

Squirrel Cage Three Phase Asynchronous Machine fed by an NPC Multilevel Inverter

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Abstract— This work focused on the association of a Neutral Point Clamped inverter and a squirrel cage three phase asynchronous motor. In order to improve the asynchronous machine performances (stator current and electromagnetic torque), two techniques are used; the increase of NPC inverter levels and the variation of SPWM switching frequency. In this study the NPC inverter and SPWM strategy are presented. Then a section which gives a brief recall of a squirrel cage three phase asynchronous machine. A comparison between the simulations results based on the THD is made. Simulations are carried out by PSIM program.

Keywords— Modulation index, Sinusoidal Pulse Width Modulation SPWM, Total harmonic distortion THD, the stator current, electromagnetic torque.

I. INTRODUCTION

For several years (approximately 20 years), we are witnessing a renewed interest for the study of multilevel techniques, particularly the multilevel inverters [1].

The evolution of forced switching components (GTO, IGBT) and the improvement of the control techniques have made the level increase of multilevel inverters more achievable.

Through progress in power electronics field that the multilevel inverters are playing a major role in the medium-sized and high power alternating current engine control.

The use of such inverters in industrial equipment was justified by advantages such as harmonic reduction, power factor improvement, filtering reduction, and high efficiency of drive system [2].

The paper starts with a presentation of the Neutral point clamped (NPC) multilevel inverter followed by a recall of the asynchronous machine. Definitions of the triangular multicarrier SPWM control strategy is given on the ensuing section. Finally a discussion of the simulated results is presented.

II. NEUTRAL POINT CLAMPED (NPC) MULTILEVEL INVERTER

The NPC inverter was proposed by Baker [3]. The objective was to reduce the harmonic amplitude injected by the inverter into the load for engine power applications. This inverter makes it possible to have an odd level of voltage. The middle voltage balance is facilitated by this topology. While other sources are reduced to mere capacitors, the total voltage is connected to an active source. This results in a better distribution of energy [4][5]. The direct input voltage distribution on the various series switches is ensured by the diodes (clamped) connected to capacitive middle points.

The number of levels is computed by the following formula:

$N=P-1$ [6];

N: number of voltage levels;

P: number of complementary switches per phase

The figures (1) and (2) represent respectively the structure of one-leg NPC multilevel inverter of 3 and 5 levels.

