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Simulation and Comparison of Three Level Inverter Using SVPWM & SPWM

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Abstract: **Sinusoidal pulse width modulation (SPWM) and space vector pulse width modulation (SVPWM) are the most popular modulation strategies for Multi level inverters. This paper provides the theoretical analysis and simulation results of SPWM and SVPWM for three level inverter. Also this paper gives comparison between three level SVPWM & SPWM inverter. This paper concludes that SVPWM can produce about 15% higher output voltage and also it utilizes DC bus voltage more efficiently and generates less harmonic distortion when compared with SPWM technique.**

Keywords: **SVPWM, SPWM, THD, NPC.**

I. INTRODUCTION

Multilevel inverters are used in high voltage and high power applications with less harmonic contents. Multilevel inverters are recognized due to the limitation of the two level inverters. To control multilevel converters, various pulse width modulation (PWM) techniques are used; SPWM and SVPWM techniques are widely used. In Sinusoidal Pulse width modulation (SPWM) we generate the gating signals by comparing sinusoidal reference signal with a triangular carrier wave. In Space vector Modulation (SVPWM) we consider a rotating phased which is obtained by adding all the three voltages. SVPWM technique is mostly used for Multi level inverters compared to SPWM.SVPWM technique was originally developed as a vector approach to PWM for three phase inverters. It is an advanced and computation method and it is quite different from reaming methods. SPWM inverter output voltage maintains good performance of the drive in the entire range of operation between zero and 78 % of the value that would reached by square wave operation with less control on each switching instant and produces lager THD.SVPWM inverter technique, it utilizes dc bus voltage more efficiently and the maximum output voltage based on the space vector technique is 1.155 times as large as the SPWM. It generates less harmonic distortion in a three phase voltage source inverter.

$V_{max} = V_{dc}\backslash 2$: Sinusoidal PWM
$V_{max} = V_{dc}\backslash \sqrt{3}$: SVPWM

This means SVPWM can produce about 15% higher output voltage than SPWM. The space vector modulation technique is more popular than conventional technique because of the following advantages.

ADVANTAGES OF SVPWM

1. Fast dynamic response, wide linear range of fundamental voltage, Easy digital implementation.
2. Simplicity in hardware and software.
3. Good performance at low modulation ratio, Lower switching losses, Better harmonic performance.
4. Improving D.C bus utilization, Microcontroller implementation.
5. SVPWM increases 15% higher output voltage compared to SPWM.

The main difficulty in this SVPWM is it becomes very difficult when the levels increases and it is complex in some steps that is selection of switching states.

