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Simulation of a Space Vector PWM Controller for a Five-Level Voltage-Fed Inverter Motor Drive

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Abstract: *As per the power quality IEEE 519-1992 STD the inverter output voltage should follow limit of harmonics standards specified. For the low power demand sine pulse width techniques has proven good performance. But as the power demand increases it becomes necessity to replace switching technique SPWM with the SVPWM. In order to implement SVPWM for multilevel inverter we find the difficulty in determining the location of reference vector, calculation of ON time and calculation and estimation of switching states. Thus with the increase in the number of level, the complexity increases. In the proposed scheme, five-level space vector PWM inverter is easily implemented as conventional two-level space vector PWM inverter. Therefore, the proposed method can also be applied to multilevel inverters. The design of LC filter for the reduction in harmonics is shown*

Keywords: *Multilevel inverter, space vector pulse width modulation (SVPWM), switching state, two-level inverter.*

I. Introduction

Multilevel converters have the later years been looked upon as a good choice for medium- and high-voltage applications. It was first presented in [1]. Before the introduction of multilevel converters the traditional solution has been to connect semiconductors in series to withstand the high voltages. This requires fast switching to avoid unequal voltage sharing between the devices, which could lead to a breakdown. Multilevel converters have the advantage of clamping the voltages, which prevents the need of fast switching. MLC also have a smoother output voltage than traditional two-level converters. As machines load demand are increasing, multilevel converters can be well suited in such applications.

The most popular multilevel converter and the one that will be studied in this paper is the diode clamped five-level converter. One of the challenges with the five-level converter is the increased complexity in the control of it. A lot of research have been done on this converter topology and a numerous of control methods have been presented in the literatures.

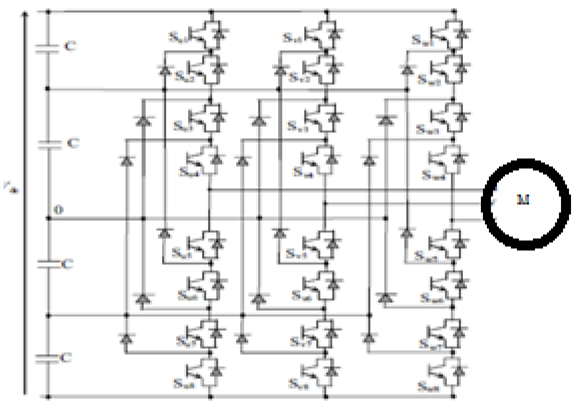

Fig.1 topology of 5 level diode clamped inverter Fed Motor

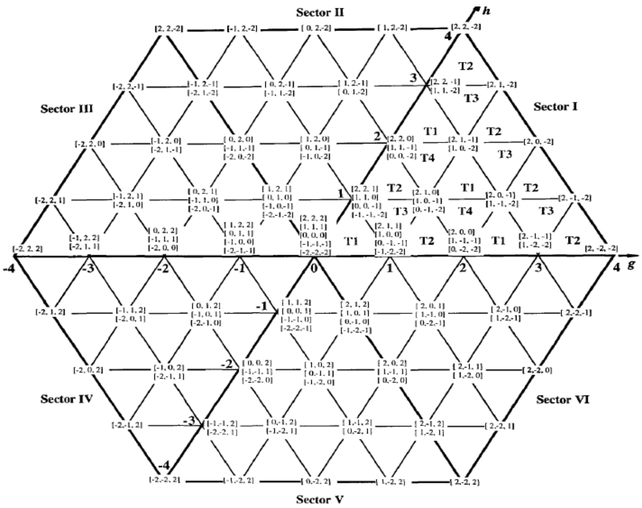

Fig. 2 Space Vector of 5 level inverter

One or many switching states can be represented by the switching vector. For a 5 level inverter, there is 125 switching states. We are using "Nearest Three Vector" (NTV) for deciding and calculating the on-timers for respective triangle. This selection of switching states determines the efficiency of inverter.

In this paper we have implemented using the different approach; we are implementing using 2D system, thus making it simple. The feature of this method is as follows:

1. In this approach, we are using 2 level SVPWM, thus it is simple to calculate on-time, and moreover this calculation doesn't change with the time.
2. The naming of the triangle is done as .The Δj^{th} triangle represents the number of triangle out of 16 triangles of a sector. Thus this helps to effective implementation of switching sequence.
3. This approach can be implemented for 7 level inverter without any increase in the computational burden.
4. Since this approach is based on 2 level, the usage of DSP, which is normally used for 2 level, can be used to implement for 5 level.

