European Journal of Scientific Research
ISSN 1450-216X Vol.32 No.1 (2009), pp.78-88

http://www.eurojournals.com/ejsr.htm

A Study of New Techniques of Controlled PWM Inverters

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Abstract

The studies of the sets converters machine in general use in an implicit way the concept of reference frame machine and reference frame inverter. Indeed, the policies of the most traditional control consider that these two points are with the same potential. In fact, it is not necessary to define the voltages in two different reference frames.

On the other hand for the new technique of pulse width modulation PWM (injection of harmonic, vectorial modulation) the points of reference are not with the same potential. The current tendency is to use these new types of modulation in order to increase the output voltages of the inverter for the same continuous voltage of supply.

The results obtained show the superiority of controlled SVPWM and THIPWM compared to SPWM in the drive at adjustable speed.

Keywords: Inverters, harmonics, THIPWM, SPWM and SVPWM technique,

1. Introduction

The waves delivered by the inverters with controlled full wave or shifted order are rich in harmonics. To attenuate these harmonics we can place at the output of the inverter a filter. The filtering of the voltage or the output current of an inverter delivering square voltage or current by alternation is difficult and expensive, because the first harmonic to be eliminated (harmonic 3 or 5) at a frequency very close to that to the fundamental one.

The pulse width modulation is proven to be the technique most adapted for the controlled inverter while having a good neutralization of the output wave.

2. Characteristic of the Pulse Width Modulation (PWM)

The essential parameters of the MLI are:

- The index of modulation is:

$$m = \frac{f_p}{f_r}$$

Where:

f_r is the frequency of the reference.

f_p is the frequency of the carrying wave.

The control factor in voltage is:

$$r = \frac{A_r}{A_p} \tag{1}$$

Where:

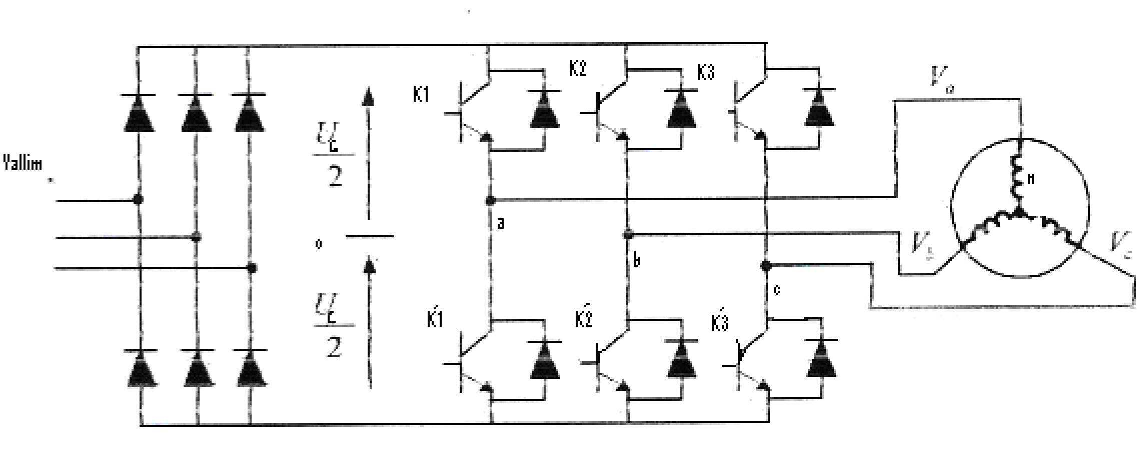
A_r : Amplitude of the reference.