II. ANALYSIS OF THREE LEVEL SVPWM INVERTER

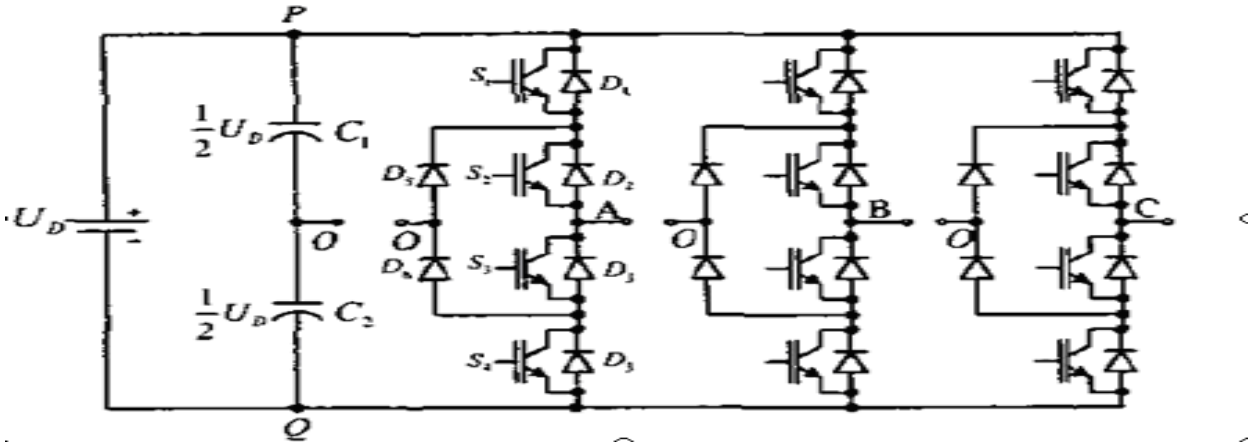

Figure.1 Three phase three level voltage source inverter

Basically NPC multilevel inverters synthesize the small step of staircase output voltage from several levels of DC capacitors voltages. An m-level NPC inverter consists of (m-1) capacitors on the DC bus, 2(m-1) switching devices per phase and 2(m-2) clamping diodes per phase [4].The circuit employs 12 power switching devices and 6 clamping diodes. Each arm contains four IGBTs, four anti parallel diodes and two neutral clamping diodes. And the dc bus voltage is split into three levels by two series connected bulk capacitors C_1, C_2 two capacitors have been used to divide the DC link voltage into three voltage levels, thus the name of 3-level.The middle point of the two capacitors can be defined as the neutral point 0. The output voltage V_{ao} has three different states: $V_{dc}/2$, 0 and $-V_{dc}/2$.For voltage level $+V_{dc}/2$, switches S_1 & S_2 need to be turned on.For voltage level 0, switches S_2 & S_3 need to be turned on. For voltage level $-V_{dc}/2$ switches S_3 & S_4 need to be turned on. We can define these states as 2, 1, and 0. Using switching variable S_a and dc bus voltage V_{dc}, the output phase voltage V_{ao} is obtained as follows:

$V_{ao} = (S_a\text{-}1)/2 \times V_{dc}$

TABLE I. THE SWITCHING VARIABLE OF PHASE A

V_{ao}	S_{a1}	S_{a2}	S_{a3}	S_{a4}	S_a
$+V_{dc}/2$	1	1	0	0	2
0	0	1	1	0	1
$-V_{dc}/2$	0	0	1	1	0

For example $S_a = 2$

$V_{ao} = (2\text{-}1)/2 \times V_{dc}$, $V_{ao} = V_{dc}/2$

The output line voltages expressed as follows:

$V_{ab} = V_{ao}\text{-} V_{bo} = ½ \times V_{dc} \times (S_a\text{-}S_b)$

$V_{bc} = V_{bo}\text{-} V_{co} = ½ \times V_{dc} \times (S_b\text{-}S_c)$

$V_{ca} = V_{co}\text{-} V_{ao} = ½ \times V_{dc} \times (S_c\text{-}S_a)$

The output phase voltages can be expressed as follows:

$V_{an} = V_{ao} - V_{no}$

$V_{bn} = V_{bo} - V_{no}$

$V_{cn} = V_{co} - V_{no}$ and $V_{no} = 1/3(V_{ao}+V_{bo}+V_{co})$

III. DESIGN STEPS FOR THREE LEVEL SVPWM INVERTER GENERATION

There are various steps for implementing the three levels SVPWM inverter. They are

- No of switching states
- No of voltage vectors & corresponding voltages.
- Sector identification.
- Determining the region in the sector.
- Calculating the active vectors switching time periods.
- Generation of gating signals

The total number of switching states in an "N" level inverter is "N^3".So the total number of switching states in a "3" level inverter is "3^3" that is 27 switching states.24 states are active states and 3 zero states.

A. SPACE VECTOR DIAGRAM OF THREE LEVEL SVPWM INVERTER

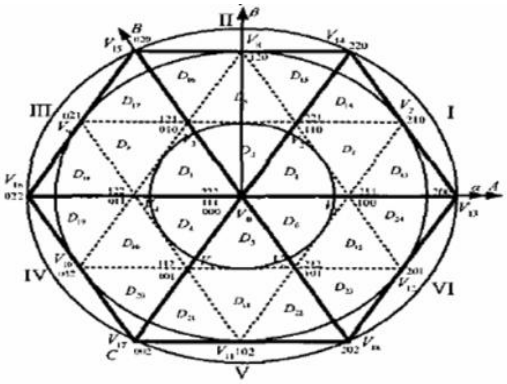

Figure.2 Space vector diagram of three level inverter

The plane can be divided into 6 major triangular sectors (I to VI) by large voltage vectors and zero voltage vectors. Each major sector represents $60^0$of the fundamental cycle. Within each major sector, there are 4 minor triangular sectors. There are totally 24 minor sectors in the plane. Large voltage vectors are V_{13}, V_{14}, V_{15}, V_{16}, V_{17}, and V_{18}. Medium voltage vectors are V_7, V_8, V_9, V_{10}, V_{11}, and V_{12}. Small voltage vectors are V_1, V_2, V_3, V_4, V_5, and V_6. Zero voltage vector is V_0.