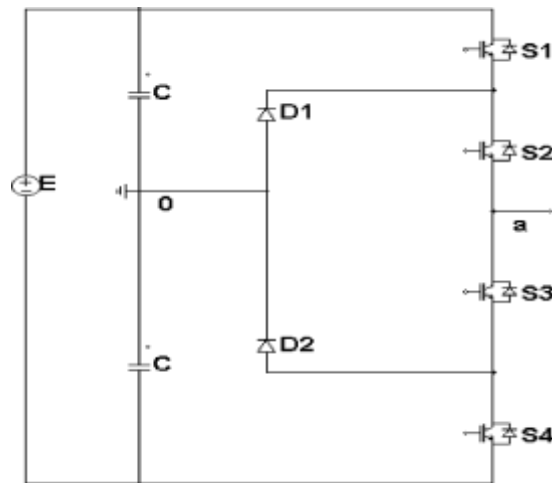


Fig. 1. Power circuit of a one leg NPC three level inverter

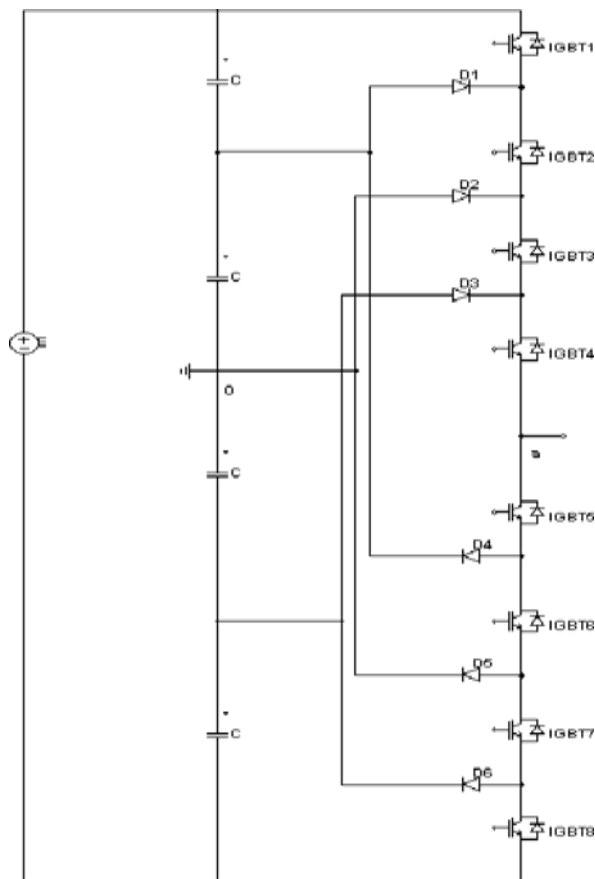


Fig. 2. Power circuit of a one leg NPC five level inverter

In order to generate the most possible sinusoidal wave voltage, various control strategies were conceived for the multilevel inverters. We find primarily selective harmonic elimination SHEPWM [7], the sine pulse width modulation SPWM [8] [9], and the vectorial SVPWM [10].

III. SINE PULSE WIDTH MODULATION SPWM

The Sine Pulse Width Modulation technique is the most used for conventional (two levels) inverter control. It is also the widely used modulation strategy in the multilevel inverters [11][12][13].

It consists to compare a reference wave or modulating signal (generally sine wave) to a carrier that is generally triangular (fig 3). The output signal state changes at each intersection of the modulating and the carrier.

The comparison gives 1 for a carrier greater than or equal to the reference. And it gives 0 for a carrier smaller than the reference.

At the modulator output the sum of results provided from the comparison is then decoded, and gives the corresponding value to each voltage level [14].

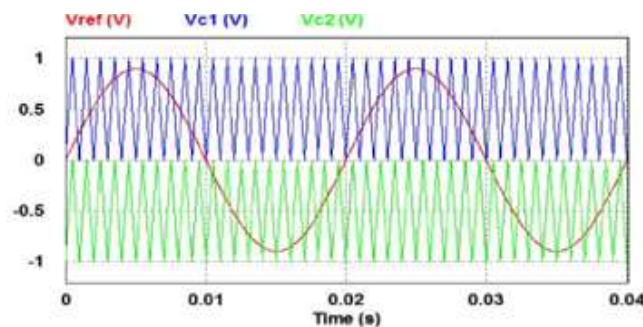


Fig.3. Reference voltage V_{ref} (V) and triangular carriers for three level inverter ($m = 0.9$)

PWM is characterized by two parameters:

$$\text{Modulation index: } m = A_r / ((N - 1) A_c) \quad (1)$$

$$\text{Modulation rate: } r = F_c / F_r \quad (2)$$

A_r : reference signal amplitude

A_c : carrier signal amplitude

F_r : reference signal frequency

F_c : carrier signal frequency

Considering the robustness, the low cost, the performances and its easy care, the asynchronous machine is chosen for the present work.

IV. SQUIRREL CAGE ASYNCHRONOUS MACHINE

The three phase asynchronous motor is widely used in industry. Its simplicity of design makes it very reliable equipment that requires little maintenance. It is constituted of a fixed part, the stator which has a winding, and a rotating part, the squirrel cage rotor. The magnetic circuits of both rotor and stator are made up of a stacking of thin metallic sheets to avoid Foucault current flow.

Due to these qualities, the three phase asynchronous motor is chosen for this study.

The parameters of this engine are given in appendix.

V. SIMULATION RESULTS

To test the efficiency of the increase of the level number of the NPC multilevel inverter and the switching frequency of the SPWM, a comparative study based on the THD of the stator current I_{sa} (A) is made.

The Squirrel cage asynchronous machine fed by a conventional inverter (two levels), NPC three level inverter and NPC five level inverter. Simulations with different commutation frequencies are carried out by PSIM program.

In order to get the THD level of the waveform, a Fast Fourier Transform (FFT) of PSIM program is applied to obtain the spectrum of the stator current I_{sa} (A) for different switching frequencies.

A. Squirrel cage asynchronous machine fed by a conventional inverter (two levels)

Fig.4, fig.5, fig. 6. and fig.7. show the stator current I_{sa} (A), the electromagnetic torque T_{em} (N.m), the stator current I_{sa} (A) and T_{em} (N.m) in steady state respectively for the Squirrel cage asynchronous machine fed by a conventional inverter SPWM with $m=0.9$ and $F_c=2$ kHz.

