A DSP TMS320LF2407 BASED IMPLEMENTATION OF PWM FOR SINGLE-PHASE AC-DC BIPOLAR CONVERTER WITH A UNITY POWER FACTOR

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***Abstract**: This paper deals with the study and the implementation of a D.S.P (TMS320LF2407) controlled single-phase AC/DC converter using PWM strategy, including sinusoidal triangular strategy (SPWM). After the description of its functioning principles, its modeling and the converter control system, we have analyzed the modeling parameters influence on the converter behavior using that strategy. The study has been led by simulation and validated experimentally on testing ground with a DSP designed and built in the laboratory.*

Key words:** Triangulo-sinusoidal strategy, Unity power-factor, Insulated Gate Bipolar Transistor I.G.B.T, single-phase converter, Digital Signal Processor (DSP), Matlab Simulation.**

1. Introduction

Single-phase converters are widely used in industrial applications , such as standby power supplies and uninterruptible supplies.

A block diagram representation of a single-phase converter is given in (figure 1). The converter consists of four switching devices (represented as ideal switches) connected in the form of a bridge.

The control scheme is implemented using TMS320LF2407 DSP controller.

The power supply of variable speed systems requires the use of AC/DC converters with diodes or thyristors; however, these converters generate harmonics in the input network causing voltage wave form distortions, leading to power factor deterioration of the input network [1], [2].

To avoid these disturbances, the traditional rectifiers are replaced by pulse width modulation converters which are able to:

- impose a sinusoidal current waveform whatever the type of load;
- control the network power-factor;
- ensure the functional reversibility of the installation without resort to an auxiliary bridge contrary to the traditional converters [3], [4].

In this work, we present a study of a single-phase rectifier controlled by PWM strategy, allowing the fulfillment of all these requirements.

We look at its constitution, its principle of operation and its modelling, then we show the theoretical results obtained by a digital simulation by applying control technique of pulse width modulation namely the triangulo-sinusoidal strategy. The practical realization of this converter enabled us to carry out tests at the laboratory. The obtained results of the practical tests are compared with those obtained by simulation.

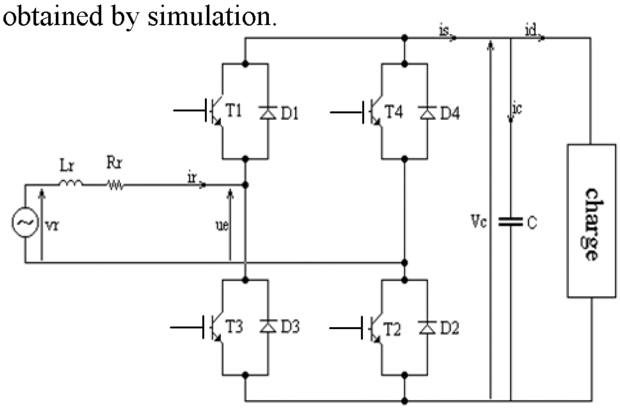


Fig.1. Single phase AC/DC Converter

2. Modelling of the studied system

(Figure.1) shows the schematic diagram of the studied system and indicates the adopted notations. The converter is made of four switches K_i (i=1,4) ordered bidirectional while running. Each one contains an I.G.B.T transistor T_i and one diode D_i placed in antiparallel with the transistor.

The converter is connected at the output of the input transformer.

L_r indicates the total inductance of the network and of the leakage inductance of transformer referred to the secondary. Under these conditions, v_r is the presumably sinusoidal voltage referred to the secondary which is constant. A capacity C is placed at output of the converter which is fed by a current source because of inductance L_r,

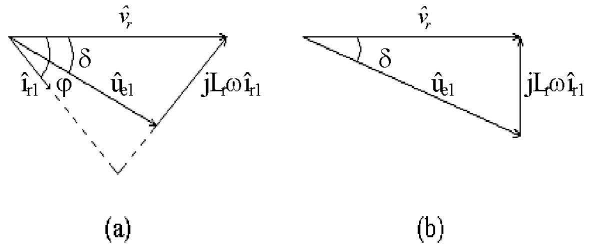


Fig.2. Vector diagram

The system operation can be described by the vector diagram shown in (figure2) where i_{r1} and u_{e1} are the fundamental values of current i_r and the voltage u_e.

