Original Article

ISSN: 2349 - 4891

International
Journal of Recent Research and Applied Studies
(Multidisciplinary Open Access Refereed e-Journal)

A 5-level Space Vector PWM Scheme for Inverters

Mohammed Shaffi.J

Assistant Professor, Department of ECE, LBS Institute of Technology for Women, Poojappura, Thiruvananthapuram, Kerala, India.

Received 20th December 2015, Accepted 14th January 2016

Abstract

Multilevel inverters are increasingly being used in high-power medium voltage applications due to their superior performance compared to 2-level inverters. Among various modulation techniques for a multilevel inverter, the space vector pulse width modulation (SVPWM) is widely used. In this paper, a simple space-vector pulse width modulation (SVPWM) scheme for multilevel inverter is presented. The method involves the conversion of space vector diagram of N-level inverter to that of a 2-level inverter. Here 60^0 coordinate system is used to represent space vectors instead of using cartesian coordinate system. In 60^0 coordinate system only integer coordinates are involved. So the computational complexity is reduced. The scheme doesn't use any sector identification and switching vectors are generated automatically. The proposed scheme for generating SVPWM for multilevel inverters is explained for a 5-level inverter and simulation results are presented.

Keywords: Starting vector, Adjacent vector.

Introduction

Multilevel inverters [1] are increasingly being used in high-power medium voltage applications due to their superior performance compared to two-level inverters[2]. Multilevel inverters can produce variable voltages and frequencies from discrete voltage levels by exploiting pulse width modulation (PWM) methods. The main advantage of using multilevel inverter is the low harmonic distortion obtained due to the multiple voltage levels at the output and reduced stresses on the switching devices. Several methods can be found in literature to achieve pulse width modulation [3]-[7]. The two main methods are Sine triangle Pulse width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM)[3],[7]. Space vector PWM involves approximating the reference vector by switching among the nearest three voltage space vectors. The various steps involved in the implementation of SVPWM are

Correspondence
Mohammed Shaffi. J
E-mail: shaffitvm@gmail.com, Ph. +9198950 29472

- Sector identification
- Determination of switching voltage space vectors
- Determination of duration of switching voltage space vectors
- Determination of an optimum switching sequence

Many novel techniques have been found in literature [8], [9] which doesn't require sector identification for PWM implementation. In [8] is proposed a view that the space vector locations of multilevel inverters possess a fractal structure, and the properties of fractal structure together with the simplicity of fractal arithmetic are exploited to generate the SVPWM. A similar technique is found in [9] which doesn't require identifying the actual sector containing the tip of the reference space vector.

Proposed Model

In the proposed method only the vectors of a two level inverter referred to as starting vector and adjacent vector are used to generate Sub Hexagon Center vectors of any N level inverter. Fig. 1 shows the space vector diagram of a 5-level inverter in 60^0coordinate system. The redundant vectors are not shown for simplicity. The space vector diagram of any multilevel inverter can be viewed as a hexagonal structure with one inner hexagon and several outer sub hexagons. Each hexagon is identified with a center referred as sub hexagon center (SHC). Fig. 1 shows the sub hexagon centers of a 5- level inverter. Each hexagon is divided into six small triangular region called sectors. There are 96 such sectors in the space vector diagram of a 5-level inverter. In the proposed scheme the reference space vector is expressed in 60^0 coordinate system.

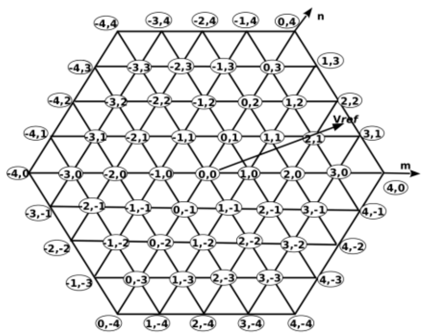

Figure 1. Space Vectors in 60^0coordinate system for a 5-

Level Inverter

A. 60^0 Coordinate representation of space vectors

If V_a, V_b and V_c represents the instantaneous amplitudes of three phase reference sinusoid, then corresponding 60^0coordinates (Vm,Vn) of reference vector V_{ref} can be found using the equations 1 and 2

$$V_m = V_a - V_b \quad (1)$$

$$V_n = V_b - V_c \quad (2)$$

B. Steps involved in the Implementation of SVPWM

The major steps involved in the implementation of SVPWM are explained in the following section.