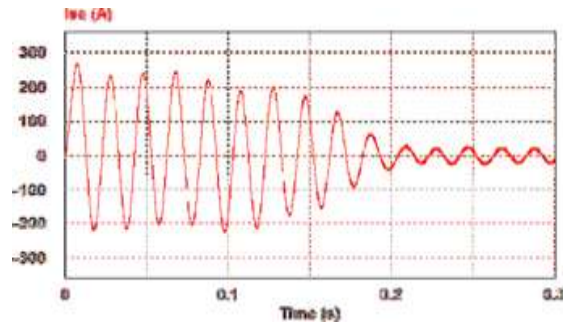


Fig.4. Waveform of the stator current I_{sa}

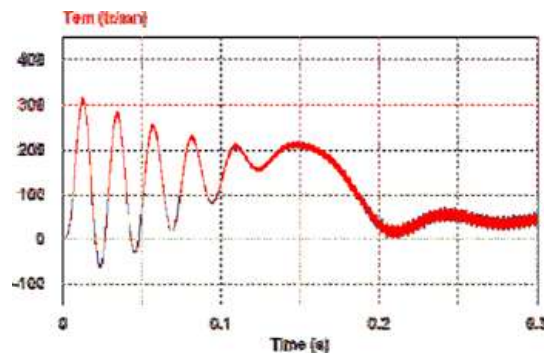


Fig.5. Asynchronous machine electromagnetic torque

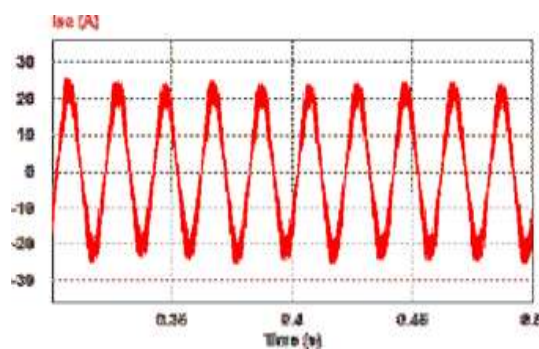


Fig.6. Waveform of the stator current I_{sa} (A) in steady state

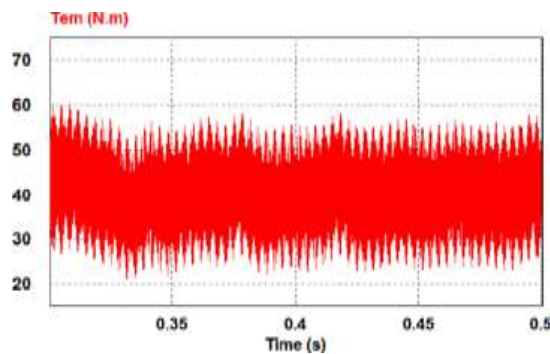


Fig.7. Asynchronous machine electromagnetic torque in steady state

B. Squirrel cage asynchronous machine fed by an NPC three level inverter

Fig.8, fig.9 and fig.10 show the stator current I_{sa} (A), its harmonic spectra and the electromagnetic torque T_{em} (N.m) in steady state respectively for the squirrel cage asynchronous machine fed by a NPC three level inverter SPWM controlled with $m=0.9$ and $F_c=2\text{kHz}$.