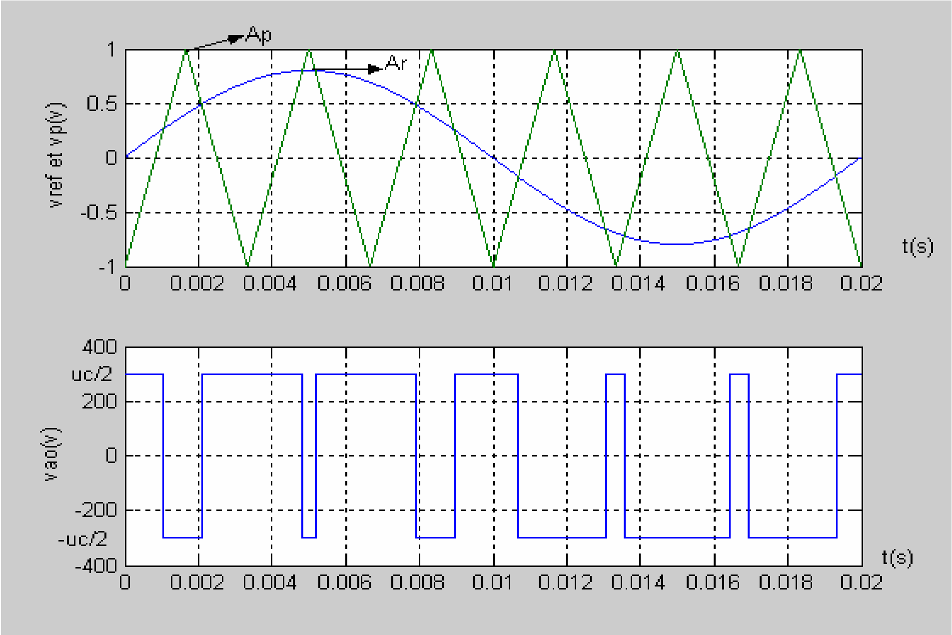
A_p : Amplitude of the carrying wave

Sinusoidal Modulation with Bidirectional Carrying Wave

This method uses the general principle of the controlled PWM which consists in directly comparing the signal of carrying waves with the sinusoidal reference.

Figure 1: Three phase voltage inverter - Sinusoidal modulation with bidirectional carrying wave





Reference Signals

They are sinusoidal signals shifted between them of 120° and are characterized by the amplitude *Ar* and its frequency *f*:

$$V_{ref\,a} = A_r \sin(2\pi.f..t)$$
$$v_{ref\,b} = A_r \sin(2\pi.f..t - \frac{2\pi}{3}) \qquad (2)$$
$$V_{refc} = A_r \sin(2\pi.f.t - \frac{4\pi}{3})$$

The Carrying Wave

The carrying triangular wave is characterized by the amplitude *Ap* and the frequency fp $f_p = \frac{1}{T_p}$

The intersections between the reference voltage standards and the carrying wave give the time of opening and closing of the switches.

3. Space Vector Pulse Width Modulation (SVPWM)

The vectorial PWM is the method recently best adapted to control of the asynchronous motors. Contrary to other methods, the vectorial PWM is not based on separate calculations of the modulations for each arm of the inverter.

This technique of PWM follows the following principles [1] [6] [7] [10]:

- A vector voltage of control $\overrightarrow{V_{ref}}$ is calculated overall is approximated over one period of modulation “Tm” by a voltage means.
- For each phase realization of a pulse of width T centred over the period whose average value is equal to the reference voltage standard to the time of sampling.
- All the switches of the same half bridge have a state identical to the center and the two ends of the period.

3.1. Clarcke Transformation

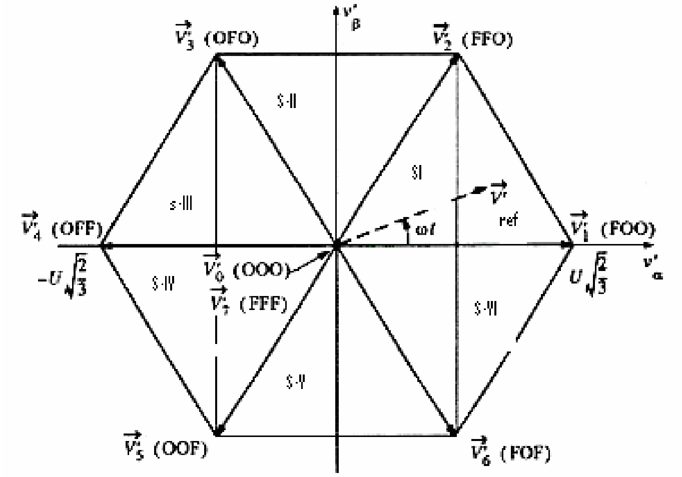
To simplify calculations in the vectorial modulation one used the transformation of clarcke **[4] [7]**, the latter enables us to replace the three-phase system of three V' voltage has, V' B, V' C of null sum by a diphase system respecting the transfer of power.

