

Comparative Analysis of SVPWM and the Standard PWM Technique for Three Level Diode Clamped Inverter fed Induction Motor

L. Lakhdari, B. Bouchiba, M. Bechar

Abstract—The multi-level inverters present an important novelty in the field of energy control with high voltage and power. The major advantage of all multi-level inverters is the improvement and spectral quality of its generated output signals. In recent years, various pulse width modulation techniques have been developed. From these techniques we have: Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM). This work presents a detailed analysis of the comparative advantage of space vector pulse width modulation (SVPWM) and the standard SPWM technique for Three Level Diode Clamped Inverter fed Induction Motor. The comparison is based on the evaluation of harmonic distortion THD

Keywords—Induction motor, multi-level inverters, NPC inverter, sinusoidal pulse width modulation, space vector pulse width modulation.

I. INTRODUCTION

MULTILEVEL inverters are widely used and marketed in various industrial areas of high voltage and high power. It's possible to increase the power delivered to the load from its topology. Thus, it enables not only the most sinusoidal voltage to be generated but also to improve the harmonic ratio to the high number of voltage levels offered by the structure of this type of converter.

Multi-level inverters are of great interest for the drive applications as they reduce the ratings of solid-state power electronic devices. Reduction in stresses because of voltage changes, better electromagnetic compatibility while operating at high voltages, less harmonic contents in output voltages, lower switching losses and less distortion are the key advantages of these inverters [1], [2].

In high-power applications, the structure of three-level inverters is more suited to the conventional structure because the output voltages and currents exhibit a much lower harmonic content. The voltage at the terminals of each switch is halved and the switching frequency is lower [4]. PWM is well known for multi-level inverters. Its principle is to compare a generally sinusoidal reference voltage to one or more carriers having a triangular shape. The switching times are determined by the intersection points between the carrier and the modulating. The switches of the switching frequency are fixed by the carrier. In three-phase, the three sinusoidal references

are phase-shifted by $2\pi/3$ at the same frequency f [5]. SVPWM are a variation of SPWM that result in different quality and computational requirements, this structure has imposed with the time thanks to the progress in costs and performances achieved by the power switches.

Induction motors are broadly used in industrial applications and the majority of power in the world is currently consumed by them [8], [9]. They are used because of their benefits compared to other types of rotating electrical machines, such as robustness, reliability, and reduced maintenance [8], [9].

The three-phase induction machine drive system fed by SVM inverter is an unbeatable economical solution in rotating industrial applications. However, induction motor control has always been one of the most challenging problems. Due to its high non-linearity, and its coupled friction structure. [10].

An asynchronous machine controlled by a vector controller behaves as a DC machine with separate excitation, in which the torque and flux are decoupled and independently controlled, to obtain a good control accuracy and high dynamic performance [9].

The clamped multilevel inverter is presented in section II, section III shows the control techniques of multilevel inverter, section IV shows the simulation results using matlab Simulink, finally the conclusion drawn in section VII.

II. CLAMPED MULTILEVEL INVERTER

The three-level NPC inverter is shown in Fig. 1. The input DC bus is composed of two capacitors in series (C1 and C2), forming a midpoint marked (0) which allows the inverter to access a supplementary voltage level.

Each of the three arms (a, b and c) of the inverter is composed of four controlled switches (K1, K2, K3 and K4 for arm a) and two holding diodes connected to the DC bus midpoint. The controlled switches are unidirectional in voltage and bidirectional in current there are classic combinations of a transistor and an antiparallel diode [6].

TABLE I
THREE-LEVEL SWITCHING SEQUENCES [7]

Terminal voltages	Switching Sequences			
	K1	K2	K3	K4
+VDC	On	On	Off	Off
0	Off	On	On	Off
-VDC	Off	Off	On	On

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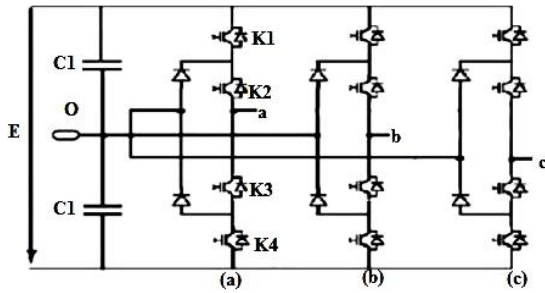


Fig. 1 Three level diode clamped multilevel inverter

III. CONTROL TECHNIQUES OF MULTI-LEVEL INVERTER

A. Sinusoidal Pulse Width Modulation (SPWM)

SPWM is realized by comparing a low frequency modulated wave (reference voltage) with a high carrier wave Frequency of triangular shape [3]. The switching times are determined by the points of intersection between the carrier wave and the modulated wave, the switching frequency of the switches is set by the carrier wave [3]. In three-phase system, the three sinusoidal references are out of phase with $2\pi/3$ to the same frequency f [3].