II. Implementation of the scheme

2.1 Estimation of "on time"

SVPWM is used for volt-second balance with different switching states and their "on times". For calculation of "on times" of triangle of five level inverter we have to solve three equations at a time. Instead of that we can use tow level space vector method for estimation of turn "on time" of multilevel inverters.

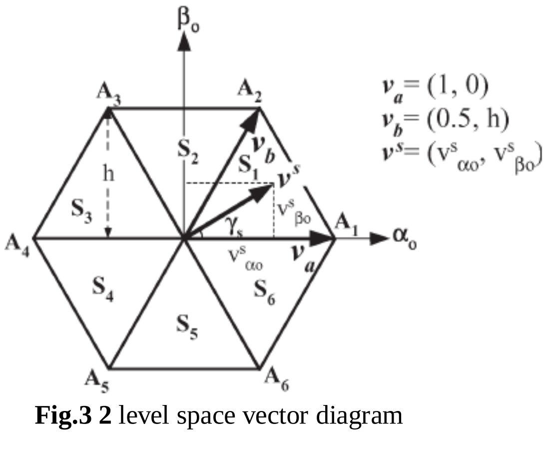

Fig.3 2 level space vector diagram

Fig shows space vector diagram of two level inverter. In this each sector is considered as triangle with its sides are of unite length and height of the triangle is the$\sqrt{3}/2$.now "on time" calculation same for all the sectors. "On time" estimation for sector 1 is given below.

"On time" estimation is decided with use of volt second balance equation for the vector with use of its location in any of the sector as shown in eq. 1

$v^s = v_a t_a + v_b t_b$ - (1)

Total time is equal to the switching time given by eq.3

$$T_a = t_a + t_b + t_o \qquad - (2)$$

$$v^s_{\alpha o} T_s = t_a + 0.5 t_b \qquad - (3)$$

$$v^s_{\beta o} T_s = h t_b \qquad - (4)$$

The t_a is calculated using eq. 5

$$t_a = T_s [v^s_{\alpha o} - \frac{v^s_{\beta o}}{2h}] \qquad - (5)$$

The t_b is calculated using eq. 6

$$t_b = T_s [\frac{v^s_{\beta o}}{h}] \qquad - (6)$$

The t_0 is calculated using eq. 7

$$t_o = T_s - t_a - t_b \qquad - (7)$$

Fig 4 shows the method of on time estimation of five- level inverter. In five- level inverter, sector is divided in sixteen triangles for easy calculation of time. Triangles are divided into two groups of type1 and type2.Type1 triangle base is parallel with base of the sector while type2 triangle base side is opposite to that.

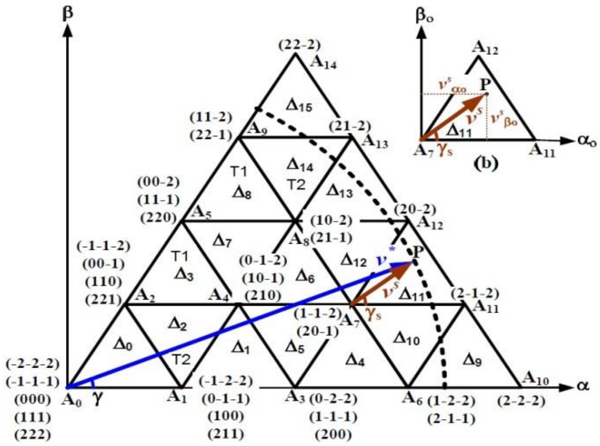

Fig.4 Space vector diagram for 5 level inverter in terms of 2 level inverter

For estimation of "on time" we know that triangle side length is unity and its height h (=$\sqrt{3}/2$).in the above figure reference vector is shown with value of v^* and it is making angle γ to the axis of the $\alpha - \beta$ pane.As shown in the figure to decide the "on time" we shift the reference vector in the particular triangle by considering it's as sector and then get the small vector with (α_0, β_0).now for the estimation we get the volt second balance of the small vectorv^s which is equal to the main vector. By using the above volt second balance equations we can directly get the switching times of nearest vectors.

For getting volt-second balance for vector in any sector of the five-level inverter, first we have to get in which triangle reference vector is falling. After that as explained above we can use small vector concept and equations we get the switching time.