TABLE II. SWITCHING STATES OF 3 LEVEL INVERTER

Switching states	S_a	S_b	S_c	Voltage Vectors
S_1	0	0	0	V_0
S_2	1	1	1	V_0
S_3	2	2	2	V_0
S4	1	0	0	V_1
S_5	1	1	0	V_2
S_6	0	1	0	V_3
S_7	0	1	1	V_4
S_8	0	0	1	V_5
S_9	1	0	1	V_6
S_{10}	2	1	1	V_7
S_{11}	2	2	1	V_8
S_{12}	1	2	1	V_9
S_{13}	1	2	2	V_{10}
S_{14}	1	1	2	V_{11}
S_{15}	2	1	2	V_{12}

S_{16}	2	1	0	V_{13}
S_{17}	1	2	0	V_{14}
S_{18}	0	2	1	V_{15}
S_{19}	0	1	2	V_{16}
S_{20}	1	0	2	V_{17}
S_{21}	2	0	1	V_{18}
S_{22}	2	0	0	V_{19}
S_{23}	2	2	0	V_{20}
S_{24}	0	2	0	V_{21}
S_{25}	0	2	2	V_{22}
S_{a26}	0	0	2	V_{23}
S_{27}	2	0	2	V_{24}

B. SECTOR IDENTIFICATION

Each major sector can be identified by using space vector phase angle (α). α is calculated and then sector , in which the command vector V* is located , is determined as:If α is between $0 \leq \alpha < 60^0$, and V* will be in major sector I. If α is between $60 \leq \alpha < 120^0$, and V* will be in major sector II. If α is between $120 \leq \alpha < 180^0$, and V* will be in major sector III. If α is between $180 \leq \alpha < 240^0$, and V* will be in major sector IV. If α is between $240 \leq \alpha < 300^0$, and V* will be in major sector V. If α is between $300 \leq \alpha < 360^0$, and V* will be in major sector VI.

C. DETERMINATION OF REGION IN A PARTICULAR SECTOR

For example we are taking the space vector diagram of sector I for determining the particular region in a sector 1. Sector I contains 4 minor triangular sectors. D_1, D_7, D_{13} and D_{14} are 4 minor triangular sectors. In each of the four minor regions, the reference vector $V_{ref\ is}$ located in one of the 4 regions, where each region is limited by three adjacent vectors. Then V_{ref} is equal to:

$V_{ref} = V^* = V_x (T_x/ T_s) + V_y (T_y/ T_s) + V_z (T_z/ T_s)$

$T_x / T_s + T_y/ T_s + T_z/ T_s = 1$, $T_x / T_s = X$, $Ty/ T_s = Y$, $Tz/ T_s = Z$, $T_x + T_y + T_z = T_s$, $X + Y + Z = 1$ $V_x X + V_y Y + V_z Z = V^*$ Modulation ratio $M = (V^* / 2/3\ V_{dc}) = (3\ V^* /2\ V_{dc})$

As shown in figure.2, the boundaries of modulation ratio are Mark1, Mark 2, and Mark3.The equation forms of them are obtained as follows: [1]

$$Mark1 = \frac{\sqrt{3}/2}{\sqrt{3}\cos\theta + \sin\theta}$$

$$Mark\ 2 = \frac{\sqrt{3}/2}{\sqrt{3}\cos\theta - \sin\theta}, \theta \leq \pi/6$$

$$Mark3 = \frac{\sqrt{3}/4}{\sin\theta}, \frac{\pi}{6} < \theta \leq \frac{\pi}{3}$$

$$= \frac{\sqrt{3}}{\sqrt{3}\cos\theta + \sin\theta}$$

D. CALCULATION OF ACTIVE VECTOR SWITCHING TIME PERIOD

a) When the modulation ratio M < Mark1, then the rotating voltage vector V* will be in sector D_1 (Region 1). In a three level inverter, switching time calculation is based on the location of reference vector with in a sector. In one sampling interval, the output voltage vector V* can be written,

$V^* = V_x (T_x/ T_s) + V_y (T_y/ T_s) + V_z (T_z/ T_s)$

As shown in figure-5 V* is synthesized by V_0, V_1, and V_2. In sector D_1, the length of zero voltage vector V_0 is zero and length of large voltage vector is 1.Then

$V^* T_s = V_1 (T_1/T_s) + V_2 (T_2/T_s) + V_0 (T_0/ T_s)$
$V_1 X + V_2 Y + V_0 Z = V^*$ $V^* = M (\cos \theta + j \sin \theta)$,
$V_1 = ½$, $V_2 = ½ (\cos 60^0 + j \sin 60^0)$ and $V_0 = 0$.
$M (\cos \theta + j \sin \theta) = ½ X + ½ (\cos 60^0 + j \sin 60^0) Y$ (1)
$X + Y + Z = 1$ (2)