By neglecting $R_r\ \hat{i}_{r1}$ in front of $L_r\omega\hat{i}_{r1}$, we can write:

$$\hat{v}_r = \hat{u}_{e1} + jL_r\omega\,\hat{i}_{r1} \qquad (1)$$

$\hat{v}_r$ $\hat{u}_{e1}$ $\hat{i}_r$, are complex representations of v_r, u_{e1} and i_r respectively.

Usually, we seek to put the input fundamental current i_{r1} in phase with the v_r voltage, the vector diagram is then that of (figure 2-b).

In this case, we can write:

$$U_{e1} = \sqrt{V_r^2 + (L_r\omega I_{r1})^2} \qquad (2)$$

With:

$$tg\delta = \frac{L_r\omega I_{r1}}{V_r} \qquad (3)$$

δ: indicates the phase-shift of the input voltage fundamental u_{e1} with respect to the v_r voltage.

For a pulse width modulation control:

- δ: is the phase-shift of the reference being used to determine the commutation times of the switches, regarding to the supply voltage.

The direction of phase-shift depends on the direction of the power flow:

- It is a lagging phase-shift if the source provides power to the load through the converter.
- It is a leading phase-shift when the load returns power to the source (inverter).

The fundamental value of the input voltage can be given by the relationship:

$$U_{e1} = r\frac{V_{c0}}{\sqrt{2}} \qquad (4)$$

V_{c0} is the average value of the voltage v_c.

As r is lower than 1, V_{c0} is higher than $\sqrt{2}\ U_{e1}$

Contrary to the traditional rectifier which functions as depressor transformers, this converter functions as an elevator rectifier voltage.

The reversible operation of the converter can be represented by the following model:

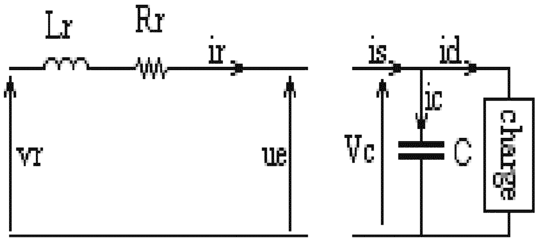


Fig.3. Converter model

This enables us to express the relationships between the input values and those of the converter output that is:

$$\begin{cases} u_e = K_f v_c \\ i_s = K_f i_r \end{cases} \qquad (5)$$

k_f: is the converter control function, it depends on the switches K_i closing and opening sequences:

$$K_f = \begin{cases} 1 \text{ if } (K_1, K_2) \text{ close and } (K_3, K_4) \text{ open} \\ 0 \text{ if } (K_1, K_4) \text{ close and } (K_3, K_2) \text{ open} \\ \quad or (K_1, K_4) \text{ open and } (K_3, K_2) \text{ close} \\ -1 \text{ if } (K_1, K_2) \text{ open and } (K_3, K_4) \text{ close} \end{cases} \qquad (6)$$

The current and the voltage equations at the converter input and output are:

$$\frac{di_r}{dt} = \frac{v_r - R_r i_r - u_e}{L_r}$$
$$\frac{dv_c}{dt} = \frac{i_s - i_d}{C} \qquad (7)$$

i_d is the current absorbed by the load, its equation depends on the nature of this one.

- No load: $i_d = 0$;
- For a resistive load R_d:

$$i_d = \frac{v_c}{R_d} \qquad (8)$$

- For a passive inductive load (L_d, R_d):

$$\frac{di_d}{dt} = \frac{v_c - R_d i_d}{L_d} \qquad (9)$$

- For an active inductive load (L_d , R_d , E):

$$\frac{di_d}{dt} = \frac{v_c - R_d i_d - E}{L_d} \qquad (10)$$

3. Application of the modulation strategy

In order to study the converter performances in rectifying mode and its control responses, a digital simulation by applying a pulse width modulation technique is performed; it is about the triangulo-sinusoidal strategy (S.P.W.M).