1. **Sector Identification:** The space vector representations of inverter consist of six sectors. The location of the reference vector can be obtained from the instantaneous reference amplitudes. If Va, Vb and Vc represents the instantaneous amplitudes of three phase reference sinusoids, the sector of operation can be obtained as given in Table1.

Table I.

Basic Sector	Instantaneous Reference Vector Amplitude
1	Va>Vb>Vc
2	Vb>Va>Vc
3	Vb>Vc>Va
4	Vc>Vb>Va
5	Vc>Va>Vb
6	Va>Vc>Vb

2. **Sub Hexagon Center Identification**: In the proposed method, the possible sub hexagon center vectors are obtained from the two basic vectors of the inner sub hexagon. These two vectors are referred to as starting vector and adjacent vector. In order to determine the sub hexagon centers layer number [9] is calculated as given in the equation 3

$$L = 1 + int\left(\frac{v_{jmax}}{\frac{\sqrt{3}V_{dc}}{2(n-1)}}\right) \quad (3)$$

Where v_{jmax} is the maximum magnitude among the three resolved components of v_{ja} v_{jb} and v_{jc} axis respectively as is given by equations 4 – 6

$$v_{ja} = \sqrt{3}/2(v_a - v_c) \quad (4)$$

$$v_{jb} = \sqrt{3}/2(v_b - v_a) \quad (5)$$

$$v_{jc} = \sqrt{3}/2(v_c - v_b) \quad (6)$$

Table II. Starting and Adjacent Vectors for Sub Hexagon Center Generation

Basic Sector	Starting Vector	Adjacent vector
1	(1,0)	(0,1)
2	(0,1)	(-1,1)
3	(-1,1)	(-1,0)
4	(-1,0)	(0,-1)
5	(0,-1)	(1,-1)
6	(1,-1)	(1,0)

The starting vector and adjacent vector for different basic sectors are shown in Table II. The layer number L gives the number of candidate sub hexagon center vectors in a particular layer. Let m represent the candidate sub hexagon center vector number . For a layer number equal to L; m varies from 1 to L.

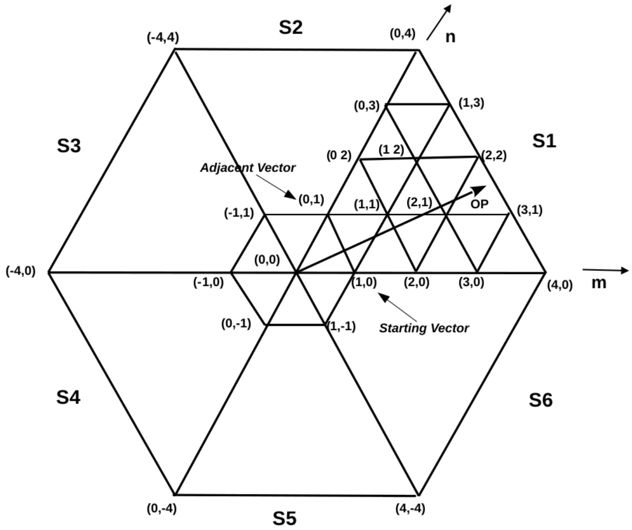

Figure 2. Space Vectors with reference OP in Basic sector1 and layer 4

For generating m^{th} sub hexagon center vector in layer L ; the starting vector is repeated L - m times and added with adjacent vector repeated m-1 times Figure 2 shows the space vector diagram of a 5 level inverter with the reference vector in layer, L= 4 of sector, S= 1.So the number of candidate sub hexagon centers is 4.

- 1^{st} candidate vector,m=1
  The starting vector is (1,0) and adjacent vector is (0,1).The 1^{st} sub hexagon center is obtained by repeating starting vector 3 times (L=4,m=1; L-m=3); so the 1^{st} sub hexagon center is 30 (10+10+10 = 30).
- 2^{nd} candidate vector, m=2
  The 2^{nd} sub hexagon center is obtained by repeating starting vector 2 times (L=4,m=2; L-m= 2) and adding with adjacent vector (m=2;m-1=1); so the second sub hexagon center is 21 (10+10+01 = 21).
- 3^{rd} candidate center vector, m=3
  The 3^{rd} sub hexagon center is obtained by adding starting vector (L=4,m=3; L-m= 1) and adding with

adjacent vector (m=3; m-1= 2) repeated 2 times; so the 3rd sub hexagon center is 12 (10+01+01 = 12).

