

## Rectifiers Comparative Study Between Two Levels and Multilevels PWM Order

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**Abstract:** The research presents a comparative study between two and three levels commanded PWM rectifiers current. The study is based on the performance analysis of each type of rectifier, through cascades made up of 2 and 3 levels commanded PWM rectifiers and three-phase structure NPC inverters, fuelling a three-phase asynchronous motor, regarded as a burden-phase balanced the output of the inverter. For that we present at first deal with modeling and control of 2 types of rectifiers. At the end we will address the problem of the mid-point of the inverter at three levels whose interest to have a stable system of tension at the terminals of the machine. The simulation results obtained are quite satisfactory.

**Key words:** Three-level inverter, Neutral-Point-Clamped-NPC, Pulse-Width Modulation (PWM)

### INTRODUCTION

This study will explore some devices to generate tension continuous from an alternative network 50 Hz and we will present the waterfalls following:

- A three-phase rectifier Cascade at two levels-three-phase inverter at three levels.
- Two rectifiers series Cascade a three-phase at two levels-three-phase inverter at 3 levels.
- A three-phase rectifier Cascade at three levels-three-phase inverter at three levels.

These waterfalls are a real power of the machine asynchronous which will be considered as a load balanced phase out of the voltage inverter commissioned by the strategy PWM.

After analyses of performance brought on converters on show at the beginning, the performance of multilevels rectifiers and their role in improving the spectral quality of the current report by the rectifiers at 2 levels, then we will expose the problem of the current phase by compared to the voltage of the rectifier and remedy to this problem, it proposes to use the command to hysteresis running. At the end we will end showing the role of bridge in clamping continuous tension stability at the entrance of the continuing source of the inverter voltage at 3 levels.

### MODELING OF RECTIFIERS

**Rectifier two-levels:** The device that generates tension continues from alternative network is presented in Fig. 1 the complementary used is as follows:

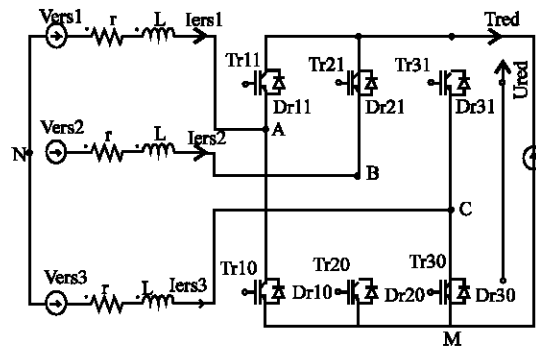


Fig. 1: Structure of the rectifier current two-level

$$B_{K1} = \bar{B}_{K0} \quad (1)$$

K: Number of arms rectifier (K = 1, 2, 3).

Tensions simple input rectifier is given by the following system:

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} F_{11} \\ F_{21} \\ F_{31} \end{bmatrix} U_{red} \quad (2)$$

By using the functions of connecting switches (Berkouk, 1995; Caron and Hautier, 1995).

The current output rectifier two levels are as follows:

$$I_{red} = F_{11} I_{res1} + F_{21} I_{res2} + F_{31} I_{res3} \quad (3)$$

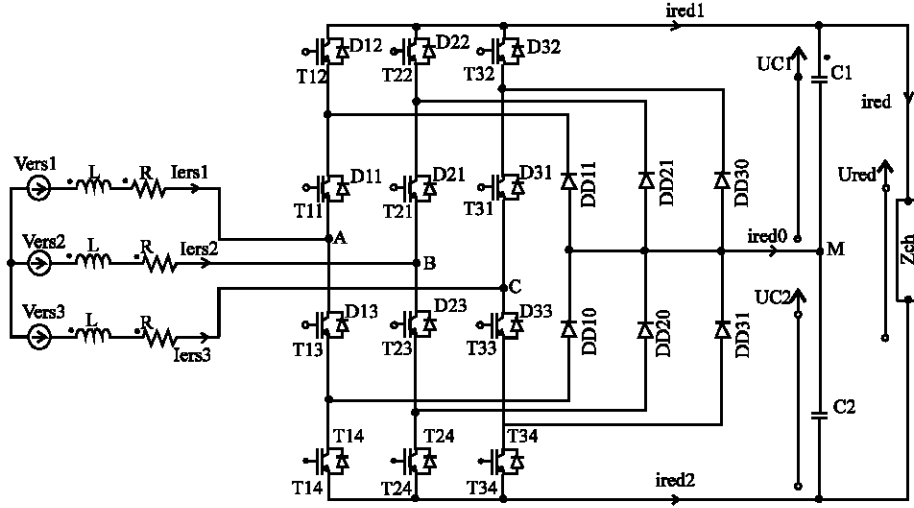


Fig. 2: Structure of the NPC rectifier current three-phase three-level

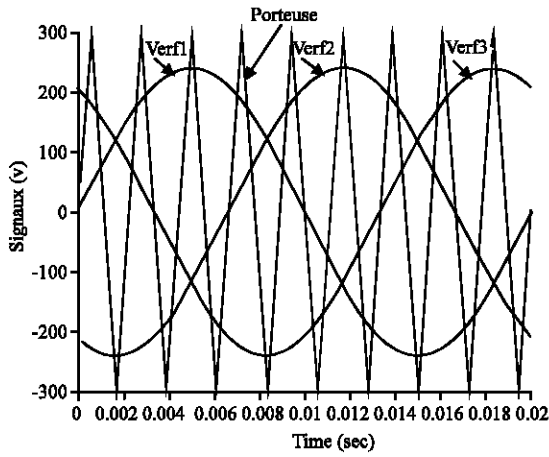


Fig. 3: Different signals the strategy triangular-sinusoidal of the rectifier at two levels ( $m = 9$ ,  $r = 0.8$ )

Figure 2 shows the structure of the NPC rectifier current three levels. Three orders are possible for this rectifier. The most optimal is given by the relationship Eq. (4) (Berkouk, 1995; Berkouk and Manasse, 1998).