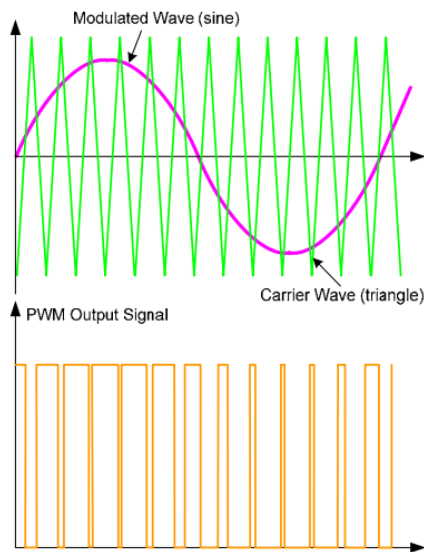


Fig. 2 SPWM Waveform Generation

B. Space Vector Pulse Width Modulation (SVPWM)

For each calculation step, the reference vector consists of three of the nineteen vectors that constitute the vector diagram of the three-level inverter, Fig. 3 Thereby, the waveform of the output voltage obtained is better than those obtained by conventional PWM. This strategy consists of the seven steps shown in Fig. 6 [4].

1. Stationary Space Vectors

1. Zero vector (V_0, V_1, V_2), representing three switching states $[1 \ 1 \ 1]$, $[0 \ 0 \ 0]$ and $[-1 \ -1 \ -1]$. The magnitude of V_0 is Zero.
2. Small vector (V_4 to V_{15}), all having a magnitude of $V_d/3$. Each small sector has two switching states, one containing

$[1]$ and the other containing $[-1]$ and they are classified into P- or N- type small vector.

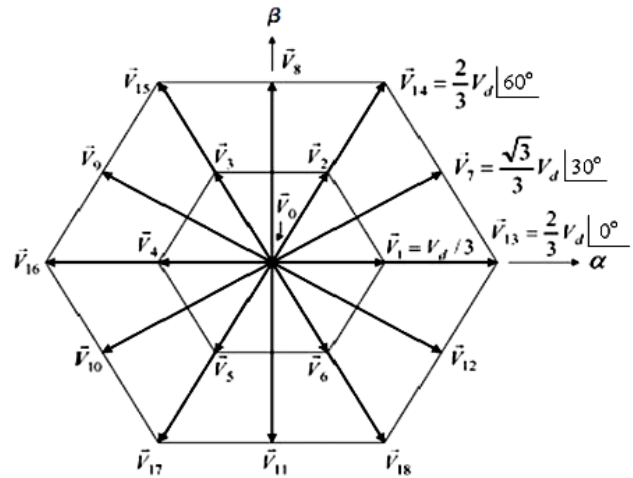


Fig. 3 Space vector diagram of the three-level inverter

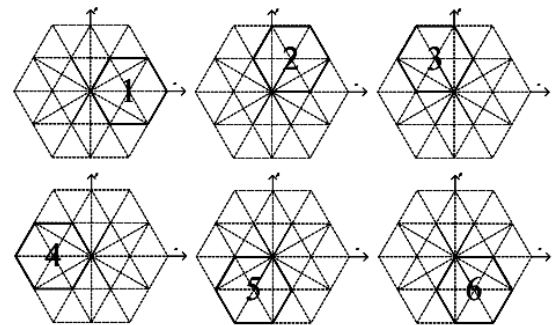
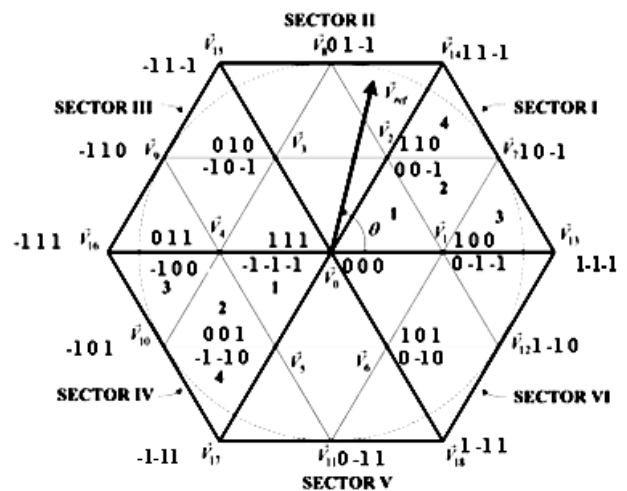