$$\begin{bmatrix} V_\alpha \\ V_B \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V'_a \\ V'_b \\ V'_c \end{bmatrix} \qquad (3)$$

Possible configurations

If we regards the components V_α and V_B as projection on two axes perpendicular of a vector $\overrightarrow{V_{ref}}$, this vector is enough to characterize the three-phase system (Figure .2) **[3] [4]**.

Figure 2: Representation of the commutation polygon



The states of closing or opening switches K1, K2, K3 (the switches K'1, K'2, K'3 are complementary) give to the three-phase inverter eight possible configurations (figure 2.), six non null indicated by $\overrightarrow{V'_1},\overrightarrow{V'_2},\overrightarrow{V'_3},\overrightarrow{V'_4},\overrightarrow{V_5},\overrightarrow{V'_6}$ and two null vectors $\overrightarrow{V'_0},et\overrightarrow{V'_7}$ **[6]** (beside each vector, it is indicated the closed state (F) or opened state(0) of the three switches (K1, K2, K3). The six vector have the same module equalizes with $u.\sqrt{\frac{2}{3}}$, the ends of these six vectors define the tops of a regular hexagon (figure 2), since between two vectors we have an angle $\alpha = \frac{\pi}{3}$.

3.2: Definition of the vector voltage of desired control (vector of reference)

The desired vector reference voltage standard can be defined in the three-phase plan by: [1] [10].

$$\begin{aligned} V_{aref} &= r.\frac{u_c}{2}.\cos(wt) \\ V_{bref} &= r.\frac{u_c}{2}.\cos(wt-\frac{2\pi}{3}) \\ V_{cref} &= r.\frac{u_c}{2}\cos(wt-\frac{4\pi}{3}) \end{aligned} \tag{4}$$

And components of clarcke by:

$$\begin{aligned} V_{\alpha ref} &= r.\frac{\sqrt{3}}{2}.\frac{u_c}{2}\cos(wt) \\ V_{Bref} &= r.\frac{\sqrt{3}}{2}.\frac{u_c}{2}.\sin(wt) \end{aligned} \tag{5}$$

The relations giving the periods of validity of the vectors are
Written then for a period **[1]**.

$$T_i = \frac{\sqrt{3}}{2}.r.T_m.\sin(i.\frac{\pi}{3}-wt) \tag{6}$$

$$T_{i+1} = \frac{\sqrt{3}}{2}.r.T_m.\sin(wt-(i-1)\frac{\pi}{3}) \tag{7}$$

$$T_0 = \frac{T_m}{2} - (T_i + T_{i+1})$$
$$i = 1,2,3,4,,5,6. \tag{8}$$

With:

T_i, T_{i+1}: Periods of validity of the adjacent vectors respectively $\overrightarrow{V_i}$ and $\overrightarrow{V_{i+1}}$.

To: period of validity of the vector null $\overrightarrow{V_0}$ or $\overrightarrow{V_7}$

It average vector of the vector $\overrightarrow{V_{ref}}$ can be written **[1]**.

$$\overrightarrow{V_{ref}} = \frac{1}{T_m}\left[T_i.\overrightarrow{V_i} + T_{i+1}.\overrightarrow{V_{i+1}}\right] \tag{9}$$