Using (1) & (2), we can obtain X, Y, and Z as follows:

$$\begin{cases} X = 2m.\left[\cos\theta - \dfrac{\sin\theta}{\sqrt{3}}\right] \\ Y = m.\dfrac{4\sin\theta}{\sqrt{3}} \\ Z = 1 - 2m\left[\cos\theta + \dfrac{\sin\theta}{\sqrt{3}}\right] \end{cases}$$

b) Similarly when the modulation ratio Mark1<M< Mark2, then V* will be in sector D_7 (Region 2).
V* can be synthesized by V_1, V_2, and V_7.
$V^* = V_x (T_x/ T_s) + V_y (T_y/ T_s) + V_z (T_z/ T_s)$
In sector D_7, the length of zero voltage vector V_7 is zero, and length of large voltage vector is 1
$V^* T_s = V_1 (T_1/T_s) + V_2 (T_2/T_s) + V_7 (T_7/ T_s)$
$V_1 X + V_2 Y + V_7 Z = V^*$ (3)

Using (3) & (2), we can obtain X, Y, and Z as follows

$$X = 1 - m.\frac{4\sin\theta}{\sqrt{3}}$$
$$Y = 1 - 2m\left[\cos\theta - \frac{\sin\theta}{\sqrt{3}}\right]$$
$$Z = -1 + 2m\left[\cos\theta + \frac{\sin\theta}{\sqrt{3}}\right]$$

c) When the modulation ratio Mark2 < M < Mark3 and $0 < \theta < 30^0$, then V* will be in sector D_{13} (Region 3). V_1, V_{13} and V_7 are selected to synthesize V*.
$V^* = V_x (T_x/ T_s) + V_y (T_y/ T_s) + V_z (T_z/ T_s)$
In sector D_7, the length of zero voltage vector V_7 is zero, and length of large voltage vector is 1.
$V^* T_s = V_1 (T_1/T_s) + V_{13} (T_{13}/T_s) + V_7 (T_7/ T_s)$
$V^* T_s = V_1 (T_1/T_s) + V_{13} (T_{13}/T_s) + V_7 (T_7/ T_s)$
$V_1 X + V_{13} Y + V_7 Z = V^*$ (3)
Using (3) & (2), we can obtain X, Y, and Z as follows

$$X = -1 + 2m\left[\cos\theta - \frac{\sin\theta}{\sqrt{3}}\right]$$
$$Y = m.\frac{4\sin\theta}{\sqrt{3}}$$
$$Z = 2 - 2m\left[\cos\theta + \frac{\sin\theta}{\sqrt{3}}\right]$$

d) When the modulation ratio Mark2 < M < Mark3 and $0 < \theta < 30^0$, then V* will be in sector D_{13} (Region 3). V_2, V_7 and V_{14} are selected to synthesize V*.
$V^* = V_x (T_x/ T_s) + V_y (T_y/ T_s) + V_z (T_z/ T_s)$
In sector D_{14}, the length of zero voltage vector V_7 is zero, and length of large voltage vector is 1
$V^* T_s = V_1 (T_1/T_s) + V_{13} (T_{13}/T_s) + V_7 (T_7/ T_s)$
$V_1 X + V_{13} Y + V_7 Z = V^*$ (4)
Using (4) & (2), we can obtain X, Y, and Z as follows

$$X = 2m\left[\cos\theta - \frac{\sin\theta}{\sqrt{3}}\right]$$
$$Y = -1 + m.\frac{4\sin\theta}{\sqrt{3}}$$
$$Z = 2 - 2m\left[\cos\theta + \frac{\sin\theta}{\sqrt{3}}\right]$$

IV. ANALYSIS OF THREE LEVEL SPWM INVERTER

The sinusoidal PWM compares a high frequency triangular carrier with three sinusoidal reference signals, knows as the modulating signals, to generate the gating signals for the inverter switches. This is basically an analog domain technique and is commonly used in power conversion with both analog and digital implementation. In this method of modulation, several pulses per half cycle are used as in the case of multiple pulse width modulation. Instead of maintaining the width of all pulses the same as in the case of multiple pulse width modulation, the width of each pulse is varied proportional to the amplitude of a sine wave evaluated at the center of the same pulse. By comparing a sinusoidal reference signal with a triangular carrier wave of frequency F_c, gating signals are generated. The frequency of reference signal ($Fr_)$, determines the inverter output frequency (F_O) and its peak amplitude (E_r), controls the modulation index M and then in turn the RMS output voltage. The number of pulses per half cycle depends on the carrier frequency. Within the constraint that two transistors of the same arm cannot conduct at the same time.

