp, Rotor resistance (Rr) =2.5Ω; Stator resistance(Rs)=2.3Ω;Statorleakage inductance(Ls)=0.25Ω; Rotor leakage inductance(Lr)=0.25Ω; Magnetizing inductance(Lm)=0.25Ω;mutualinductance(M)=0.0905H;RatedFrequency=50Hz;dampingcoefficient(B)=0.000124;Momentof inertia=0.019J; Number of poles=4; .

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The simulation results are shown.

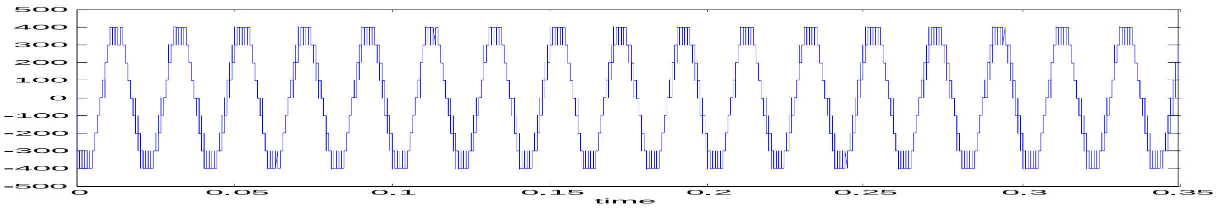

Figure 3: The Line voltage of the five level inverter with mi of 0.8.

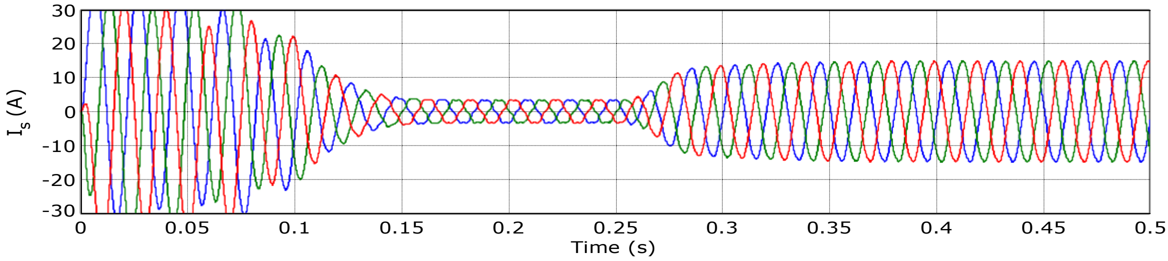

Figure 4: Three Phase Stator currents of induction motor with m_i of 0.8.

Fig 4 shows the simulated waveforms of stator current. The motor starts under rated voltage and frequency without mechanical load; The peak value of starting current is around 35A.The starting time is 0.15 seconds, due to inertia and high starting current. At 0.25 seconds load torque of 30Nm is applied which causes currents to increase.

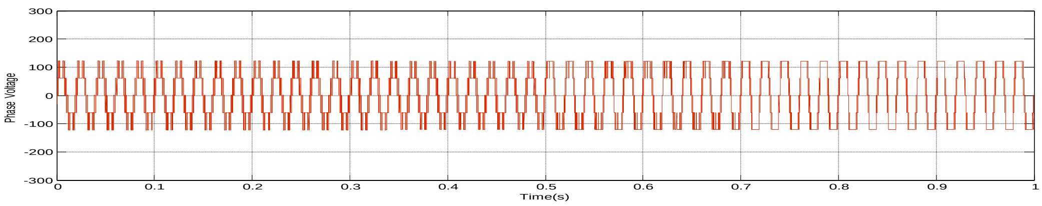

Figure5: The Phase voltage of the inverter with variation of m

The value of modulation index is varied with o.6 at starting to 0.9 at 0.5 sec and 0.99 at 0.7 sec