Fig. 4 Main Sectors for 3-Level SVPWM



2. Determining the Sector

θ is calculated and then the sector, in which the command vector V^* is located, is determined as follows:

- If θ is between $0^\circ \leq \theta < 60^\circ$, then V_{ref} will be in sector I
- If θ is between $60^\circ \leq \theta < 120^\circ$, then V_{ref} will be in sector II
- If θ is between $120^\circ \leq \theta < 180^\circ$, then V_{ref} will be in sector III
- If θ is between $180^\circ \leq \theta < 240^\circ$, then V_{ref} will be in sector IV
- If θ is between $240^\circ \leq \theta < 300^\circ$, then V_{ref} will be in sector V
- If θ is between $300^\circ \leq \theta < 360^\circ$, then V_{ref} will be in sector VI

3. Mathematical Modeling of SVPWM

The revolving voltage reference vector is obtained assuming a balanced set of voltages (1):

$$\begin{aligned} V_a &= V_m \sin \omega t \\ V_a &= V_m \sin(\omega t - \frac{2\pi}{3}) \\ V_c &= V_m \sin(\omega t - \frac{4\pi}{3}) \end{aligned} \quad (1)$$

Three phase reference voltages are transformed into diphas α - β components by Clark's transformation (2):

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad (2)$$

$$V_{ref} = \sqrt{(V_\alpha)^2 + (V_\beta)^2}; \theta = \tan^{-1}(\frac{V_\beta}{V_\alpha}) \quad (3)$$

IV. SIMULATION RESULTS

The simulation studies are carried out by the parameters of an asynchronous motor of 5.4 hp, 400v, 50 hz 1430 rmp Fig. 7. The output waveform obtained from the SPWM based NPC inverter with three phase fed induction motor is shown in Fig.

8. Similarly Fig. 9 shows output voltage wave of SVPWM based inverter. Figs 10 and 11 show the Modulating Wave for both SPWM and SVPWM. Figs. 12 and 13 show the speed, the torque and the waveform of stator current of an induction motor in both technics SPWM and SVPWM.

In the SPWM control technics of the inverter the speed curve reach the stable state at 0.22 ms (Fig. 12 (a)), and the torque curve achieve its permanent phase at the second 0.21 ms (Fig. 12 (b)) also the stator current attain the permanent phase at 0.13 ms (fig. 12 (c)). On the contrary, the SVPWM control technics of the inverter the speed curve reach the stable state at 0.19 ms (Fig. 13 (a)) and the torque curve achieve its permanent phase at the second 0.19 ms (Fig. 13 (b)) also the stator current attain the permanent phase at 0.10 ms. (Fig. 13 (c)) Figs. 14 and 15 show the FFT analysis of the induction motor states.