It defines the command complementary to an arm  $k$  as follows:

$$\begin{aligned} B_{K1} &= \overline{B_{K4}} \\ B_{K2} &= \overline{B_{K3}} \end{aligned} \quad (4)$$

With command of the base of the transistor  $T_{KS}$ . In controlled mode, simple tensions for this rectifier expressed thanks to the functions of connecting a half-arm, according to the system Eq. (5).

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = 1/3 \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \cdot \left\{ \begin{bmatrix} F_{11}^b \\ F_{21}^b \\ F_{31}^b \end{bmatrix} \cdot U_{c1} - \begin{bmatrix} F_{10}^b \\ F_{20}^b \\ F_{30}^b \end{bmatrix} \cdot U_{c2} \right\}$$

## STRATEGIES OF COMMAND

**Rectifier two-levels:** The three-phase rectifier two-levels is controlled by the strategy triangular-sinusoidal sampling natural carrier with a triangular bipolar (Guedouani, 1998) (Fig. 3 and 4).

**Rectifier three-levels:** The rectifier and inverter are controlled by the same strategy triangular-sinusoidal natural sampling 2 carriers triangular bipolar (Fig. 5 and 6).

## STUDY AND SIMULATION OF CASCADES

The simulation of various waterfalls was made with SIMULINK under the MATLAB environment. Knowing that network parameters remain unchanged for all simulations for the different waterfalls discussed in this study (Bouchaffa *et al.*, 2004; Guedouani *et al.*, 2004).

The parameters used in these simulations are as follows (Berkouk, 1995):

- Network is a balanced three-phase direct parameters:  
 $V_{eff} = 230 \text{ V}$ ,  $F = 50 \text{ Hz}$ ,  
 $R = 0,25 \Omega$ ,  $L = 1 \text{ mH}$
- Filter capacitance is a filter between the rectifier and inverter  
 $C_1 = C_2 = C = 2e^{-3} \text{ F}$

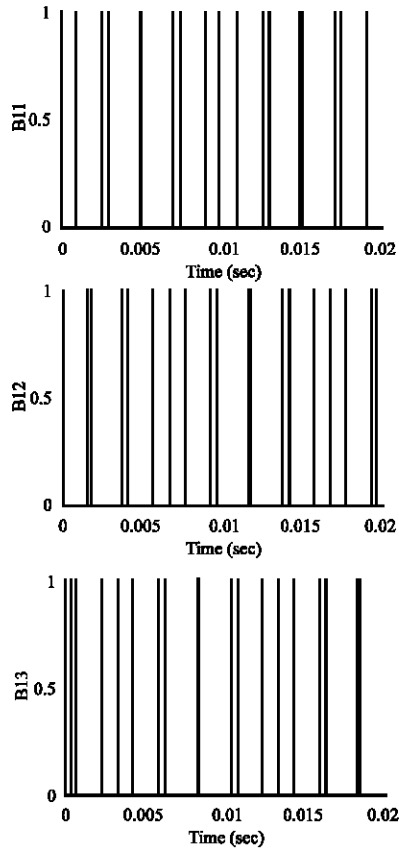


Fig. 4: Impulses orders three arms of a three-phase rectifier two levels ( $m = 9$ )

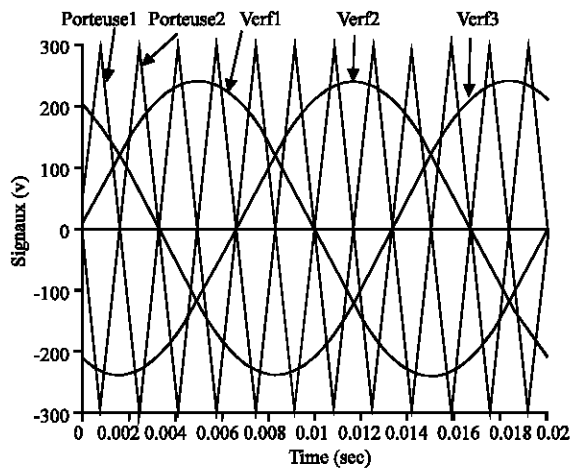


Fig. 5: Different signals the strategy triangulo-sinusoidal two carriers triangular bipolar ( $m = 6$ ,  $r = 0.8$ )

- The burden: the parameters of the machine asynchronous :  $S_n = 2.2 \text{ kVA}$ ,  $P = 2$ ,  $V_n = 230\text{V}$ ,  $F = 50 \text{ Hz}$ ,  $R_s = 0.435\Omega$ ,  $R_r = 0.816\Omega$ ,  $L_s = 4e^{-3} \text{ H}$ ,  $L_r = 2e^{-3} \text{ H}$ ,  $L_m = 69.31e^{-3} \text{ H}$ ,  $J = 0.089 \text{ kgm}$

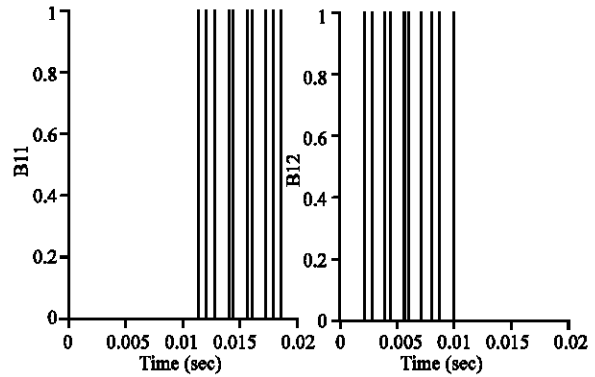


Fig. 6: impulses commands an arm of the three-phase rectifier at three levels ( $m = 6$ )

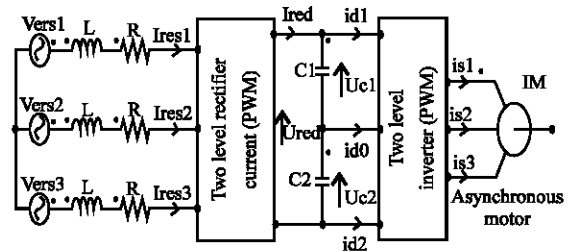


Fig. 7: Cascade of a rectifier current three phase at two levels-inverter at three levels-three-phase asynchronous motor

#### Cascade rectifier current three phase at two levels-inverter at three levels-three phase asynchronous motor:

The structure of this cascade is given by the pattern shown in Fig. 7.

