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MULTILEVEL INVERTER APPROACH TO IMPROVE PERFORMANCE OF INDUCTION MOTOR DRIVES

Sonal Sapra[1], Shailesh Gupta[2], Vikas Rajput[3]

[1,2,3] Raj Kumar Goel Institute of Technology, Ghaziabad (U.P.)

ABSTRACT

The conventional PWM inverters are able to generate mostly two level output waveforms. Many improvements have been proposed to classic configuration as regards the circuit structures, the control schemes, but the inverter performance was limited by the available number of levels to build the output voltage. To overcome these difficulties several topologies of multilevel inverter have been recently designed and they are now capturing the attention of many industries, specially for high power converters on account of certain advantages that these inverters have as compared to conventional PWM inverters like less switching losses, reduced harmonic losses, etc. In spite of these advantages some problem are also associated with these inverters. Out of these, capacitor voltage unbalance is prominent one. In this paper the SVM technique has been applied to formulate the switching pattern for three level inverter that minimizes the harmonic distortion at the inverter output.

Keywords: Multilevel Inverter, PWM, SVM, Induction Motor Drives, MATLAB

I. INTRODUCTION

Recent years have seen a sea change in factory automation. The manufacturing lines in an industrial plant typically involve one or more variable speed motor drives that serve to various requirements of the plant like, power conveyor belts, robot arms, overhead cranes, steel process lines, paper mills and other processing lines. Prior to 1950s all such applications required the use of DC motor drive as the AC motor were not so flexible with respect to adjustable and smoothly varying speeds. But the inherent disadvantages of the DC drive promoted development on the side and eventually AC drives emerged as cost-effective and rugged compared to their DC counterparts. The reliability was also high. However the control flexibility with these drives is very limited and these proved to be suitable in applications where the speed need be regulated roughly like fan, pump, compressor etc. But high performance applications like machine tools, spindles, high-speed elevators etc. need a much more sophisticated regulation of various variables such as speed, position, acceleration etc. Until recently this area was dominated by the DC drives. But with suitable control the induction motor drives are more than a match for DC drives in these high performance applications. The advances in microelectronics have simplified most of the control complexities of these drives and brought about an improved drive performance. The most common drive for the AC motor is the Voltage Source Inverter (VSI) Drive.

Akira Nabae et. al. [1] has made a clear distinction between the conventional and the multilevel inverters vis-a-vis the harmonic spectra. The multilevel technique was introduced here in combination with the already existing PWM technique. A new PWM method for three-level inverter considering DC-link capacitor balancing problem using Motorola DSP 56000 is presented by L. Liu, Nam S. Choi and Gyu H. Cho [2]. In this paper each voltage vector on space vector plane is classified in relation to charging discharging action of DC capacitors. Masato Koyama, Toshiyuki Fuzzi, Ryohei Uchida, Takao Kawabata [3] in their publication discussed new PWM method for three-level inverter based on the space voltage vectors to minimize the harmonic components of the output voltage under the minimum pulse width limitation of GTO's and also suppress the fluctuation of the neutral-point voltage. Annette von Jouanne, Shaoan Dai, Haoran Zhang [4] presents a simple control method for balancing the dc-link voltage of three-level neutral-point-clamped inverters, while providing enhanced ride-through and common-mode voltage (CMV) elimination. The suitability of multilevel converters for high power and/or high voltage electric motor drives is proved by Leon M. Tolben, Fang Zheng Peng and Thomas G. Habetler.

In this paper SVM technique has been applied to formulate the switching pattern for three level inverter that minimize the harmonic distortion at the inverter output. The performance of these inverters was investigated under various conditions of the load (Both R-L and Induction Motor) by changing output frequency using MATLAB 6.5.

II. GENERAL BACKGROUND

Multilevel inverter technology has emerged recently as a very important alternative in the area of high-power medium-voltage energy control. The term multilevel starts with the 3-level inverter introduced by "Akari Nabae "in 1981[1]. By increasing the number of levels in inverter the output voltages have more steps generating staircase waveform which has reduced harmonic distortion. The unique structure of multilevel inverters allows them to reach high voltages and therefore lower voltage rating devices can be used. As the number of levels increases the synthesized output waveform has more steps producing a very fine stair case wave and approaching very closely to the desired sine wave. Hence multi level inverters offer a better choice at a high power end because the high volt-ampere ratings are possible with these inverters without the problems of high dv/dt and the other associated ones.

The topologies available in multilevel inverters are: Series connected 2-level inverter (SC2L), 3-level neutral point clamped MLI (3LNPC) and Multilevel Inverter. In this work, multilevel inverter topology is used due to reduced harmonic content, reduced dv/dt, low switching frequency devices, low switching losses and high voltage/power output with reduced rating of individual devices. Here, we have used Three – level inverter using space vector modulation.

