# 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 technics 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 hash 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

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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-I EVEL 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			



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

- Zero vector (V<sub>0</sub>, V<sub>1</sub>, V<sub>2</sub>), representing three switching states [1 1 1], [0 0 0] and [-1 -1 -1]. The magnitude of V<sub>0</sub> is Zero.
- Small vector (V<sub>4</sub> to V<sub>15</sub>), all having a magnitude of Vd/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



Fig. 5 Division of sectors and regions for three-level inverter

- 3. Medium vectors  $(V_{17}, V_{19}, V_{21}, V_{23}, V_{25}, V_{27})$  whose magnitude is  $(\sqrt{3}/3)$ Vd.
- 4. Large vectors  $(V_{16}, V_{18}, V_{20}, V_{22}, V_{24}, V_{26})$  all having a magnitude of (2/3)Vd

2. Determining the Sector

 $\theta$  is calculated and then the sector, in which the command vector V\* is located, is determined as follows:

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

# 3. Mathematical Modeling of SVPWM

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

$$Va = Vm \sin \omega t$$
  

$$Va = Vm \sin(\omega t - \frac{2\pi}{3})$$
 (1)  

$$Vc = Vm \sin(\omega t - \frac{4\pi}{3})$$

Three phase reference voltages are transformed into diphase  $\alpha$ - $\beta$  components by Clark's transformation (2):

$$\begin{bmatrix} V\alpha\\V\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & -1/2 & -1/2\\0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \cdot \begin{bmatrix} Van\\Vbn\\Vcn \end{bmatrix}$$
(2)

$$Vref = \sqrt{(V\alpha)^2 + (V\beta)^2}; \theta = \tan^{-1}(\frac{V\beta}{V\alpha})$$
(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 0.19 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.









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







(c)

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





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









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





(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

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 technics for multi-level NPC inverter show that the SVPWM technic is more advantageous then the SPWM and produce less total harmonic distortion (THD) percentage.

## References

- Y. S Lai and F. S. Shyu, "Topology for hybrid multilevel inverter, IEEE Proceedings of Electric Power Applications", Volume 149, Issue 6, pp. 449-458, 2002.
- [2] N. F. Mailah, S. M. Bashi, I. Aris and N. Mariun, "Neutral-point clamped multilevel inverter using space vector modulation", European Journal of Scientific Research ISSN 1450-216X, Vol. 28, No. 1,pp.82-91, 2009.
- [3] ELOUED university Elearning., "Cours Electronique de puissance avancée", http://elearning.univalguad.dc/courses/JBA01/d-guard.
- eloued.dz/courses/EPA01/document/Cours\_Master2\_ChapitreI.pdf?cidR eq=EPA01, Accessed on 26/04/2017
- [4] T. Abdelkrim, E.M. Berkouk, K. Aliouane, K. Benamrane and T. Benslimane, "Etude et réalisation d'un onduleur à trois niveaux commandé par MLI vectorielle", Revue des Energies Renouvelables, Vol. 14 N°2 (2011) 211 217.
- [5] Baldé, These Présentée À l'université du québec à trois-rivières, comme exigence partielle de la maîtrise en génie électrique, "étude d'un compensateur statique pour éoliennes à vitesse fixe à base de génératrice asynchrone à cage".
- [6] Daniel depernet, these présentée pour l'obtention du grade de docteur de l'université de reims champagne-ardenne, "optimisation de la commande d'un onduleur mli a trois niveaux de tension pour machine asynchrone".
- [7] P. Vanaja, R. Arun Prasaath, P. Ganesh, "Total Harmonic Distortion Analysis and Comparison of Diode Clamped Multilevel Z-Source Inverter", International Journal of Modern Engineering Research (IJMER), Vol.3, Issue.2, March-April. 2013 pp-1000-1005.
- [8] C. Ben Regaya, A. Zaafouri, and A. Chaari, "Electric Drive Control with Rotor Resistance and Rotor Speed Observers Based on Fuzzy Logic," Mathematical Problems in Engineering, vol. 2014, Article ID 207826, 9 pages, 2014. doi:10.1155/2014/207826

# International Journal of Electrical, Electronic and Communication Sciences ISSN: 2517-9438 Vol:12, No:1, 2018

- [9] C. Ben Regaya, A. Zaafouri and A. Chaari, "Speed sensorless indirect field-oriented of induction motor using two type of adaptive observer," 2013 International Conference on Electrical Engineering and Software Applications, Hammamet, 2013, pp. 1-5. doi: 10.1109/ICEESA.2013.6578380.
  [10] E. Fachani, C. Ben Paerum, A. Zaefouri and A. Chaeri, "A queri linear sector of the sector of the
- 10.1109/ICEESA.2013.65/8380.
   [10] F. Farhani, C. Ben Regaya, A. Zaafouri and A. Chaari, "A quasi linear parameter varying approach to robust control of an Induction machine," 10th International Multi-Conferences on Systems, Signals & Devices 2013 (SSD13), Hammamet, 2013, pp. 1-5. doi: 10.1109/SSD.2013.6564053.