**Application and simulation results:** The two-levels three-phase rectifier is controlled by the triangular-sinusoidal strategy natural sampling and a triangular carrier bipolar ( $m = 15$ ,  $r = 0.8$ ). The three-phase inverter at three levels is controlled by the same strategy with 2 carriers triangular bipolar ( $m = 16$ ,  $r = 0.8$ ), waterfall feeds a three-phase asynchronous motor ( $C_r = 12 \text{ Nm}$ ).

The figures represent the simulation results of the cascade shown in the Fig. 7.

**Interpretation:** It is noted that the tension recovered  $U_{red}$  is the sum of the 2 input voltages of the three-phase inverter at three levels  $U_{red} = U_{c1} + U_{c2}$  which are opposed by one over the other and their difference  $U_{c1} - U_{c2}$  is considerable (Fig. 8a), which shows the instability of the mid-point M of the inverter and the need to solve this problem by any appropriate means to have stable tensions at the entrance to the inverter and provide the engine a balanced three-phase power.

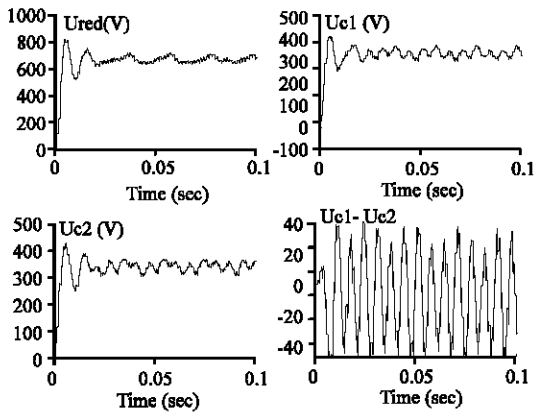


Fig. 8a: Voltage recovered Ured the rectifier two levels and voltage Uc1 and Uc2 and their difference

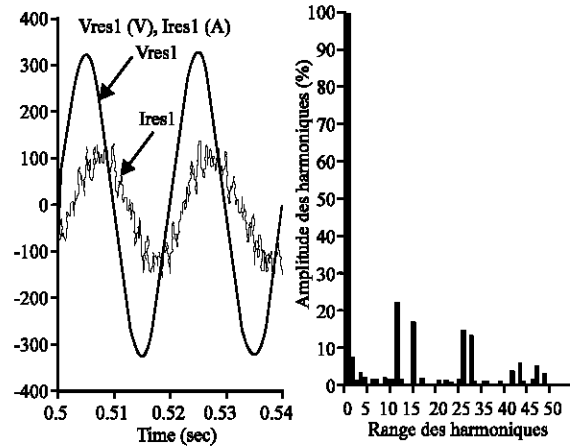


Fig. 8c: Spectre harmonic current Ires1 upstream of the rectifier on two levels and voltage Vres1

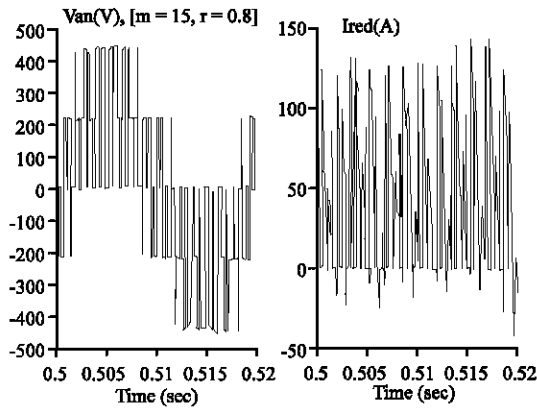


Fig. 8b: Current righted Ired of a rectifier two levels and Van voltage at the entrance to the same rectifier

Figure 8b shows the current Ired recovered at the exit of three-phase rectifier two levels and two levels of tension simple Van, at the entrance of the rectifier. The latest Fig. 8c illustrates the allure of Ires1 current phase of the network supplying the bridge rectifier and its phase compared to the power supply network Vres1 and its harmonic spectrum match. This shows that odd multiple harmonics category of three will be void and a few harmonics peers exist. These harmonics are grouped into families centered around multiple frequencies from those of the carrier  $F_p = 15f$ . The first family centered around the frequency  $mf$  is the most important point of view amplitude, in our case harmonics  $h13$  and  $h17$ .

Although, THDI is equal to 28.27%, the current pace is a bit close to a sine wave.

**Cascade two rectifiers current at two levels-inverter at three levels-three phase asynchronous motor:** Figure 9 shows the structure of this cascade.

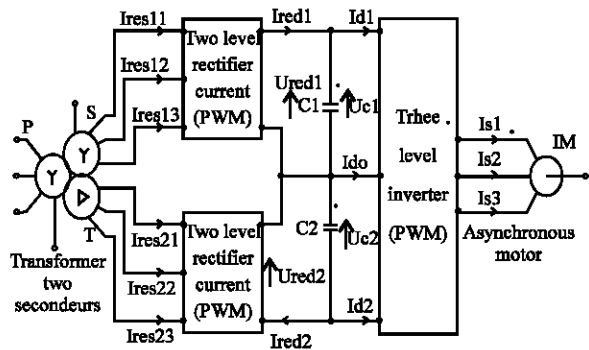


Fig. 9: Cascade 2 rectifiers current at 2 levels-three-phase inverter at three levels-three-phase asynchronous motor

**Application and simulation results:** The three-phase inverter at three levels is controlled by the same strategy as the previous cascade ( $m = 16$ ,  $r = 0.8$ ). The two current rectifiers are mounted in series and each is powered by a 115 V effective voltage and frequency of 50 Hz, which aims to keep the same tension straightened  $U_{red} = 600V$ . The two bridges are driven by the strategy triangular-sinusoidal carrier to a bipolar ( $m = 15$ ,  $r = 0.8$ ). The Fig. 10 represent the simulation results of the cascade given by the Fig. 9. The waterfall feeds the engine for  $Cr = 12 Nm$ .