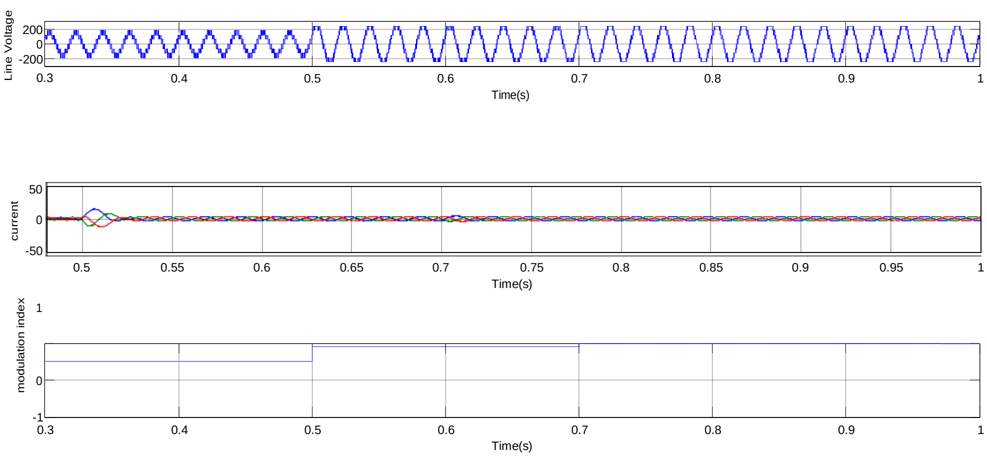

Figure 6:.The Line voltage and current of the inverter with variation of m

From the above Figure it can be seen that the magnitude of Current increases at 0.5seconds due to increase of m_i, and stabilizes and further increases with increase of m to 0.99.

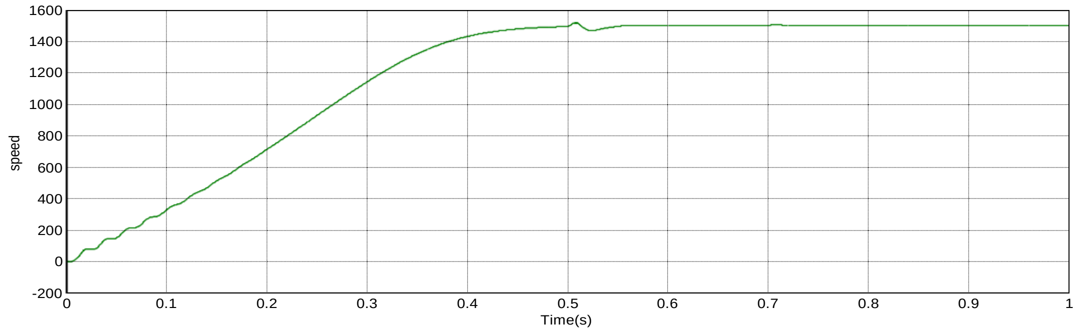

Figure 7: The speed of induction motor with variation mi with respect to time

Table 3: Voltage and Current THD as a percentage of fundamental for Five level Cascaded H- Bridge Inverter for switching frequency of 3600.

S.No	m	$\%V_{LTHD}$	$\%V_{PTHD}$	$\%I_{THD}$
1	0.82	17.5	34.5	1.6
2	0.87	18.1	30.7	2.5
3	0.9	16.4	26.6	2.5
4	0.96	14.2	28.3	3.7
5	0.99	14.7	27.6	3

VI CONCLUSIONS

The proposed SVPWM technique is effective in terms of reducing computational complexity by which the co-ordinates of the space vector are in integer values, and easily extended for over modulation region with combination of reference voltage vector modification and on time modification. The results corresponding to the various values of m_i indicates the linear characteristics in the over modulation region. The current and voltage THD increases slightly due to increase of sub harmonic components for higher m_i, but the rms value of the output line voltage magnitude also increased giving the effective utilization of DC bus voltage.

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