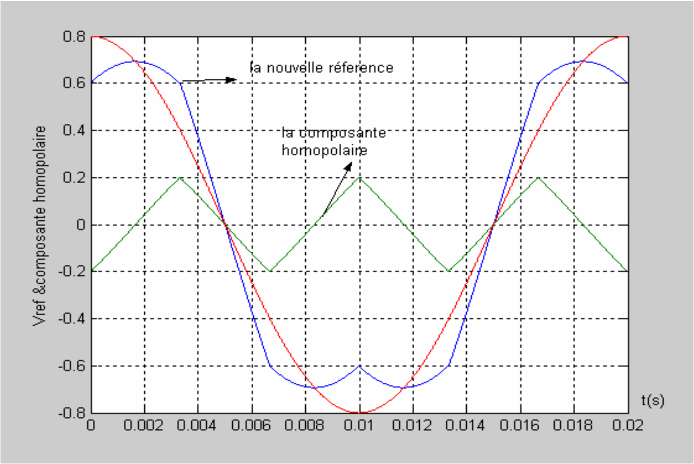
$\overrightarrow{V_i}$ $\overrightarrow{V_{i+1}}$: are the two vectors of state which delimit the sector

(I) plan of the voltage or is located $\overrightarrow{V_{ref}}$ (figure 2).

The reference voltage standards are reconstituted and carry out of it a temporal average of the states of the utilization periods of the vectors and $\overrightarrow{V_i}$ and $\overrightarrow{V_{ref}}$ the null vector.

The space of modulating and the homopolar component are given by the figure 3.

Figure 3: Modulating space and the homopolar component



The control factor in voltage r can arrive until: r=1, 155 [1].

4. Third Harmonic Injection Pulse Width Modulation (THIPWM)

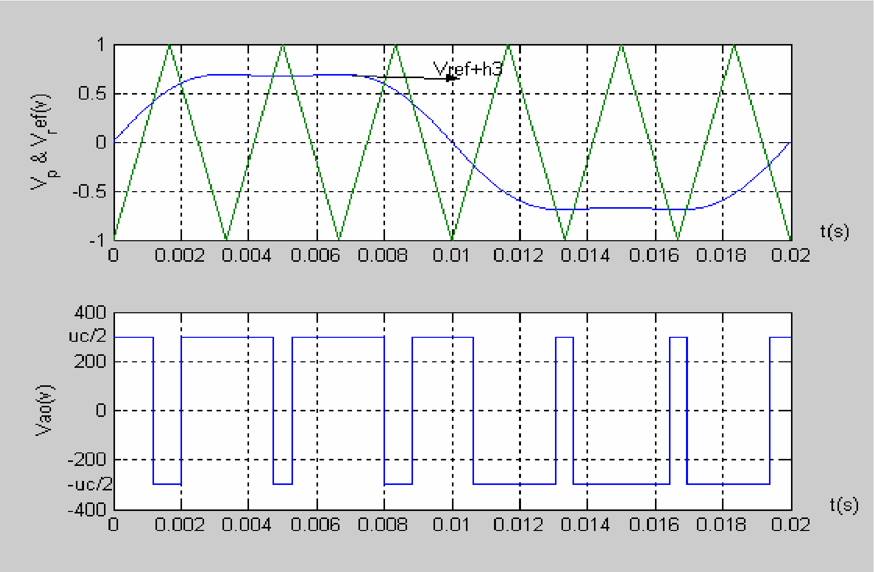
In three phases current, we can improve the performances of the modulation by using this technique which consists in adding a third harmonic to the sinusoid of frequency “f” to form the wave of reference [4].

$$\begin{aligned}
V_{ref_a}(t) &= \frac{uc}{2}(r.\sin(\omega t) + a.\sin(3.\omega t)) \\
v_{ref_b}(t) &= \frac{uc}{2}(r.\sin(\omega t - \frac{2\pi}{3}) + a.\sin 3.(\omega t - \frac{2\pi}{3})) \\
V_{refc}(t) &= \frac{uc}{2}(r.\sin(\omega t - \frac{4\pi}{3}) + a.\sin 3.(\omega t - \frac{4\pi}{3}))
\end{aligned} \tag{10}$$

Let E=a. sin 3ωt, E: coefficient of eccentricity **[3] [5]**.

The addition of harmonic makes it possible to increase the maximum amplitude of fundamental in the reference, and in the output voltages **[4]**.

Figure 4: MLI with the injection of the third harmonic



5. Simulation and Results

The simulation of different techniques is carried out using Simulink Matlab program.

5.1. Simulation of Space Pulse Width Modulation SPWM technique

Fig. 5 and 7 show the waveforms of the three phase system with the carrying wave and the output voltage of phase A with different m and r.