**Interpretation:** Figure 10a shows the 2 strains recovered issued by the two bridges rectifiers phase two levels and although there is  $U_{red} = U_{red1} + U_{red2}$  with  $U_{red1} = U_{c1}$  and  $U_{red2} = U_{c2}$ . Despite the change in the structure of the waterfall and more particularly in the power inverter, the difference between the 2 voltages

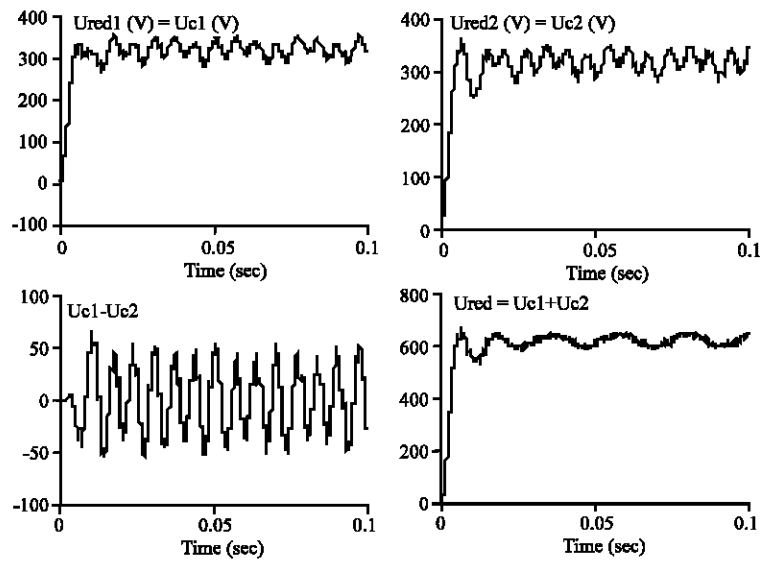


Fig. 10a: Voltages righted Ured1 Ured2 and two bridges rectifiers phase two levels and their difference Uc1-Uc2

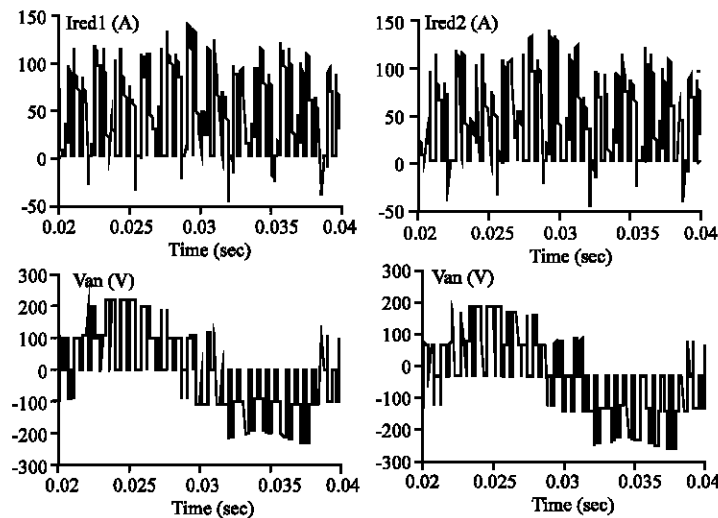


Fig. 10b: Currents recovered Ired1 and Ired2 respectively for the first and second bridge rectifier 2 levels and voltages Van singles at the entrance of each bridge

Uc1 and Uc2 still exists and until this difference is not zero, the inverter is subject to ongoing voltages unstable.

There is also after the Fig. 10b the two levels of simple voltage Van at the entrance of each bridge rectifier on two levels and currents recovered Ired1 and Ired2 issued by the two bridges rectifiers.

According to Fig. 10 c and d, we find that setting series of two rectifiers at two levels will improve the current THD network, which is about 9.86% and although we can see the current network side is the sum of 2 currents absorbed by each bridge rectifier. Harmonic

peers and odd multiple of 3 are invalid. The harmonics that exist are small in magnitude, compared with only one bridge rectifier two levels and are grouped into families always centered around multiple frequencies than the carrier. The current pace is improved and the gap still exists between current and voltage which is about  $45^\circ$  which explains the constraint of phase and consumption of reactive power.

**Cascade rectifier current three phase at three levels-inverter at three levels-three phase asynchronous motor:** By combining the three-phase rectifier three-levels

structure to the NPC three-phase inverter three-levels structure NPC, we get the frequency changer indirect presented by the Fig. 11.

**Application and simulation results:** The rectifier and inverter are controlled by the same s triangular-sinusoidal strategy natural sampling two carriers triangular bipolar ( $m = 16$ ,  $r = 0.8$ ). The waterfall feeds a three-phase asynchronous motor

Table 1: PWM rectifier based D'IGBT results

Structure of rectifier	PWM Rectifier based D'IGBT		
	A bridge rectifier two-level	Two bridges rectifiers at two levels in series	Rectifier three-level
THDI (%)	28.27	9.86	4.11

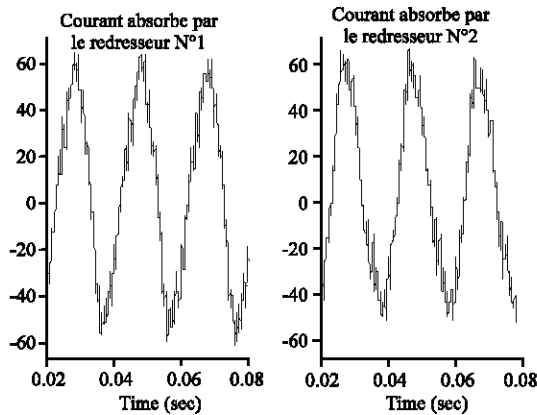


Fig.10c: Current absorbed by the two bridges rectifiers two levels of the first phase