- 4th candidate center vector, m=4
  The 4th sub hexagon center is obtained by repeating the adjacent vector 3 times (m= 4; m-1= 3); so the 4th sub hexagon center is 03 (01+01+01 = 03)
  The generation process is depicted in figure 3.

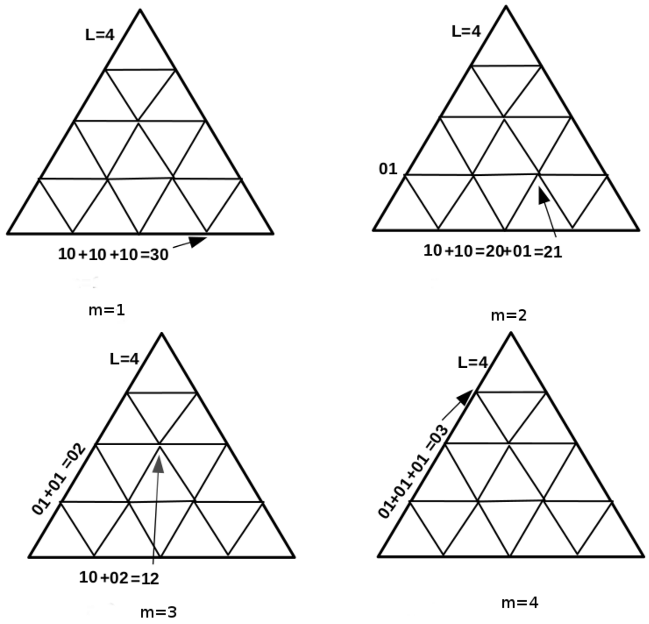

Figure 3. Sub hexagon center generation from starting vector 10 and adjacent vector 01 for L=4;S=1

Having generated the sub hexagon center vectors, now we can determine the sub hexagon center closest to the tip of Vre f by comparing the distance from the tip of Vref to each of the four points using equation (7).

$$d\sqrt{(V_m - V_{ms})^2 + (V_n - V_{ns})^2 + (V_m - V_{ms})(V_n - V_{ns})} \quad (7)$$

Where Vms and Vns are 60^0 cordinates of the sub hexagon center vectors. The sub hexagon center with least value of d is selected.

3. **Mapping of Vre f into inner hexagon:** Once the sub hexagon center is identified, the sub hexagon containing the tip of Vref is mapped to the inner sub hexagon to determine the duration of the switching vectors [8], [11]. The phase voltage timing for switching vectors can be determined by using the conventional equations for 2 level inverter [11]. Mapping is done by subtracting the instantaneous reference vectors Vms and Vns from the selected sub hexagon center vector obtained by selecting the vector having minimum value of d in equation (7). The new coordinates of mapped reference vector is given by equations (8) and (9)

$$V_{mmap} = V_m - V_{ms} \quad (8)$$

$$V_{nmap} = V_n - V_{ns} \quad (9)$$

Figure 4 shows the principle of mapping the reference vector in to the inner hexagon. Here the vector CT,

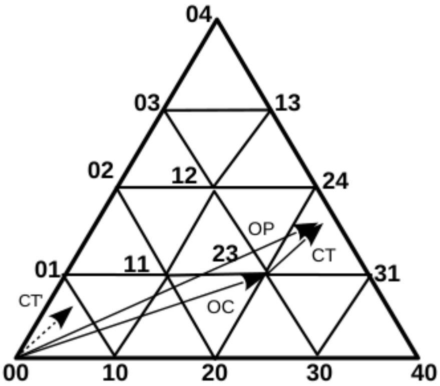

Figure 4. Mapping reference vector to inner hexagon

4. **Determination of duration of switching voltage space vectors:** The new phase values Vas, V bs and Vcs of mapped reference vector can be found using equations given below,[10].

$$V_{as} = (2V_{mmap} + V_{nmap})/3 \quad (10)$$
$$V_{bs} = (V_{nmap} - V_{mmap})/3 \quad (11)$$
$$V_{cs} = (-V_{mmap} - 2V_{nmap})/3 \quad (12)$$

The phase voltage timings Tga, Tgb and Tgc corresponding to the three phases are computed as in [11]. Once the switching vectors are resolved and their switching durations are calculated, it should be ensured that the vectors are switched in an optimum sequence so that only one switching occurs when the inverter changes its state.