The spectrum of the output voltage of phase A is shown in Fig. 6 and 8, obtained by using Fast Fourier Transform algorithm (FFT)

Figure 5: Forms of waves of SPWM technique for m=15 and r= 0.8

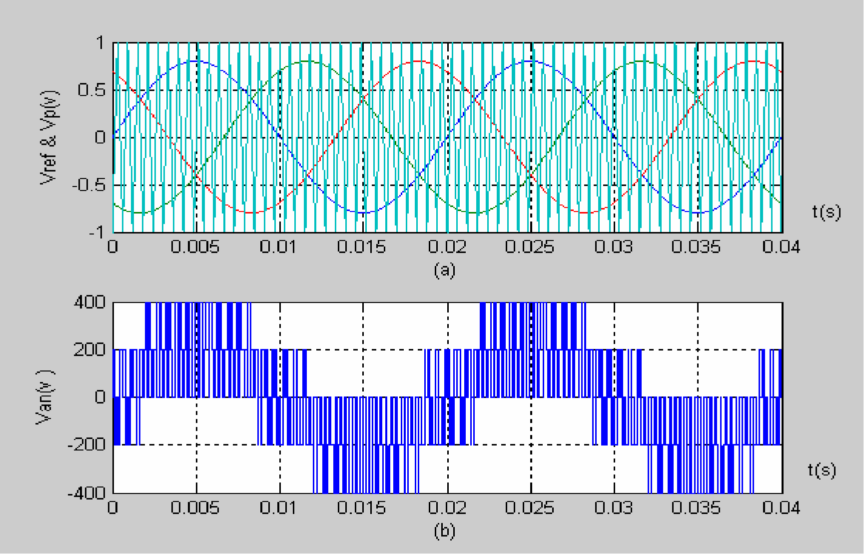