3.1. Triangulo-sinusoidal strategy

Pulse width modulation (PWM) techniques are effective means to control the output voltage frequency and magnitude. It has been the subject of intensive research during the last few decades. Various PWM control schemes have been discussed in literature. Basically they can be classified into two main categories, one is carrier based PWM and the other is space-vector PWM Especially, the space-vector PWM is used for three-phase converter applications. Here we mainly consider the carrier based PWM approaches that are often applied to the single-phase applications [12].

(Figure 4) above is a general scheme of PWM modulation. In order to produce a sinusoidal voltage at desired frequency, say f_1, a sinusoidal control signal $V_{control}$ at the desired frequency () is compared with a triangular waveform $V_{carrier}$ as shown in (figure 4), at each compare match point, a transition in PWM waveform is generated as shown in (Figure4). When $V_{control}$ is greater than $V_{carrier}$, the PWM output is positive and When $V_{control}$ is smaller than $V_{carrier}$, the PWM waveform is negative. The frequency of triangle waveform $V_{carrier}$ establishes the rectifier's switching frequency. We define the modulation index *m* as:

$$m_i = \frac{V_{control}}{V_{tri}} \qquad (11)$$

Where $V_{control}$ is the peak amplitude of the control signal, while V_{tri} is the peak amplitude of the triangle signal (carrier). Also the frequency modulation ratio is defined as:

$$m_f = \frac{f_s}{f_1} \qquad (12)$$

m_f is the ratio between the carrier and control frequency.

According to its definition, the triangulo-sinusoidal command technique allows an adjustment by two parameters:

- The modulation index m_f that influences the desired wave harmonic contents.
- The ratio of adjustment m_i which influences directly the effective value of u_e.

The comparison of the reference sinusoidal signal with the triangular waveform is done in the PWM generator of the DSP to generate the control signals for the switching devices along with the inverted signals with the required dead band. A 16-bit counter register is used to measure the frequency of the triangular wave. A centred symmetric PWM signal is used which has maximum count up of 2^{16} and count down 2^{16}. The PWM signals and the control signals generated are given in (figure 4).

By taking the following parameters:

$m_i = 0.7$, $m_f = 18$, f=50Hz, Vreff=50V, C=4500 µF, $R_r = 5\Omega$, $L_r = 0.02H$, $R_C = 80\Omega$, $L_C = 0.5H$.

The obtained simulation results are illustrated by (figure 5).

(Figure 5 a) shows the steady state current i_r which is in phase with the voltage v_r after shifting the carrier v_p by an angle with respect to the voltage v_r .

Referring to the current ir form, it is clear that its form is sinusoidal with a form which follows the commutation switches sequences.

(Figure 5-c) illustrates the converter input voltage u_e, (Figure 5-d) indicates the output converter current; we notice that it can take negative values in the case of the bipolar order; on the other hand, it is always positive for the unipolar order that justifies the irreversibility of this order.

(Figures 5-e and 5-f) show the voltage v_c and the current load; it is seen that the voltage increases to reach a constant value. The increasing time of the voltage depends on the used capacitance; it increases with the increasing of this one. The current load has practically the same form as v_c voltage.