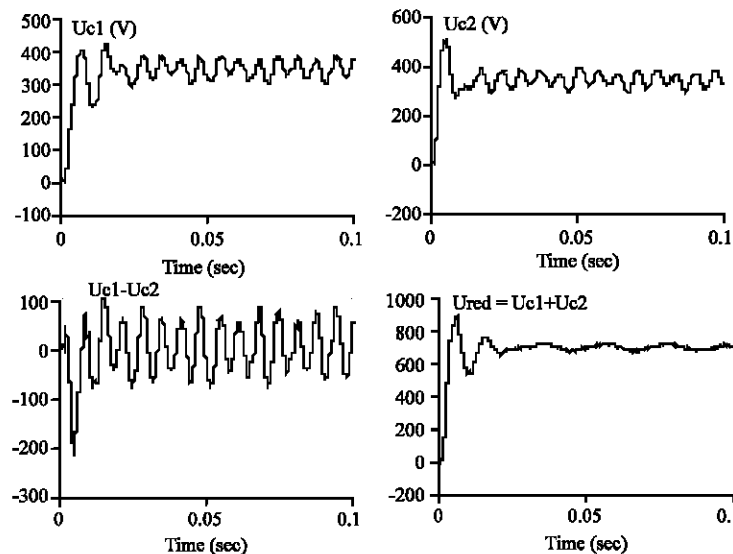


Fig. 12a: Voltages  $U_{c1}$  and  $U_{c2}$  at the entrance to the inverter at three levels and their differences  $U_{c1}-U_{c2}$

$C_r = 12Nm$ ). The Fig. 12 represent the simulation results of the cascade shown in the Fig. 11.

**Interpretation:** Voltages  $U_{c1}$  and  $U_{c2}$  illustrated in Fig. 12a are very close and the difference in voltage

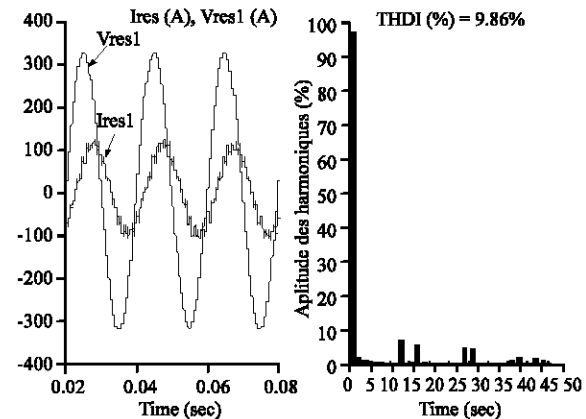


Fig. 10d: Spectre harmonic current  $I_{res1}$  absorbed by the two bridges rectifiers and voltage  $V_{res1}$

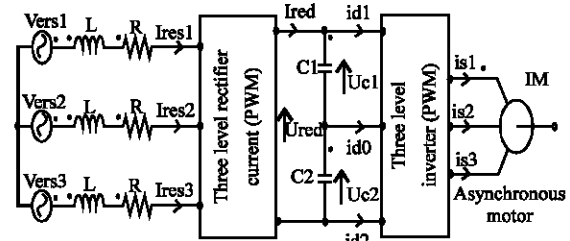


Fig. 11: Cascade rectifier current three-phase three-level inverter three levels-three-phase asynchronous motor

(Uc1-Uc2) values ranged around a small compared to that of Uc1 and Uc2. This difference is greater capacity for low-value, causing the instability of the input voltage at the inverter and what affects supplying the engine. The decrease in the difference voltages (Uc1-Uc2) is possible by increasing the value of capacity.

Note well the allure of the simple Van voltage out of the three-phase inverter at three levels, which presents three levels of voltage,  $2U_{red}/3$ ,  $U_{red}/2$ ,  $U_{red}/3$  with  $U_{red} = 600$  V (Fig. 12b).

The Fig. 12c shows the three levels of simple voltage Van at the entrance of the rectifier at three levels and the speed of currents Ired1, Ired2 which have the same speed but reversed one over the other, Current Ired0 to an inextant average value practically zero. This is very important for the balance of capacitive bridge.

It appears from Fig. 12d that the use of the rectifier at three levels can improve a lot more THD current network side which is around 4.11% (Table 1). The harmonics that exist are very small in magnitude compared with the harmonic spectrum rectifiers two bridges at two levels.

The current pace is much improved in comparison with the current absorbed by the rectifier on two levels. The current phase voltage network sides still persist in the order of  $45^\circ$ .

#### RESOLUTION OF THE DISCREPANCY BETWEEN CURRENT AND VOLTAGE

Now we to resolve the problem of discrepancy between current absorbed by the rectifier and voltage network, using the command hysteresis current to drive the rectifier and at the same time to have a phase zero.

So, this strategy of command allows us to have a current network virtually sinusoidal and consistent with its voltage (Boulkhrachef, 2001).

**Command hysteresis current:** The principle of command hysteresis current is to compare the reference current  $i_{réf}$  with current input rectifier  $i_k$ . Starting from the gap between these two streams, one deducts the orders of the rectifier switches as follows:

$$\begin{cases} [(\varepsilon_k \geq \Delta i) \text{ and } (\varepsilon_k \leq 2\Delta i)] \\ \text{or} \\ [(\varepsilon_k \leq -\Delta i) \text{ and } (\varepsilon_k \leq -2\Delta i)] \end{cases} \Rightarrow \begin{cases} B_{K1} = 1 \\ B_{K2} = 0 \end{cases}$$