Figure 6: harmonic spectrum of voltage (SPWM) for m=15 and r= 0.8

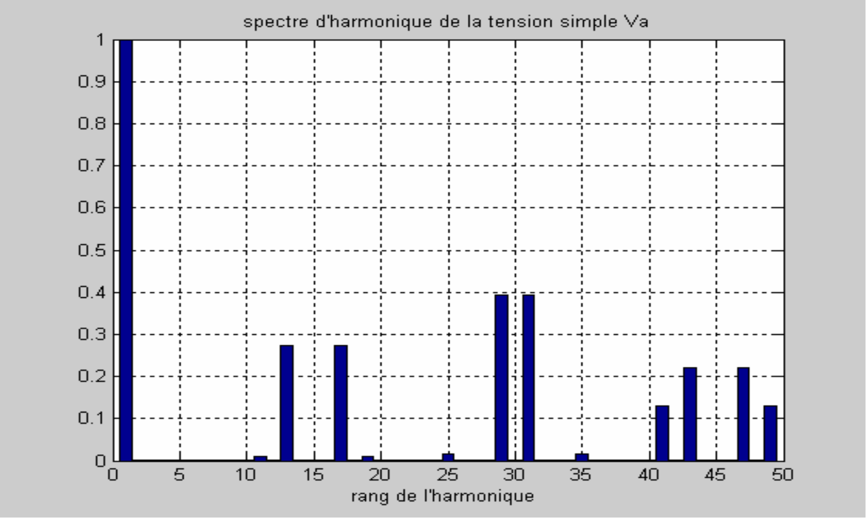


Figure 7: Waves forms of SPWM technique for m=33 and r = 0.8

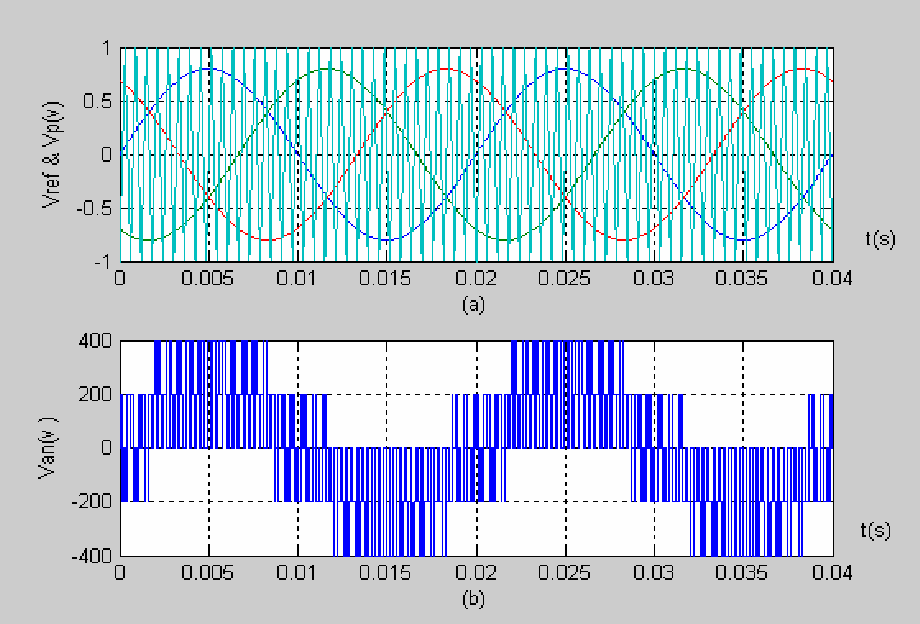
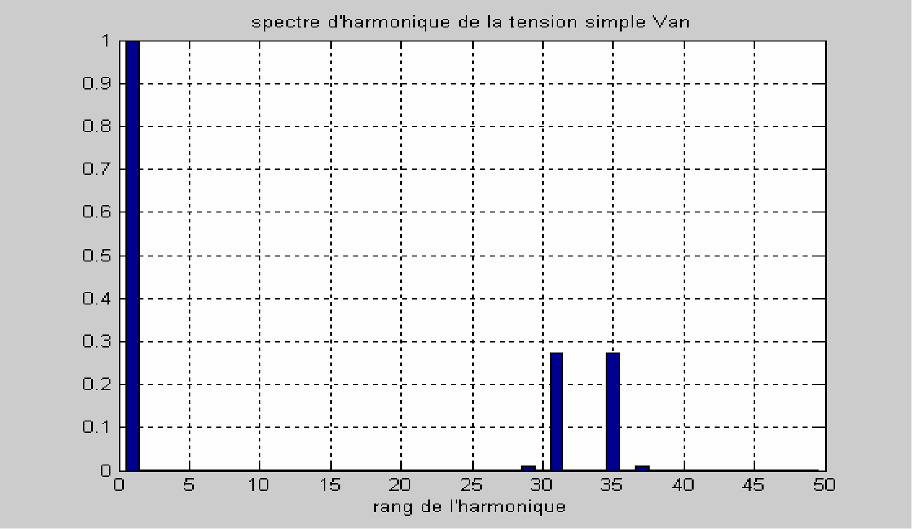