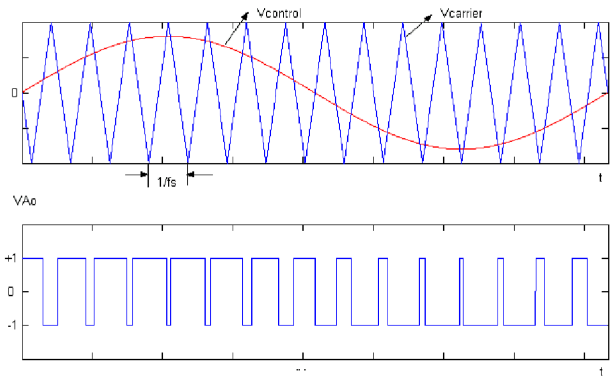


Fig.4. Description of bipolar PWM modulation

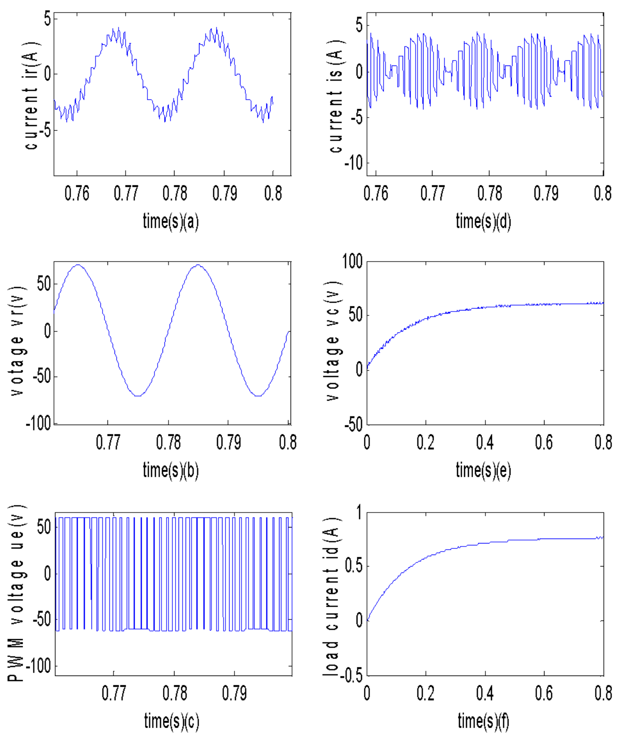


Fig.5. Bipolar triangulo-sinusoidal strategy

3.2. Bipolar PWM Spectrum Analysis

The total harmonic distortion (THD) for this bipolar PWM waveform is about 84.97% as simulated by MATLAB. In (figure 6), the resulted fundamental frequency component is 1.0, which means the magnitude of desired output frequency equal to the value of DC input voltage V_d The high frequency harmonics appears at around 45^{th} harmonics and again at around 90^{th} harmonics. This indicates that for bipolar PWM, the high frequency harmonics will appear around, 2, 3… and so on. To eliminate those high frequency harmonic interferences, typical second-order low-pass LC filters can be used to filter them out.

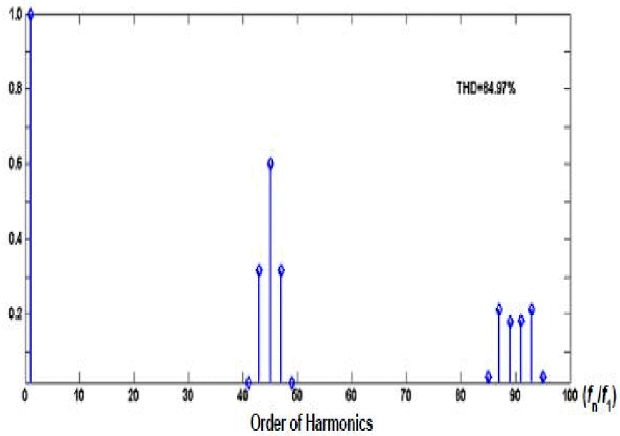


Fig.6. Frequency spectrum for bipolar PWM with m_i=1.0 and m_f =45

4. Experimental test

The schematic diagram of the converter circuit implemented is given in (figure7). It has two parts, the control circuit and the power circuit.

The shaded part is the control circuit containing the DSP controller TMS320LF2407 that generates the PWM signals and also provides soft start function.

Set point for the modulation index and Frequency is set by a computer through serial interface. The low pass filter was designed in such way that the output voltage waveform of the converter is sinusoidal.

To start with, the single-phase converter with the bipolar switching scheme is simulated using *simulink in Matlab* and its performance is studied [13],[14].

Later on, the single-phase converter was implemented using DSP TMS320LF2407 and its performance was studied. A comparison is made of the results obtained through simulation and experimental work under the same operating conditions. To verify the theoretical results obtained on the AC/DC converter, we designed and built the various circuits forming the full converter.

A power circuit formed by two arms, formed by four transistors I.G.B.T and four diodes connected in anti-parallel. The generated control signals were obtained using several control cards such as conditioning, monitoring, D/A conversion cards.