III. SPACE VECTOR MODULATION OF THREE-LEVEL INVERTER

Fig.3.4 shows the circuit of a 3-level, three phase inverter .The dc link capacitor C has been split to create the neutral point 'o'. The devices S^{1U} and S^{4U} function as main switches and remaining middle switches are auxiliary switches which help to clamp the inverter output to the neutral point with the help of clamping diodes.

Since three switching level are found in these inverter so there are 27 switching states in total for three level inverter. Fig. 1 shows the switching states of three level inverter in the form of space voltage vector. According to the magnitude of voltage vectors we divide them into four group vectors: the zero group vectors (V^0), the small voltage vectors $(V_1,V_4,V_7,V_{10},V_{13},V_{16})$ the middle voltage vectors $(V_3,V_6,V_9,V_{12},V_{15},V_{18})$ and the large voltage vectors $(V_2,V_5,V_8,V_{11},V_{14},V_{17})$. Fig. 2 shows the switching states of all these states in space vector diagram.

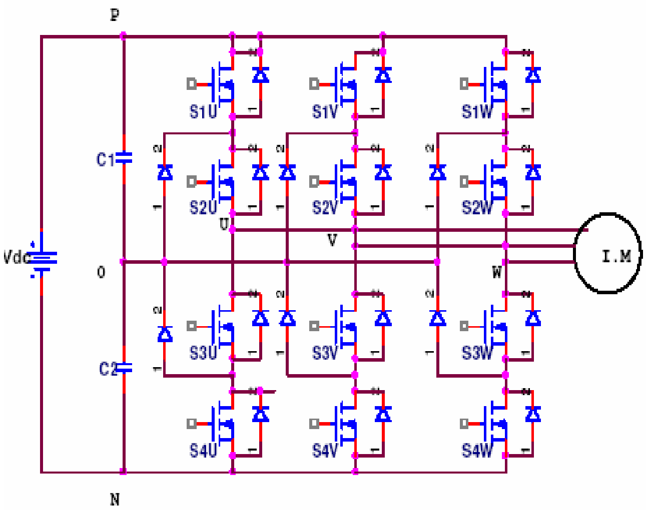

Fig 1. Three Phase Three Level Inverter

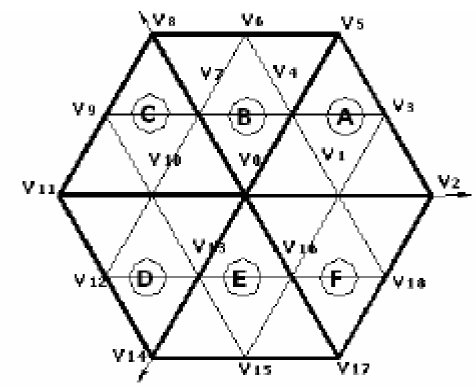

Fig. 2. Space Vector Representation Of Three Level Inverter

3.1 Voltage Vector and their Representation

Fig.3.6 shows a triangle formed by voltage vectors V_0,V_2,V_5.This triangle is divided into four smaller region 1,2,3and 4.In space voltage vector PWM generally the reference voltage vector is formed by its nearest three voltage vectors in order to minimize the THD.

From analysis point of view if the reference voltage vector V^* into the region 3 the duration of the each voltage vectors can be calculated by following sequences. First, if the voltage vector and reference voltage vector can be expressed by the exponential form as follows

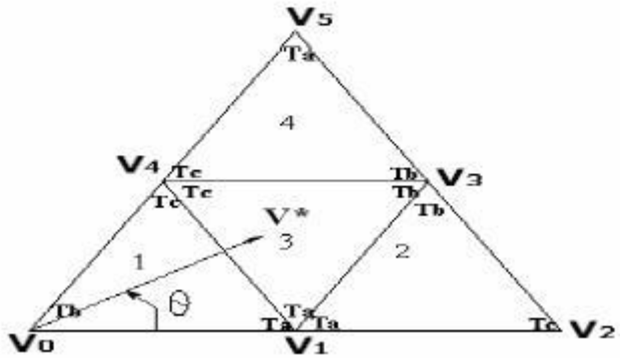

Fig.3 Region in sector 0

$$V_1 = \frac{1}{2} \quad (1)$$

$$V_3 = \frac{\sqrt{3}}{2} e^{j\frac{\pi}{6}} \quad (2)$$

$$V_4 = \frac{1}{2} e^{j\frac{\pi}{6}} \quad (3)$$

$$V^* = Ve^{j\theta} \quad (4)$$

Second, the following two equations should be satisfied as space vector PWM for the conventional two level inverters