Figure 8: harmonic spectrum of the voltage (SPWM) for: m=33 and r= 0.8



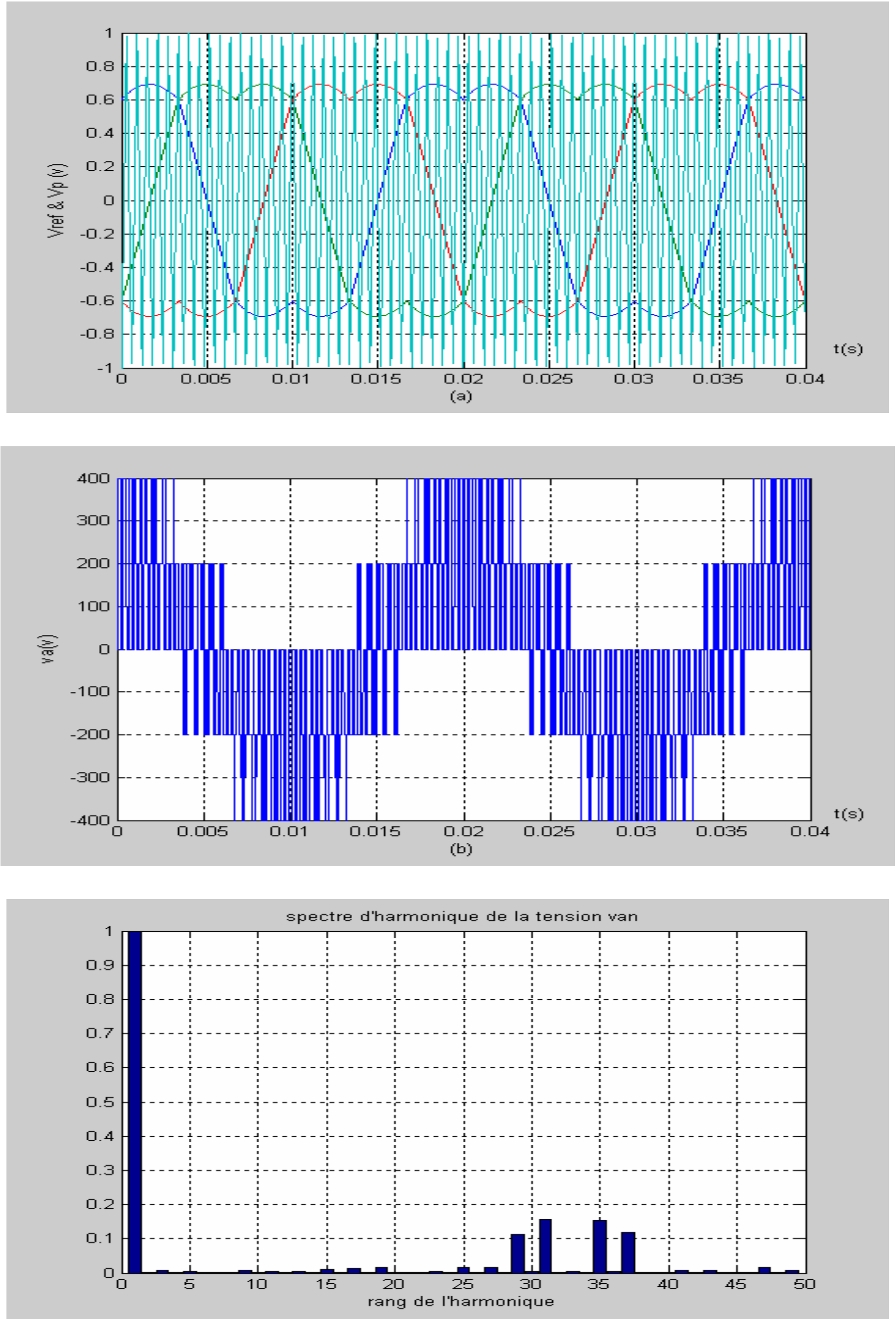
It can be seen from the simulation results that:

- it possible to vary the value of fundamental of the output voltage using the SPWM.
- the harmonic of row 3 or multiple of 3 are removed in the output voltage.
- the increase in the index of modulation “m” rejects the first harmonics non null worms of the higher frequencies, and thus facilitates filtering.
- appearance of the voltage waste (d=21,46%).

5.2. Simulation of Space Vectorial Pulse Width Modulation SVPWM technique

The simulation results of the SVPWM technique are shown in figure 9.

Figure 9: Waves forms of SVPWM technique for m=33 and r=0.8 a) reference voltage standards and carrying wave b) wave forms of voltage Van c) harmonic spectrum of the voltage Van



