A Simple Algorithm for Three Phase Three Level Space Vector PWM

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Abstract— All renewable sources use power electronic devices specially multilevel inverters to convert DC source obtained from renewable sources into AC. These inverters can give their best results when the proper scheme is applied for obtaining desired output. There are many PWM schemes available for inverter operation to obtain variable voltage and frequency supply for inverter. The carrier based sinusoidal and space vector PWM(SVPWM) is the most widely used scheme for the voltage source inverters due to their easier digital realization and better DC link utilization. A simplified algorithm for the three-level SVPWM is proposed. Due to the geometrical symmetry of six sectors, there exist the close relationships in on time calculations and on time arrangement for switches between them. So it can complete the computation of the three-level SVPWM in one sector.

Key words: Three Level NPC Inverter; Space Vector Pulse Width Modulation

I. INTRODUCTION

Nowadays multilevel schemes have caught great attention in the field of high-power and high-voltage applications. These schemes improve quality of output waveform of voltage source inverter by increasing waveform steps and reduce the voltage stress across switches by using multiple switches. As there is low voltage stress produced, the dv/dt ratio is also become less, which causes less EMI problems. Among these topologies, the neutral-point clamped (NPC) three-level topologies is widely used for such applications. Researches on topics covering soft switching, neutral point voltage self-balancing and all kinds of modulations are going on now a days. As one of most promising modulation technologies in three phase systems, space vector PWM (SVPWM) for three-level converter has an advantage over sinusoidal PWM in voltage utility, for modulation range of SVPWM is 15% higher than that of sinusoidal PWM [4]. Although three-level SVPWM technique is derived from two level SVPWM, three-level SVPWM is considerably more complex than that of two-level converter because of large number of balancing. Due to its complexity in computation, three-level SVPWM algorithm is almost implemented using software based on DSP or MCU according to reported literatures [5]. This method demonstrates high flexibility and adaptability to various applications, but it also suffers some disadvantages:

1) As a sequence controller, these type processors interpret instructions line by line, which results in time delay and leads to deteriorate the performance of a control system.
2) With most computation resources devoting to the periodic events such as sampling, control algorithm calculating and PWM gating signals generating, limited resources are left to other functions.

In order to resolve these problems, multi-DSP systems are often adopted in these applications, but hardware and software design for such multi-DSP systems will complicate the design process greatly. An alternative to the problems is a new hardware-software partition, in which time-critical and periodic intensive computation tasks can be undertaken by hardware featuring parallelism. Therefore, the processor can be relieved from the onerous periodic computation tasks and gain more computation resources to cope with other tasks.

However, implementation of three-level SVPWM totally based on hardware technology has so far still not been reported in the literature. This paper presents simplified algorithm for the three-level SVPWM.

II. 3 LEVEL NEUTRAL POINT CLAMPED INVERTER

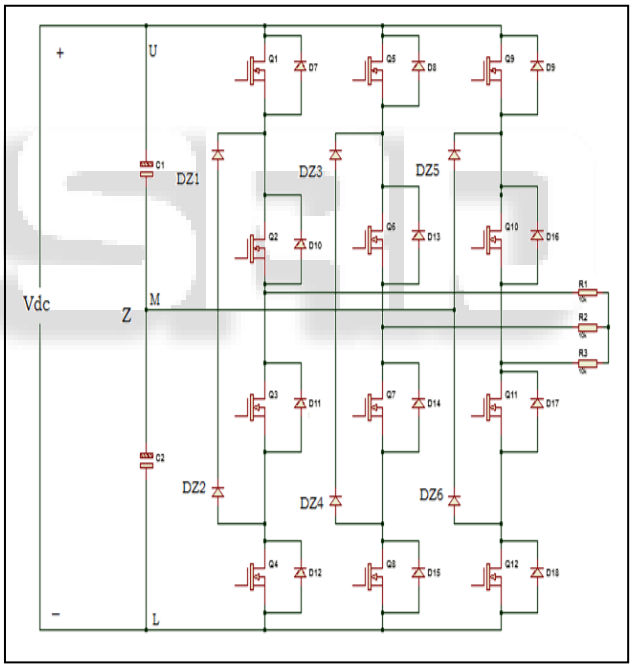

Fig. 1: Three Level NPC Inverter

A. SVPWM Algorithm:

Fig.1 shows a three-level neutral point clamped inverter. It contains 12 controllable power switching devices and also supplied with two capacitors connected in series. Both are charged with VDC. The point between these capacitors is the DC-voltage neutral point. Each phase leg consists of 4 series-connected switching devices (IGBT's) and two clamping diodes. Their job is to clamp the six middle switches potential to the DC-link point at zero. Specific combinations of the twelve switches gives the three level output voltage. The four switches in one phase leg can only be turned on two at a time and so be connected to the DC-link points U,M and L. This means that the three level voltage can be obtained by using O as reference. Here U=

Upper two switches are ON, M=Middle two switches are ON and L= Lower two switches are ON.