$$V_1 \cdot T_a + V_3 \cdot T_b + V_4 \cdot T_c = V^* T_S \quad (5)$$

$$T_a + T_b + T_C = T_S$$

Substituting equations (1) to (4) into above equations and changing above eq. into trigonometric form we get

$$\frac{1}{2}T_a + \frac{\sqrt{3}}{2}(\cos\frac{\pi}{6} + j\sin\frac{\pi}{6})T_b + \frac{1}{2}(\cos\frac{\pi}{3} + j\sin\frac{\pi}{3})T_c = (V\cos\theta + jV\sin\theta)T_S \quad (6)$$

Separating real and imaginary parts of eq. (6)

Real part:

$$\frac{1}{2}T_a + \frac{\sqrt{3}}{2}(\cos\frac{\pi}{6})T_b + \frac{1}{2}(\cos\frac{\pi}{3})T_C = V(\cos\theta)T_S \quad (7)$$

Imaginary part:

$$\frac{\sqrt{3}}{2}(\sin\frac{\pi}{6})T_b + \frac{1}{2}(\sin\frac{\pi}{3})T_c = V(\sin\theta)T_S \quad (8)$$

from eq. (6), (7) and (8) T_a, T_b, T_c can be calculated as follows

$$T_a = (1 - 2k\sin\theta) \quad (9)$$

Table I shows duration of the voltage vectors in each region.

R	T_a	T_b	T_c
1	$2kT_S \sin(\frac{\pi}{3}-\theta)$	$T_S[1-2k\sin(\frac{\pi}{3}+\theta)$	$2kT_S \sin\theta$
2	$2T_S[1-k\sin(\frac{\pi}{3}+\theta)$	$2kT_S \sin\theta$	$T_S[2k\sin(\frac{\pi}{3}-\theta)-1]$
3	$T_S[1-2k\sin\theta]$	$T_S[2k\sin(\frac{\pi}{3}+\theta)-1]$	$T_S[2k\sin(\theta-\frac{\pi}{3})+1]$
4	$T_S[2k\sin\theta-1]$	$2kT_S \sin(\frac{\pi}{3}-\theta)$	$2T_S[1-k\sin(\frac{\pi}{3}+\theta)$

$$T_b = T_S[2k\sin(\theta+\frac{\pi}{3})-1] \qquad (10)$$

$$T_c = T_S[2k\sin(\theta-\frac{\pi}{3})+1] \qquad (11)$$

Where $k = \frac{2V}{\sqrt{3}}$

In other regions such as 1, 2, 4 etc. the duration of each voltage vector can be calculated in similar fashion.

IV. SIMULATION RESULTS

Simulation of various inverters using sinusoidal pulse width modulation was carried out with the help of "MATLAB 6.5". Simulation was carried out to observe the improvement in the line voltage THD and Line Current THD for both R-L Load, Motor Load as the inverter level increases from 2-level and 3-level. V/f analysis of the drive has been done using 2-level and 3-level inverters. Here it has been assumed that modulation index is proportional to output voltage of inverter.

$$MI=K*V_1 \text{ (}V_1\text{- Fundamental Component)}$$

where k is constant. So for variable speed drive at different frequencies following quantities have been observed.

1. Line Voltage waveform
2. Line current waveform for both R-L load and Motor Load
3. Variation of Line Voltage THD and frequency

Load Specifications:

1. R-L load
2. Motor Load: 1 HP, RPM: 1440, Current: 2 Amps.

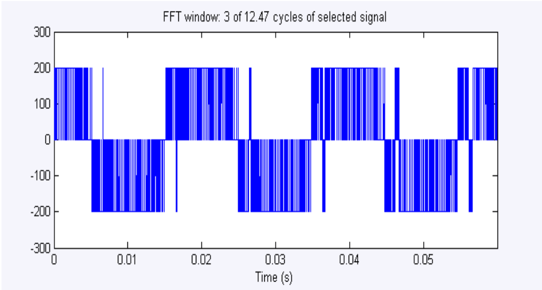

Fig.4 Line Voltage for 2-Level Inverter for R=50, L=30mH

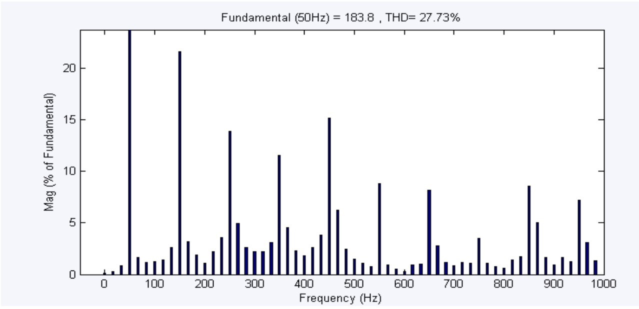

Fig.5 Harmonic Spectrum of 2-level Inverter for R=50, L=30mH

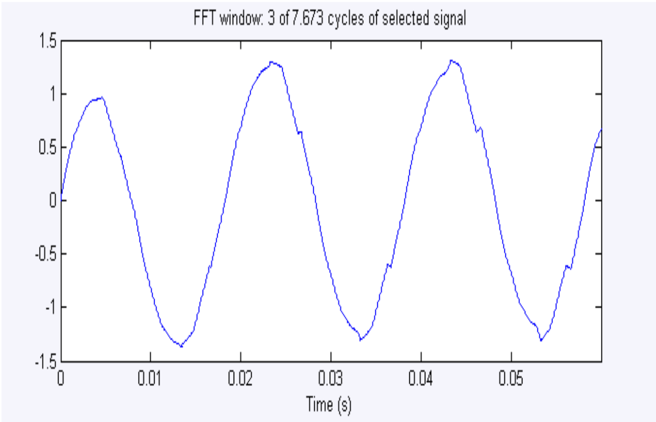

Fig. 6 Line current of 2-level inverter for R=50, L=30mH

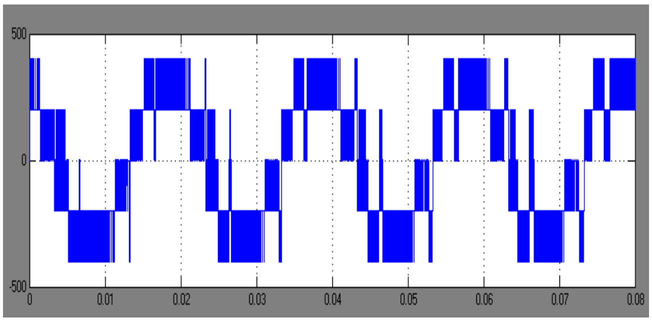

Fig.7 Line voltage of 3-level inverter for R=50ohm, L=30mH

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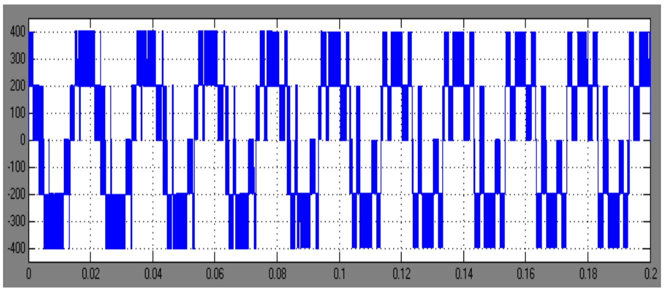

Fig.8 Line voltage of 3-level inverter for R=100 ohm, L=80mH

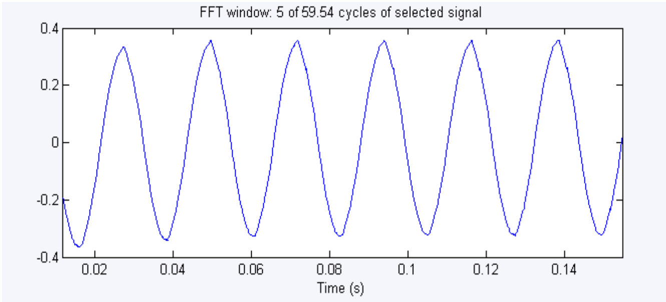

Fig.9 Line current of 3-level inverter for R=100 ohm,L=80mH

V. CONCLUSION

Multilevel power converters go a long way in overcoming the problems of PWM inverters and this is the reason that they have gained so much attention in recent years. The simulation of the inverters namely conventional three-phase, two-level and three-level was carried using Space Vector Pulse Width Modulation (SVPWM). It was shown that large decrease in voltage and current THD in moving from three-phase two-level inverter to three-level inverter.

The space-vector PWM (SVPWM) method is an advanced, computation-intensive PWM method and is possibly the best among all the PWM techniques for variable-frequency drive applications. Because of its superior performance, it has been finding widespread application in recent years. This thesis briefly explains theory of Space Vector Pulse Width Modulation (SVPWM) for three-phase two-level and three-level inverter and performance of the both inverters was tested using R-L load. It was shown that load currents for the three-level inverter are much more sinusoidal for all frequencies and improvement in the line current waveform and decrease in the THD from two-level to three-level inverter and relative comparison has been given.

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