2.2Block Diagram

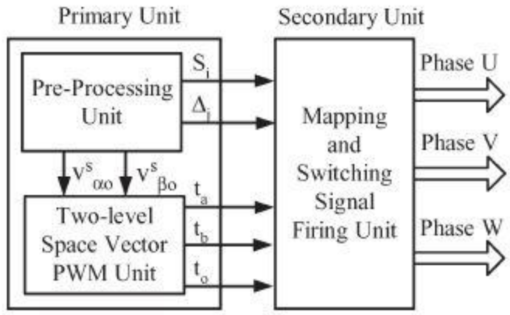

Fig. 5 block diagram for SVPWM implementation

There are 2units in the proposed diagram, primary unit and secondary unit. Primary unit is of DSP or microcontroller. The main function of primary unit is to determine the vector address v^s in 2D space and to determine the position of the vector location in the triangle for a respective sector. Based on the location of vector, the "on time" is calculated. The role of secondary unit is to generate the pulse for the inviter based on the "on time", which was generated by the primary unit. For the triangle vertex, there will always be he redundancies. Thus the scheme will consider any triangle vertex zero vectors and switching sequence will be calculated accordingly.

2.2.1 Role of primary unit

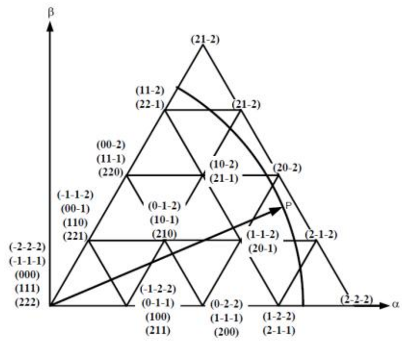

Fig.6 Space vector diagram of 5 level inverter

For the use of SVPWM, we have to first determine the sector and the angle. The below equation gives the sector and angle

$S_i = \text{int}\left(\frac{\theta}{60}\right) + 1$ - (8)

$\gamma = \text{rem}\left(\frac{\theta}{60}\right)$ – (9)

Here the θ represents the angle vector for 2D axis.

Here by using PARK's transformation we are getting 2D values from 2D values. By using the 2D values we are obtaining the values of K1 and K2.

$K_1 = \text{int}\left(v_\alpha + \frac{v_\beta}{\sqrt{3}}\right)$ – (10)

$K_2 = \text{int}\left(\frac{v_\beta}{h}\right)$ - (11)

Small vector co-ordinates are represented by $v_{\alpha i}$ and$v_{\beta i}$, which is given by the following equation,

$v_{\alpha i} = v_\alpha - K_1 + 0.5K_2$ - (12)

$v_{\beta i} = v_\beta - K_2 h$ – (13)

From the values of $v_{\alpha i}$ and $v_{\beta i}$ we are determining the location of the triangle.
For type 1 triangle it is given by,

$\Delta_j = K_1^2 + 2K_2$

For type 2 triangle it is given by,
$\Delta_j = K_1^2 + 2K_2 + 1$

2.2.2 Role of secondary unit

From the primary unit, we obtain the sector number, the respective triangle number location and the on-time. By obtaining the above values the secondary unit generates the switching sequence for the 5 level inverter.

Vertex	A1	A2	A3`	A1	A2	A3	A1
S_U	0	1	1	1	2	2	2
S_V	-1	-1	0	0	0	1	1
S_W	-2	-2	-2	-1	-1	-1	0
On-time	t_o	t_a	t_b	t_o	t_a	t_b	t_o

Table 1. Switching sequence for Δ6 for 5 level inverter

In the secondary unit, there will be look up table in the memory of it. This look up table will provide the information of the switching sequence

The table 1 gives the information for the triangle number 6 of a sector 1.

The flowchart for the implementation of SVPWM for 5 level inverter is given below

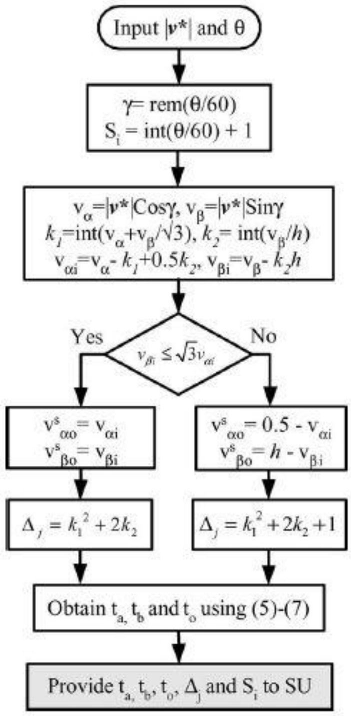

Fig. 7 Flowchart for 5 level SVPWM

III. Simulated results:

The following algorithm was implemented on a dSPACE. The proposed algorithm can be easily implemented on a DSP module.