S_{1x}	on	off	off
S_{2x}	on	on	off
S_{3x}	off	on	on
S_{4x}	off	off	on
V_{x0}	V_{dc}	0	$-V_{dc}$
Switching state	U	m	l

Table 1: Switching combination and switching states for a three-level inverter (one phase-leg)1

B. αβ Transformation:

The voltage vectors: Va, Vb, Vc is replaced with Vα and Vβ, Vα and Vβ have the same direction, but different magnitude. With the αβ-transformation the signals are demonstrated in a two-dimensional plane, making it easier to use in the calculations done in the other parts.

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$|u| = \sqrt{V\alpha^2 + V\beta^2}$$

$$m = \frac{(\sqrt{3})Vref}{Vdc}$$

Where, m=modulation index

$$\theta = \tan^{-1}(V\beta/V\alpha)$$

The modulation index m, and voltage is calculated by this formula. The operation of 12 controllable switches in SVPWM topology creates 3^3 =27 switching states and 18 space vectors including zero vectors, small vectors, medium vectors and large vectors. The space vector diagram of Three level inverter is shown in figure 2.

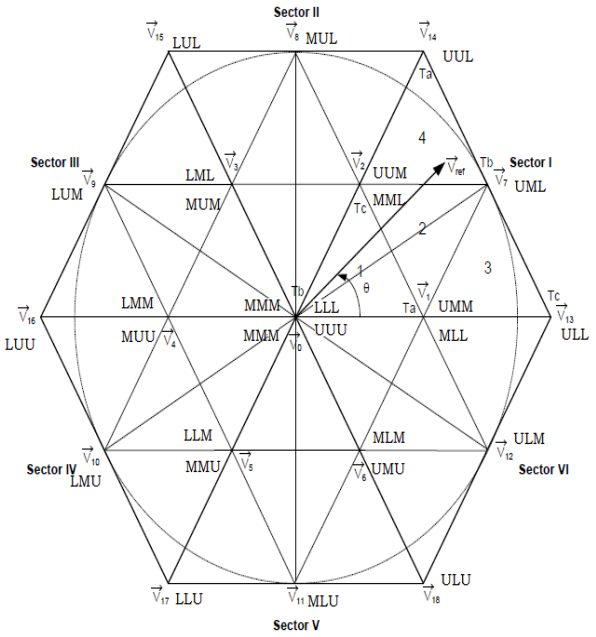

Fig. 2: Space Vector Diagram of Three Level SVPWM

C. Switching States:

For a three-level three-phase inverter there are 27 switching states (Table 2). These states represent the connection to the different DC-link points. If there is a load connected to the output of these states the inverter will generate a output phase voltage. This can be calculated as follows:

Va0= (2S1a−S1b−S1c)+(2S2a−S 2b−S 2c)

Vb0= (2S1b−S1a−S1c)+(2S2b−S2a−S2c)

Vc0= (2S1c−S 1b−S_{1a})+(2S2c−S 2b−S2a)

These are the line-to-neutral voltages. To receive the line-to-line voltage:

Vab=V a0−V b0

Vbc=Vb0−Vc0

Vca=V c0−Va0

In two level inverter the reference vector is given with the help of three nearest vector whereas in three level SVPWM, each sector is further divided into more four regions.

Switching States	Voltage vector	Angle	Vector megnitude
U-U-U M-M-M L-L-L	V0	0	oV
U-M-M M-L-L	V1	0	2/3Vdc
U-L-L	V2	0	4/3Vdc
U-M-L	V3	30	2/√3Vdc
U-U-L M-M-L	V4	60	2/3Vdc
U-U-L	V5	60	4/3Vdc
M-U-L	V6	90	2/√3Vdc
M-U-M L-M-L	V7	120	2/3Vdc
L-U-L	V8	120	4/3Vdc
L-U-M	V9	150	2/√3Vdc
M-U-U	V10	180	2/3Vdc

L-M-M			
L-U-U	V11	180	4/3Vdc
L-M-U	V12	-150	2/√3Vdc
M-M-U L-L-M	V13	-120	2/3Vdc
L-L-U	V14	-120	4/3Vdc
M-L-U	V15	-90	2/√3Vdc
U-M-U M-L-M	V16	-60	2/3Vdc
U-L-U	V17	-60	4/3Vdc
U-L-M	V18	-30	2/√3Vdc

Table 2: All Switching States and Space Vectors

D. Sector Determination:

θ is calculated and from that the sector in which the reference voltage vector is determined as follows:

1) if θ is between 0≤<θ<60 then, the ref. vector is in sector 1
2) if θ is between 60≤<θ<120 then, the ref. vector is in sector 2
3) if θ is between 120≤<θ<180 then, the ref. vector is in sector 3
4) if θ is between 180≤<θ<240 then, the ref. vector is in sector 4
5) if θ is between 240≤<θ<300 then, the ref. vector is in sector 5
6) if θ is between 300≤<θ<360 then, the ref. vector is in sector 6

III. TIME CALCULATION

The reference voltage Vref is given by,

$$Vref = 2/3(Va0 + Vb0e^{j2\pi/3} + Vc0e^{-j2\pi/3}$$

Vref is calculated by using three nearest voltage space vectors.

$$TsVref = TaVx + TbVy + TVz$$

In figure3, it is shown how the reference vector passes from sector 1 to sector 2.

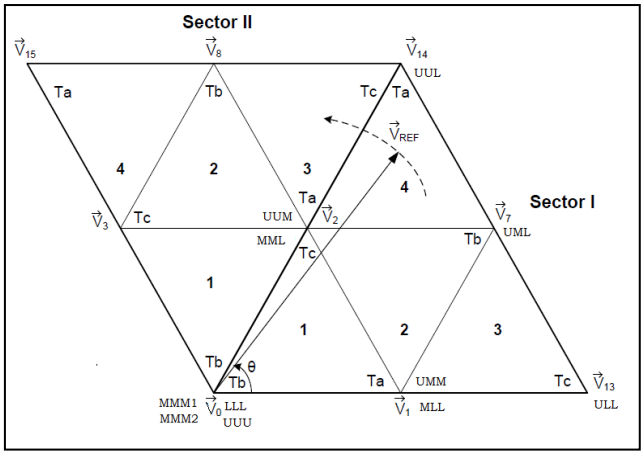

Fig. 3: VREF Transition between Two Sectors

Vectors: $\overrightarrow{V2}$, $\overrightarrow{V7}$ and $\overrightarrow{V14}$ are used when $\overrightarrow{Vref}$ is in region four of sector I:

$\vec{V}_{14}\,T_a + \vec{V}_7 T_b + \vec{V}_2\,T_c = \vec{V}_{ref}\,Ts$ (equation 1.1)

Where,

$$\vec{V}_{14} = 2/3V_{DC}\,e^{j\Pi/3},$$

$$\vec{V}_7 = \sqrt{3}/3V_{DC}e^{j\Pi/6},$$

$$\vec{V}_2 = 1/3V_{DC}\,e^{j\Pi/3}$$

Solving equation (1.1)

$$[cos(\frac{\Pi}{3}) + j\,sin(\frac{\Pi}{3})]Ta + \frac{\sqrt{3}}{3}[cos(\frac{\Pi}{6}) + jsin(\frac{\Pi}{6})]Tb + 1/3\,[cos(\Pi/6) + jsin(\Pi/6)\,]Tc = Vref/Vdc\,[cos(\theta) + jsin(\theta\,)\,]Ts$$

Real part,

$$\frac{1}{3}Ta + \frac{1}{2}Tb + \frac{1}{6}Tc = \frac{Vref}{Vdc}cos(\theta)$$

Imaginary Part,

$$\frac{\sqrt{3}}{3}Ta + \frac{\sqrt{3}}{6}Tb + \frac{\sqrt{3}}{6}Tc = \frac{Vref}{Vdc}sin(\theta)$$

Together with:

$$Ta + Tb + Tc = Ts$$

The set of above equations can be created to calculate dwell times Ta, Tb and Tc.

The dwell times of all regions of sector 1 is given in the table.

Region	Ta	Tb	Tc
1	$Ts[2msin(\frac{\pi}{3} - \theta)]$	$Ts[1 - 2msin(\frac{\pi}{3} + \theta)$	$Ts[2msin(\theta)]$
2	$Ts[1 - 2msin(\theta)]$	$Ts[2msin\left(\frac{\pi}{3} + \theta\right) - 1]$	$Ts[1 - 2msin(\frac{\pi}{3} - \theta)]$
3	$Ts[2 - 2msin(\frac{\pi}{3} + \theta)]$	$Ts[2msin(\theta)]$	$Ts[2msin\left(\frac{\pi}{3} - \theta\right) - 1]$
4	$Ts[2msin(\theta) - 1]$	$Ts[2msin(\frac{\pi}{3} - \theta)]$	$Ts[2 - 2msin(\frac{\pi}{3} + \theta)]$

Table 3: Dwell Times for Sector 1

Similarly the duty cycles for each region of each sectors can be calculated which gives the information regarding the switch ON- OFF time.

IV. CONCLUSION

In this paper, an algorithm is provided for three level three phase SVPWM topology. Switching states, Sector determination and time calculation of reference voltage vector in specified region of any sector is calculated in this paper.

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