5. **Generation of Actual Switching Vectors**

The principle of generating actual switching vectors is shown in Fig.5. The (m,n) coordinates of the sub hexagon center(Vms;Vns) are converted to switching vectors S_a and S_b and S_c. The switching vector corresponding to sub hexagon center is then added with the mapped 2-level PWM signal to obtain the actual switching vectors [9].

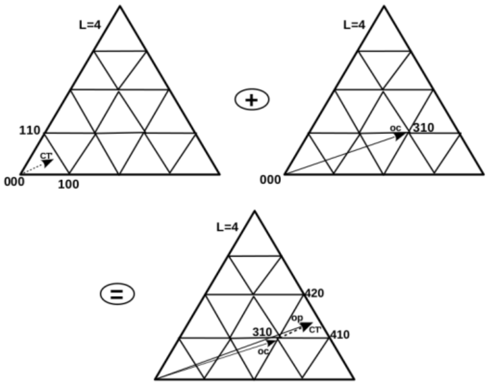

Figure 5. Mapping reference vector to inner hexagon

Simulation and Results

The proposed scheme was verified using MATLAB/SIMULINK for 3-level and 5-level operation. Figure 5 shows the Simulink code

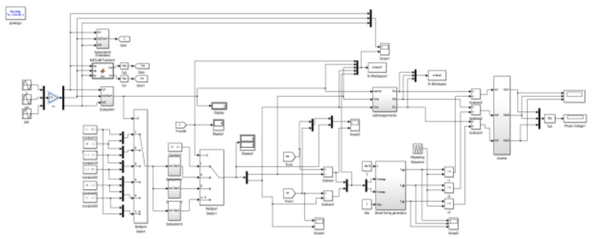

Figure 6. MATLAB/SIMULINK Block

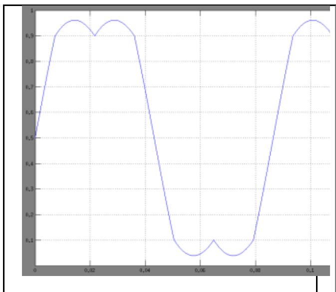

Fig 7. Timing waveform for 2 – level operation

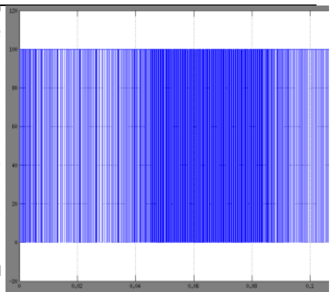

Fig 8. Pole Voltage Waveform – 2 level

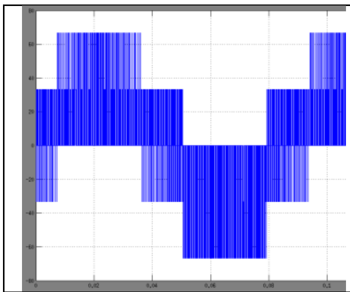

Fig 9. Phase VoltageWaveform 2-level

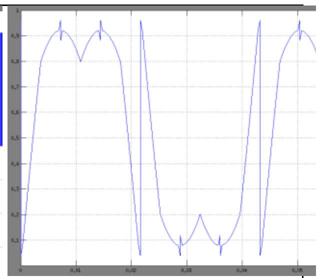

Fig 10. Timing waveform– 3 level operation

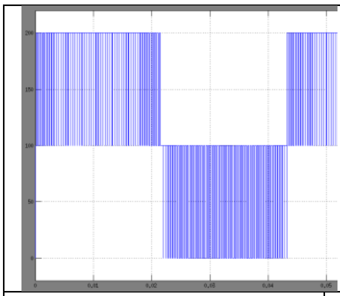

Fig 11. Pole VoltageWaveform–3 level operation

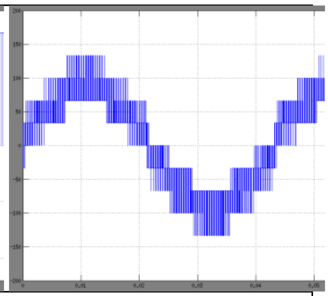

Fig 12. Phase VoltageWaveform–3 level operation

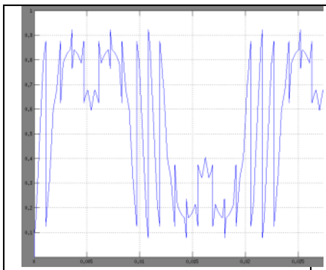

Fig 13. Timing waveform– 5 level operation

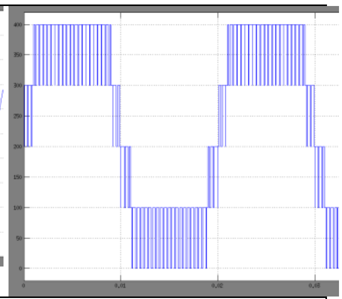

Fig 14. Pole VoltageWaveform–5 level

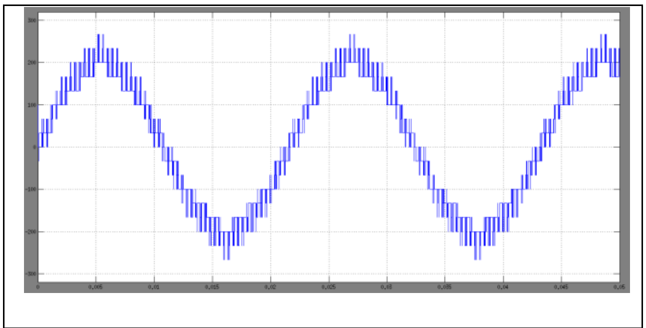

Fig 15. Phase VoltageWaveform–5 level

The figures 7 -9 show the timing diagram, pole and phase voltage waveforms of 2-level operation. Figures 10-15 shows the waveforms for 3-level and 5-level operation respectively.

Conclusions

The scheme was successfully simulated for 2, 3 and 5 level inverter using MATLAB/SIMULINK. The method could also be extended to any level.

References

1. Anish Gopinath, Aneesh Mohamed A. S., and M. R. Baiju,“A Simple Space Vector PWM Generation Scheme for Any General n –Level Inverter”, IEEE Transactions on Industrial Electronics,vol. 56,no.5, April 2009