4. Steps of the SVPWM

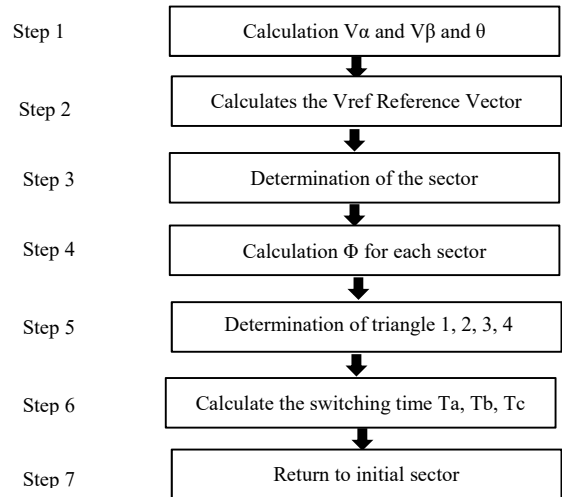


Fig. 6 Steps of the SVPWM

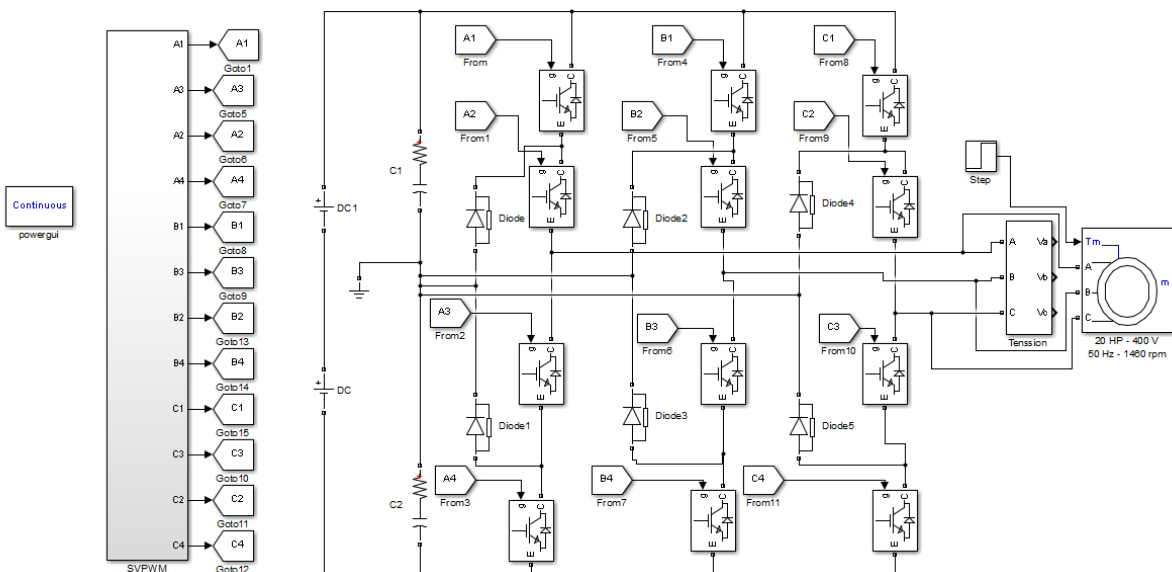


Fig. 7 Simulation block diagram for the whole system

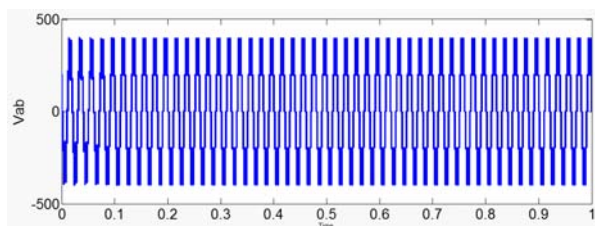


Fig. 8 SPWM waveforms of 3 level inverter voltages fed induction motor

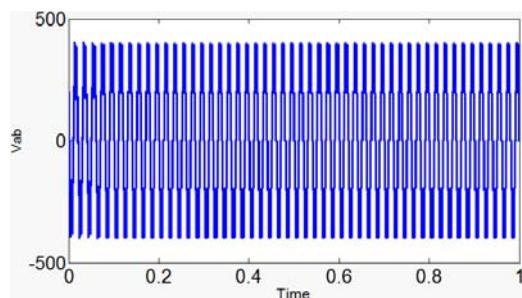


Fig. 9 SVPWM waveforms of 3 level inverter voltages fed induction motor

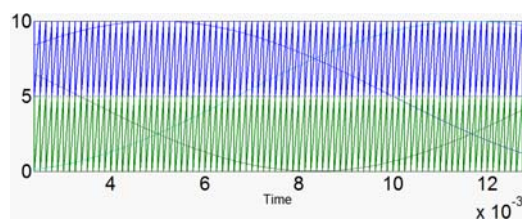


Fig. 10 SPWM Modulating Wave 3 level inverter voltages fed induction motor