The fig. 8 and fig.9 shows the current and line voltage waveform respectively. The dc link voltage is 400 V, modulation index is 0.85, switching frequency is 3 kHz and the fundamental frequency is 50Hz.

The THD waveform was obtained up to 10kHz, and the THD obtained was 16.5% but with the usage of LC filter, the THD obtained was 0.28, with the usage of minimum value of L is 2.5mh and C is 100 uF value. As shown in fig. 10

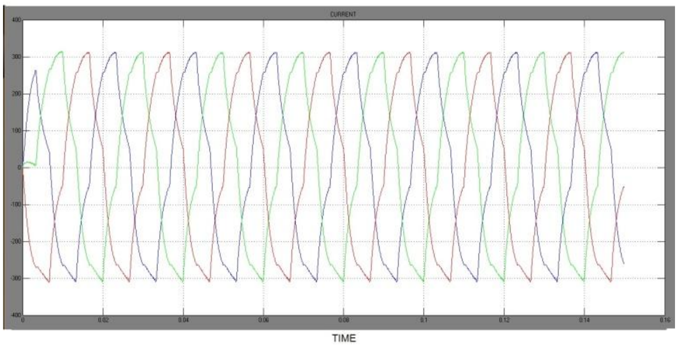

Fig. 8 Current waveform

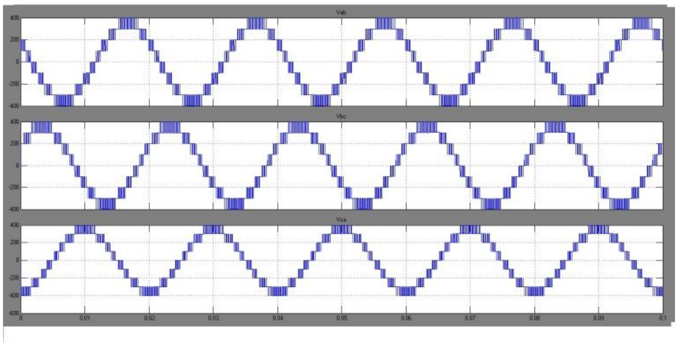

Fig.8 line voltage for the 5 level inverter.

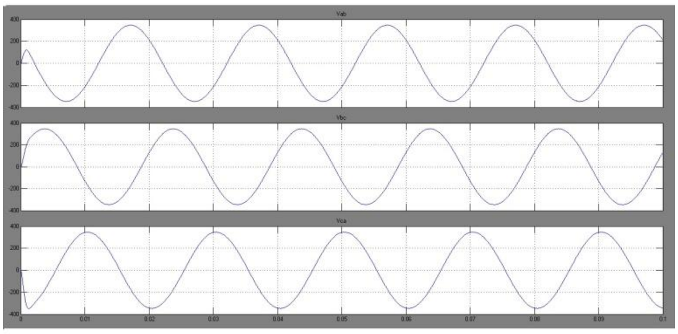

Fig.10 filtered line Voltage waveform of the 5 level inverter

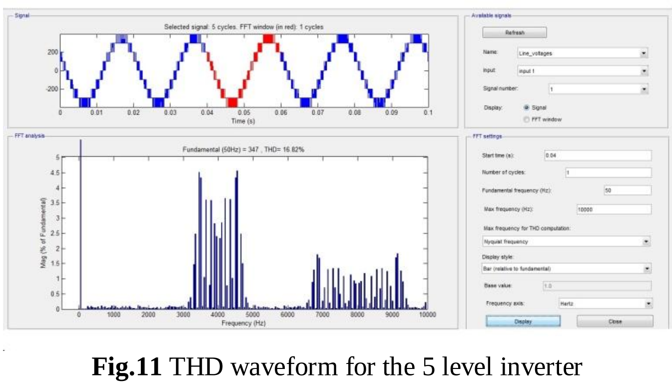

Fig.11 THD waveform for the 5 level inverter

IV. Conclusion

In the proposed paper, a 2 level based 5 level SVPWM has been implemented. Since the implementation is very simple, it can be easily implemented using DSP processor. In the proposed paper, LC filter has also been designed for the reduction of harmonics. With the usage of LC filter and SVPWM, we are able to obtain the THD of about 0.28%.

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