2. Anish Gopinath, Aneesh Mohamed A. S., and M. R. Baiju,“Fractal Based Space Vector PWM for Multilevel Inverters-A Novel Approach” IEEE Transactions on Industrial Electronics, vol. 56,no.4, April 2009

3. Heinz Willi Van Der Broeck, Hans-Christoph Skudelny, and Georg ViktorStanke, “Analysis and realization of a pulsewidth modulator basedon voltage space vectors”, IEEE Transactions on Industry Applications,vol. 24, no. 1, pp.142-150, January/February 1988
4. J. Holtz, “Pulse width modulation-A survey”, IEEE Transacation on Industrial Electronics. , vol.39 no. 5, pp. 410-420,Dec. 1992
5. J. Rodriguez, Leopoldo G. Franquelo etal.,“Multilevel Converters: An Enabling Technology for High-Power Applications”, Proceedings of the IEEE — Vol. 97, No. 11, pp. 1786-1817 November 2009
6. J.. Rodriguez, J. S. Lai, and F. Z. Peng,“Multilevel inverters: A survey of topologies, controls, and applications”, IEEE Transaction on Industrial Electronics, vol. 49, no. 4, pp. 724-738,2006.
7. Joohn-Sheok Kim and Seung-Ki Sul, “A Novel Voltage Modulation Technique of the Space Vector PWM,” IPEC Yokohama-95,pp. 742- 747.
8. K. Gupta and A. M. Khambadkone,“A space vector modulationscheme to reduce common mode voltage for cascaded multilevel inverters,”IEEE Trans. Power Electron., vol. 22, no. 5, pp. 1672-1681,Sep.2007
9. N.Celanovic and Dushan Boroyevich, “A Fast Space Vector Mod- ulation Algorithm for Multilevel Three Phase Converters”, IEEE Transactions on Industry Applications,vol. 37,no. 2,pp. 637-641, March/April 2001
10. Shiny G., M.R.Baiju, “A Low Computation Space Vector PWM Scheme for Multilevel Inverters based on Fractal Approach”, IEEE Symposium on Industrial Electronics and Applications, October 3-10, 2010.
11. Wenxi Yao, Haibing Hu, and Zhengyu Lu,“Comparison of Space Vector Modulation and Carrier based Modulation of Multilevel Inverter”, IEEE Transactions on Power Electronics, vol. 23, no. 1,pp. 45–41,January2008.