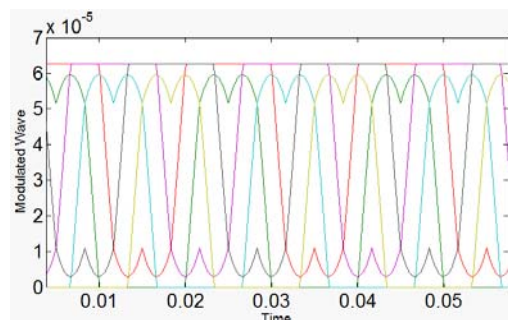
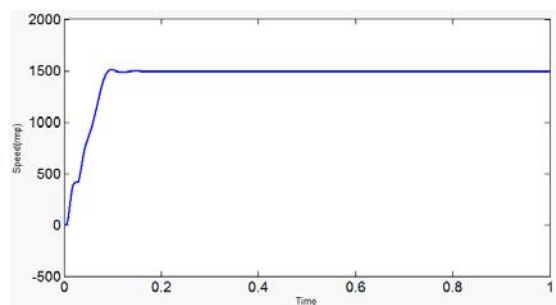
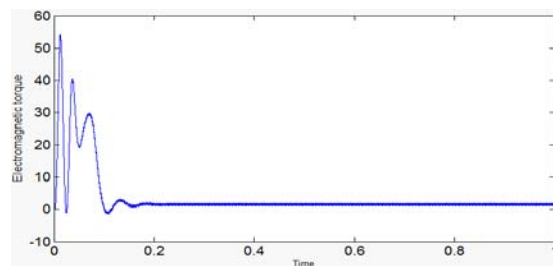


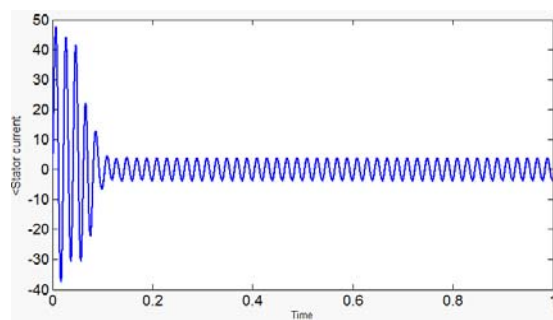
Fig. 11 SVPWM Modulating Wave 3 level inverter voltages fed induction motor



(a)

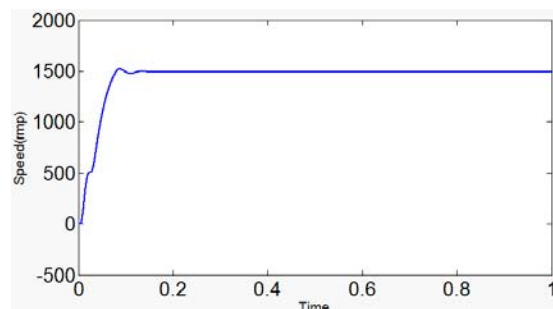


(b)

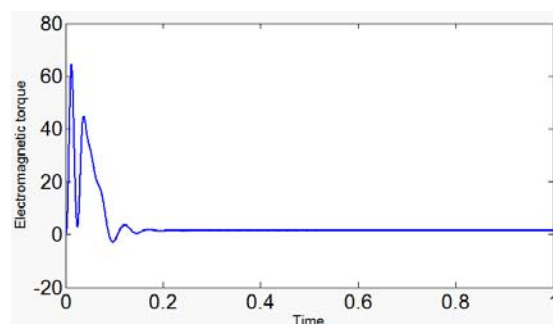


(c)

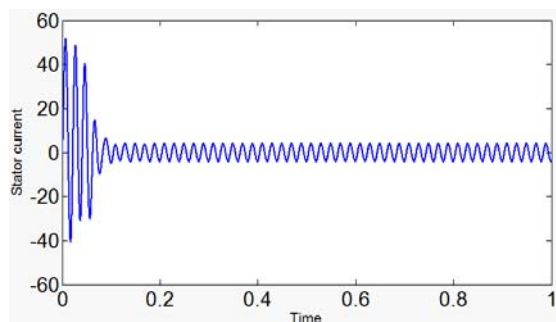
Fig. 12 Simulation output of SPWM based NPC fed induction motor
(a) Speed (b) Torque (c) Stator Current



(a)