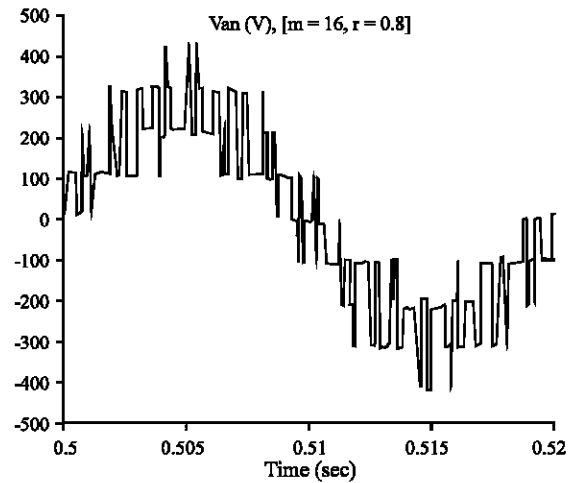


Fig. 12b: Simple voltage out of the three-phase inverter at three levels

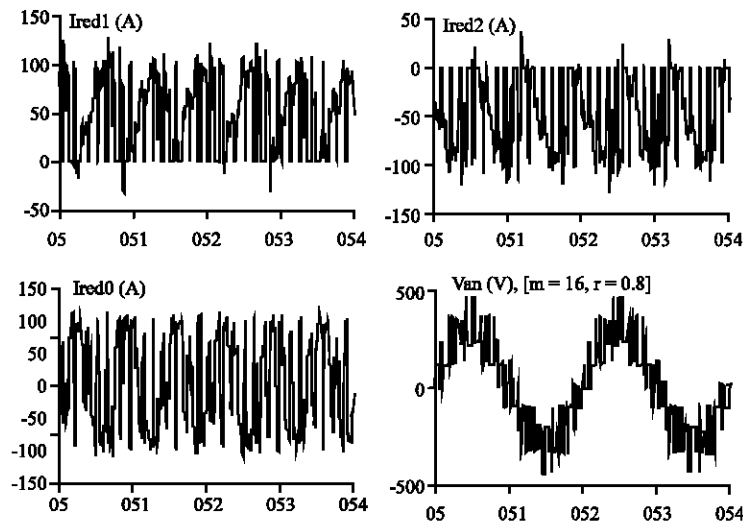


Fig. 12c: Ired1, Ired2 and ired0 the rectifier three levels and simple voltage at the entrance to the same rectifier

$$\begin{aligned} \epsilon_K \succ 2\Delta i &\Rightarrow B_{K1} = 0, B_{K2} = 0 \\ \epsilon_K \prec -2\Delta i &\Rightarrow B_{K1} = 1, B_{K2} = 1 \end{aligned} \quad (4)$$

$\epsilon$ : As the gap between current reference and current real arm k rectifier and  $\Delta i$  this band width hysteresis.

The current references you want to establish a network of lines feeding our three-phase rectifier at three levels are defined by the system Eq. (5).

$$\begin{aligned} Ir_{ef1}(t) &= I_{eff}\sqrt{2}\sin(\omega t) \\ Ir_{ef2}(t) &= I_{eff}\sqrt{2}\sin(\omega t - \frac{2\pi}{3}) \\ Ir_{ef3}(t) &= I_{eff}\sqrt{2}\sin(\omega t + \frac{2\pi}{3}) \end{aligned} \quad (5)$$

**Application of the command hysteresis the cascade rectifier NPC at three levels-inverter NPC has three levels-asynchronous motor:** For network side low harmonic currents and voltages and a closest power factor of unity, we have chosen for this cascade an order by hysteresis currents called by the rectifier floor at three levels, with  $\Delta i = 2A$ . While, the voltage inverter three levels is controlled by the strategy PWM, the triangular-sinusoidal two carriers triangular ( $m = 36$ ,  $r = 0.8$ ).

The structure of this cascade is given by the scheme's Back Figure 11. The waterfall feeds a three-phase motor regarded as a burden phase leading to a balanced load imposing a couple resistant  $Cr = 12 \text{ N m}$ .

**Application and simulation results:** The Fig. 13 represent the simulation results of the cascade illustrated by the Fig. 11.

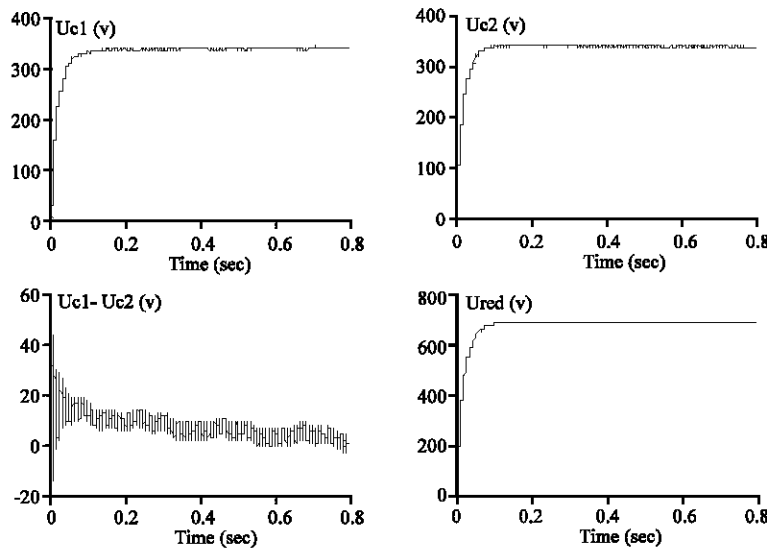


Fig. 13a: Voltage filter intermediate and their differences and tension straightened Ured

**Interpretation:** It is noted that the input voltage inverter to the three levels are decreasing the difference  $U_{c1}-U_{c2}$  is relatively high and the voltage recovered at the rectifier leaving is decreasing (Fig. 13a).

Note well the pace of current  $i_{s1}$  absorbed by the asynchronous motor which approached a sine wave and simple voltage  $V_{an}$  out of the inverter, which presents three levels of voltages,  $2U_{red}/3$ ,  $U_{red}/2$ ,  $U_{red}/3$  (Fig. 13b).

Voltages  $V_{an}$ ,  $V_{bn}$ ,  $V_{cn}$  the inverter are balanced and offset one  $2\pi/3$ . Against the other the current  $I_{red1}$  and  $I_{red2}$  have the same reversed shape but, with  $I_{red0}$  average value of zero. The current network follows its well-reference and the gap between voltage and current network is virtually zero (Fig. 13c).