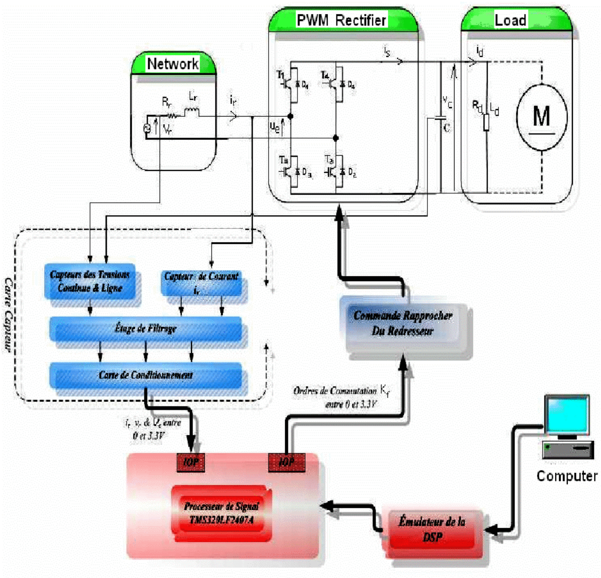


Fig.7. D.S.P. TMS320LF2407 implementation diagram.

(Figure 7) Shows the D.S.P. TMS320LF2407 implementation diagram.

The DSP programming was based on the software developed by Texas Instruments "*Code composer*".

The control algorithm has been written in assembly language in order to optimize the whole tasks of operation and communication between the DSP, the Converter and the Load [8], [9],[10],[11].

After the construction of the various circuits, the converter was tested in the laboratory; it functioned as a rectifier supplying a passive load formed by a resistance and an inductance. The oscillographic results obtained are given in (figures 9-a, b, c, d, and e).

For a triangulo-sinusoidal strategy, a cyclic ratio equal to 0.7 and the index of modulation equals 12 were taken. The effective value of the voltage delivered by the auto-transformer is 50V. The filtering capacitance at the out put of the converter is 4500 μF.

(Figure 9-b) clearly shows that the current i_r is in phase with the voltage v_r, therefore the converter runs at unit power-factor. The input voltage follows perfectly the imposed bipolar control.

The v_c voltage rises from zero to a final constant value, the rising time depends on the filtering elements used; it increases when the placed capacitance C and inductance L_r take high values.

The influence of the initial capacitor charge was also checked.