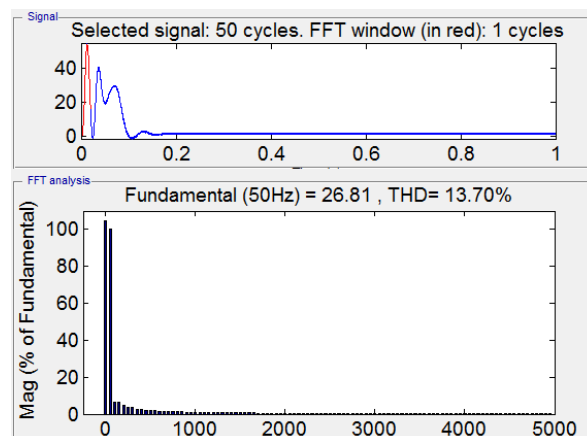


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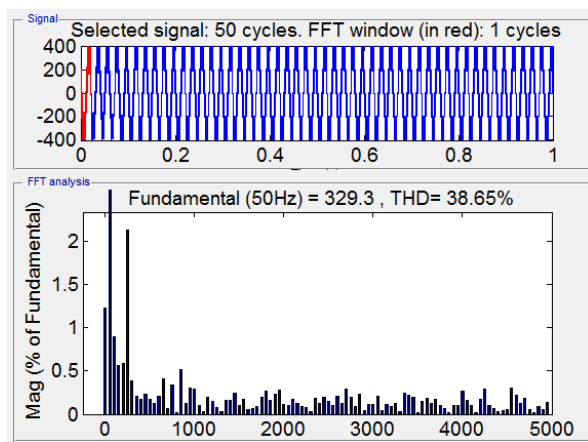


(c)

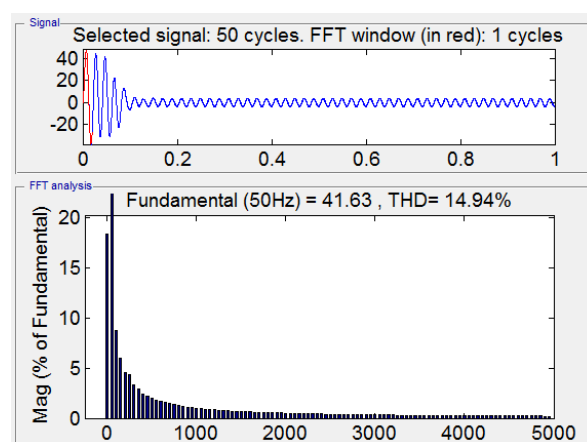
Fig. 13 Simulation output of SVPWM based NPC fed induction motor (a) Speed (b) Torque (c) Stator Current



(c)

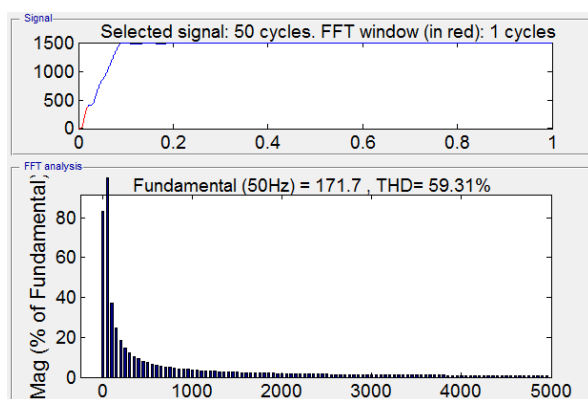


(a)

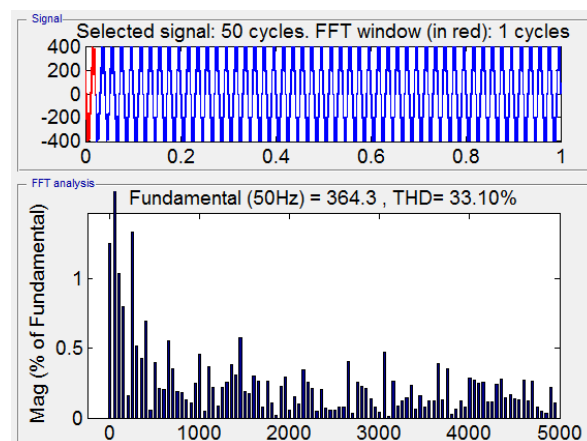


(d)