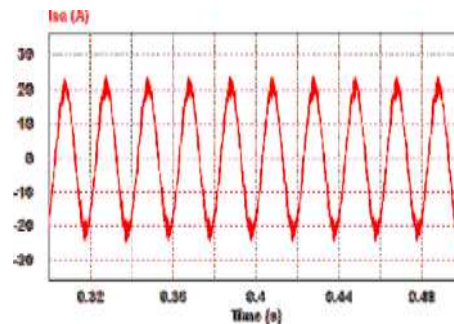


Fig.8. Waveform of the stator current I_{sa} (A) in steady state

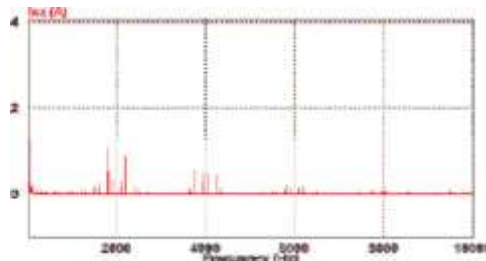


Fig. 9. FFT analysis of the stator current I_{sa} (A) in steady state

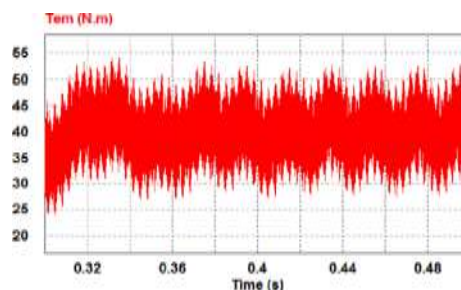


Fig.10. Asynchronous machine electromagnetic torque in steady state

Fig.11, fig.12 and fig.13 show the stator current $I_{sa}(A)$, its harmonic spectra and the electromagnetic torque T_{em} (N.m) in steady state respectively for the squirrel cage asynchronous machine fed by a NPC three level inverter SPWM controlled with $m=0.9$ and $F_c=10\text{ kHz}$.

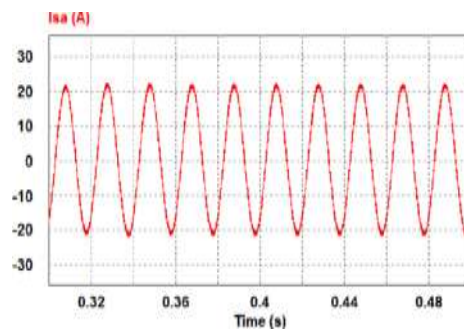


Fig.11. Waveform of the stator current $I_{s\alpha}$ (A) in steady state

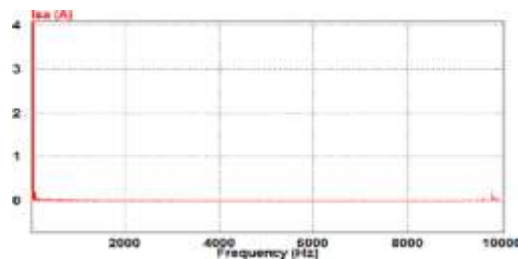


Fig.12. FFT analysis of the stator current $I_{s\alpha}$ (A) in steady state

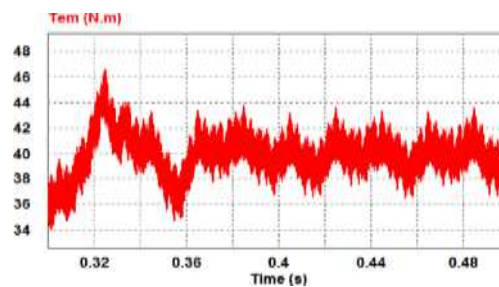


Fig.13. Asynchronous machine electromagnetic torque in steady state

Table.1 shows the total harmonic distortion THD and the fundamental of the stator current $I_{s\alpha}$ (A), for the NPC three level inverter with SPWM modulation technique with a switching frequency of 2 kHz and 10kHz for a modulation index of 0.9

Table 1: THD and fundamental of stator current $I_{s\alpha}$ (A) for 3 level NPC inverter

Switching frequency (Khz)	THD (%)	Fondamental (A)
2	9.80	20.22
10	2.81	20.92

C. Squirrel cage asynchronous machine fed by an NPC five level inverter

Fig.14, fig.15 and fig.16 show the stator current $I_{s\alpha}$ (A), its harmonic spectra and the electromagnetic torque T_{em} (N.m) in steady state respectively for the squirrel cage asynchronous machine fed by a NPC five level inverter SPWM controlled with $m=0.9$ and $F_c=2$ kHz.