Sinusoidal pulse width modulation is used to control the inverter output voltage and maintains good performance to synthesize AC voltage wave forms in several applications, such as uninterruptible power supplies, motor drives and active filters. SPWM technique has been extensively used, because it improves the harmonic spectrum of the inverter by moving the harmonic components to higher frequencies.

Inverter output voltage has the following features
1) PWM frequency is same as the frequency of trigging voltage V_{tri}.
2) Amplitude is controlled by the peak value of control voltage V_{cntr}.
3) Fundamental frequency is controlled by the frequency of control voltage V_{cntr}.

The generation of gating signals with sinusoidal PWM is shown in figure-3.A carrier wave is compared with the reference signal corresponding to a phase to generate the gating signals for that phase. Comparing the carrier signal ($V_{cr)}$ with the reference phases (V_{ra}, V_{rb}, and V_{rc}) produces g_1, g_3 and g_5. The instantaneous line to line output voltages is $V_{ab} = V_s(g_1\text{-}g_3)$. The output voltage as shown in figure-3 is generated by eliminating the condition that the two switching devices in the same arm cannot conduct at the same time. The normalized carrier frequency should be odd multiple of three. Thus all phase voltages are identical, but 120^0 out of phase without even harmonics: moreover, harmonics at frequencies multiple of three are identical in amplitude and phase in all phases.