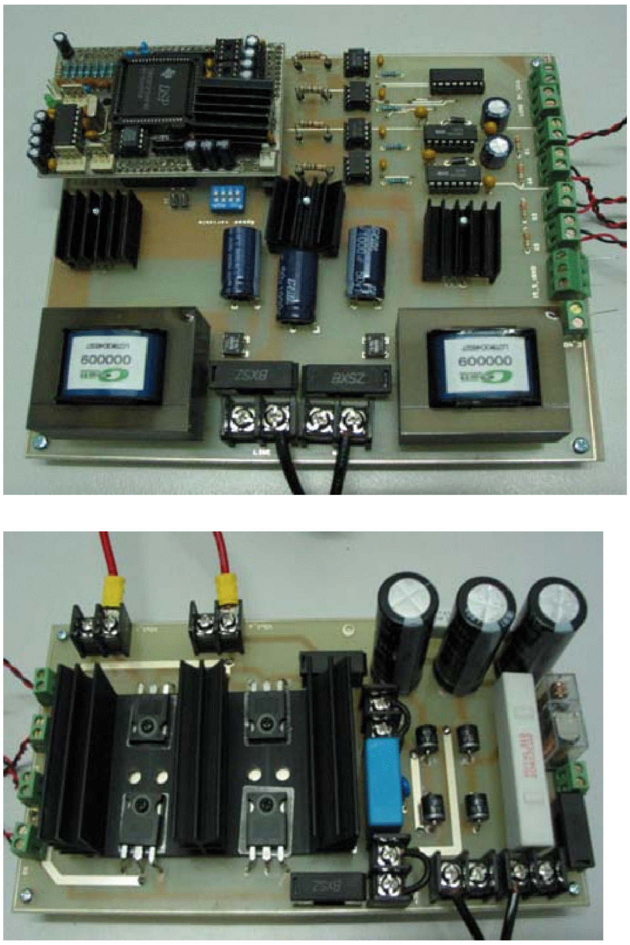
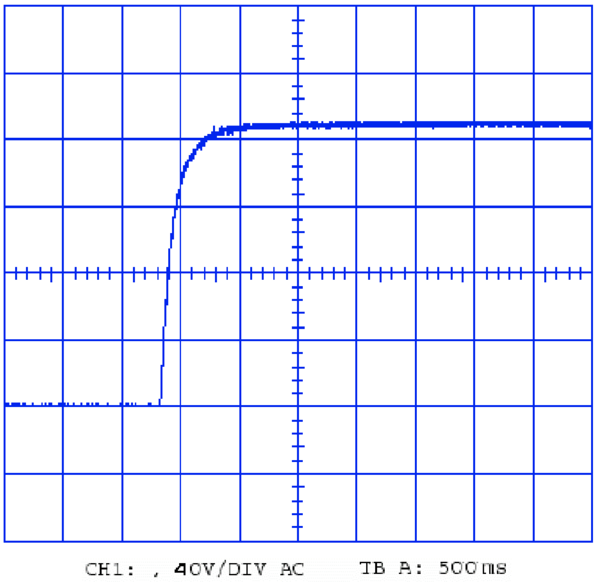
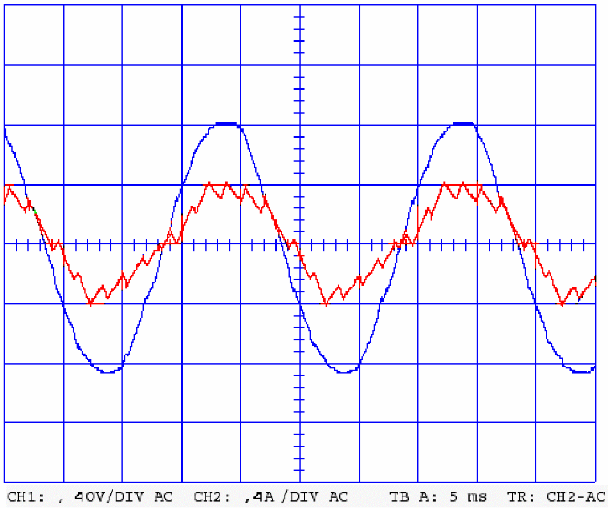


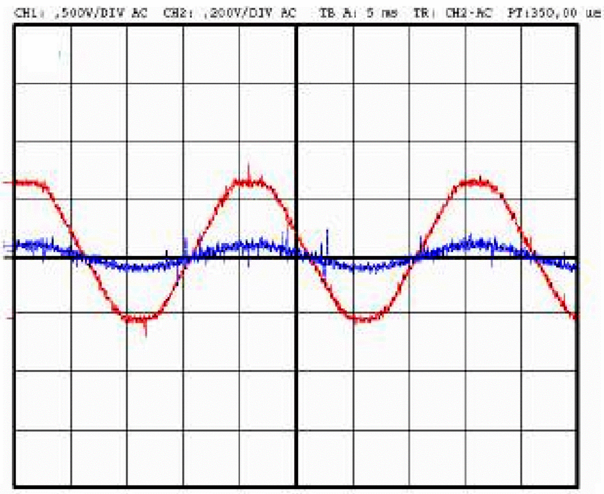
Fig.8. Laboratory bipolar converter board (Control circuit and power circuit)



a- The voltage v_c

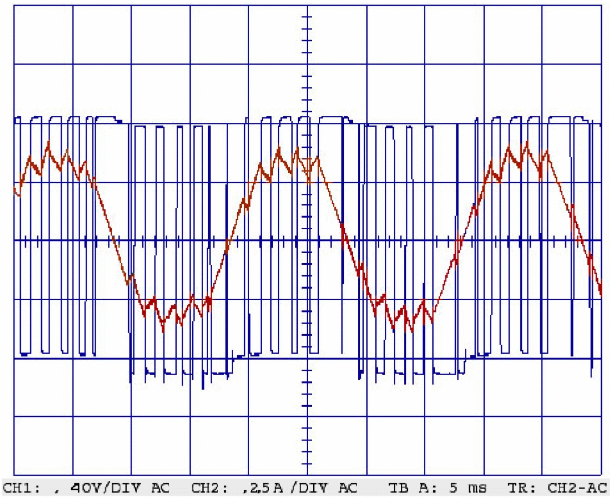


b- The current i_r and the voltage v_r



e- The current i_r and the voltage $\mathbf{v_r}$

Fig.9. some experimental results obtained by the application of the triangulo-sinusoidal strategy.