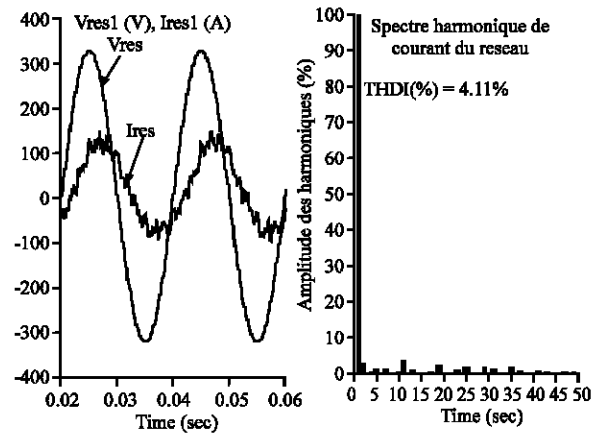


Fig. 12d: Specter harmonic current  $I_{res1}$  absorbed by the rectifier current three levels and voltage  $V_{res1}$



## REGULATION OF SOURCE CONTINUOUS INVERTER

To minimize the imbalance between the two input voltages of the continuing source of the inverter (output voltages three levels rectifier), it is proposed to insert a bridge balancing, said clamping bridge, consisting of a transistor and a resistance to the terminals of each capacitor (Bouchafaa *et al.*, 2004; Guedouani *et al.*, 2004; Boulkhrachef, 2001). The transistors are controlled so as to maintain equal tensions  $U_{c1}$  and  $U_{c2}$ . Thus the new filter between the three-levels voltage inverter and three-levels current rectifier is represented by the Fig. 14.

**Modeling bridge clamping-filter:** The structure of the intermediate filter is as shown in Fig. 15.

The model of these filters is defined by the following system:

$$\begin{cases} C1 \frac{dU_{c1}}{dt} = I_{c1} = I_{red1} - I_{d1} - I_{r1} \\ C2 \frac{dU_{c2}}{dt} = I_{c2} = I_{d2} - I_{red2} - I_{r2} \end{cases} \quad (6)$$

$$\text{With } \begin{cases} I_{r1} = \frac{U_{c1}}{R_p} \\ I_{r2} = \frac{U_{c2}}{R_p} \end{cases} \quad (7)$$

The algorithm command of transistors is defined as follows:

With  $\begin{cases} B_K: \text{Being the orders of the two transistors} \\ \Delta U_{12} = U_{c1} - U_{c2} \end{cases}$

## Application and simulation results

**Interpretation:** This cascade has already been studied and simulated without clamping bridge and we obtained the Fig. 13 a and the Fig. 16 a.

It was noted that voltages input source continues ( $U_{c1}$  and  $U_{c2}$ ) are unstable and different values and the difference  $U_{c1}-U_{c2}$  is quite considerable.

To improve voltages  $U_{c1}$  and  $U_{c2}$  minimizing the imbalance and the difference between these tensions, has studied the same cascade but this time on using a bridge clamping.

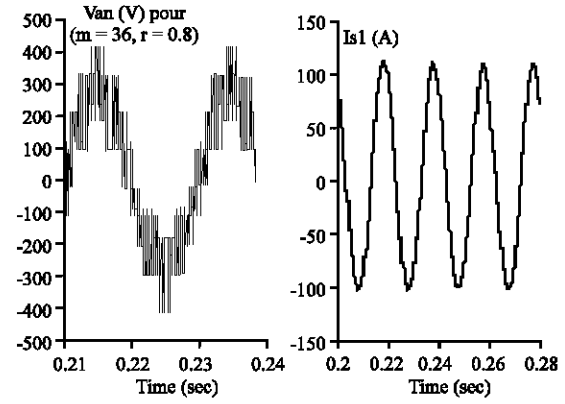


Fig. 13b: Voltage simple  $V_{an}$  of the three-phase inverter at three levels and the current  $I_{s1}$  of phase one of the three-phase motor

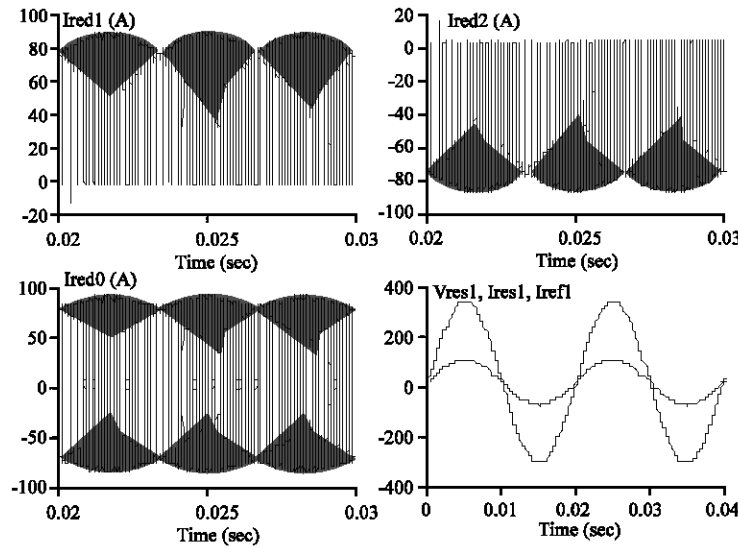


Fig. 13c:  $I_{red1}$ ,  $I_{red2}$ ,  $I_{red0}$  the rectifier phase three levels and  $V_{res1}$ ,  $I_{res1}$ ,  $I_{ref1}$  network supplying the same rectifier

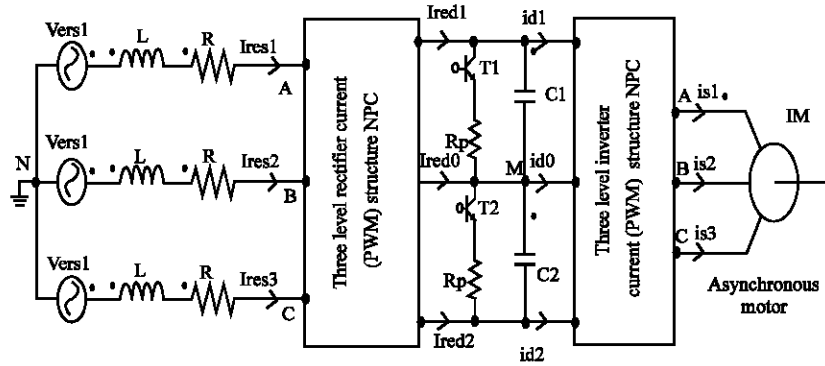


Fig. 14: Structure of the cascade rectifier current three-levels-clamping bridge-inverter at three levels-asynchronous motor