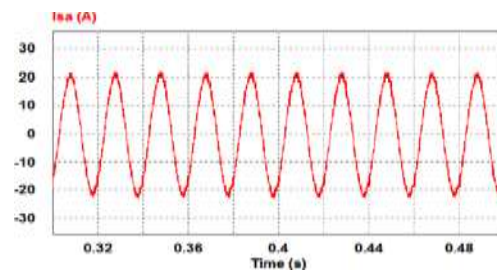


Fig.14. Waveform of the stator current I_{sa} (A) in steady state

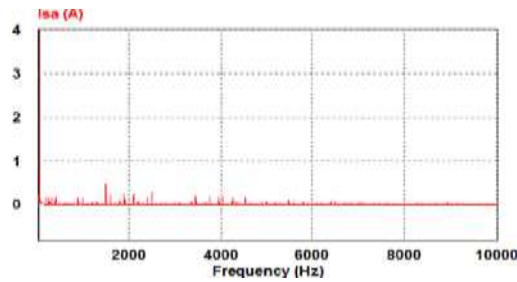


Fig. 15. FFT analysis of the stator current I_{sa} (A) in steady state

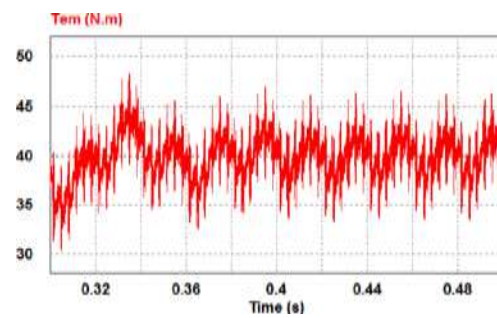


Fig.16. Asynchronous machine electromagnetic torque in steady state

Fig.17, fig.18 and fig.19 show the stator current I_{sa} (A), its harmonic spectra and the electromagnetic torque T_{em} (N.m) in steady state respectively for the squirrel cage asynchronous machine fed by a NPC five level inverter SPWM controlled with $m=0.9$ and $F_c=10$ kHz.

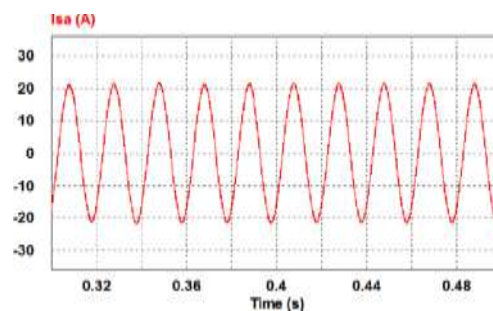


Fig.17. Waveform of the stator current I_{sa} (A) in steady state

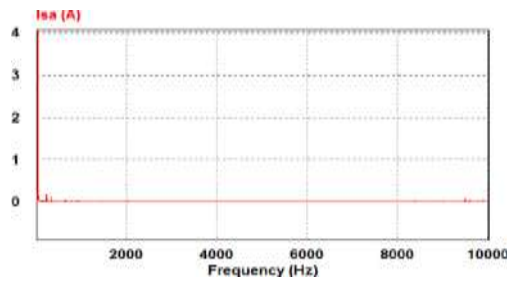


Fig. 18. FFT analysis of the stator current I_{sa} (A) in steady state

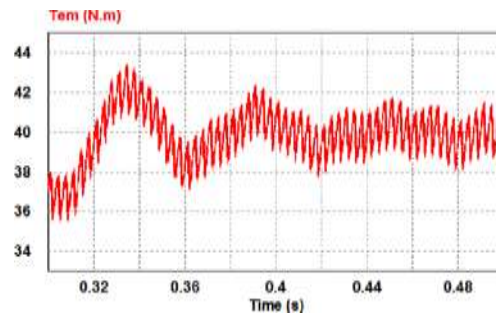


Fig.19. Asynchronous machine electromagnetic torque in steady state

Table.2 shows the total harmonic distortion THD and the fundamental of stator current I_{sa} (A), for the NPC five level inverter with SPWM modulation technique with a switching frequency of 2 kHz and 10 kHz for a modulation index of 0.9.

Table 2: THD and fundamental of stator current I_{sa} (A) for 5 level NPC inverter.

Switching frequency khz	THD (%)	Fondamental (A)
2	5.93	21.01
10	1.38	21.16

VI. ANALYSIS OF THE RESULTS

The table below collects the THD obtained results for the conventional inverter, the NPC three level and NPC five level inverters.

Table 3: THD obtained results

Switching frequency (khz)	2 level NPC inverter	3 level NPC inverter	5 level NPC inverter
2	5.85	9.80	
10	-	1.38	1.38

According to the tables above, it is noticed that the increase of NPC inverter levels produces a reduction in THD. The change of switching frequency of the SPWM from 2 kHz to 10 kHz leads to a considerable reduction of the THD.

The THD of the NPC three level for a switching frequency $f_c=10$ kHz is better than the THD of the NPC five level for a switching frequency $f_c=2$ kHz.

The THD of NPC five levels for a switching frequency $F_c=10$ kHz is better than the THD of NPC three levels for a switching frequency $F_c=10$ kHz, except that the THD difference is not as big as the one where the switching frequency is equal to 2 kHz. Moreover, the level increase of NPC inverter and the switching frequency change have an effect on the squirrel cage asynchronous motor performances:

- An electromagnetic torque of better quality;
- Reduction of the transitory.
- Improvement of the fundamental value.