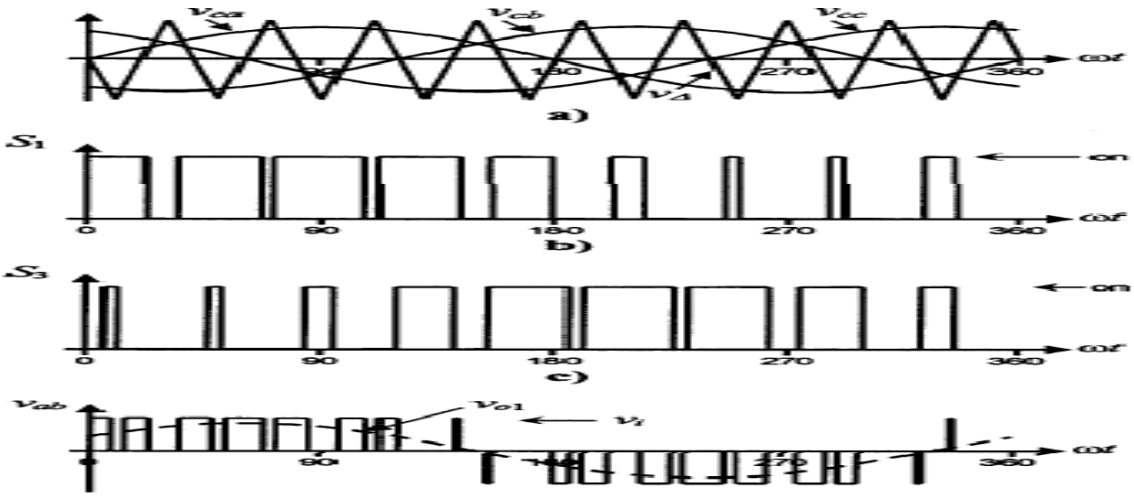

Figure. 3 waveforms of SPWM

V. SIMULINK MODEL OF SPWM INVERTER

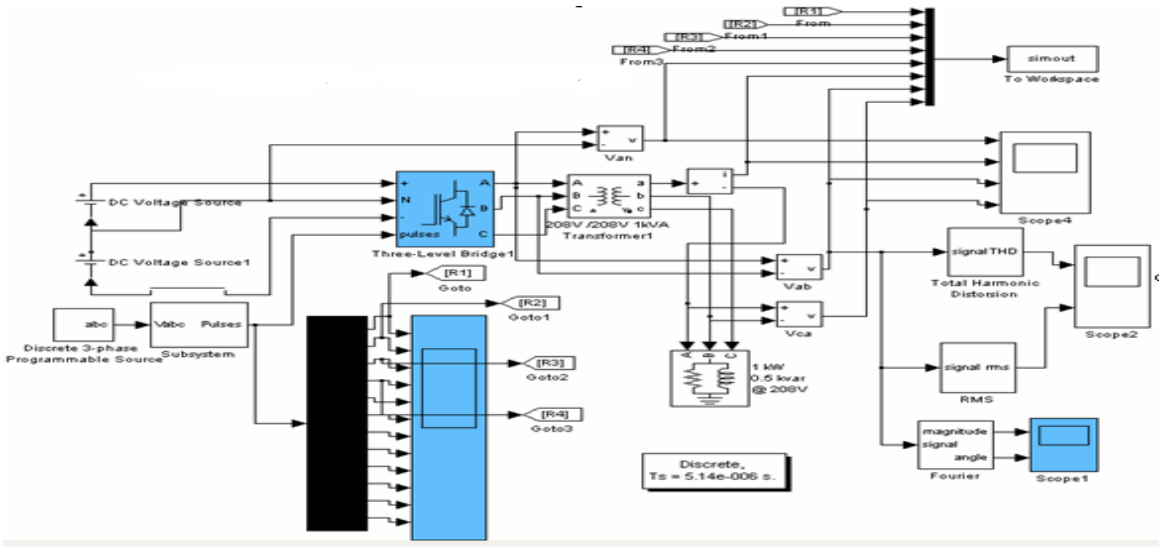

Figure. 4

VI. SIMULINK MODEL OF SVPWM INVERTER

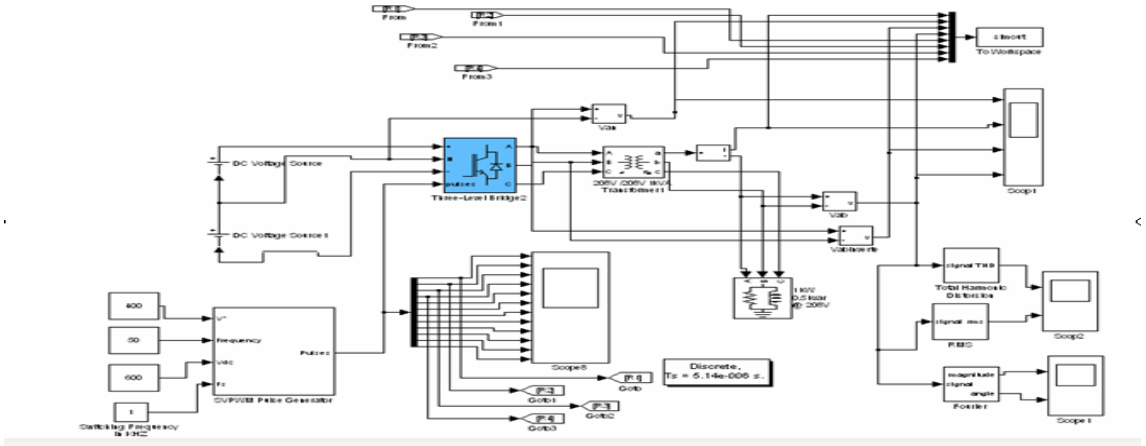

Figure. 5

VII. SIMULATION RESULTS

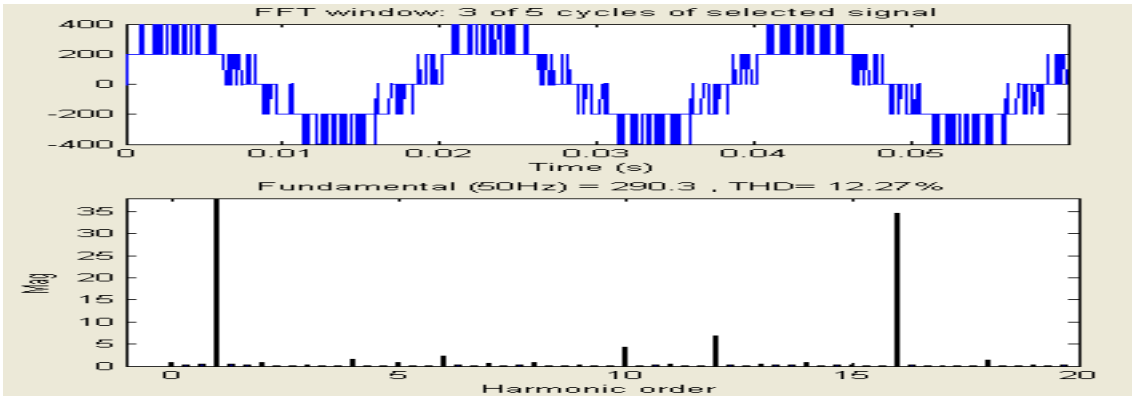

Figure.6 THD waveforms SVPWM inverter voltages

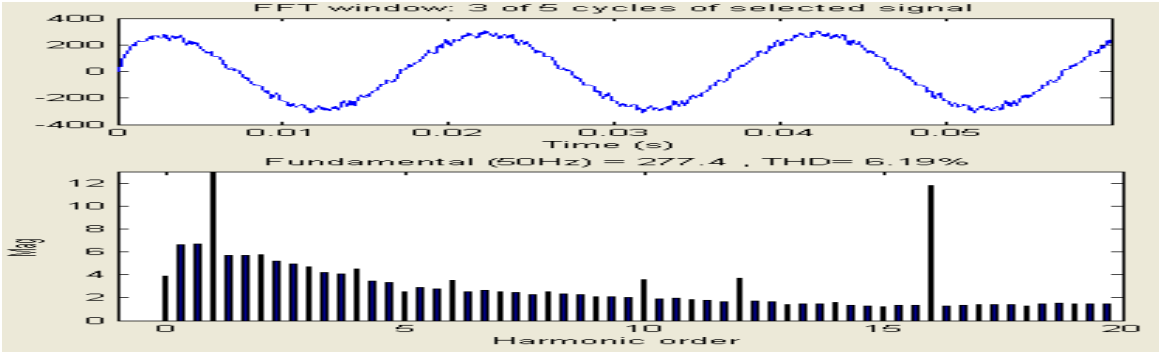

Figure.7 THD waveforms of SVPWM load voltage

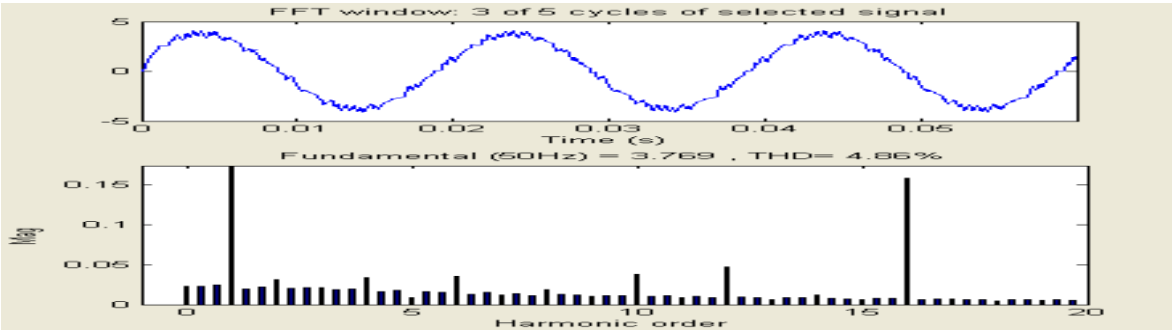

Figure.8 THD waveforms of SVPWM inverter current

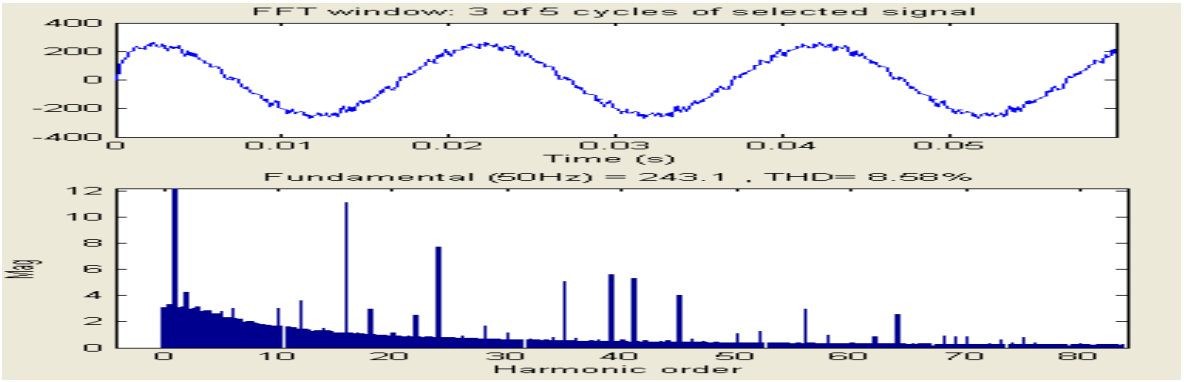

Figure.9 THD waveforms of SPWM inverter load voltage

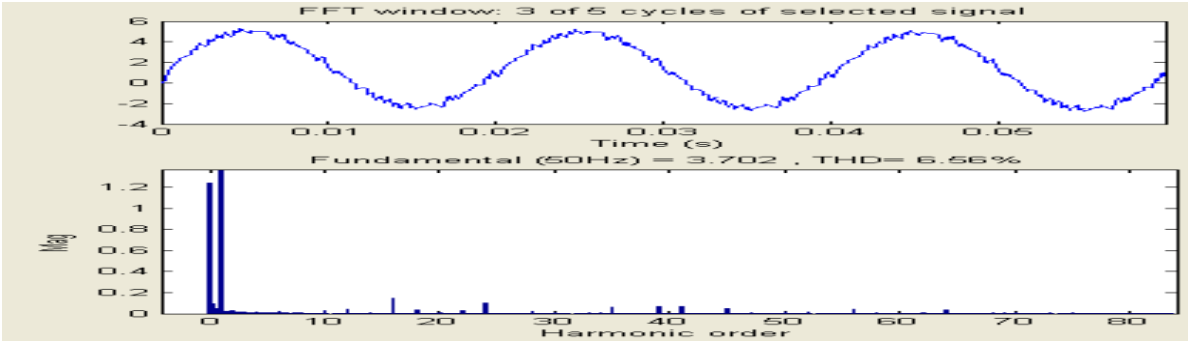

Figure.10 THD waveforms of SPWM inverter current

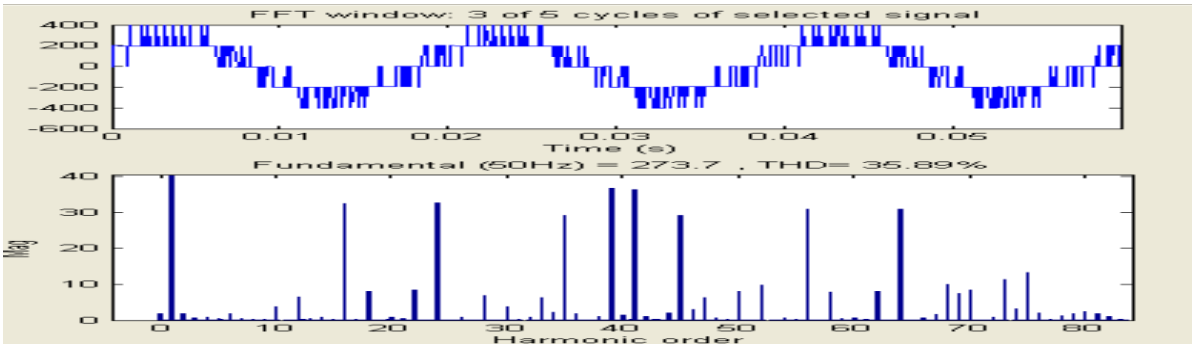