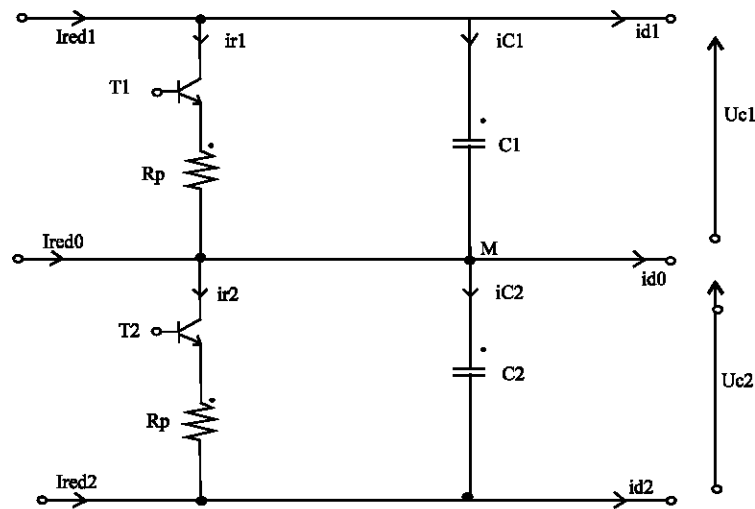


Fig.15: Structure of the bridge clamping

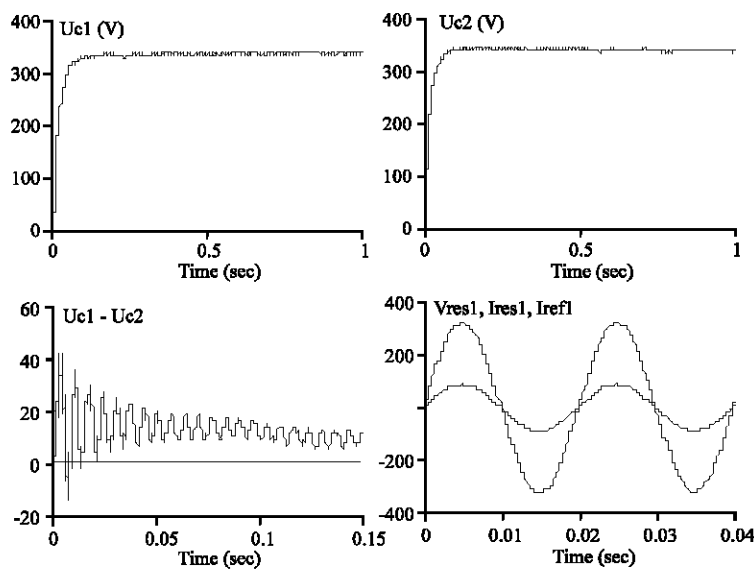


Fig. 16a: Forms of continuing voltage and bridge differences without Clamping

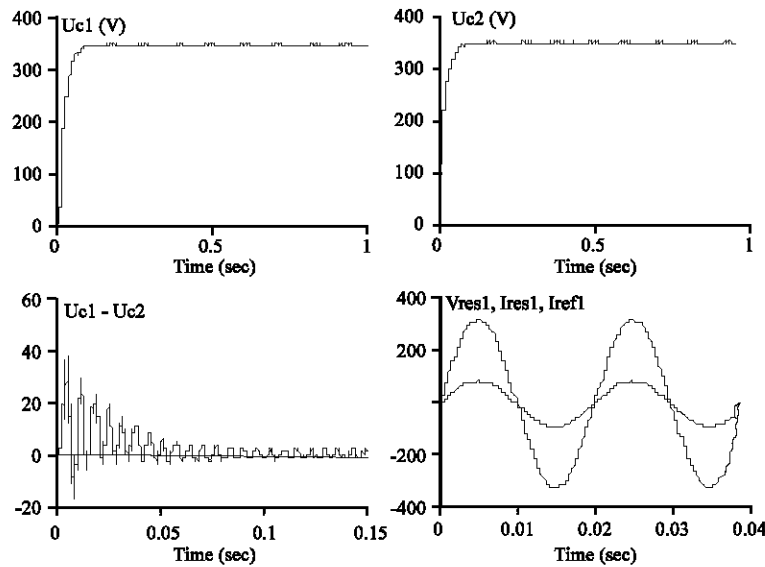


Fig. 16b: Forms of continuing voltage and bridge differences with clamping

The Fig. 16 b shows forms voltages issued by balancing the bridge for a value of  $R_p = 30 \Omega$  and values of capacity  $C_1 = C_2 = 20 \text{ mF}$ .

As we can see the difference between the input voltage inverter of the three-levels falls considerably and forfeits the permanent regime. As voltages become equal.

The course of the first phase of the network always follows a sinusoidal phase with a draw (Fig. 16 a and b).

The results are very promising for use of this cascade in the fields of high power.

## CONCLUSION

In this research we studied different frequency changers with the inverter three-phase three-tier structure NPC as a bridge exit.

It was shown in particular the application of the concept of multi-level rectifiers and their interest in improving the spectral quality of current and its best performance in relation to rectifying two levels, as shown in the table below.

It showed the imbalance between input voltages of the inverter  $U_{c1}$  and  $U_{c2}$  and it highlighted the value of having a continuous supply stable midpoint of the inverter at three levels and in order to have a stable system of voltage at the terminals of the machine.

We note in particular that the imbalance of input voltage inverter of three levels is less important in the case of using two current rectifiers at two levels.

The research presented in this article is a contribution to the study of the stability of input voltages of the inverter at three levels. This stability enables the smooth functioning of all rectifier current three-tier-voltage inverter at three levels-asynchronous motor.

While, the insertion of a bridge clamping the terminal each capacitor reduces considerably fluctuating voltages entrance of the inverter at three levels.

Coercion phase shift and consumption of reactive power we have to use the order by hysteresis, which allows us to have a possible current network side and a sinusoidal power factor near unity to the entrance to the rectifier current. The results are satisfactory using capacitors filtering values quite high. To decrease the value of these capacitors, while safeguarding the stability of the system, the enslavement of continuing voltages at the entrance to the inverter is recommended.

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