VII. CONCLUSION

In this paper, an association of a Neutral Point Clamped inverter and a squirrel cage three phase asynchronous motor is implemented in PSIM environment for a modulation index of 0.9 and for a switching frequency of 2 kHz and 10 kHz.

Total harmonic distortions THD are measured, regrouped and analyzed.

It is found that the NPC five level inverter has better THD than the NPC three level inverter for both switching frequencies (2 kHz and 10 kHz). Except that for the switching frequency of 10 kHz, the NPC three and five level inverters have an enhanced THD.

Thus, it is noticed that to obtain good quality performances, the increase of NPC inverter levels is not necessary. We need to simply increase the switching frequency of SPWM control. Very interesting cost saving pane.

Appendix:

Asynchronous machine parameters:

Stator resistance: $R_s = 0.294 \text{ Ohm}$

Rotor resistance: $R_r = 0.156 \text{ Ohm}$

Stator inductance: $L_s = 1.39 \text{ mH}$

Rotor inductance: $L_r = 0.74 \text{ mH}$

Mutual inductance: $L_m = 41 \text{ mH}$

Number of poles: $P = 6$

Inertia moment: $J = 0.2 \text{ Kg}m^2$

Load torque: $C_r = 40 \text{ Nm}$

REFERENCES

- [1] Y. Sahali et M.K. Fellah - Principe de la compensation harmonique des ondes multiniveaux, Conférence on electrical engineering, Batna, ALGERIA, 10-11 dec, 2002
- [2] Y. Djeriri, A. Meroufel, B. Belabbes and A. Missoum - Three level NPC voltage source converter based direct power control of the doubly fed induction generator at low constant switching frequency, Revue des énergies renouvelables, Vol. 16, n°1, 2013, pg. 91-103
- [3] F. Hadj Benali, F. Azzouz- Comparison of Instantaneous Reactive and Notch Filter Algorithms Seven Level Parallel Active Filter, IJECE journal, Vol. 7, n°3, Aug, 2017, pg. 1779-1788
- [4] Sagar U. Shinde, Mithun Aush, Dr. K. Vadirajacharya- Performance analysis of VLSI based multilevel inverter, International conference on innovations in engineering and technology (ICIET'14), College of engineering, Madurai, Tamil Nadu, India, March 21-22, 2014
- [5] F. Hadj Benali, F. Azzouz - Comparison of various levels of parallel multilevel active filter using NPC multilevel inverter, IJAAS journal, Vol. 5, n°1, March, 2016, pg. 21-23
- [6] J. Willey and sons - Handbook of power quality, Edited by Angelo Baggingi, university of Bergamo, Italy, 2008
- [7] P. N. Enjety, J. F. Lindsay - nonlinear equations of harmonic elimination PWM in power control, IEEE transactions on industry applications, Vol. 23, n°12, June, 1987, pg. 656-657
- [8] S. Mariethoz - Etude formelle pour la synthèse de convertisseurs multiniveaux asymétriques, topologies, modulation et commande, Ecole polytechnique de Lausanne, EPFL, Suisse, Thèse n°3188, 2005
- [9] B. P. Mc Grathn D.G. Holmes - Multicarrier PWM strategies of multilevel inverters IEEE transactions on power electronics, Vol 49, n°4, Aug, 2002, pg. 858-867
- [10] P. Satich Kumar, T. Abhiram, J. Armanathn S. V. L. Narasimham - Space vector pulse width modulation for multilevel inverter using decomposition method, Journal of electrical engineering, Theory and application, Vol. 1, 2010, pg. 60-68
- [11] M. R. Baiju, K. Gopakumar, K. K. Mohapatran V. T. Somasekhar, L. Umanand - A high resolution multilevel voltage space phasor generation for an open winding induction motor drive, European power electronics and drive journal, Vol. 13, n°4, 2003, pg. 29-37
- [12] S. Bernet, T. Bruckner, P. Stiemer - Three point converter and method for its operation, U.S. Patent number 06.219.265, assigned to ABB research limited, Apr, 2001

- [13] F. Hadj Benali, F. Azzouz - The operating improvement of the supply source and the optimization of PWM control, JPEDS journal, Vol. 6, n°3, Sept, 2015, pg. 603-614
- [14] J. S. Manguelle, Convertisseurs multiniveaux asymétriques alimentés par transformateurs multi-secondaires basse fréquence: Réactions au réseau d'alimentation, Ecole polytechnique fédérale de Lausanne, Suisse, Thèse n°3033, 2004