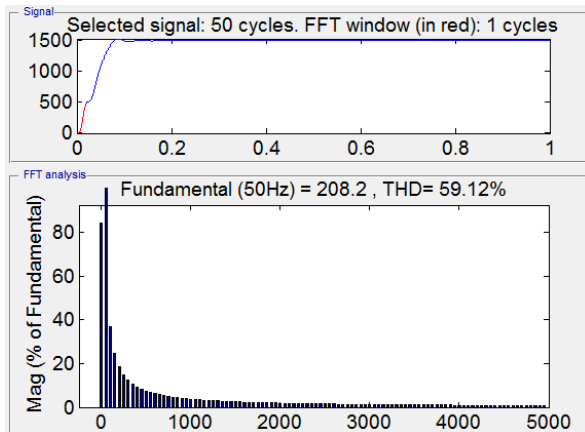
Fig. 14 SPWM Waveform and FFT analysis of (a) Vab, (b) Speed, (c) Torque and (d) Stator Current



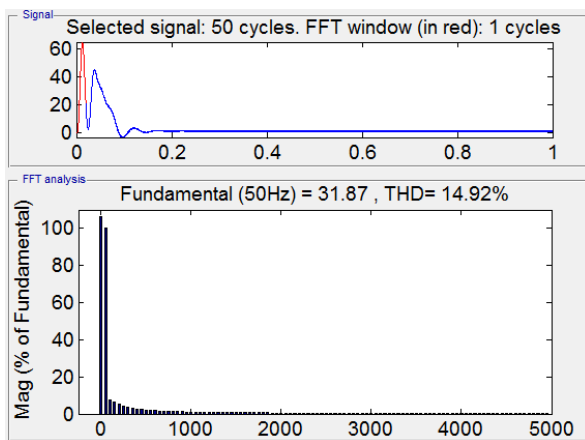
(b)



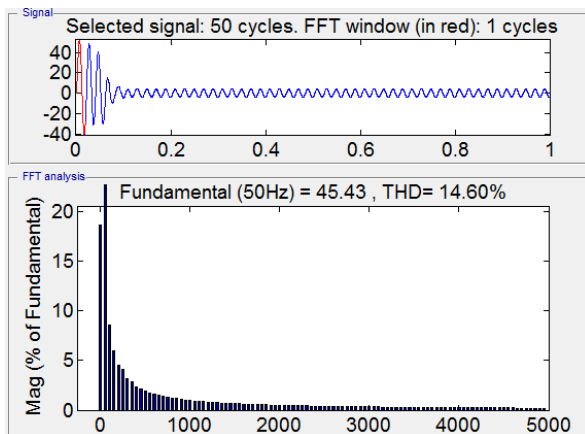
(a)



(b)



(c)



(d)

Fig. 15 SVPWM Waveform and FFT analysis of (a) Vab, (b) Speed, (c) Torque and (d) Stator Current

V. COMPARISON OF SPWM AND SVPWM

In Table II, we summarize the simulation results of SPWM and SVPWM methods.

TABLE II
THD VALUES FOR THE NPC INVERTER WITH THREE PHASE FED INDUCTION MOTOR

Control methods	THD %			
	Vab	Speed	Torque	Stator
SPWM	38.65	59.31	13.70	14.94
SVPWM	33.10	59.12	14.92	14.60

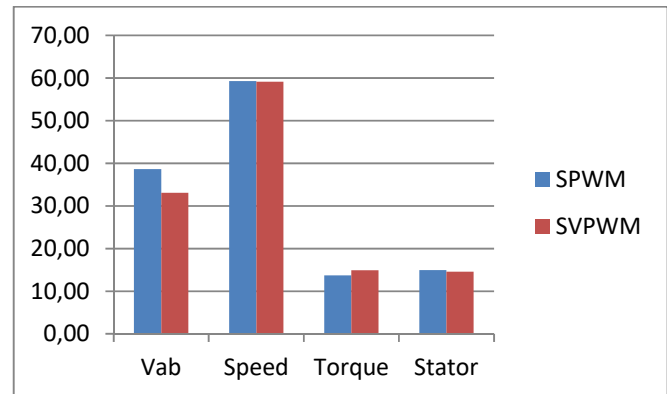


Fig. 16 Total Harmonic Distortion Rate THD (%)

VI. CONCLUSION

SVPWM technique is an important method to generate pulse widths for multi-level inverter. The main advantage is its high performance and simplicity. The analysis results of the SPWM and SVPWM control techniques for multi-level NPC inverter show that the SVPWM technique is more advantageous than the SPWM and produce less total harmonic distortion (THD) percentage.

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