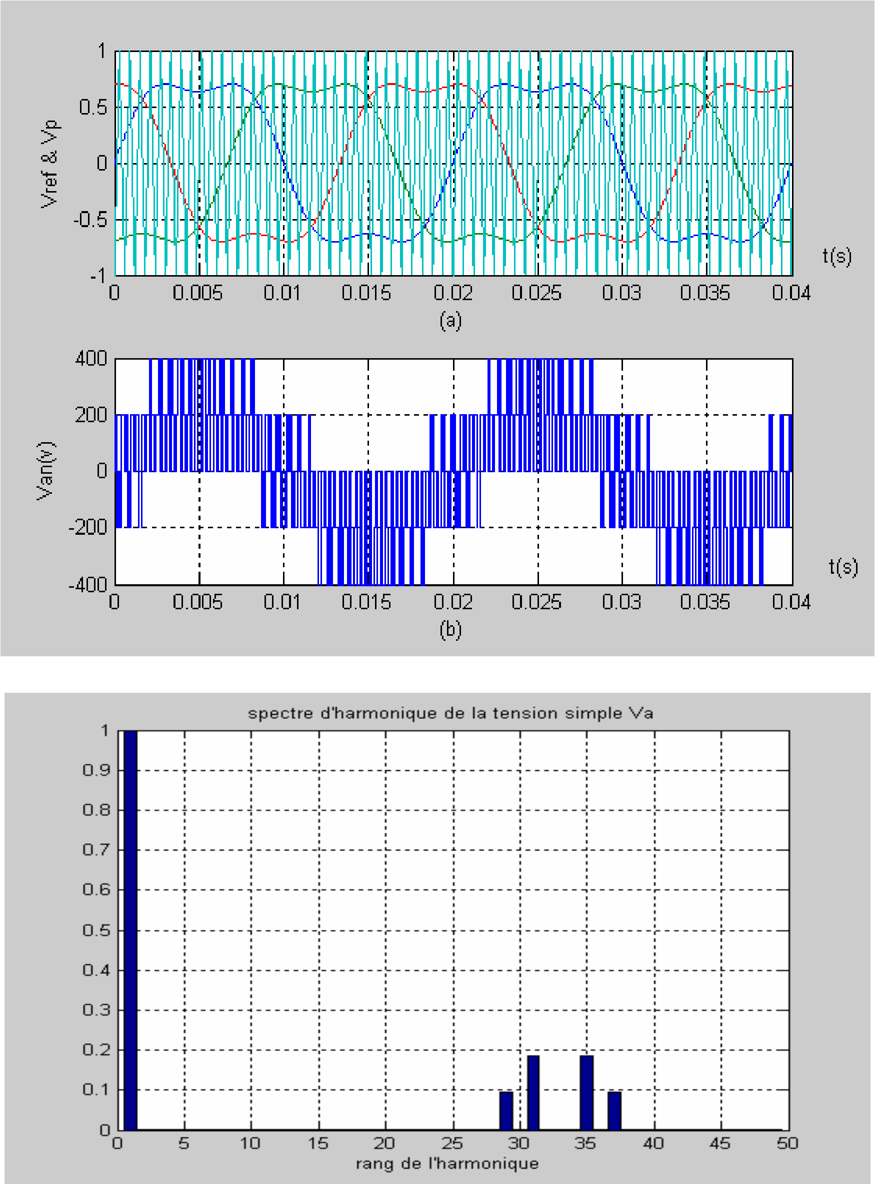
The simulation results show that:

- the space vector PWM improve the waveform of the Van voltage and increase the value of its fundamental amplitude,
- reduction of the voltage waste (d = 9,29%).
- reduction of the principal harmonics.

5.3. Simulation of Third Harmonic Injection Pulse Width Modulation THIPWM technique

The simulation results of the THIPWM technique are shown in figure 10.

Figure 10: Waves forms of THIPWM technique for m=33 and r=0.8 a) reference voltage standards and carrying wave b) wave forms of voltage Van c) harmonic spectrum of the voltage Van



The simulation results show that:

- the injection of harmonic 3 in the reference voltage standard makes it possible to improve the form of the output voltage and to increase the maximum amplitude of fundamental in the reference and by in the output voltage.
- the analysis of the results of simulation shows that the spectrum of harmonic of the voltage of Van phase is improved compared to the triangular sinusoidal PWM.
- the injection of a harmonic 3 in the reference makes it possible to decrease the waste of voltage (d=9,29%).

6. Conclusion

After a comparative study of these three techniques from the point of view of their harmonics spectrum and rate of distortion as well as the voltage waste, it is proven that the techniques SVPWM and THIPWM have better performances compared to technique SPWM.

In spite of the similarity of voltage waste in both techniques SVPWM and THIPWM, we can notice that the SVPWM technique is better from point of view rate of distortion and harmonic spectrum.

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