Figure.11 THD waveforms of SPWM inverter line voltage

TABLE IV. COMPARISION OF SVPWM and SPWM INVETERS

Type	V_{ab} inverter	V_{ab} load	Inverter current
SPWM INVERTER	35.89%	8.58%	6.56%
SVPWM INVERTER	12.27%	6.19%	4.86%

The simulation results suggest that SVPWM can achieve less harmonic distortion compared to SPWM.

VIII. CONCLUSION

In this paper, SVPWM technique is used to reduce the harmonics. 3-level NPC inverter simulation model has been successfully developed with RL load in this paper. Sinusoidal PWM method has intermediate switching losses, but its THD is significantly higher compared to other techniques of PWM. It is concluded that harmonic content is very less in case of SPACE VECTOR technique. The voltage THD values of the SVPWM inverter are lower than SPWM.

The proposed scheme has been successfully implemented by using Simulink MATLAB. It is used for the further research in high voltage and high power application. The basic implementation is used for future works with high levels that is more than three level inverters. And also the present implementation is used for a new simplified space vector PWM method for three-level inverters.

TABLE V. SIMULATION PARAMETERS FOR THREE LEVEL SVPWM & SPWM INVERTER

Input DC link voltage (Vdc1)	200V
Input DC link voltage (Vdc2)	200V
Input voltage (V*)	400V
Fundamental frequency (F)	50HZ
Switching frequency (Fs)	1000HZ
Transformer	Transformer (208/208V 1KVA)
Three phase ac parallel RL load Active power	1kw
Three phase ac parallel RL load Reactive power	500KVAR

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