c- The voltage u_e and the current i_r

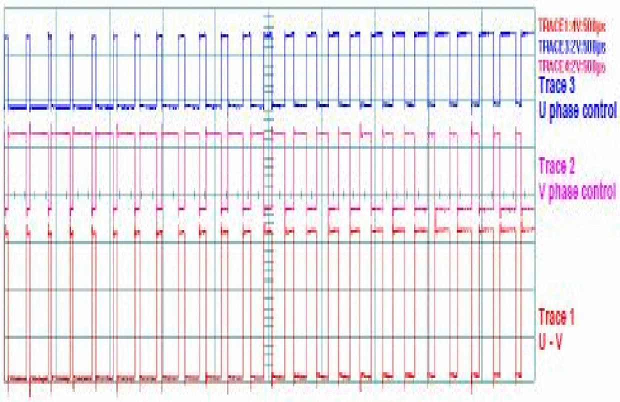
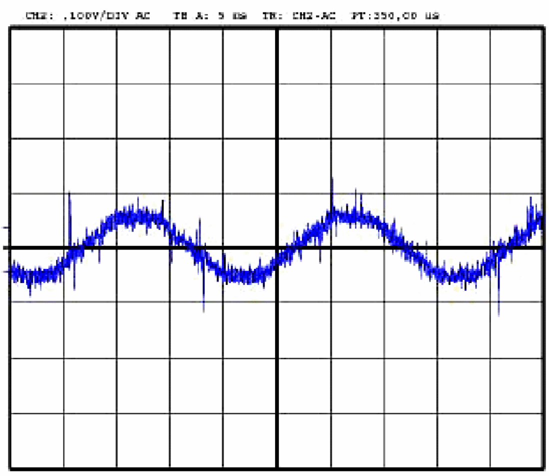


Fig.10. DSP control output for bipolar at 50 Hz



d- The current i_r

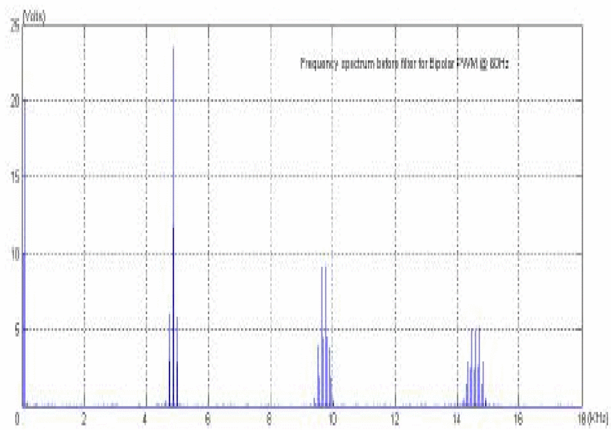


Fig.11. Frequency spectrum of H-bridge output for bipolar at 50Hz

5. Conclusion

A laboratory model of a bipolar single-phase converter was successfully implemented using DSP TMS320LF2407 and tested.

The rectifier unit consists of four, discrete I.G.B.Ts connected as a bridge and drive with a low cost driver. The experimental result matched with simulation results. Although any parameters are adjusted for giving fundamental frequency.

Thus AC/DC single-phase converter was studied and built. This converter allows an operation at a unit power-factor by introducing a phase-shift of the carrier signal with respect to the supply voltage for the triangulo-sinusoidal strategy. The results obtained by simulation or experimentally are very close. They show that:

- The amplitudes of the converter input and output values depend on the cyclic ratio for the triangulo-sinusoidal strategy.

- The waveform values are affected by the modulation index for the triangulo-sinusoidal strategy.

- The functional reversibility of the converter is assured.

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